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Air quality monitoring, emission inventory and source apportionment study for Indian cities

National Summary Report

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Central Pollution Control Board

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(भारत सरकार का संगठन)
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FOREWORD

India has number of non-attainment towns and cities with regard to particulate matter concentrations in ambient air where air quality improvement efforts require a comprehensive science based approach. It could involve (i) identification of emission sources; (ii) assessment of their contribution; (iii) prioritizing the sources; (iv) evaluation of control options with regard to feasibility and economic viability; and (v) formulation and implementation of appropriate action plans. Viewing this and as a follow-up to the Auto Fuel Policy Report, 2003, Air Quality Monitoring, Emission Inventory and Source Apportionment Studies were taken in six cities viz; Bangalore, Chennai, Delhi, Kanpur, Mumbai and Pune.

It is a comprehensive study focusing on apportionment of fine particulates (PM_{10} & $PM_{2.5}$) and based on an integrated approach involving major factors influencing air quality. Air quality measurements, chemical speciation and application of CMB-8 model provided vital informations on contribution of various source groups like vehicles, re-suspension of roadside dust, industries, etc., which helps in identifying and evaluating technologies and management based control options for different source groups such as fuel options, banning of old vehicles, paving of unpaved roads, etc., using dispersion model & city-level emission inventory, for prioritizing and preparing action plans. In India for the first time, Source Emission Profiles of a large number of vehicular and non-vehicular sources have been developed, which is employable for future receptor modeling based source apportionment studies in this region.

The Report is an outcome of the extensive work undertaken by CPCB with premier Research Institutes like IITs, ARAI, TERI and NEERI. The summary report was reviewed by Steering and Technical Committees, and Peer Reviewed by International Experts. It is a good initiative towards air quality management in India, which provides the scientific basis, evidence and insight into urban air quality issues. However, the findings are based on the 2007 data.

The project teams of ARAI, IITs of Kanpur, Mumbai & Chennai, NEERI and TERI deserve appreciation. On this occasion I acknowledge my predecessors Dr. V. Rajagopalan and Shri J. M. Mauskar; Members of Steering & Technical Committees; Oil Companies; SIAM; ASEM-GTZ; Dr. B. Sengupta, former Member Secretary, CPCB; and my colleagues Ms. Sakshi Batra, Shri Abhijit Pathak and Shri J. S. Kamyotra, Member Secretary, CPCB, Dr. A. L. Aggarwal and Dr. Prashant Gargava, who led this entire effort.

This report would be a useful reference to all the concerned with urban air quality management.

February 01, 2011

(S. P. Gautam)

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3. Prof. H. B. Mathur, Retired Professor, IIT, Delhi
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5. Dr. S. A. Dutta, DGM, Tata Motors Ltd., Pune
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3. Prof. S.P. Gautam, Chairman, CPCB
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9. Ms. Sakshi Batra, CPCB

This summary report is based on the detailed study reports, prepared by National Environmental Engineering Research Institute (NEERI), The Energy and Resources Institute (TERI), Automotive Research Association of India (ARAI), Indian Institute of Technology, Kanpur (IITK), Indian Institute of Technology, Madras (IITM) in respect of cities of Delhi & Mumbai, Bangalore, Pune, Kanpur and Chennai respectively.

AIR QUALITY MONITORING, EMISSION INVENTORY AND SOURCE APPORTIONMENT STUDY

Institutes, approved by Project Steering Committee	**Project Teams**	***Overall Guidance***	***Supervision***	**Report preparation Group***	**Funded by**	***Technical Consultant***	***Peer Reviewed by***	***Project Coordination***
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Indian Institute of Technology Bombay (IITB), Mumbai	Prof. Virendra Sethi, Prof. (Ms) Rashmi Patil, Dr. Neetu Saraf, Dr. Sumit Kumar Gautam & others							
National Environmental Engineering Research Institute (NEERI), Zonal Lab, Mumbai	Dr. Rakesh Kumar, Dr. (Ms) Indrani Gupta, Shri Shivaji, Ms. Elizabeth Joseph, Shri Mihir Herlekar & others							
Indian Institute of Technology Kanpur (IITK), Kanpur	Prof. Mukesh Sharma, Shri Sailesh Behera, Shri S. P. Shukla, Shri Pranveer Satvat & others							
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The Energy and Resources Institute (TERI), New Delhi	Dr. T. S. Panwar, Shri Sumit Sharma, Shri Rakesh K Hooda, Dr. Sumit Kumar Gautam & others							

* Shri M. K. Chaudhari, Ms. Sakshi Batra, Shri Mihir Herlekar, Shri Shivaji and Shri Abhijit Pathak

contributed significantly

Report Structure

This synthesis report provides outcome of the Air Quality Monitoring, Emission Inventory and Source Apportionment Study carried out in the cities of Bangalore, Chennai, Delhi, Kanpur, Mumbai and Pune. The primary focus of the study was on respirable particulate matter (PM_{10}), although it also deals with other pollutants like NO_x, SO_2, Ozone (O_3), $PM_{2.5}$, etc. The report is intended to provide scientific basis to the policy makers and other stakeholders, for formulation of strategies and prioritizing actions for improving air quality in urban areas. It draws and integrates the information, data, findings and conclusions contained in detailed city reports prepared by the respective Institutes. The report deals with various elements covered in the study and which are key to urban air quality management. These include air quality monitoring, emission inventory, chemical speciation and source apportionment of PM_{10} and evaluation of control options using dispersion modeling for evolving city-specific action plans.

The report is divided into ten chapters. *Chapter One* provides background to the study. Chapter two describes project overview including need; objectives, scope of work, an outline of the approach followed, and project administration. *Chapter Three* deals with air quality monitoring including air quality levels with respect to PM_{10}, NO_x, SO_2, and a few air toxics in different project cities; chemical speciation data for PM_{10} as well as $PM_{2.5}$; Data are given in the form of tables, graphs, charts, etc. for better understanding of air quality status in the project cities. In *Chapter Four*, methodology adopted for building up emission inventory, results of study on development of emission factors for vehicular exhaust, emission estimates for the baseline year 2007 as well as Business as Usual (BaU) scenarios for 2012 and 2017 in respect of PM_{10} and NO_x are discussed. It provides information on contribution of various source groups viz. vehicles, industries, domestic combustion, road side dust, and other fugitive area sources in emission loads. Besides, within vehicular sources, contributions from different categories of vehicles (e.g. two wheeler, three wheeler, passenger cars, heavy duty commercial vehicles, etc) are also discussed. *Chapter Five* presents results of Factor Analysis and Chemical Mass Balance (CMB) receptor models and source apportionment for PM_{10} and $PM_{2.5}$. Dispersion modeling was carried out for generating air quality profiles under different scenarios, details of which are given in *Chapter Six*. *Chapter Seven* is on evaluation of control options and city specific action plans. Based on source apportionment in different cities, a wide range of potential control options were evaluated for their efficacies; and subsequent delineating appropriate city-specific plans. As such, this chapter provides suggestions for improving the air quality. *Chapter Eight* summarizes the conclusions focusing on key issues in urban air quality management. *Chapter Nine* briefly mentions about some of the accomplishments made through the project. *Chapter Ten* on 'Way Forward' enlists the next steps, in terms of actions, further research/studies that are required to expand the knowledge base and understanding on urban air quality.

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Background

Ambient air quality monitoring carried out at various cities/towns in the country, under National Air Monitoring Programme (NAMP) provide air quality information that form the basis for identifying areas with high air pollution levels and subsequently, for planning the strategies for control and abatement of air pollution. Data generated over the years reveal that Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM/PM_{10}) exceed permissible levels at many locations, particularly in urban areas. Air pollution problem becomes complex due to multiplicity and complexity of air polluting source mix (e.g. industries, automobiles, generator sets, domestic fuel burning, road side dusts, construction activities, etc.). A cost-effective approach for improving air quality in polluted areas involves (i) identification of emission sources; (ii) assessment of extent of contribution of these sources to ambient air; (iii) prioritization of sources that need to be addressed; (iv) evaluation of various options for controlling the sources with regard to feasibility and economic viability; and (v) formulation and implementation of appropriate action plans. Source apportionment study, which is primarily based on measurements and tracking down the sources through receptor modeling, can help in identifying the sources and extent of their contribution to ambient air pollution. The Auto Fuel Policy (AFP) of Government of India (http://petroleum.nic.in/autoeng.pdf) also recommended for carrying out source apportionment studies for better planning related to air pollution reduction.

1.1 Recommendations of Auto Fuel Policy

The AFP document of Government of India made recommendations on implementation of EURO III equivalent norms for new vehicles except two and three wheelers for entire country and EURO IV equivalent norms for all private vehicles, city public service vehicles and city commercial vehicles in respect of 11 major cities with effect from April 01, 2010. While dealing with air pollution scenarios, the policy document, observed that there were no reliable emission inventories and there was a need to develop realistic emission inventories based on representative emission and vehicle utilization factors and undertake source apportionment studies. It also suggested that for assessing source contribution to ambient air, an integrated approach, which uses dispersion and receptor (Chemical Mass Balance – CMB-8) models, could be followed.

1.2 Initiatives taken by Oil Companies

Oil companies, led by Indian Oil Corporation Limited (IOCL) initiated source apportionment studies in August 2003 with National Environmental Engineering Research Institute (NEERI), Nagpur for source apportionment study in Delhi and with Automotive Research Association of India (ARAI), Pune for development of emission factors for vehicles. Subsequently, Memoranda of Collaborations (MoCs) were entered into with The Energy and Resources Institute (TERI) in December 2004 and The Automotive Research association of India (ARAI) in January 2005 for studies in Bangalore and Pune respectively. The focus of the above studies was on PM_{10} (particles of size less than or equal to10µm).

Steering and Technical Committees, coordinated by IOC, were constituted to oversee the implementation of the above studies.

1.3 Taking over of Project Management by Ministry of Environment & Forests (MoEF) and Central Pollution Control Board (CPCB)

In October 2004, Oil and Automobile industries met the Secretary (E & F) and proposed that MoEF should take over the project management and get source apportionment studies done under its guidance. Although the studies had made little progress at that stage, to ensure greater credibility, co-ordination by MoEF was agreed upon. Steering and Technical Committees, headed by Secretary (E&F) and Chairman, CPCB respectively, were reconstituted.

1.4 Need for evolving an Appropriate Common Methodology

In order to ensure that the six studies produce consistent and comparable results, it was necessary that the various institutes, conducting the studies adopted a common methodology. CPCB reviewed the scope of work/methodology for identifying the gaps, and for evolving an appropriate common approach and methodology that could be followed by all the participating institutes. Some of the important modifications made in the earlier scope of work are presented below:

- It was earlier proposed to conduct ambient air quality monitoring with respect to PM_{10} & a few other pollutants and subsequent chemical speciation of PM_{10} for a limited number of parameters. Monitoring frequency was as per National Ambient Air Quality Standards protocol (i.e. total 104 observations in a year @ twice a week). It was realized that instead of analyzing a few parameters, a detailed chemical analysis (ions, elements, carbon, and molecular markers) would provide more in-depth understanding of the constituents and origin of fine particulates. Besides, this being a specific objective oriented study and not compliance monitoring, number of observation was changed from 104 in a year to continuous monitoring for 20 – 30 days in each of the three seasons viz. summer, post-monsoon and winter. These alterations would be more appropriate for analyzing the impact of different sources and working out management options using air quality models. Accordingly, a detailed monitoring protocol including parameters, their measurement principles, sampling and analytical procedures, frequency of measurements, etc. was prepared.

- Besides PM_{10}, limited monitoring and source apportionment of $PM_{2.5}$ (particles of size less than or equal to 2.5µm) was also included. As a result, assessment of contributions of different source categories to concentrations of fine particles ($PM_{2.5}$) that have more severe health impacts was also possible.
- In urban areas, except for large industries in a few cases, most of the sources are low-height sources and air quality monitoring should specifically capture impact of these polluting sources. Therefore, for deriving meaningful interpretation through the study, an extensive primary survey of spatial distribution of sources and preparation of detailed emission inventory based on primary surveys for zone of influence (i.e. 2x2 km^2 area) around each ambient air quality monitoring location were included in the scope.
- Earlier scope envisaged use of source emission profiles, available from developed countries, as input to CMB-8 model for estimating contributions from different source categories. It was felt that use of these emission profiles for the sources that are relevant in Indian context may not be appropriate. Therefore, two new studies on developing profiles for vehicular and other sources (construction activities, roadside dust, DG sets, combustion, etc.) were included in the scope.

The Technical Committee approved the common methodology in its meeting held on October 20, 2005 and the same was presented before the Steering Committee on October 25, 2005 for concurrence. The revised scope of work and common methodology had implications in terms of requirement of additional financial resources, which are met through Plan allocations of CPCB. New MoCs with revised scope of work and costs were finalized.

2

Project Overview

Prevailing air quality scenario in major Indian cities demands formulation of comprehensive action plans for improvement in the non-attainment cities and towns. These Action Plans need to be realistic, technically feasible & economically viable to deliver the intended benefits.

In order to gainfully utilize the existing expertise and infrastructure available within India, the project was initiated in collaboration with premier research institutes like The Automotive Research Association of India (ARAI), Indian Institute of Technology (IIT), National Environmental Engineering Research Institute (NEERI) and The Energy and Resources Institute (TERI). Various studies were commissioned to these institutes, as per details given in *Table 2.1.*

Table 2.1: Institutes responsible for carrying out various studies

Study	Institute
Source Apportionment Studies	
Delhi	NEERI
Bangalore	TERI
Pune	ARAI
Mumbai	NEERI
Chennai	IITM
Kanpur	IITK
Development of Emission Factors for Vehicles	ARAI
Development of Source Emission Profiles	
Vehicles	ARAI
Non-vehicular sources	IITB

2.1 Objectives of the Study

Since, air quality in urban areas are affected by a variety of complex source mix, the objectives of the study were defined so as to have better understanding of major sources and their contributions to air pollution; and to formulate strategies for improving air quality that are based on detailed scientific investigations.

The study objectives are:

- To profile Ground Level Concentration (GLC) of air pollutants in different parts of the city including background, residential, commercial/mixed areas and source specific "hot spots" viz. kerbside/roadside, industrial zones, etc.
- To develop emission factors (EF) for different categories of vehicles with due consideration to variations in fuel quality, technology, size and vintage, control systems, etc.
- To arrive at appropriate EF for non-vehicular sources viz. industries, industrial and domestic fuel combustions, roadside dust, construction activities, DG sets, etc.
- To prepare inventory for different air pollutants, their emission rates and pollution loads from various sources along with spatial and temporal distribution.
- To profile the source emission characteristics of various sources typically present in urban areas.
- To apportion the sources of PM_{10} and $PM_{2.5}$ (limited) and prioritize the source categories for evolving city-specific air pollution management strategies/plan.
- To assess the impact of sources on ambient air quality under different management/ interventions/control options and draw a roadmap of short and long term measures as considered appropriate and cost effective to ensure "*cleaner air in urban areas*".

2.2 Focus on PM_{10}

Among all the criteria air pollutants, particulate matter (SPM and RSPM) has emerged as the most critical pollutant in almost all urban areas of the country. Coarser fraction (> PM_{10}) of SPM concentrations are primarily irritants and may not have much relevance to direct health consequences as compared to effects of its respirable fractions (PM_{10} and $PM_{2.5}$), which can penetrate the human respiratory systems deeper. Since the year 2000, focus has shifted from SPM to PM_{10} monitoring. In view of this, the main focus of this study is on characterization and source apportionment of PM_{10}. Limited exercise on characterization and source apportionment of $PM_{2.5}$ – a relatively more hazardous particulate fraction, has also been included in order to have a better understanding and correlation between these two fractions.

2.3 Scope of the Project

A comprehensive scope of work was drawn for the project. The scope is based on an integrated approach that includes (i) building up emission inventories, (ii) monitoring of ambient air quality for various pollutants relevant to urban areas viz. SPM, PM_{10}, $PM_{2.5}$, SO_2, NO_x , CO, O_3, Benzene, etc. and meteorological parameters at identified locations representing various land use and activity profiles, (iii) chemical speciation of ambient PM_{10} & $PM_{2.5}$ and that of source emissions for applying dispersion and CMB-8 models to assess the contribution from various sources, and (v) future projections and evaluation of various control options to develop cost-effective action plans.

2.4 Study Framework

It is a comprehensive study that is based on an integrated approach involving all major factors influencing urban air quality management. The approach was evolved based on the study objectives, existing scientific understanding & knowledge, technical capabilities, expertise & infrastructure available with leading Institutes in the country, resources, etc.

In order to ensure uniformity in approach and methodology to be followed for conducting the study, a document on 'Conceptual guidelines and common methodology for air quality monitoring, emission inventory and source apportionment studies for Indian cities' (http://cpcb.nic.in/sourceapportionmentstudies.pdf) was prepared for the guidance/use of participating institutes.

The entire study framework was designed taking into account inter-linkages among key components of the study viz. (i) ambient air quality monitoring; (ii) detailed chemical speciation of PM_{10} and $PM_{2.5}$; (iii) developing emission inventory; (iv) receptor modeling; (v) dispersion modeling; and (vi) broad techno-economic analysis of the prioritized control options & interventions. The other support activities included: (i) development of emission factors for vehicular exhaust emissions; (ii) adoption of common approach or emission factors for non-vehicular sources; and (iii) development of indigenous source emission profiles for vehicular and non-vehicular sources. Integrated analysis of these components facilitates policy decisions with adequate scientific basis; and poses unresolved questions that need to be investigated through further research initiatives.

A schematic presentation of the framework is given in *Figure 2.1* and important elements are discussed below:

2.5 Selection and Background of Project Cities

It is learnt from past experiences that implementation of same interventions in two cities having different distinctiveness in terms of source configurations, geography, meteorology, etc may not yield similar results. Though the choice of interventions to control urban air pollution has to be city-specific, project cities were selected covering wide range of characteristic distinctions so that control strategies could be applied to other similar cities. In addition, other important factors that played key role in identification of the cities included past data on air quality, access to various city level information, and availability of appropriate Institutes that could take up the study in the identified cities.

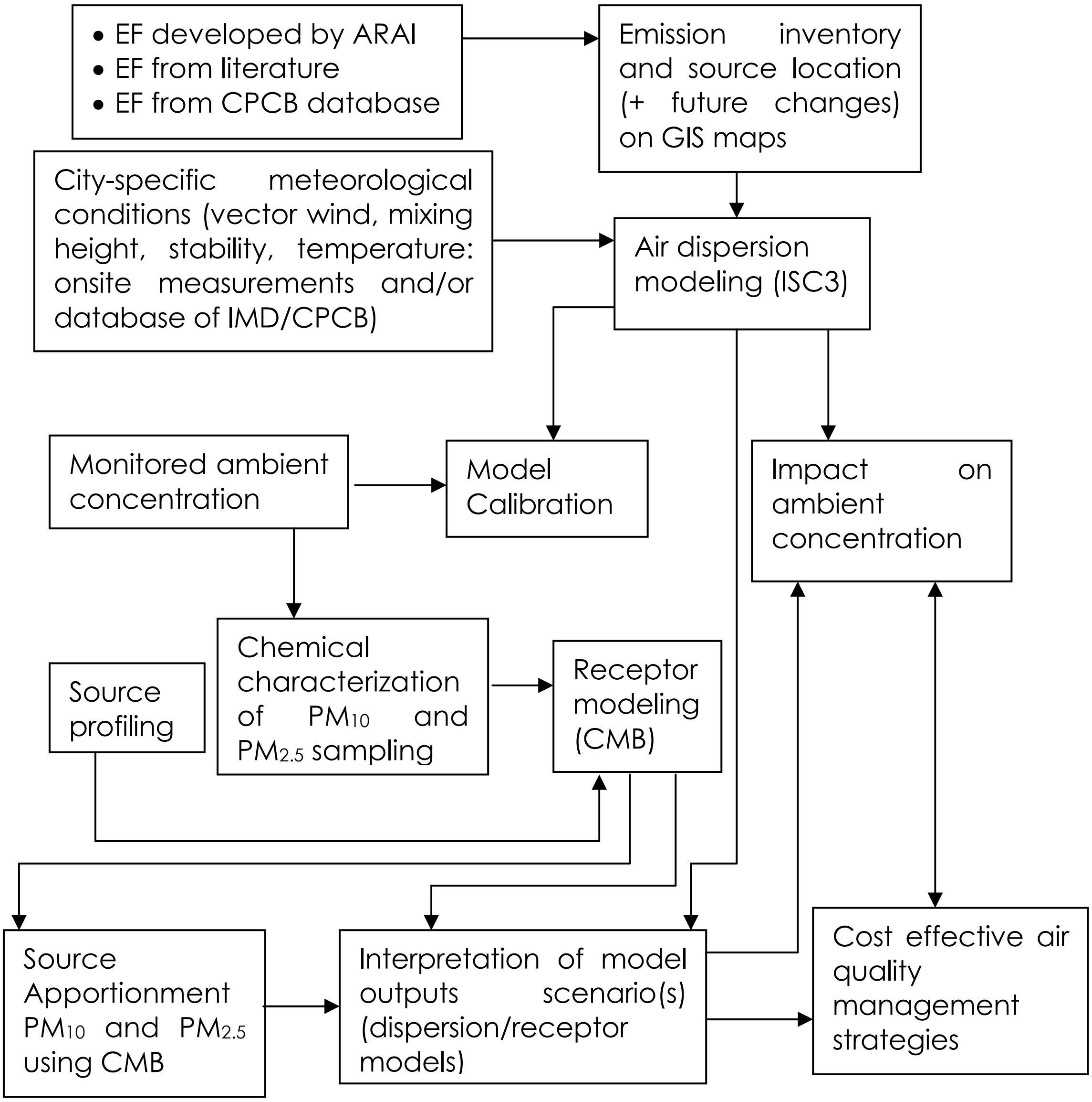


Figure 2.1: Study Framework

Source apportionment studies were planned for following six cities: Bangalore, Chennai, Delhi, Kanpur, Mumbai and Pune (*Figure 2.2*).

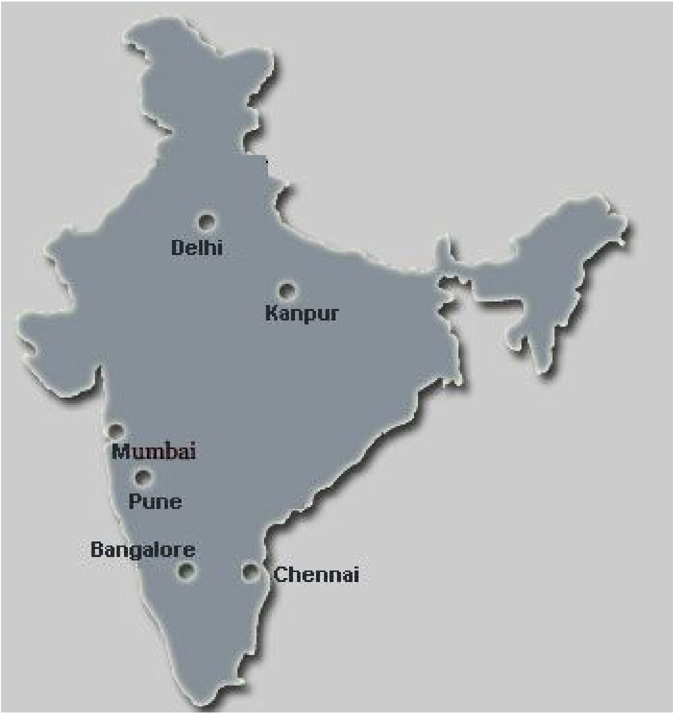


Figure 2.2 : Location of Project Cities (map not to scale)

City Profiles: Cities chosen under the project represent a wide spectrum of activities, socio-economic development, geophysical character, climate, sources of pollution, etc. Delhi and Kanpur are in Northern India with typical dry climate and mix of industrial and commercial activities. Mumbai and Chennai are coastal cities, which experience land/sea breeze influencing dispersion of pollutants. Bangalore and Pune are upcoming cities that have more of commercial/institutional activities than industrial. Delhi and Mumbai are megacities with population of more than 13 million. The profiles of these cities are given in Table 2.2.

Table 2.2: Characteristics of the Project Cities

City	Area (Km²)	Population (million)		Vehicle population 2007 (million)*	Climate	Remarks (including Socio-economic Activities)
		2001 Census	Projected for 2011			
Bangalore	565	5.7	7.6	2.53	• Pleasant climate throughout the year. • Max. Temp: 25-34°C, Min. Temp: 15-21°C. • Receives rainfall from both the northeast and the southwest monsoons. The wettest months are September and October. • Avg. rainfall: 970 mm/yr	Bangalore is commonly known as the Silicon Valley of India because of its pre-eminent position as the nation's leading IT employer. It is home to innumerous software companies, well-recognized colleges and research institutions, aerospace, telecommunications, and defence organizations
Chennai	176	4.34	4.95	2.27	• Weather is typically hot and humid. There is only a small variation between the seasons due to the location and proximity to the Indian Ocean. • Max. Temp.: 42° C and Min. Temp: 20° C • Receives most of the rainfall from the north east monsoon (mid September to mid December) while some rainfall is also there during the	Chennai has commercial activities with a large number of educational and medical institutions. Industrial activities are limited and located on the outskirts.

City	Area (Km^2)	Population (million)		Vehicle population 2007 (million)*	Climate	Remarks (including Socio-economic Activities)
		2001 Census	Projected for 2011			
					south west monsoon (July-August).	
Delhi	1500	13.8	19.0	5.2	• Both summer and winter are severe with June being the hottest month and January, the coldest. • Dust storm-cum-heat waves occur during summer. • The annual rainfall is around 700 mm. Maximum rain occurs during July to August.	Delhi is capital city with mix of activities, such as commercial, small scale industries, power plants. The city is surrounded by other major growth centres of adjoining states such as Haryana and Uttar Pradesh.
Kanpur	230	2.57	3.19	0.59	• In winters minimum of -1^{0}C with maximum at almost 12 to 14^{0}C. • In summer (April-June) Max. Temp. Spiral up to 47.5^{0}C and re accomplished by dust storm-cum-heat-waves. • During the rainy season the relative humidity is generally high over 70% • The average annual rainfall is 792 mm.	Kanpur, the largest industrial city in Uttar Pradesh mainly having leather industries.
Mumbai	468	16	22.4	1.5	• Rainfall : June to September, 2,200 mm • Mild Winter : Nov to February. • Annual Temp. High of	It is known as the financial & commercial capital. City is surrounded by coastline on western, eastern and southern side.

City	Area (Km²)	Population (million)		Vehicle population 2007 (million)*	Climate	Remarks (including Socio-economic Activities)
		2001 Census	Projected for 2011			
					38°C to a low of 11°C. • Average annual humidity is 90%	Space constraints have given rise to towering skyscrapers standing majestically next to sprawling slums (Dharavi -Asia's biggest slum is here). The biggest & busiest port in India.
Pune	243.84	2.54	3.5	1.45	• Pune experiences three distinct seasons: summer, monsoon & winter. • Typical summer months are March to May, with max temperatures ranging from 35 to 39 deg C, with high diurnal variations in temperatures. • Wind Direction: Feb to Sep – Westerly; Oct to Jan – Easterly • The city receives annual rainfall of 722 mm, mainly during June and September.	Pune is also known as a twin city with two municipal corporations of Pune (PMC) and Pimpri-Chinchwad (PCMC). The growth of Pune is not limited to only PMC or PCMC, but all the circumferential area with industries, universities, institutes coming up in that area. Pune is an auto hub and a growing IT hub.

* Registered Vehicles

2.6 Quality Assurance and Quality Control

The institutes, participating in the project, were chosen considering their expertise and experiences in conducting similar studies, and focusing on capacity building in different regions of the country. The participating institutes, being reputed scientific institutions, were responsible for ensuring Quality Assurance and Quality Control (QA/QC). However, to facilitate good quality data, guidelines on Standard Operating Procedures (SOPs) for sampling and analysis were prepared (http://cpcb.nic.in/SA-Studies%20-SOPs-for-sampling-and-analysis.pdf). The SOPs provided complete description of the measurement process, and included the following:

- Summary of measurement methods, principles, expected accuracy and precision, and the assumption for validity
- Materials, equipment, reagents, and suppliers
- Technical details
- Individuals responsible for performing each part of the procedure
- Traceability path, primary standards or reference, etc.

Approach and methodology for the project was presented and discussed in the Asian Aerosol Conference, held in Mumbai in 2005. International expert from Germany was also invited for reviewing the study design.

QA/QC was applied to various components of monitoring network design starting from conceptual designing; selection of sampling equipment, monitoring & analytical methods, monitoring sites; field planning; schedule and frequency of monitoring; and documenting QA/QC procedures. The salient features of QA/QC also included the following:

- Adopting state-of art monitoring and analysis methods as well as equipment and infrastructure support.
- Uniformity in monitoring and analysis methodology.
- Surveys for siting of appropriate monitoring location.
- Training of field as well as analytical staff by International experts. International training was organized to train the trainers representing all the participating institutes, concerned State Pollution Control Boards, with support from ASEM-GTZ.
- Samples on molecular markers from Delhi and Mumbai were analyzed at Desert Research Institute (DRI), USA.

- A city level external group was constituted incorporating local experts for regular interaction and external quality checks on methods and data generated.
- An Expert Group was also constituted, which interacted with project teams of all the six cities to provide guidance on various quality related issues.

2.7 Project Administration

- Steering and Technical Committees were set up. While the Steering Committee provides overall guidance and facilitates smooth implementation of the project, Technical Committee is responsible for resolving technical issues during the course of study. Technical Committee met regularly (Ten meetings were held during last two and half years) to monitor the progress and decide on technical issues.
- An Expert Group was constituted for overseeing study on development of emission factors for vehicles. The Group met six times for finalizing the factors for different fuel and categories & vintage of vehicles.
- A Finance Subcommittee has also been set up, which ensures timely release of payments.
- Composition of various Committees and Expert Groups are given in Annexure – I.

3

Air Quality Monitoring

3.1 Air Quality Status and Trends (2000 - 2006)

Ambient air quality is being monitored under National Ambient Air Monitoring Program (NAMP), coordinated by Central Pollution Control Board (CPCB), in over 115 cities/towns including the six project cities. Figures 3.1 to 3.6 present the air quality status and trend of previous years for Chennai, Pune, Kanpur, Bangalore, Mumbai, and Delhi in respect of RSPM, NO_2 and SO_2. These historical trends provide air quality status, prior to the study. The following conclusions come to the fore by analyzing the air quality status and trend up to the year 2006 in the six cities:

- Except for Chennai, annual RSPM standard (60 µg/m^3) exceeds in all cities in all years (2000- 2006). Kanpur shows the highest concentrations of RSPM where standard is exceeded by more than three times. It is closely followed by Delhi.
- Simple exploratory data analyses do not show any trend in RSPM levels except for Pune and Mumbai. However, in past three years, Mumbai shows slight rising trends for RSPM.
- Generally, NO_2 levels are within the air quality standard (60 µg/m^3). In past three years, Bangalore and Pune have shown decreasing trends in NO_2. However, a close examination of other cities shows a definite increasing trend of NO_2.
- SO_2 levels are within the annual standard (60 µg/m^3) in all cities. The other important point in SO_2 levels is the fact that SO_2 levels are decreasing at all cities, which is largely attributed to sulphur reduction in diesel.
- It is clear that RSPM is the most important pollution parameter especially in the urban environment.
- The variation in annual average concentrations during different years may be due to multiple factors including meteorology, neighbourhood activity pattern or levels during monitoring period, etc.

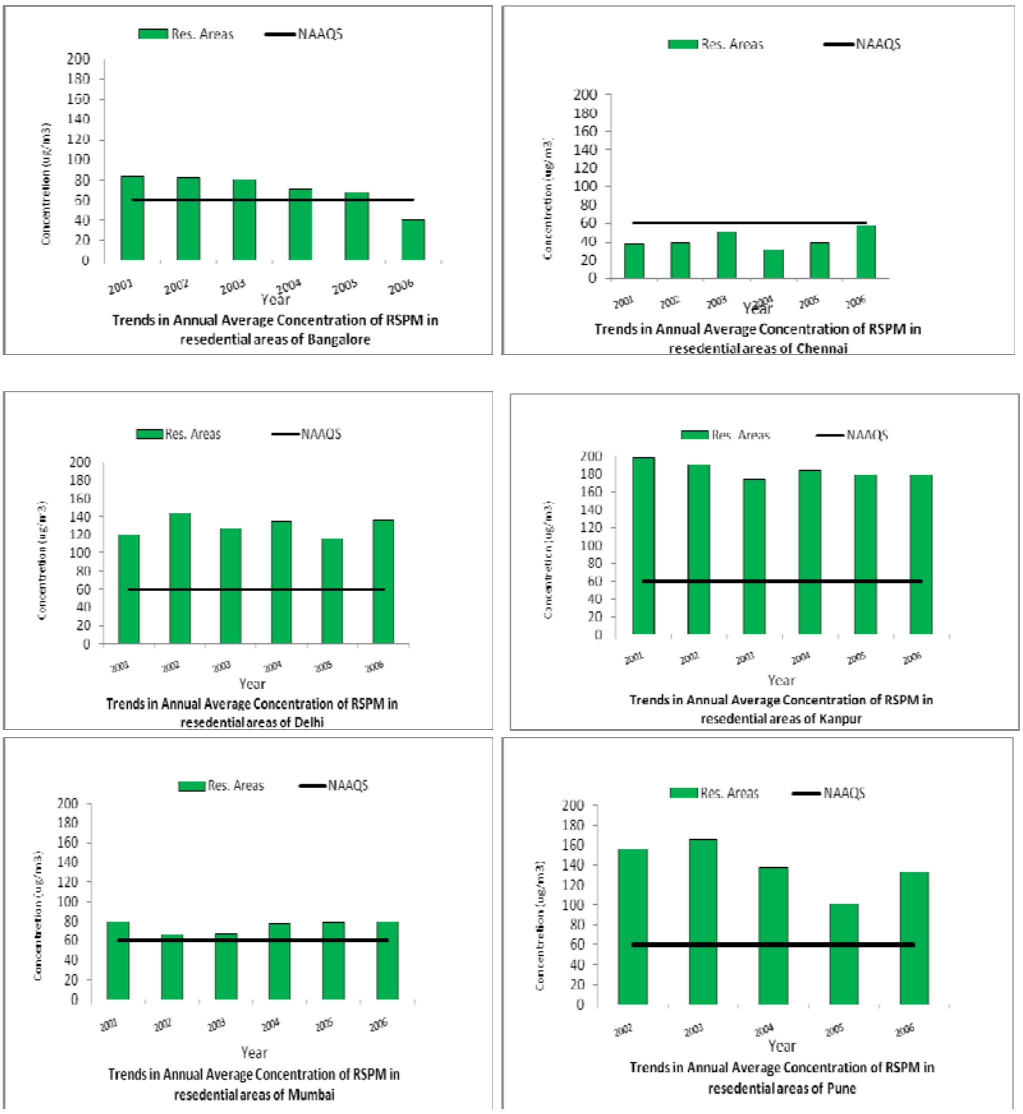
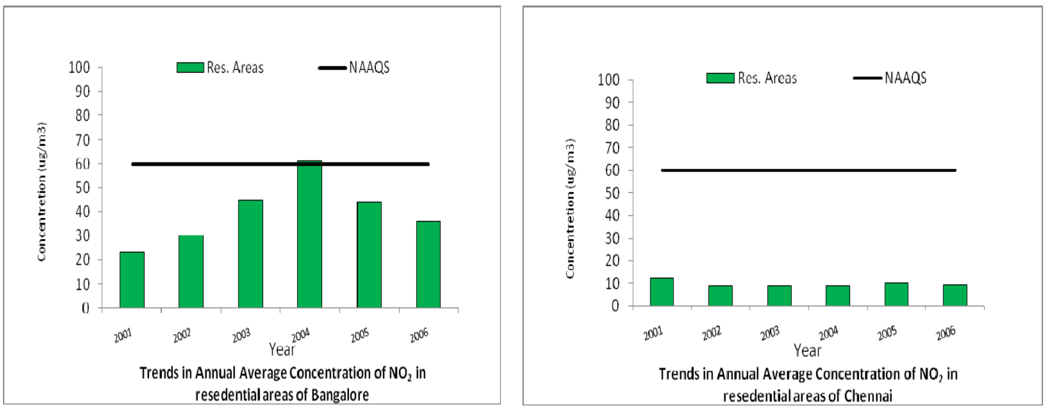


Figure 3.1: Air Quality Trends of RSPM in Residential Areas



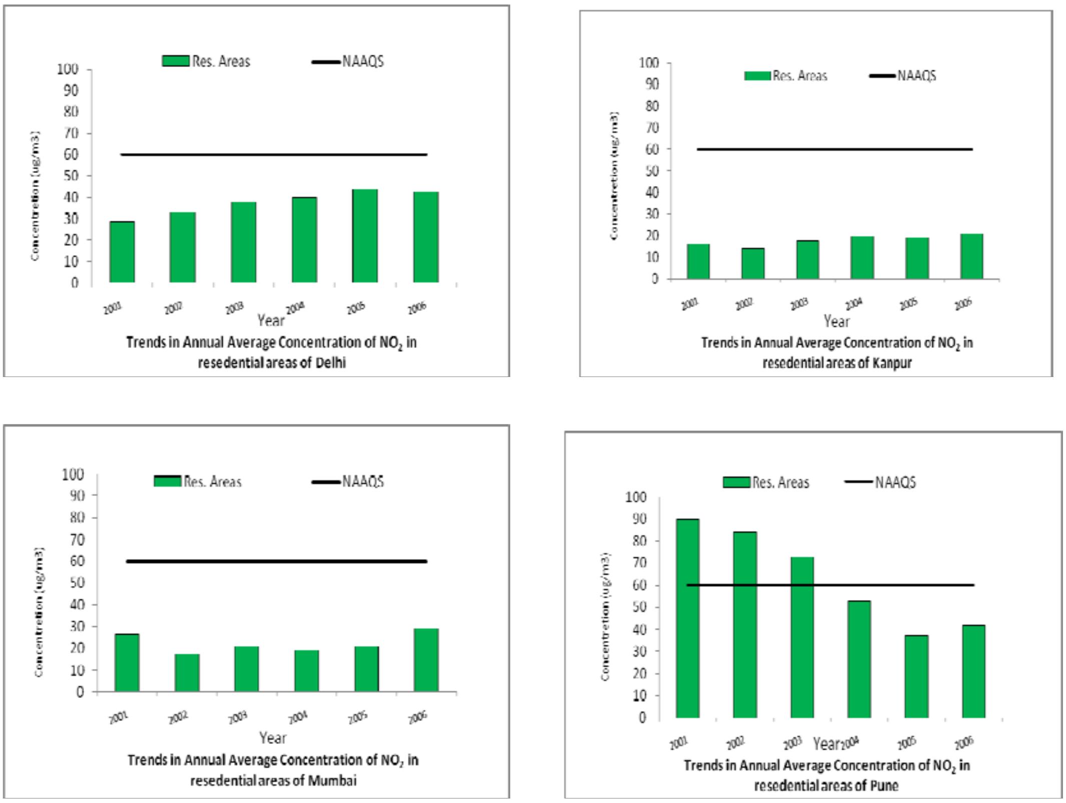
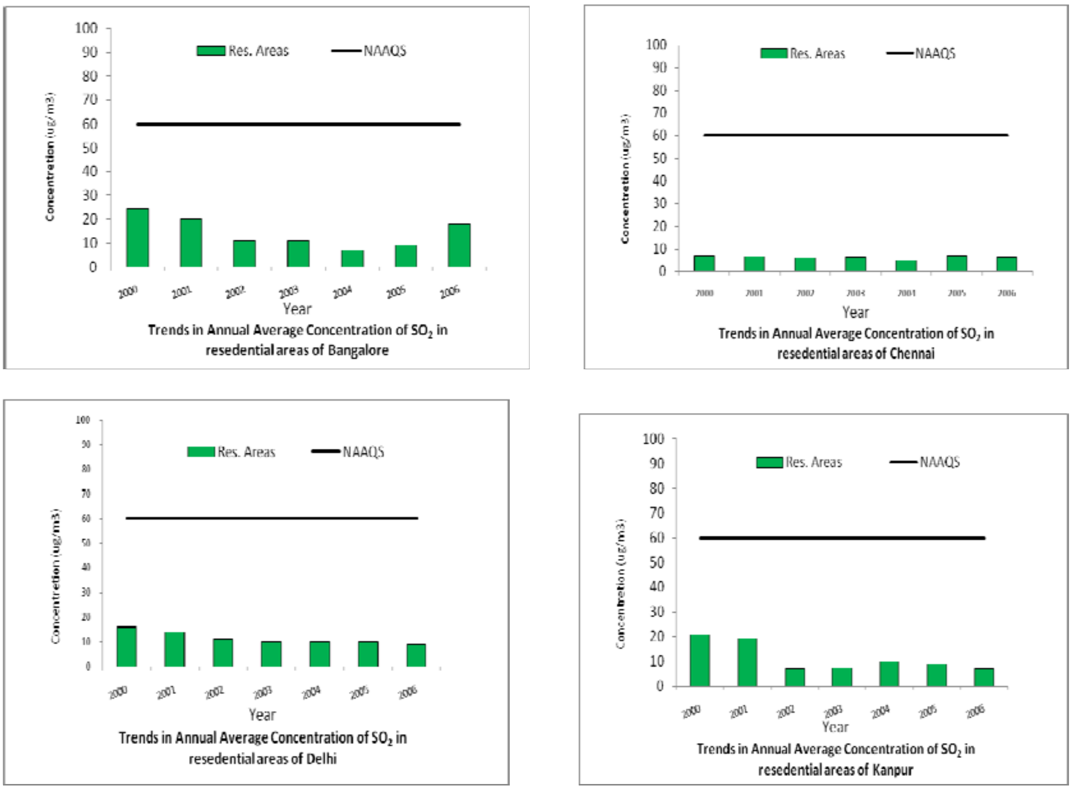
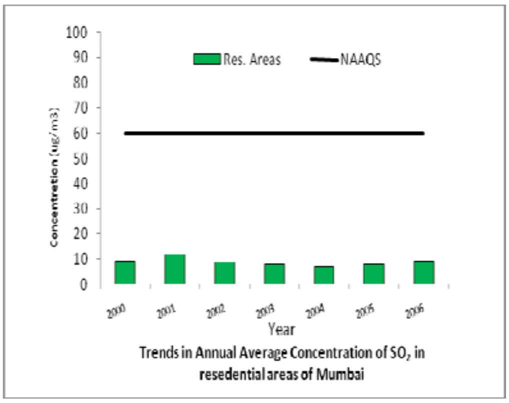


Figure 3.2: Air Quality Trends of NO_2 in Residential Areas





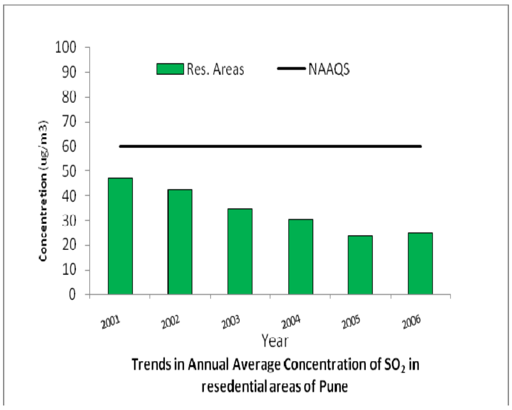


Figure 3.3: Air Quality Trends of SO_2 in Residential Areas

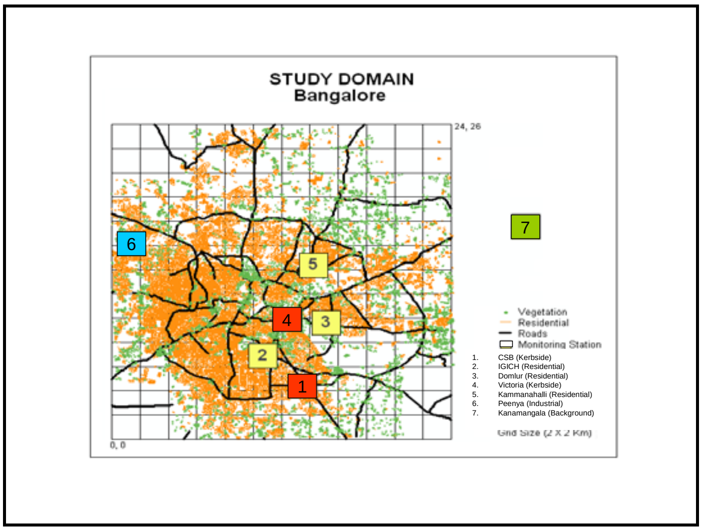
National Ambient Air Quality Standards, prevailing during period of monitoring (i.e. year 2007), and revised standards notified in November 2009 are annexed for reference (Annexure – II and III).

3.2 Ambient Air Quality Monitoring Network Design

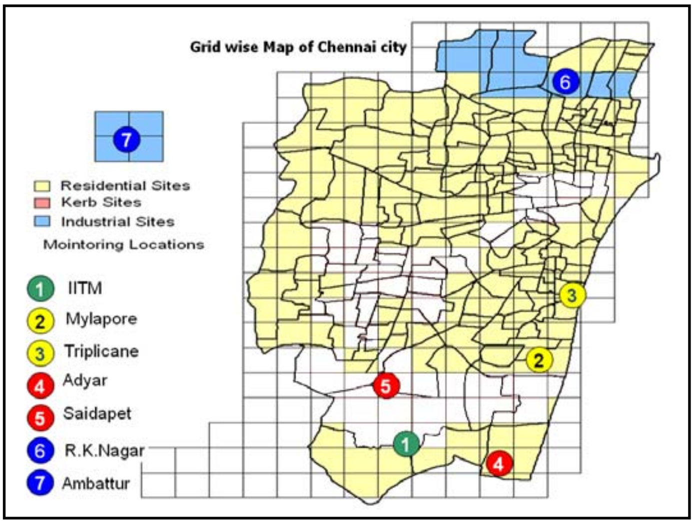
Ambient air quality monitoring network was designed to get spatial and temporal variation of ambient air concentrations addressing a wide range of pollutants that are considered relevant for evolving a strategic management plan.

The primary objective being identification of "Hot Spots" representing maximum impact zone of different land use categories and not mere compliance monitoring, a land use based network design was considered appropriate. Monitoring locations representing different land use namely kerbside, residential, industrial, etc. were selected so as to capture air quality levels under different activity profiles. In addition, one background location (away from all the sources and in upwind direction) was also included. However, in these cities with expanding peripheral activities, it becomes difficult to identify absolute background locations. These are identified, primarily, on the basis wind pattern and least polluting activities. As such, impact of local activities (e.g. Delhi), other distant sources, re-suspension of dust, etc. occurring during monitoring can not be ruled out.

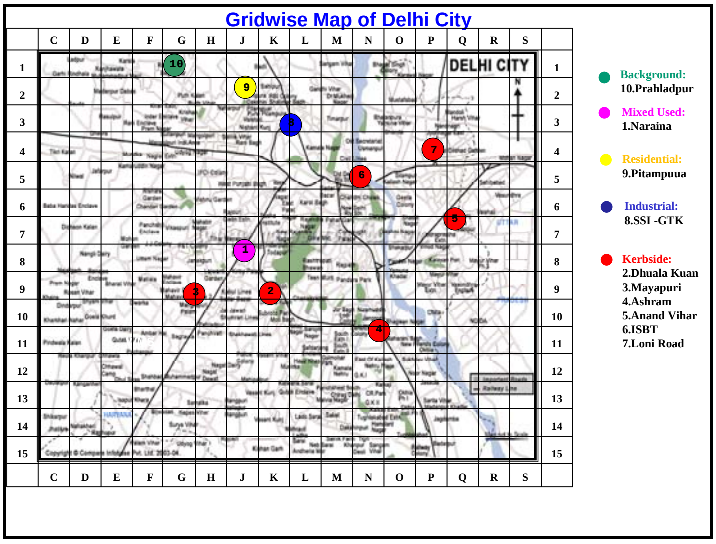
A uniform monitoring network design was followed for all the project cities except for Delhi. The network in each city comprised seven air monitoring stations (with an exception for Delhi having 10 stations). The geographical locations of monitoring sites in different cities are depicted in *Figure 3.4.*



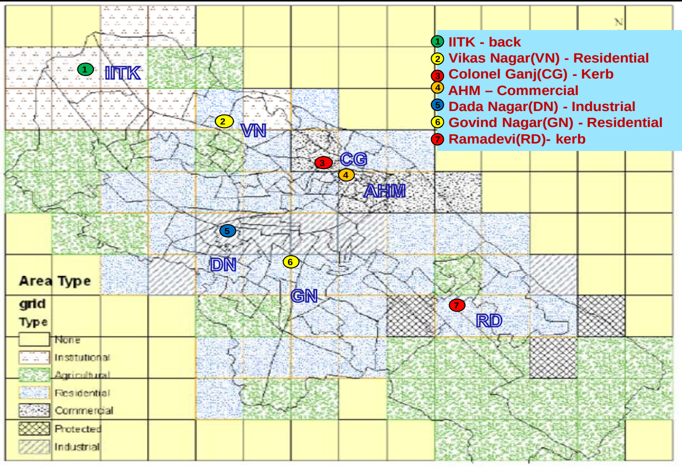
Bangalore



Chennai

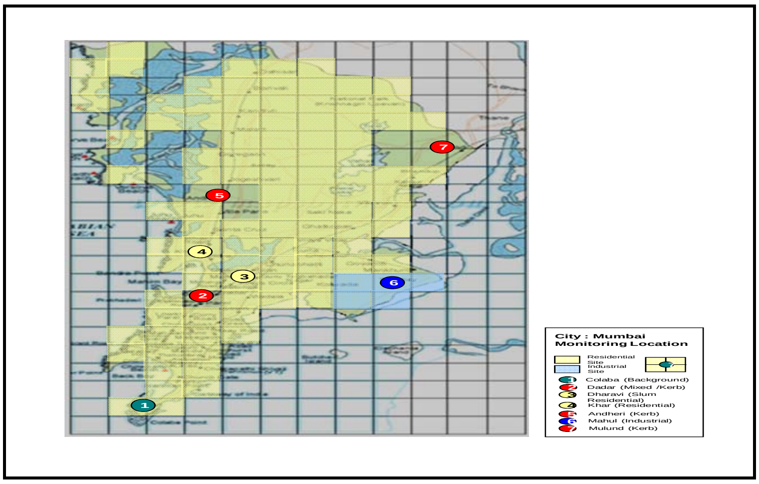


Delhi

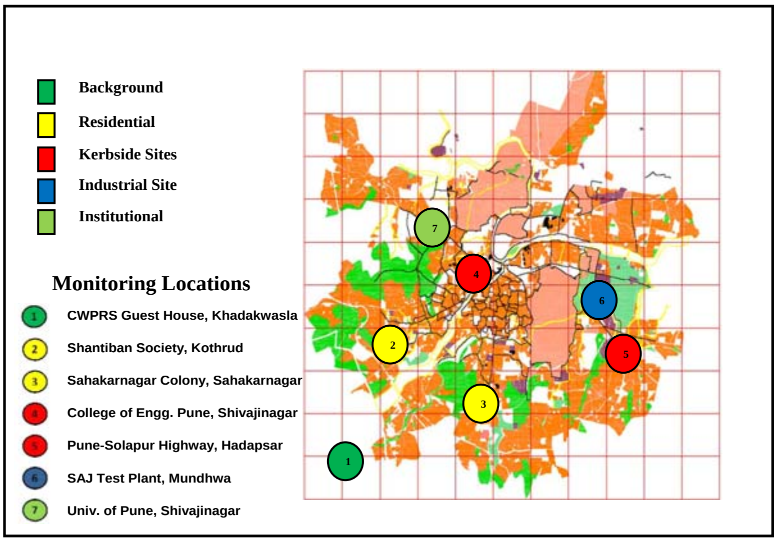


Land Use and Sampling Sites on 2x2 km Grids

Kanpur



Mumbai



Pune

Figure 3.4: Monitoring Locations

In order to address all the expected anthropogenic emission sources (including secondary pollutants) prevailing in the project cities, monitoring of criteria as well as non-criteria pollutants was included in the study. This provided insight to air quality issues including contribution from various sources and extent of presence of secondary pollutants. The major air pollutants covered in this project include: Particulate Matter (TSP, PM_{10} and $PM_{2.5}$), Sulphur Dioxide (SO_2), Oxides of Nitrogen (NO_2), Carbon Monoxide (CO), Ozone (O_3), Benzene (C_6H_6), Formaldehyde (HCHO), Poly Aromatic Hydrocarbon (PAH), etc. The PM_{10} as well as $PM_{2.5}$ samples were collected on different filter media to make detailed analysis of constituent fractions including tracer elements and molecular markers. Monitoring protocol giving details regarding schedule, frequency, averaging period, etc. is provided in Table 3.1. Annexure – IV and V provide description of monitoring sites and actual field sampling period in six cities respectively. The salient features of the network design are as under:

- 20/30 days monitoring for each of the three seasons i.e. summer, post/pre-monsoon and winter.
- Sampling frequency of 08 and 24-hours averaging period covering weekdays and weekends to get air quality corresponding to varied activity profiles was decided.
- 07-10 monitoring stations with one at background and two each in residential, traffic, industrial/commercial locations were selected. However, in case of Delhi, in the initial stages of the study design, wide spread traffic activities and dense road network were under focus. The final monitoring network of Delhi represented kerbside locations under different land-use types.
- Monitoring height was kept within typical exposure range of 3 – 5 m for obtaining ambient air pollution levels.
- PM_{10} and $PM_{2.5}$ being the focus of the study there collected masses were subjected to further analysis for ions, OC, EC, major and trace elements, SO_4^{2-}, NO_3^-, and source specific markers. Such analysis was designed considering requirements of receptor modeling.
- In general, $PM_{2.5}$ monitoring and related analysis had limitations of number of days of sampling besides the days of sampling were not concurrent. Keeping in view the changing scenario of PM control and air quality standards, a limited prospective study was undertaken in this project.

Table 3.1: Monitoring protocol

Particulars	Pollutants						
	SPM	PM_{10}/RPM	SO_2	NO_2	$PM_{2.5}$	CO	VOC
Equipment	High Volume Sampler	Multi-speciation sampler/ Respirable dust sampler (RDS)	Impingers attached to HVS/RDS	Impingers attached to HVS/RDS	FRM sampler	Automatic Analyzer	VOC Sampler
Sampling period	8/24 hrly	8/24 hrly	8/24 hrly	8/24 hrly	8/24 hrly	4/24 hrly/continuous	4/8/24 hrly
Sampling frequency	20/30 days continuous in each of the three seasons	20/30 days continuous in each of the three seasons	20/30 days continuous in each of the three seasons	20/30 days continuous in each of the three seasons	one week continuous in each of the three seasons	one week continuous in each of the three seasons	once in each of the three seasons

3.3 Air Quality Monitoring Results of Project

The air quality sampling stations selected in this study have been categorized based on the predominant land-use pattern at that location; these include background (with limited human activities), commercial/institutional, residential, industrial, kerbside, and traffic. Ambient air was characterized for SPM, PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, Formaldehyde, VOCs (Benzene, 1-3 Butadine) OC, EC, Ions, Elements, Benzene, PAHs and molecular markers. The air quality sampling was conducted for three seasons: summer, post/pre monsoon and winter.

Particulate Matter (SPM, PM_{10}, $PM_{2.5}$), Oxides of Nitrogen (NO_2) and Sulphur Dioxide (SO_2) Levels:

Table 3.2 show summary of SPM, PM_{10}, $PM_{2.5}$, NO_2, and SO_2 levels along with exceedance of 24-hr standard prevailing in 2007 (for $PM_{2.5}$, proposed standard of 60 µg/m^3 has been used). The maximum of the average values reported for different stations in a particular land-use category. Percent exceedance refers to the number of days out of 20/30 days, which have violated the 24-hourly standards in terms of pollutant concentrations. At Kanpur and Delhi, almost at all locations and in all seasons, standards of SPM, PM_{10} and $PM_{2.5}$ have exceeded (except for industrial area). Even the background locations are highly polluted because these locations also fall within the city area and are impacted from the city emissions. Although SPM levels at the industrial sites are also very high, the exceedence has been examined against the industrial area standard of 500 µg/m^3. As expected, Chennai has shown very good air quality for all PM parameters followed by air quality in Bangalore. It can also be seen that for residential area, standards are exceeded by over 90 percent time for PM_{10} except for Chennai and Bangalore. Further as expected at the kerbside in all cities, standards have exceeded on 75 percent of time. For $PM_{2.5}$ as well, standards are exceeded 100 percent of time at kerb stations, industrial and residential areas (except for Bangalore and Chennai). In case of Pune $PM_{2.5}$ standards are exceeded 100 percent of time at kerb stations only. NO_2 levels generally exceed the ambient air quality standards at kerbside locations, particularly during winter and post monsoon seasons (Bangalore 60 – 65%), Delhi 85 – 95%, Mumbai 20 – 43% and Pune 0 – 50%). In addition, the standards are also exceeded at residential locations in Delhi (35 – 65%) & Mumbai (07 – 25%), and Industrial location in Delhi (80 – 85%). During summer, the values are comparatively low. This analysis shows that PM pollution problem is severe and NO_2 is the emerging pollutant that requires immediate planning to control its emissions.

Out of three prominent seasons (winter, post-monsoon, and summer) adopted in the study design, the worst season data (post-monsoon in case of Chennai and Delhi, winter for other cities) have been considered for further analysis. Figure 3.5 presents the box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 concentrations at background locations. The upper and lower limits of box indicate 3/4th and 1/4th percentile values; and top, middle and lower lines indicate maximum, median and minimum concentration values, respectively. It can again be seen that in terms of PM pollution, Delhi and Kanpur show highest air pollution levels. Further the box plots show the variability in the observed values. Observations at Delhi and Mumbai show much higher variability than any other city. What is more alarming is the fact that SPM and PM_{10} standards are exceeded even at the background site supposed to have limited human activity with the exception of Chennai and Bangalore. As regards NO_2, levels are well within the standards except for Mumbai and in addition, Mumbai data show maximum variability for NO_2 levels.

Figure 3.6 presents the box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 concentrations at residential locations. It can be seen that in terms of SPM, standards are exceeded in all cities and most cities it is exceeded for 100 percent of time. Standards also exceed in the residential areas of all cities for PM_{10} except for Bangalore and Chennai. Similar to background locations, Delhi and Kanpur show the highest pollution levels. For $PM_{2.5}$, the pollution levels are the highest in Kanpur – Kanpur incidentally had more observations for $PM_{2.5}$ than other cities. What is interesting to note is the fact that Delhi show very high variability in PM levels (both for PM_{10} and $PM_{2.5}$). NO_2 levels exceed at the residential area sites in Delhi (35%), Pune (6%) and Mumbai (25%). Similar to background location, NO_2 levels at Mumbai show highest variability.

Figure 3.7 presents the box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 concentrations at industrial area sites in six cities. It can be seen that pollution levels are the highest at industrial sites (e.g. SPM, maximum ~ 1400 $\mu g/m^3$ and PM_{10} maximum 1000 $\mu g/m^3$ in Delhi) in all cities compared to their corresponding residential and background locations. The standard exceedence has not been analyzed here as the acceptable standard for the industrial area in terms of SPM, PM_{10} is much higher (500 $\mu g/m^3$ for SPM and 200 $\mu g/m^3$ for PM_{10}) than the standards applicable in residential areas. Delhi for SPM and PM_{10} show highest variability but for NO_2 the highest variability is at industrial site at Bangalore.

Figure 3.8 presents the box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 concentrations at the kerbside area in six cities. It can be seen that pollution levels are similar to the industrial sites but for NO_2. The NO_2 levels are much higher at kerbside locations indicating clear influence of vehicles on air quality. It may be noted that Delhi once again shows the highest pollution at the kerbside locations compared to all other cities. Cities like Kanpur, Pune and Mumbai show similar PM_{10} (250-300 $\mu g/m^3$). In case of NO_2, Pune and Mumbai show similar (70-80 $\mu g/m^3$) levels however, in Kanpur NO_2 levels are lower (46 $\mu g/m^3$).It is interesting to note that Bangalore has shown very high NO_2 level (94 $\mu g/m^3$). It signifies that while PM background levels being low the overall PM_{10} levels at kerbside locations in Bangalore may not be high but vehicular NO_2 contribution is very high at Bangalore. As for all land-use sites, variability in the concentration is the highest in Delhi.

Mumbai and Kanpur had sampling sites in a commercial area. The results of sampling at these locations (Fig. 3.9) show high PM levels at Kanpur, largely due to much higher background pollution of PM at Kanpur. However, this is to be noted that NO_2 level at the commercial site at Mumbai is much more (40-150 $\mu g/m^3$) than at Kanpur, suggesting much higher pollution of NO_2 in Mumbai.

Table 3.2: Average Air Quality Levels (in µg/m³) and Percent Exceedances with respect to 24-hourly average Standard*:

		SPM						PM10						PM2.5					
		W*		P**		S***		W		P		S		W		P		S	
		Mean	%E	Mean	%E	Mean	%E	Mean	%E	Mean	%E	Mean	%E	Mean	%E	Mean	%E	Mean	%E
Background	Bangalore	110	0	82	0	83	0	47	0	105	32	66	10	27	0	23	0	27	0
	Chennai	117	17	76	0	178	22	55	0	88	50	71	31	35	14	39	0	34	14
	Delhi	549	100	546	100	517	100	355	100	300	100	232	100	--	--	--	--	131	100
	Kanpur	361	100	329	93	342	97	204	97	169	97	187	90	172	100	132	100	136	100
	Mumbai	246	63	204	57	159	17	184	97	139	86	91	39	92	67	60	33	29	0
	Pune	257	95	204	65	139	5	123	60	63	5	76	10	45	0	32	0	22	0
Residential	Bangalore	294	100	301	100	177	25	133	88	93	35	69	14	36	0	41	33	29	0
	Chennai	164	19	173	14	175	24	82	25	200	46	86	23	78	86	34	0	34	0
	Delhi	828	100	967	100	284	90	505	100	671	100	81	40	301	100	--	--	30	0
	Kanpur	429	100	373	97	422	100	226	100	195	100	217	100	208	100	161	100	190	100
	Mumbai	523	100	445	100	277	54	267	100	236	100	119	48	97	100	87	100	54	33
	Pune	499	100	362	95	206	50	165	95	128	72	103	58	58	0	35	0	28	0
Industrial	Bangalore	262	0	245	0	171	0	171	81	171	50	69	5	30	0	21	0	22	0
	Chennai	311	8	348	11	319	5	138	31	147	44	141	38	67	57	41	0	79	30
	Delhi	965	100	1239	100	611	70	546	100	781	100	229	8	197	100	314	100	52	100
	Kanpur	603	62	577	58	591	61	396	76	371	74	388	74	305	100	273	100	232	100
	Mumbai	395	3	388	0	238	3	271	100	218	96	99	7	127	100	87	100	17	0
	Pune	400	25	164	0	270	0	216	85	71	10	121	22	63	33	26	0	37	0
Kerbside	Bangalore	306	100	287	93	411	100	199	100	184	85	109	43	64	50	43	33	38	0
	Chennai	350	78	243	59	211	36	111	48	128	77	271	67	73	57	56	29	51	14
	Delhi	1082	100	2592	100	#####	100	451	100	941	100	337	100	306	100	361	100	107	100
	Kanpur	564	100	532	100	561	100	292	100	260	100	273	100	216	100	226	100	218	100
	Mumbai	383	100	383	100	314	8	256	100	234	100	124	65	119	100	126	100	41	18
	Pune	655	100	583	100	507	100	254	100	193	95	138	95	124	100	62	67	46	0

* Standard refer to 24 hourly average standards as prevailing in 2007; PM2.5 standards refers to the proposed standards in 2007

Table 3.2: Contd…

		NO_2						SO_2					
		W		P		S		W		P		S	
		Mean	%E	Mean	%E	Mean	%E	Mean	%E	Mean	%E	Mean	%E
Background	Bangalore	18	0	45	18	91	56	6	0	14	0	9	0
	Chennai	27	0	8	0	14	0	3	0	1	0	5	0
	Delhi	31	0	33	0	25	0	8	0	15	0	8	0
	Kanpur	23	0	20	0	20	0	8	0	8	0	4	0
	Mumbai	53	10	38	0	18	3	15	0	13	0	5	0
	Pune	36	0	34	0	10	0	23	0	10	0	5	0
Residential	Bangalore	46	0	29	0	90	46	9	0	15	0	15	0
	Chennai	32	0	17	0	28	0	4	0	3	0	3	0
	Delhi	73	35	88	65	29	0	14	0	18	0	78	0
	Kanpur	49	0	32	3	19	0	14	0	8	0	4	0
	Mumbai	72	25	60	7	25	0	12	0	13	0	6	0
	Pune	41	6	43	0	14	0	18	0	11	0	6	0
Industrial	Bangalore	53	6	30	0	89	44	9	0	10	0	10	0
	Chennai	45	0	20	0	42	0	6	0	4	0	6	0
	Delhi	159	85	142	80	60	0	85	20	77	20	11	0
	Kanpur	35	0	24	0	23	0	26	0	19	0	15	0
	Mumbai	72	0	53	0	20	0	18	0	15	0	7	0
	Pune	55	0	17	0	22	0	40	0	16	0	22	0
Kerbside	Bangalore	94	62	105	65	66	26	10	0	19	0	13	0
	Chennai	45	0	33	0	43	0	6	0	1	0	4	0
	Delhi	109	85	121	95	47	0	20	0	20	0	12	0
	Kanpur	46	0	42	7	37	0	15	0	9	0	8	0
	Mumbai	82	43	64	20	33	2	14	0	15	0	6	0
	Pune	71	50	43	0	59	20	36	7	12	0	7	0

% Exceedance	0-25	25-50	50-75	75-100

* W: Winter
** P: Post Monsoon, Summer in case of Bangalore
*** S: Summer, Pre Monsoon in case of Bangalore

Background:

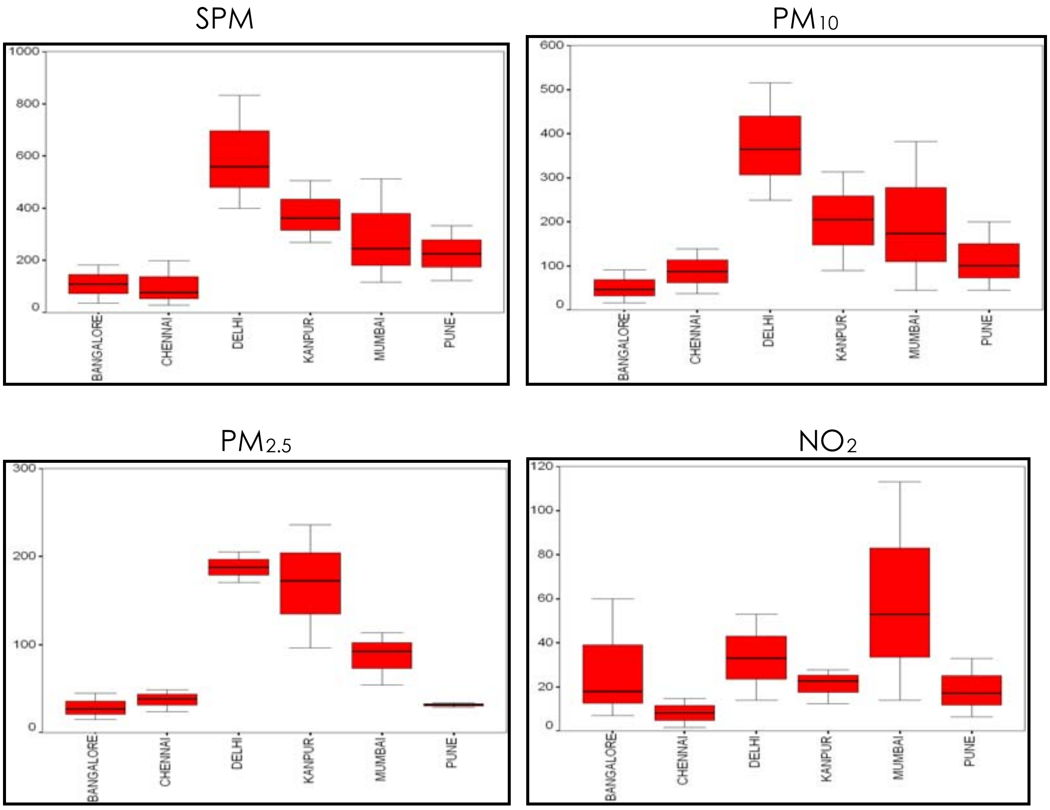
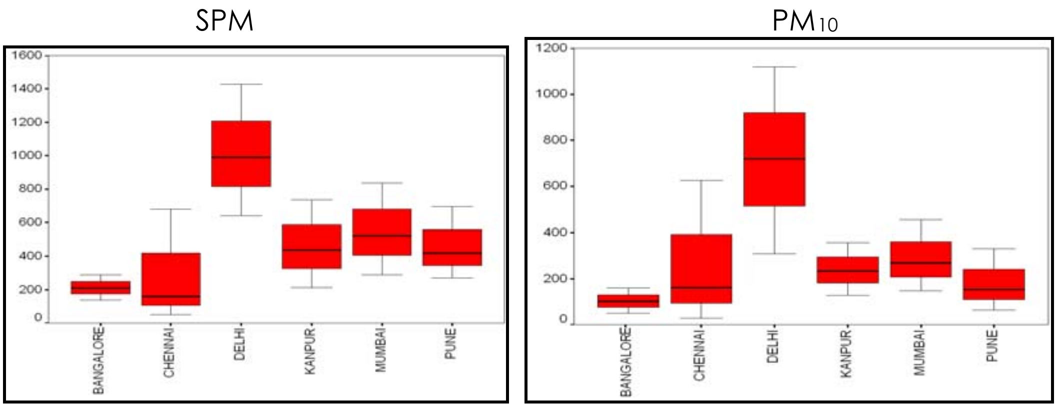


Figure 3.5: Box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 Concentrations (in µg/m³) at Background Locations

Residential:



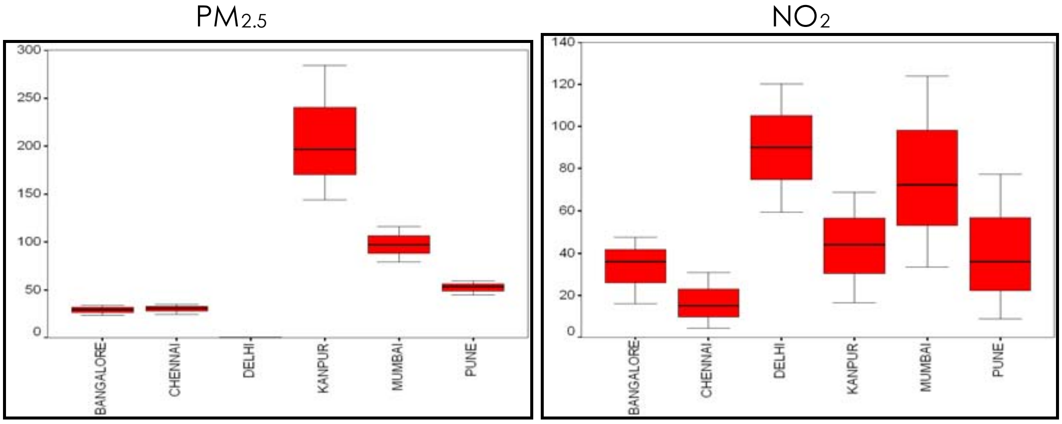


Figure 3.6: Box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 Concentrations (in µg/m³) at Residential Locations

Industrial:

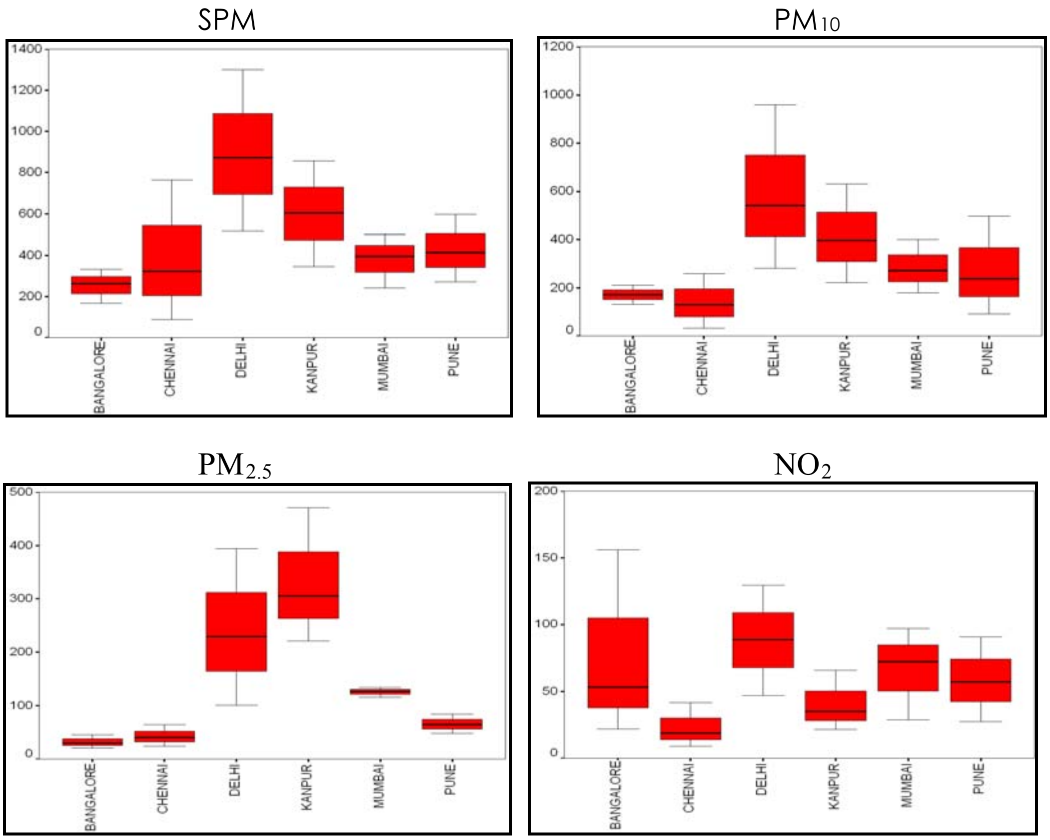


Figure 3.7: Box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 Concentrations (in µg/m³) at Industrial Locations

Kerbside:

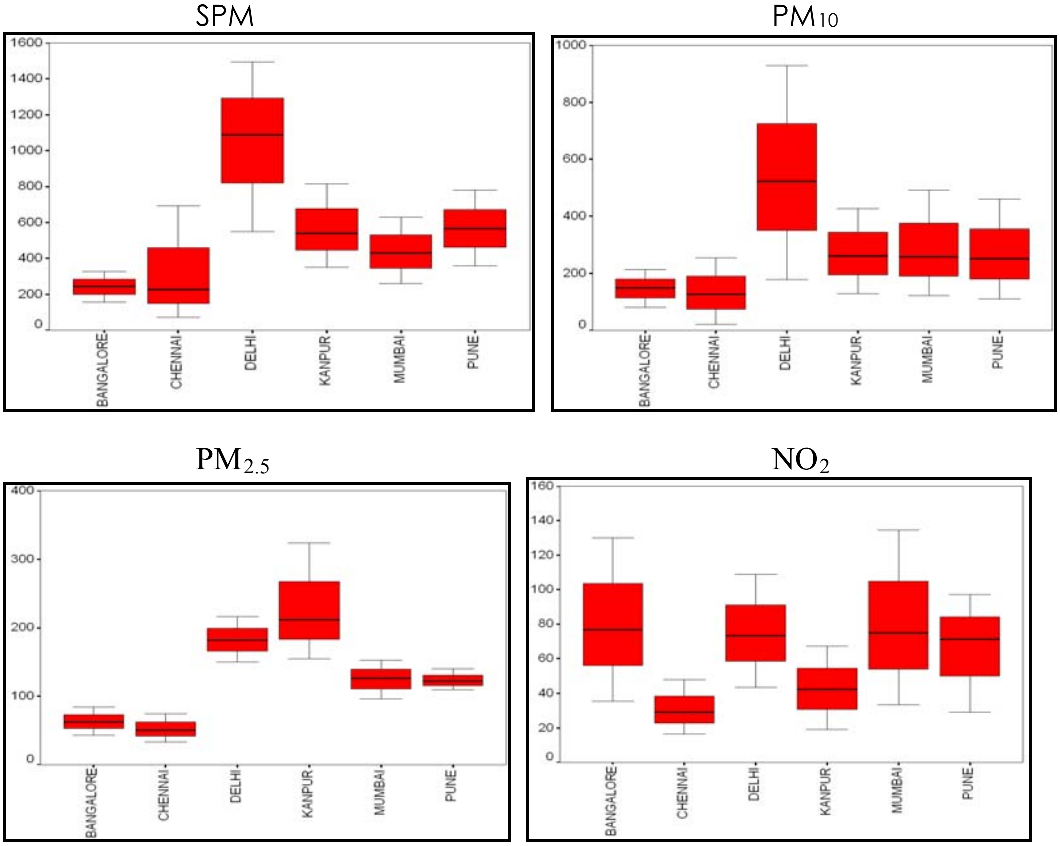
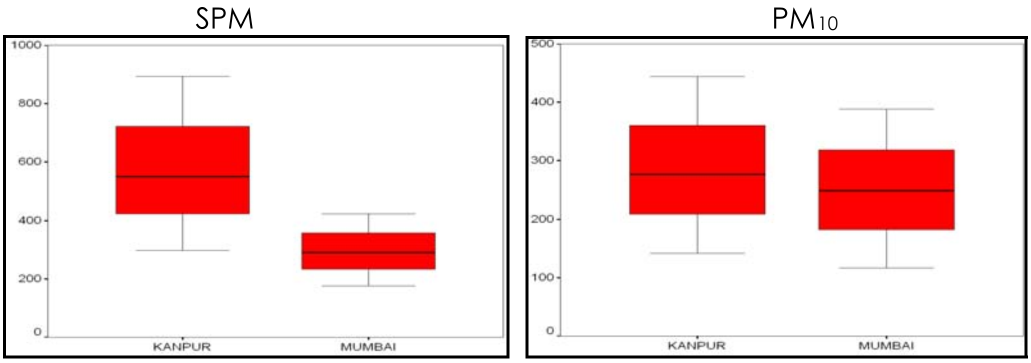
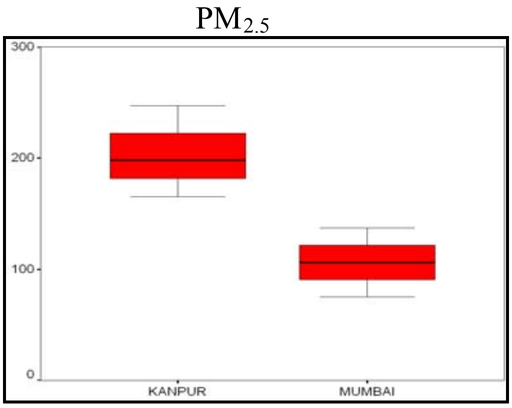


Figure 3.8: Box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 Concentrations (in µg/m³) at Kerbside Locations Commercial

Commercial:





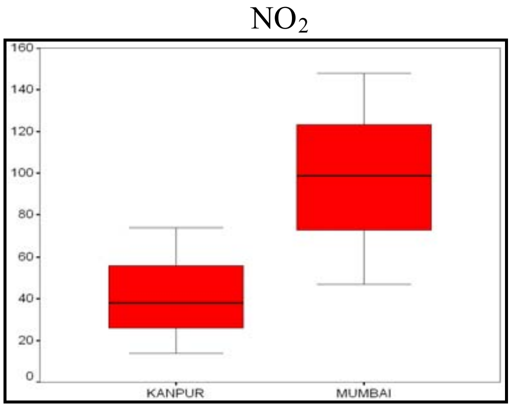


Figure 3.9: Box plots of SPM, PM_{10}, $PM_{2.5}$ and NO_2 Concentrations (in µg/m^3) at Commercial Locations

Carbon Monoxide (CO) and Ozone (O_3) Levels:

In order to study the diurnal variations of one primary pollutant (ambient air CO) and one secondary pollutant (O_3) that have direct correlation with temporal profile of vehicular activities, these parameters were monitored for one week in each season using real time monitoring system. All six cities measured CO levels at the kerbside to directly examine the impact of vehicles, whereas O_3 has been measured in four cities (Bangalore, Delhi, Mumbai, and Pune).

A typical day monitoring data of CO is shown in Figures 3.10 – 3.14 for Bangalore, Chennai, Delhi, Pune and Kanpur. Hourly concentrations may exceed marginally the standard of 4000 µg/m^3 for CO at Delhi, Chennai and Kanpur. It is expected that the CO levels will quickly drop off as one move away from the road and as such the levels will not pose any health effect. It can also be seen that in all cities, there are morning and evening peaks in CO levels corresponding to vehicular movement. However, Delhi experiences higher concentration of CO during night hours. The possible reason for this could be building up of concentrations due to unfavourable meteorological conditions, and substantial vehicular movements till late in the night.

A typical day monitoring data of O_3 are shown in Figures 3.15 – 3.18 for Bangalore, Delhi, Pune and Mumbai. Hourly concentrations is not exceeding standard of 180 µg/m^3 (= 90 ppb) at any of the locations. It is to be noted that there is no definite trend in O_3 concentration over the day. Although one would expect higher ozone concentration around 1-3 pm but good dilution and high speed winds as a possibility, might, have brought down the concentration. It can be concluded that at the sites, where limited O_3 monitoring was done, the observed concentrations were not significant.

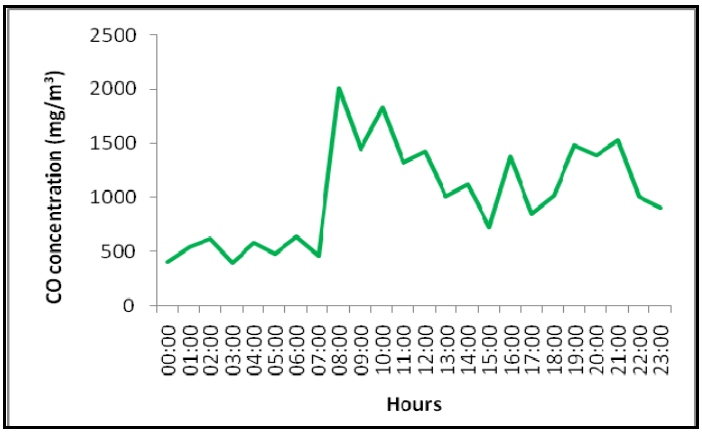


Figure 3.10: CO concentration at Kerbside location in Bangalore

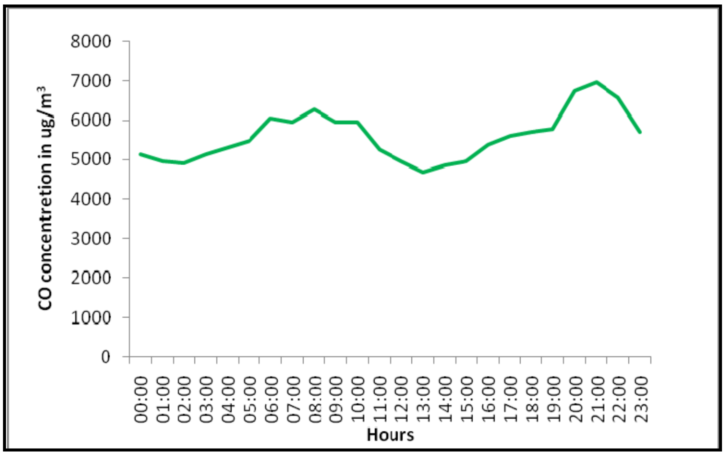


Figure 3.11: CO concentration at Kerbside location in Chennai

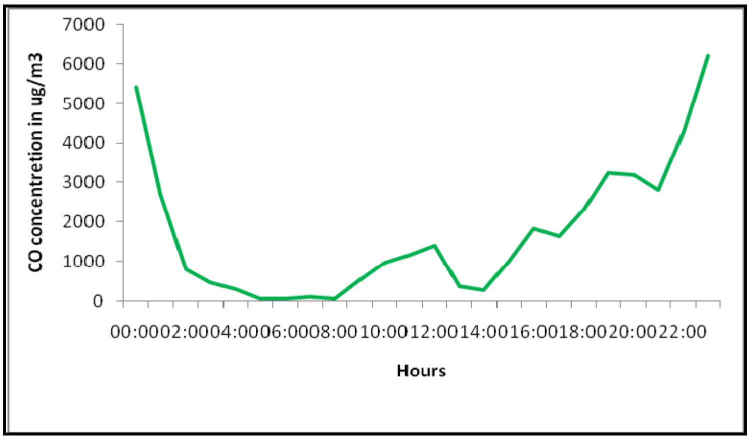


Figure 3.12: CO concentration at Kerbside location in Delhi

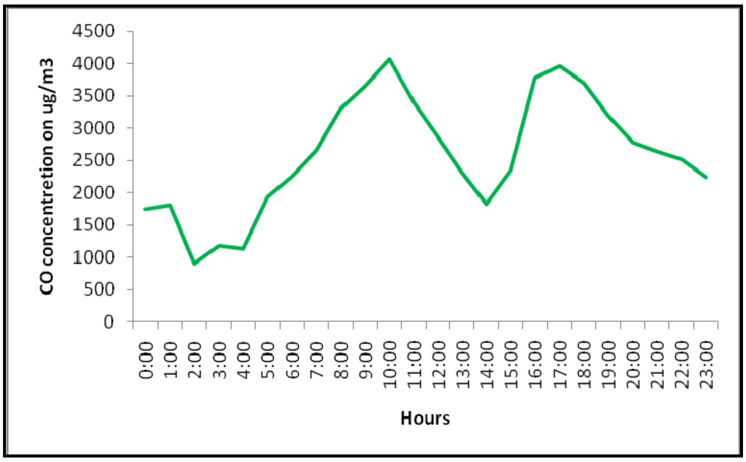


Figure 3.13: CO concentration at Kerbside location in Kanpur

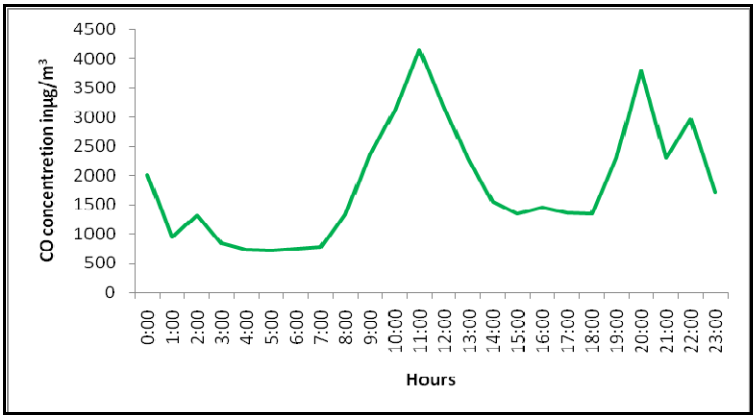


Figure 3.14: CO concentration at Kerbside location in Pune

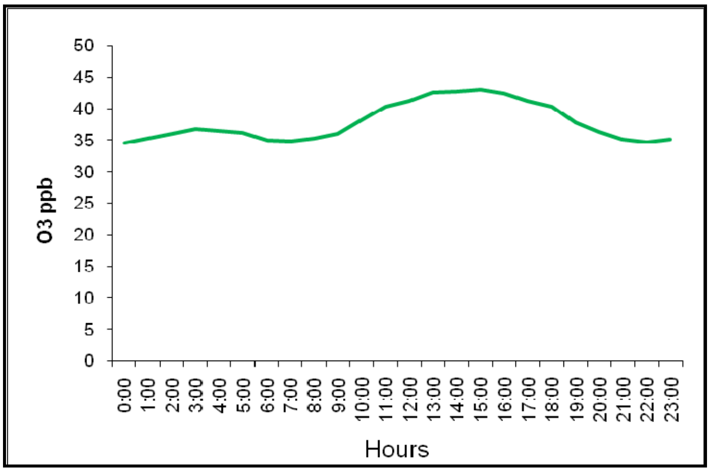


Figure 3.15: Temporal variation of O_3 concentration in Bangalore

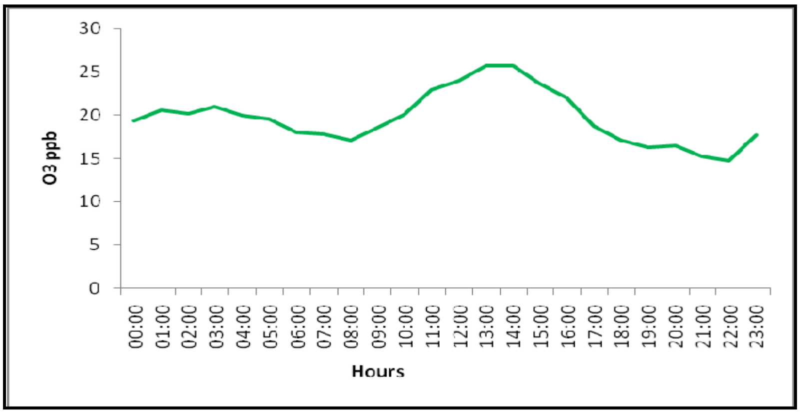


Figure 3.16: Temporal variation of O_3 concentration in Delhi

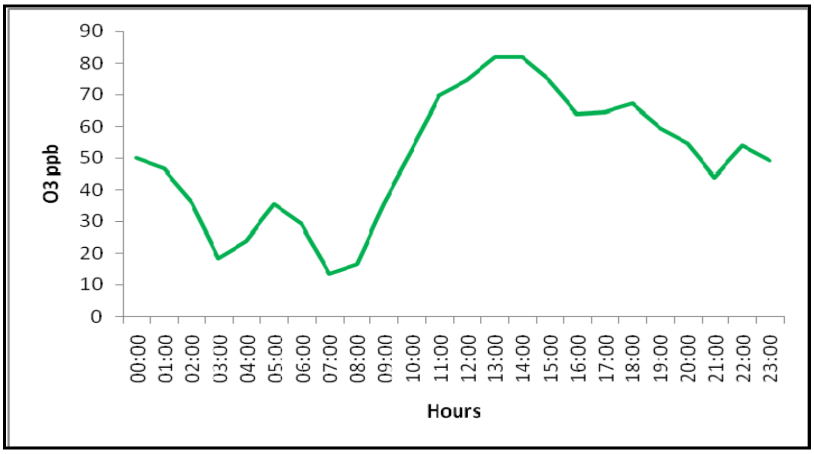


Figure 3.17: Temporal variation of O_3 concentration in Mumbai

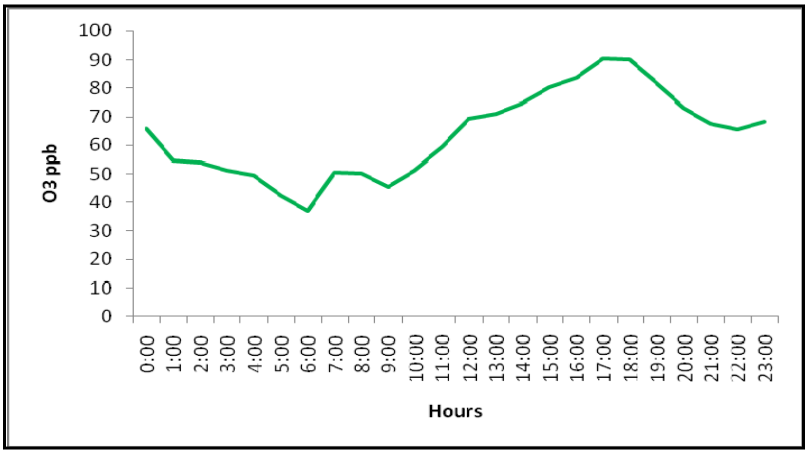


Figure 3.18: Temporal variation of O_3 concentration in Pune

Levels of Other Pollutants:

In addition to criteria pollutants, other pollutants such as Benzene, 1-3 Butadiene, Formaldehyde, Non-Methane and Total Hydrocarbon (NMHC & THC), expected in urban environment were also monitored. However, monitoring of these parameters was limited to once in each of the three seasons at each monitoring location. Summary of data of these pollutants is given in Table 3.3. The ambient concentration levels are primary governed by the contributing sources in the neighborhood, and vide variations were observed in different cities.

Benzene levels are higher in Bangalore, Pune and Kanpur. The values of formaldehyde are also matter of concern in Mumbai, Pune and Bangalore. However, more work is required to be done in future for proper understanding of these pollutants.

Table 3.3: Concentration of Organic Pollutants

	Benzene (μg/m³)			**1,3- Butadiene** (ppb)			**Formaldehyde** (μg/m³)			**NMHC** (ppm)			**HC** (ppm)		
city	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
Bangalore	7.4	237.8	119.1	0.41	3.7	2.18	8	35	20	8	12	11	9	15	13
Chennai	4	17	10.2	0.452	1.8	1.1	1.7	26	12.1	0.02	0.18	0.06	0.02	0.18	0.06
Delhi	1.92	11.19	4.96	0.2	1.6	0.78	1.94	19.0	11.27	0.2	1.7	0.9	2.6	5.3	3.7
Kanpur	4.88	68.11	26.86	-	-	-	4.39	18.43	10.08	0.06	0.255	0.14	0.07	0.26	0.15
Mumbai	Not monitored			Not monitored			8.8	93.0	32.6	0.1	24.6	2.3	1.5	25.5	4.6
Pune	28.14	96.53	57.30	0.4	2.5	1.2	3.77	41.12	17.12	1.32	3.82	2.55	1.74	4.22	2.96

3.4 Chemical Characterization of Particulate Matter

PM_{10} and $PM_{2.5}$ samples were also subjected to extensive chemical characterizations for 36 major and trace elements and 11 ions (including NO_3^-, SO_4^{2-}, NH_4^+), OC, EC, along with wide range of molecular markers (18 in numbers) for representing typical urban emission sources in India. Before undertaking receptor modeling, the chemical characteristics of PM_{10} as well as $PM_{2.5}$ were analyzed to assess the contribution of sources. Results of chemical speciation are presented below:

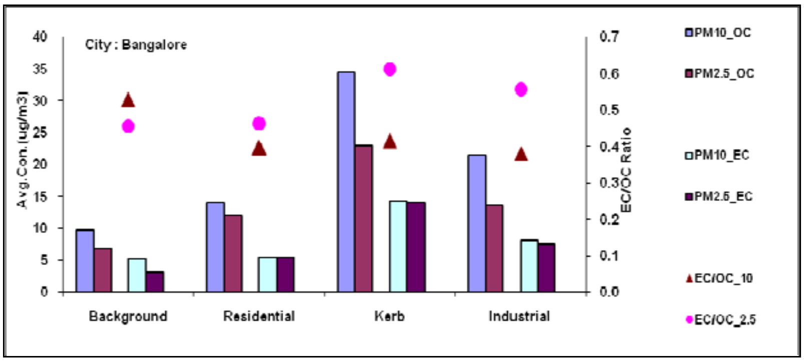
Elemental Carbon (EC), Organic Carbon (OC), Sulphate (SO_4^{2-}) and Nitrate (NO_3^-) in PM_{10} and $PM_{2.5}$:

Figures 3.19 – 3.24 show the chemical composition of both PM_{10} and $PM_{2.5}$ for EC, OC, SO_4^{2-}, and NO_3^- for the cities of Bangalore, Chennai, Delhi Kanpur, Mumbai and Pune. These parameters constitute important fraction both from public health point of view and as indicators for source group contribution at a particular location of sampling. It is important to mention that the results correspond to PM_{10} samples of 20/30 days and $PM_{2.5}$ samples of one week. The following important information and interpretations can be obtained from the EC- OC plots.

- In all cities, OC (organic carbon) levels are always much higher (2 - 4.5 times) than EC levels. The ratio of EC/OC is variable from one location to another, indicating that sources, those contribute to particulate pollution, are variable.
- In general EC and OC levels relate well with PM_{10} levels. It can be seen that Delhi and Kanpur showed the high pollution levels for PM_{10} and these two cities also show high EC and OC levels. EC levels: 15-20 µg/m^3 at Delhi and 15- 40 µg/m^3 at Kanpur; OC Levels: 50 – 100 µg/m^3 in Delhi and 35 – 105 µg/m^3 at Kanpur. The levels in other cities range 5 – 20 µg/m^3 for EC and 10 – 45 µg/m^3 for OC.
- EC and OC almost account for 20-45 percent of PM_{10}, inclusive of all cities which are quite high and reflect as to how badly the cities are affected because of combustion and/or fuel related emissions.
- High EC to OC ratio represents freshly contributed diesel/petrol/coal combustion particles. Many cities have shown this ratio to be high at kerbside and industrial locations.
- There are significant quantities of SO_4^{2-} and NO_3^-, (10-15% in most cities and 20-30% in Kanpur) in PM_{10} indicating contribution of secondary particles. These contributions are even high at the background upwind direction in all cities. It signifies long-range transport of particles in the city as well as formation of secondary particles in the city. Any control strategy for reduction of secondary particulate will have to consider control of SO_2, NO_x and NH_3.
- NO_3^{2-} concentrations at background sites are generally lower as compared to other sites. The instances of its higher concentrations are

due to reported local activities and contribution from nearby settlements.

- EC and OC contribution to $PM_{2.5}$ is even more than what it is to PM_{10}, and it varies from one city to another. Chennai has shown a very high EC and OC content (60-75% in $PM_{2.5}$), followed by Bangalore (35-50%), Delhi (30-45%), Mumbai (30-40%), Pune (25-40%) and Kanpur (25-35%). It signifies an important point that $PM_{2.5}$ has much higher component of toxic EC and OC and that mostly come from combustion sources like vehicles, coal, biomass, garbage combustion, and others.



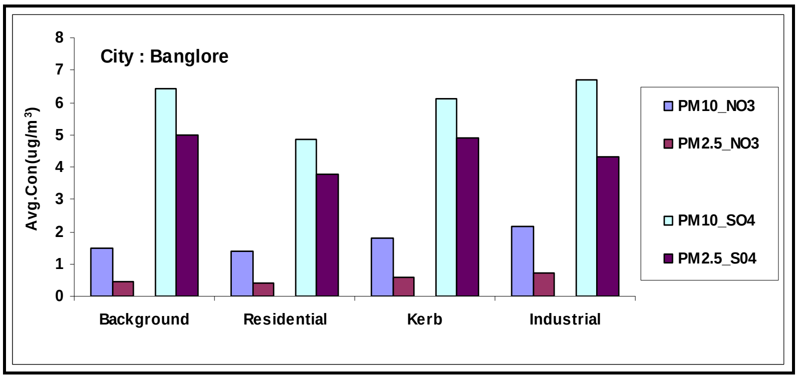
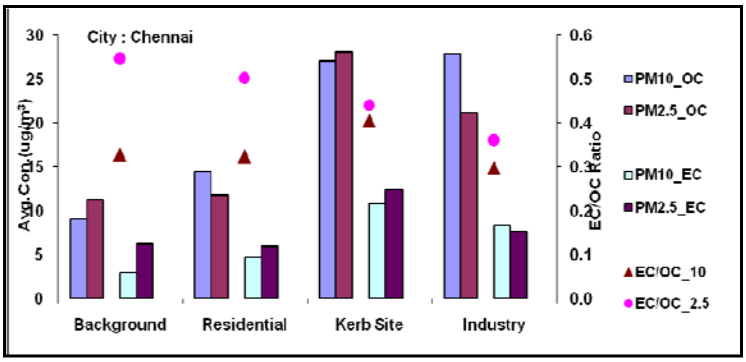


Figure 3.19: EC/OC and SO_4^{2-}/NO_3^-, in PM_{10}/$PM_{2.5}$ in Bangalore



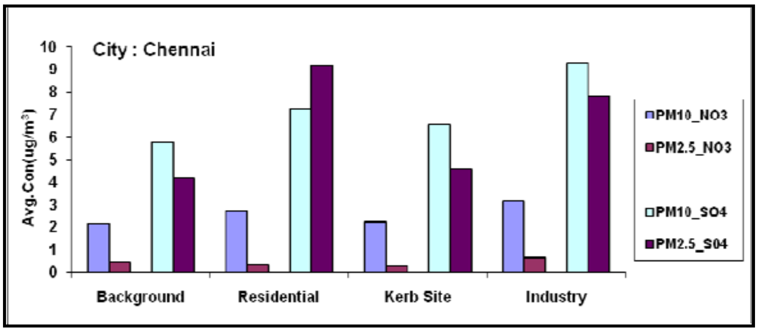


Figure 3.20: EC/OC and SO_4^{2-}/NO_3^-, in $PM_{10}/PM_{2.5}$ in Chennai

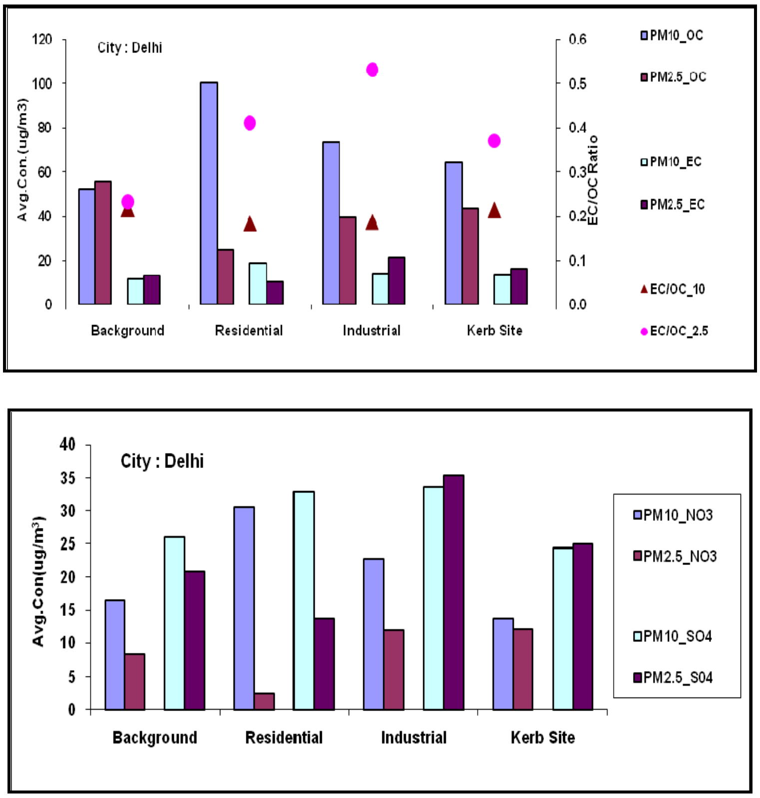
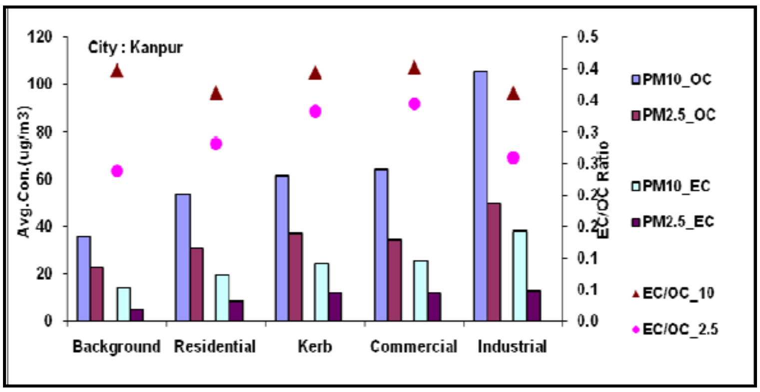


Figure 3.21: EC/OC and SO_4^{2-}/NO_3^-, in $PM_{10}/PM_{2.5}$ in Delhi



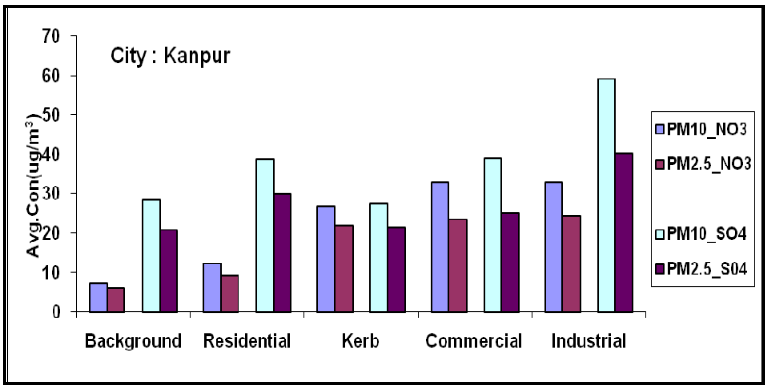


Figure 3.22: EC/OC and SO_4^{2-}/NO_3^-, in $PM_{10}/PM_{2.5}$ in Kanpur

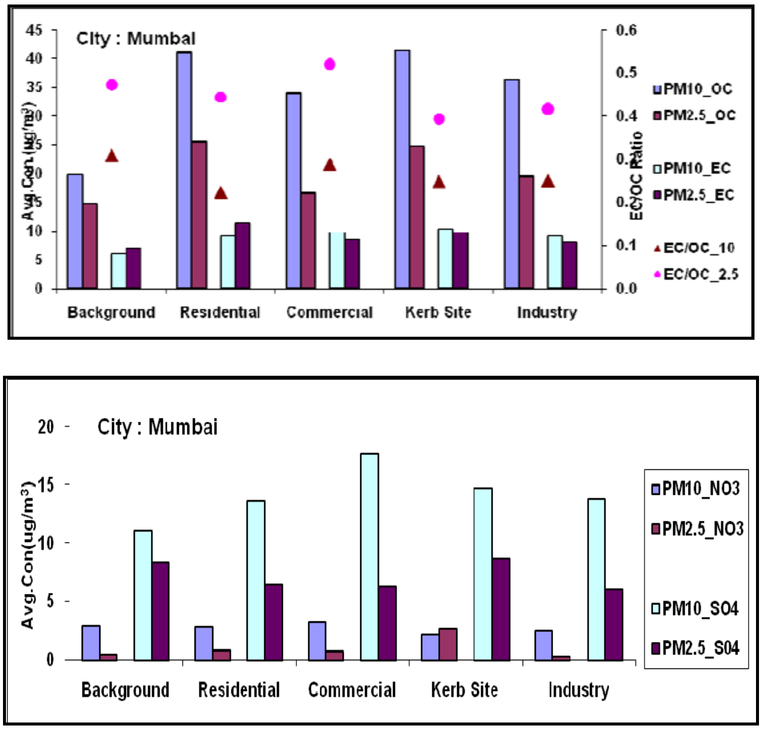
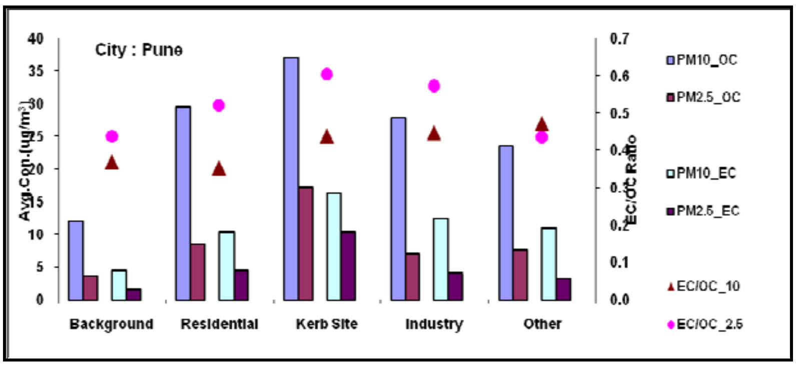


Figure 3.23: EC/OC and SO_4^{2-}/NO_3^-, in $PM_{10}/PM_{2.5}$ in Mumbai



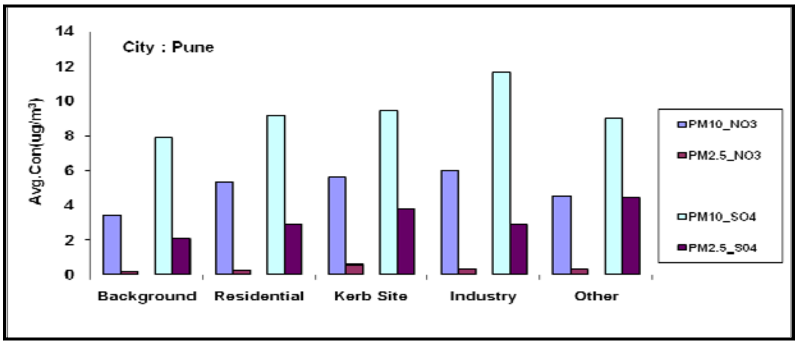


Figure 3.24: EC/OC and SO_4^{2-}/NO_3^-, in $PM_{10}/PM_{2.5}$ in Pune

Mass Closure:

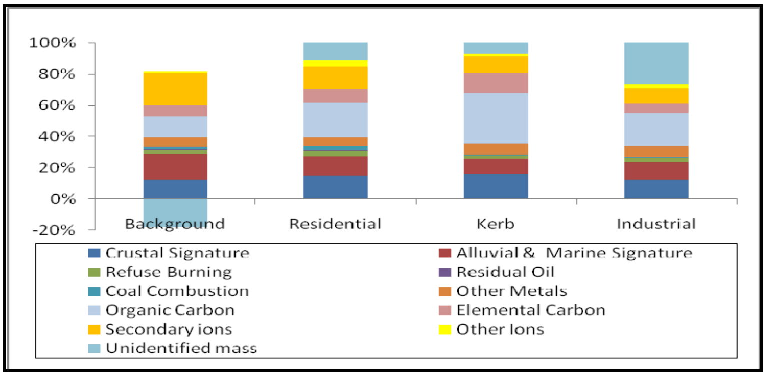
List of signature elements, identified for different sources, is given in Table 3.4. The data on concentrations of signature elements were analyzed for preliminary assessment of source contributions. Figures 3.25 – 3.30 present the overall fractions of the each component of PM_{10} and $PM_{2.5}$ constituents and show mass closure of overall mass of PM_{10} and $PM_{2.5}$. It is important to note that total mass of PM_{10} and $PM_{2.5}$ has been reasonably accounted for in most cases. About 5-30 percent of mass could not be accounted for in PM_{10} and it is reported as unidentified mass (grayish blue stack in Figures 3.25 – 3.30) except for sampling locations at Chennai, where 30-50 percent mass is reported as unidentified. OC is presented as organic carbon and not organic matter. As such, other elements like hydrogen, oxygen and nitrogen present in the organic matter are not accounted for, and reflected in the unaccounted mass. It is also pertinent to mention that sampling was done using Quartz, Teflon filters on different days for analysis of OC/EC, ions and elements. Samples using Teflon filters provided mass of $PM_{10}/PM_{2.5}$, which were used for mass closure. However, total mass of $PM_{10}/PM_{2.5}$ was not available on the days, when sampling was done using quartz filters for OC/EC analysis. Besides, in case of $PM_{2.5}$, limited sampling was carried out for seven days with data on mass available for three days. This, probably, has resulted in negative mass closure in some cases.

Elemental and ion analysis show abundance of soil constituents (e.g. Si, Fe, Ca, Na) around 20 percent. This clearly suggests that there could be significant sources of particulate pollution from soil, and road dust. It can also be seen that soil related fraction reduces dramatically in $PM_{2.5}$ (Figures 3.25 – 3.30).

Table 3.4: Sources and Associated Signature Elements *

Sources	Associated Signature Elements
Crustal Signature	Al, Ca^{++}, Ca, Si, Fe
Alluvial & Marine Signature	Cl^{-}, Na^{+}, Na, Pd
Refuse Burning	K^{+}, K, Mn, Zn
Residual Oil	V, Ni, Co
Coal Combustion	As, Se, Ti
Combustion Sources	OC, EC
Secondary Particulate Formulation	NO_3^{-}, SO_4^{2-}, NH_4^{-}
Unidentified mass	

* These signature elements grouped under different source categories were used for mass closure.



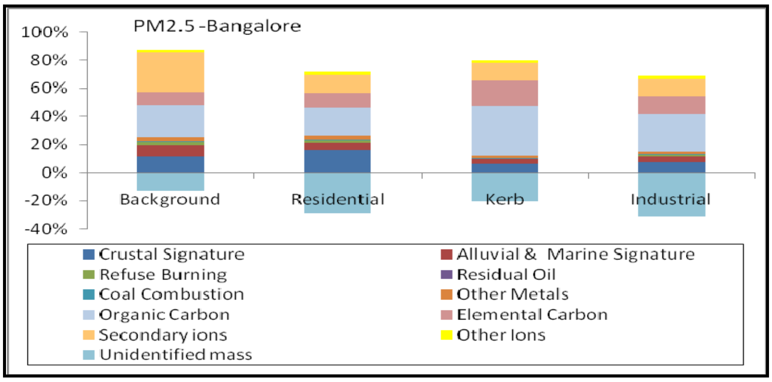


Figure 3.25: Mass Closure of PM_{10} and $PM_{2.5}$ of Bangalore

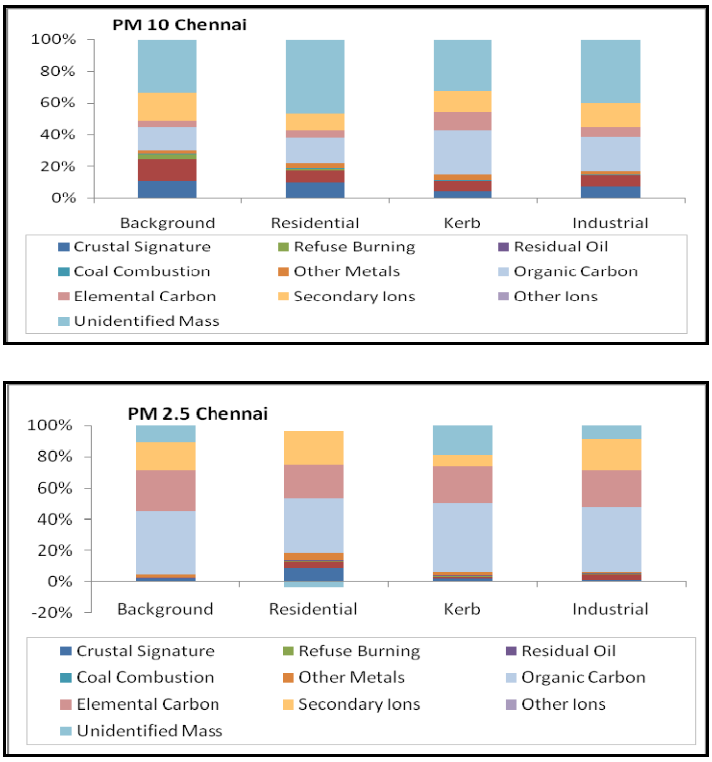


Figure 3.26: Mass Closure of PM_{10} and $PM_{2.5}$ of Chennai

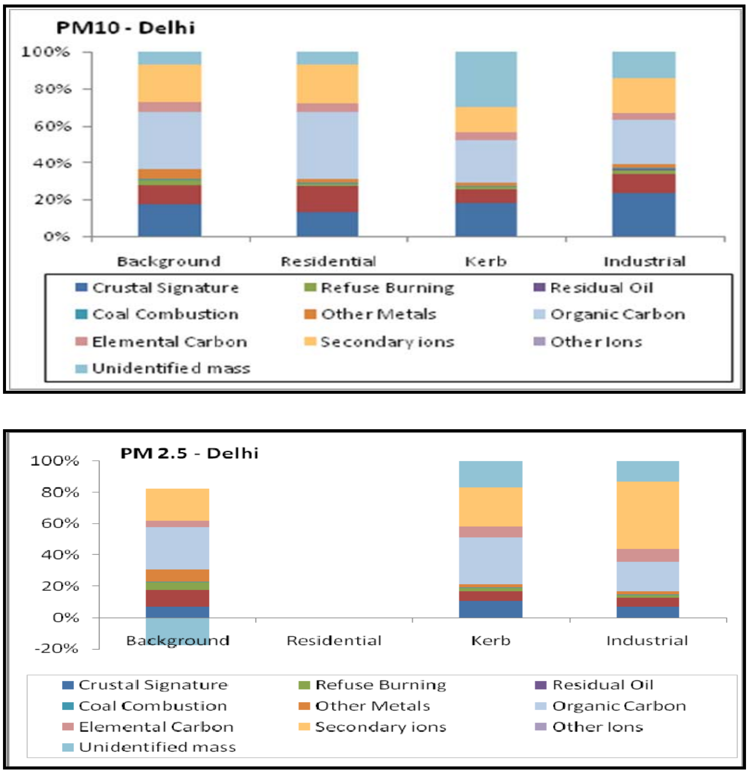
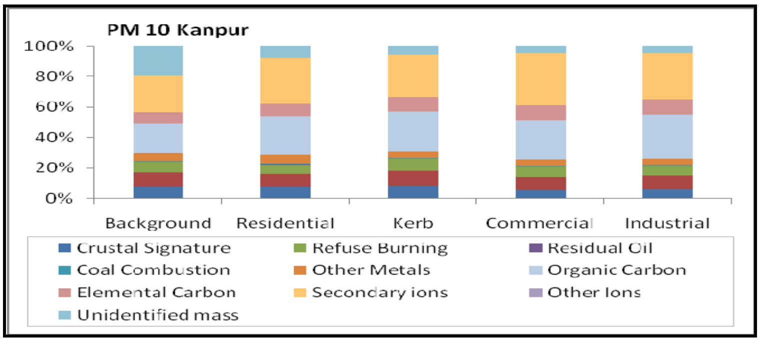


Figure 3.27: Mass Closure of PM_{10} and $PM_{2.5}$ of Delhi



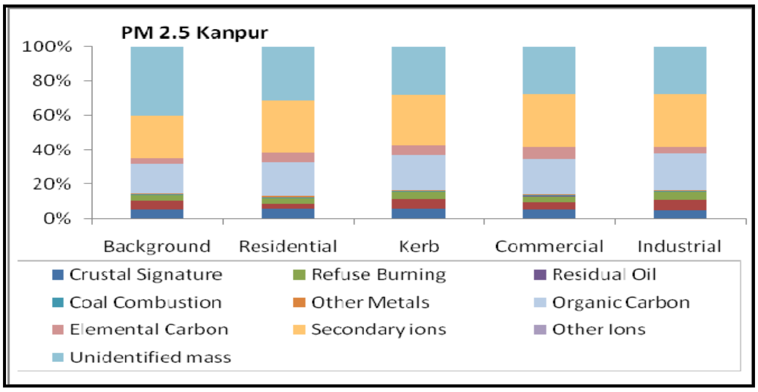
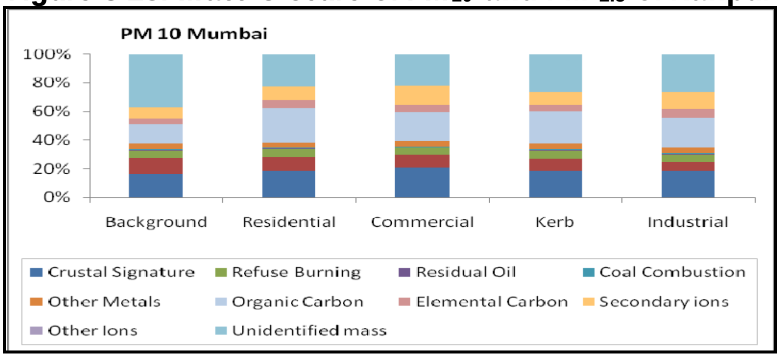


Figure 3.28: Mass Closure of PM_{10} and $PM_{2.5}$ of Kanpur



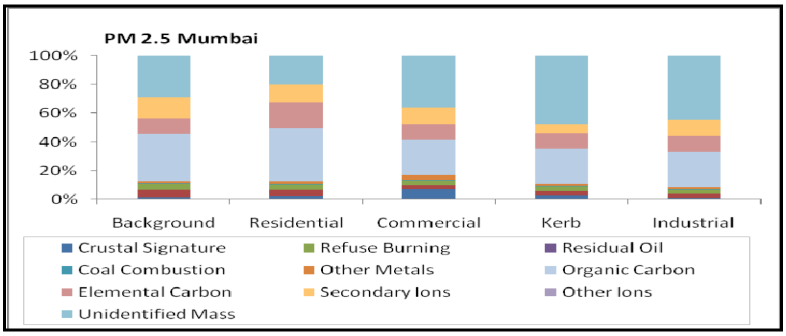
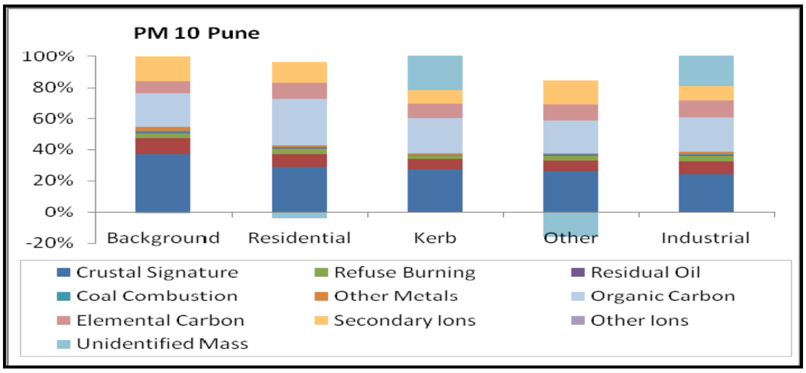


Figure 3.29: Mass Closure of PM_{10} and $PM_{2.5}$ of Mumbai



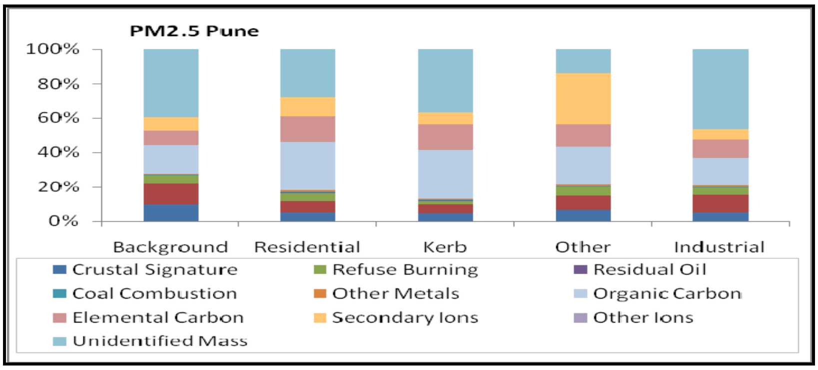


Figure 3.30: Mass Closure of PM_{10} and PM $_{2.5}$ of Pune

3.5 Molecular Markers

Organic molecular markers are individual compounds or groups of related compounds (homologous compounds such as n-alkanes, n-alkanoic acids, hopanes and PAH, which at a molecular level comprise the chemical profile or "fingerprint" for specific emission source types. An individual molecular marker or groups of marker compounds is linked quantitatively to major emission sources of urban fine particles. The molecular-level technology used in the current study matches chemical fingerprints of the PM samples collected to emission sources. Table 3.5 presents the molecular markers and their associated sources.

Figures 3.31 to 3.36 show the molecular marker concentration in winter for Bangalore, Chennai, Delhi, Kanpur, Mumbai and Pune. It can be seen that not all markers are present in all cities (except for Kanpur) but markers like hopanes those indicate gasoline and diesel burning are present in all cities. There is description for presence of each marker underneath the figures to suggest presence of the sources.

Table 3.5: Molecular Markers and their Sources

Molecule Type	Molecular Marker	Major Urban Sources
Alkanes	n- Hentriacontane n-Tritriacontane n- Pentatriacontane	Vegetative detritus, Cigarette smoke Tyre wear debris Tyre wear debris
Hopanes	22, 29, 30 – Trisnorneohopane 17α(H), 21β(H)-29Norhopane 17α(H), 21β(H) Norhopane	Gasoline, diesel, fuel oil Gasoline, diesel, fuel oil Gasoline, diesel, fuel oil
Alkanoic acid	Hexadecanamide Octadecanamide	Biomass (Cow dung) Biomass (Cow dung)
Others	Stigmasterol Levoglucosan	Biomass burning Hardwood, Softwood

Delhi emission scenario being quite complex, it is difficult to distinctly link the presence of specific markers with different land use categories. However, the presence of hopanes and steranes at all the sites in much higher quantities compared to background location indicates that effect of vehicles is prevalent at all the sites of Delhi. Higher concentration of levoglucosan confirms contribution from biomass burning. In Kanpur, the following molecular markers were present hentriacontane, tritriacontane, pentatriacontane, octadecanamide, levoglucosan, stigmasterol and PAHs. The presence of these markers suggests that possibly the following sources are also contributing to PM_{10}: vegetative detritus, tyre wear debris, gasoline, diesel, fuel oil, biomass (cow dung, hardwood, softwood) burning.

In Mumbai, data on molecular markers at locations with two extreme situations provide insight to contribution of polluting activities – Dharavi, the biggest slum area of the world, and Colaba, a cleanest location. In winter, highest concentration of PAH was observed at Dharavi (9.9 ng/m^3), which could be due to inefficient combustions of various industrial waste, biomass, coal burning, fuel oil consumption, etc. The concentrations of PAH was lowest in Colaba. Similarly, the concentration of Levoglucosan at Dharavi is 4.3 times higher than that observed in Colaba (winter), which is mainly because of more of wood and biomass burning in Dharavi. Mulund being a kerbside has hopanes and steranes concentration 12.7 and 11.7 times higher than what was observed in Colaba.

More information on measurement and observed concentrations at various locations are given in the Annexure - VI.

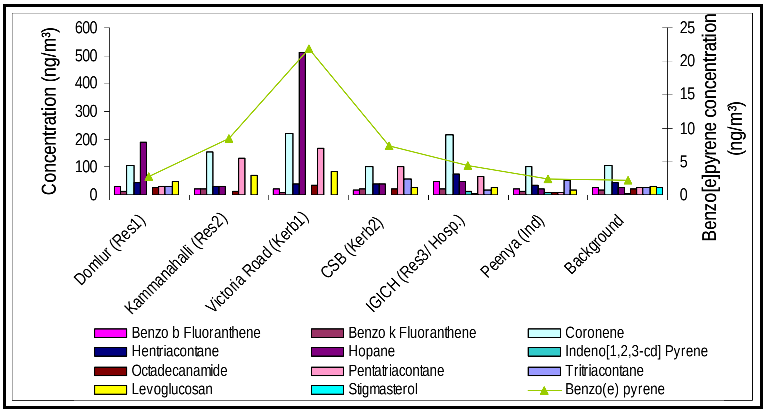


Figure 3.31: Molecular Markers at various sites of Bangalore

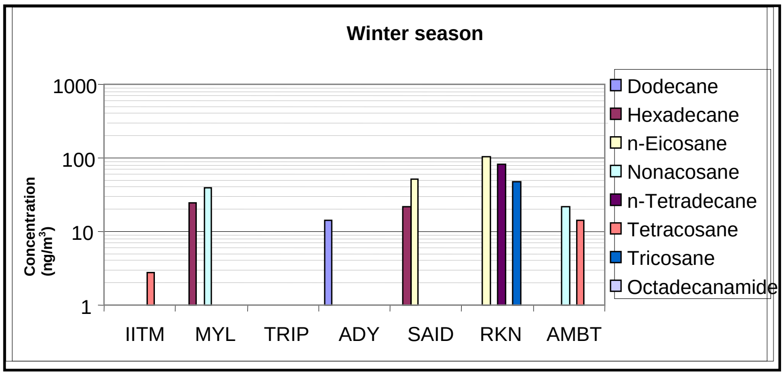


Figure 3.32: Molecular Markers at various sites of Chennai

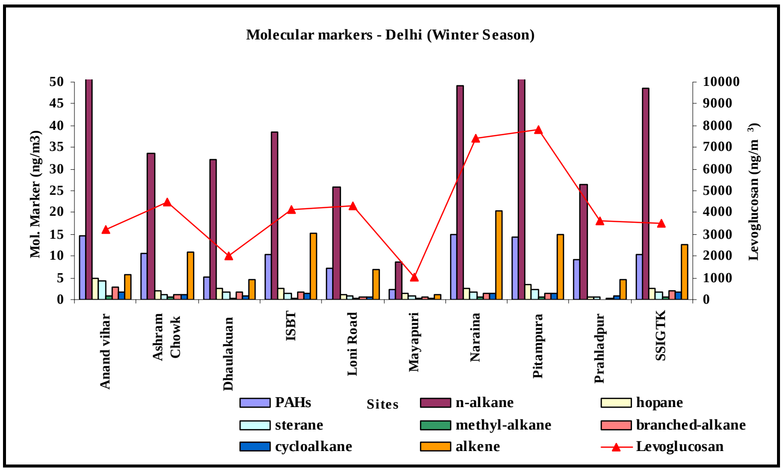


Figure 3.33: Molecular Markers at various sites of Delhi

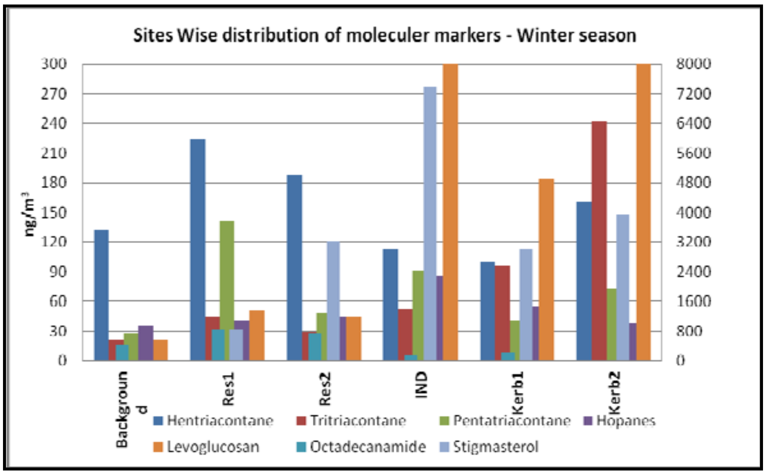


Figure 3.34: Molecular Markers at various sites of Kanpur

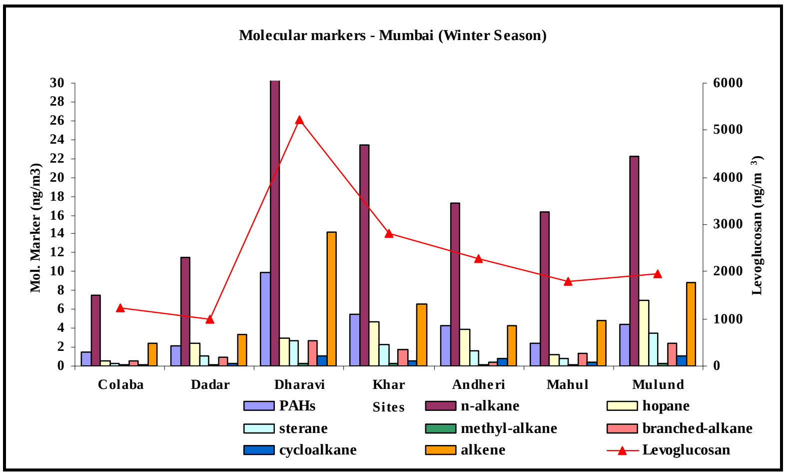


Figure 3.35: Molecular Markers at various sites of Mumbai

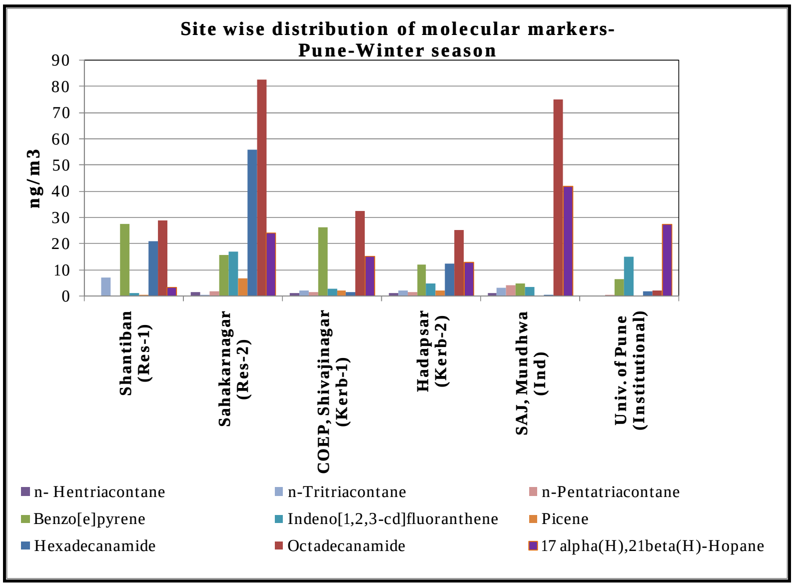


Figure 3.36: Molecular Markers at various sites of Pune

4

Emission Inventory

4.1 Approach for developing Emission Inventory

Emission Inventory is the first step towards understanding the sources and their strength. These sources depending upon where they are located, at what elevation they emit, what is their frequency and duration of emission, etc can provide the major information about the character of a city in terms of air pollution. Emissions from all sources, if identified and also quantified for a particular location and time, can be effectively used for dispersion modeling purposes. Such simulation is able to provide the predicted levels of air pollutants in the ambient air of a city grid for a future year based on growth rate of the sources. Emission Inventory tools and techniques vary widely depending upon the type and quality of data available in the city. Primary surveys combined with available information from varied sources in the city are used for estimation of all major activities, which are air polluting. These are used in conjunction with EF for building EI.

The study involved preparation of detailed emission inventory with estimation of emissions from various activities such as vehicular, industrial, residential, commercial, etc. The methodology for EI was designed with optimization of Top-Down and Bottom-Up approaches to fulfill the following requirements:

- Identification of all major emission sources and reliable estimation of emission quantities of significant pollutants like PM_{10}, NOx, SO_2, CO, etc.
- Adequate representation of various factors influencing emissions, such as, land use, socio-economic structure, spatial & temporal distribution of source activities vis-à-vis pollutants.
- Evaluation of time weighted emissions and their distribution for modeling needs.

Besides using data from secondary sources of information, activity data were also obtained, wherever necessary, through primary surveys covering, questionnaire surveys, personal interviews, house-to-house surveys, actual traffic counts, etc. While this approach provides reasonable quality of data on emission estimates, resolutions with respect to time and space are limited in view of resources and available time-frame.

In cities, except for a few large point sources, most of the sources being low-level sources may have zone of maximum impact within 2x2 km^2 area. Therefore, it was reasonable to assume that in addition to large point source, if any, air quality monitoring locations would mostly capture the contribution of sources located within the zone of influence. As such, greater emphasis was laid on primary surveys around monitoring locations. In order to fulfill the needs of the project, an optimized activity framework was followed as depicted in *Figure 4.1*, and with the following salient features:

- Detailed in-situ primary surveys within 2x2-km^2 zone of influence around each monitoring location were planned to identify all significant pollution sources (e.g. construction activities, industries fuel use, domestic fuel combustions, size and activities of DG sets, etc) and also to collect activity data through personal interviews.
- Diurnal traffic count surveys on different categories of roads along with personal interviews at parking lots/petrol pumps with vehicle owners for obtaining data on vintage, fuel use, vehicle kilometer traveled (VKT) per day, etc.
- Use of refined Emission Factors (EF) for vehicular exhaust emissions.
- Selection of appropriate EF for non-vehicular emission sources i.e. roadside dust, domestic fuel combustions, industries, construction activities, etc.
- Projections of city level EI based on detailed inventories prepared in 2x2-km^2 grids, and city land use plans.
- Future projections of emission scenarios considering developmental plans, changes in the land-use and activities and/or activity levels, (with or without implementation of given pollution control plans), etc.

Steps for building EI are given in Table 4.1.

Table 4.1: Steps for Developing Emission Inventory

Parameter	2x2 km² Criteria	2007	BAU	
			2012	2017
Vehicles	• Mapping City road network on GIS • Diurnal Vehicle count & video recording on different road categories • Parking lots and petrol pump survey and personal interviews for vehicle models and use details • Develop diurnal VKT profiles on of vehicle as well as road categories. • Use EF for respective vehicles type/model for diurnal emission load on different roads in 0.5x0.5 grids • Treat all main roads as line source and feeder roads as area source for modeling.	• Plot city road network in 2x2 km² grid in GIS • Match the road type, population density, land-use category of primary 0.5x0.5 grids to calculate diurnal VKT in 2x2 km²grids • Develop grid wise diurnal emission rate profiles for different vehicle models, fuel use, vintage etc in each 2x2 km²grid.	• Refer RTO records, future road network proposal, population & vehicle density, land use maps for vehicle growth and differential VKT growth in 2012. • For projected VKT calculate diurnal emission rates • Calculate grid wise emission rates	• Refer RTO records, future road network proposal, population and vehicle density, land use maps for vehicle growth and differential VKT growth in 2017. • For projected VKT calculate diurnal emission rates • Calculate grid wise emission rates
Road side re-suspended dust	• Conduct field survey for silt load on different roads • Incorporate vehicle weight, speed and VKT data of primary survey • Conduct laboratory analysis of road dust • Calculate diurnal road re-suspended dust emission rates in 0.5x0.5 grids • Treat all main roads as line source and feeder roads as area source for modeling.	• Plot road network on GIS • Match land use typology, as well as population densities, etc. for silt load projection • Incorporate vehicle weight and speed in VKT in put to modeling • Calculate re-suspended dust diurnal emission rates in 2x2 km²grids on USEPA	• Refer RTO records, future road network proposal, population & vehicle density, land use maps for vehicle growth and differential VKT profile in 2012. • Plot road network	• Refer RTO records, future road network proposal, population and vehicle density, land use maps for vehicle growth and differential VKT profile in 2017. • Plot road network on GIS

Parameter	2x2 km² Criteria	2007	BAU	
			2012	2017
		based model	on GIS • Match land use typology, as well as population densities, etc. for silt load projection • Incorporate vehicle weight and speed in VKT in put to modeling • Calculate re-suspended dust diurnal emission rates in 2x2 km²grids on USEPA based model	• Match land use, population density for silt load • Incorporate vehicle weight and speed in VKT in put to modeling • Calculate re-suspended dust diurnal emission rates in 2x2 km² grids on USEPA based model
Unpaved Road dust	• Mark unpaved roads in road network • Calculate VKT for likely diurnal vehicle activity • Calculate emission rates in respective 0.5x0.5 grids	• Refer road development plan and exclude roads to be paved till 2012. • Calculate emission rates in 2x2 km² city grids	Same as in 2007	Same as in 2012

Parameter	2x2 km² Criteria	2007	BAU	
			2012	2017
Construction	• Conduct field survey in each 0.5x0.5 grids to spot location and intensity of work and map the location on GIS map • Record intensity and area of construction activity in 0.5x0.5 grids • Use EF developed to calculate diurnal PM emission rates in 0.5x0.5 grid	• Refer land use plans for new area and provide GIS map for the city • Match the land use and population density observed in 0.5x0.5 grids with city grids to project construction intensity • Develop EI for 2x2 km² city grids adopting comparable construction density & intensity	• Refer future land use plan map for the city and mark land-use in GIS • Match with data base developed during field survey and project future land use activity for projected new population density • Project diurnal EI rates for 2012	• Refer future land use plan map for the city and mark land-use in GIS • Match with data base developed during field survey and project future land use activity for projected new population density • Project diurnal EI rats for 2017
Industries	• Plot industrial Estates on GIS map • Conduct field survey and personal interviews in exiting IE for product, fuel used and emission characteristics • Adopt SPCBs data wherever available for the land use. • For Large industries use SPCB data base	• Use city land use maps and match with land use, industry types/fuel of primary survey grids within existing industrial estates • Use average mass emissions rates developed during field survey and project emission rates. • For large industries use SPCB data base	• Adopt the future land use map of the city of 2012 • Use data base developed during primary survey for different industries/fuel use • Project diurnal emission rates in city 2x2 km² grid industrial estates.	• Adopt the future land use map of the city of 2o17 • Use data base developed during primary survey for different industries/fuel use • Project diurnal emission rates in city 2x2 km² grid industrial estates.
Bakeries	• Conduct primary surveys and interviews with owners in 0.5x0.5 grids • Assess quantity and type of product	• Match with land use and population density of 0.5x0.5 grids with new 2x2	• Use future land use plan and population density projections	• Use future land use plan and population density

Parameter	2x2 km^2 Criteria	2007	BAU	
			2012	2017
	and fuel used • Use EF for respective fuel and calculate emission rates in each 0.5x0.5 grids	km^2 city grids for projecting number of bakeries locations in each city 2x2 km^2 grids. • Calculate emission rates in 2x2 km^2 grids for similar fuel configurations	in different city grids for activity levels • Match with land use and population density to project bakery number in 2x2 km^2 grids • Calculate Emission rate in 2x2 km^2 grid in 2012	projection • Match with land use and population density to project bakery number in 2x2 km^2 grids • Calculate Emission rate in 2x2 km^2 grid in 2017
DG sets	• Conduct primary surveys in 0.5x0.5 grids for number/size/location/operation duration • Calculate emission rate for fuel use in 0.5x0.5 using EF developed for fuel and size of DG	• Match with land use and population density to project DG sets number/size in different 2x2 km^2 city grids • Calculate emission rates for 2x2 km^2 city grids	• Use future land use plan and population density projections in different city grids for DG set activity levels (consider power position also) • Match with land use and population density to project DG numbers and size in 2x2 km^2 grids • Calculate Emission rate in 2x2 km^2 grid in 2012	• Use future land use plan and population density projections in different city grids for DG set activity levels (consider power position also) • Match with land use and population density to project DG numbers and size in 2x2 km^2 grids • Calculate Emission rate in 2x2 km^2 grid in 2017
Hotels	• Conduct primary surveys and interviews with hotel owners in 0.5x0.5	• Match with land use, population density, etc.	• Use future land use plan and population	• Use future land use plan and

Parameter	2x2 km² Criteria	2007	BAU	
			2012	2017
	grids • Assess quantity and type of fuel used • Use EF for respective fuel and calculate emission rates in each 0.5x0.5 grids	of 0.5x0.5 grids with new 2x2 km² city grids for projecting number of hotels in each 2x2 km² grids. Large hotels should be marked on given locations • Calculate emission rates in 2x2 km² grids for similar product or fuel configurations	density projections in different city grids for hotel rooms/beds activity levels (consider tourist projections also) • Match with land use and population density to project hotel rooms/beds in 2x2 km²grids • Calculate Emission rate in 2x2 km2 grid in 2012	population density projections in different city grids for hotel rooms/beds activity levels (consider tourist projections also) • Match with land use and population density to project hotel rooms/beds in 2x2 km²grids • Calculate Emission rate in 2x2 km² grid in 2017
Open eat outs	• Conduct primary surveys and interviews with road side eat outs in 0.5x0.5 grids • Assess quantity and type of production and fuel used • Use EF for respective fuel type and quantity and calculate emission rates in each 0.5x0.5 grids	• Match with land use and population density of 0.5x0.5 grids with new 2x2 km² city grids for projecting number of eat outs with grid locations in each city 2x2 km² grids. • Calculate emission rates in 2x2 km² grids for similar nature or fuel configurations	• Use future population density projections in different city grids for quantifying the activity levels • Match with land use and population density to project eat out number in 2x2 km² grids • Calculate Emission rate in 2x2 km²grid in 2012	• Use future and population density projections in different city grids for quantifying the activity levels • Match with land use and population density to project eat out number in 2x2 km²grids • Calculate Emission rate in 2x2 km²grid in 2017

Parameter	2x2 km² Criteria	2007	BAU	
			2012	2017
domestic	• Conduct primary survey and interviews for fuel type, consumption, monthly budget, family income etc. • Develop fuel use differentials and socioeconomic status for emission rate levels • Calculate emission rate for 0.5x0.5 grids for given population character.	• Match with land use/population density and socio-economic variations for developed for 0.5x0.5 grids for calculating total fuel consumption in 2x2 km² grids • Calculate emission rate for 2x2 km² grids	• Match with 2012 population density/socio-economic profile/land use for projected population growth. • Calculate emission rate in 2x2 km² grid for 2012	• Match with 2017 population density/socio-economic profile/land use for projected population growth. • Calculate emission rate in 2x2 km² grid for 2017
Crematoria	• Mark location in GIS map • Conduct primary survey of the nature of crematoria, number of bodies disposed, fuel used per body etc • Add emission rates for the respective 0.5x0.5 grid location of crematoria and add to total emission rate from the grid having such units	• Match location of crematoria in the city and mark in the 2x2 km²city grid for its location • Use the disposed bodies counts for the unit of population (e.r.10,000) • Calculate emission rates per day and add to emission load of the respective grid location	• Mark in the future land use plan and location of crematoria sites if any or use expected rate of mortality for the religion to distribute over projected population. • Calculate emission rates in 2012 for the grid in which it is located	• Mark in the future land use plan and location of crematoria sites (if any) or use expected rate of mortality for the religion to distribute over projected population. • Calculate emission rates in 2017 for the grid in which it is located
Open burning	• Calculate domestic/garden solid waste generated in 0.5x0.5 grids based on population and use % of it openly burnet or for the amount of solid waste generated in the	• Use population density and land use/socio economic status in 2x2 km² grids at city for calculating total solid waste generation based on	• Use population density and land use/socio economic status in 2x2 km² grids for 2012 for	• Use population density and land use/socio economic status in 2x2 km² grids for

Parameter	2x2 km² Criteria	2007	BAU	
			2012	2017
	community • For the quantity of waste burnt use the EF (developed in the project) and calculate emission rate for 0.5x0.5 grids.	bench marks developed in 0.5x0.5 grids • Use percentage of total solid waste burnt in the community to calculate emission rates calculations for 2x2 km² grids	calculating total solid waste generation based on bench marks developed in 2x2 km² grids • Use percentage of total solid waste burnt in the community in each grid to calculate emission rates calculations for 2x2 km² grids	2017 for calculating total solid waste generation based on bench marks developed in 2x2 km² grids • Use percentage of total solid waste burnt in the community in each grid to calculate emission rates calculations for 2x2 km² grids

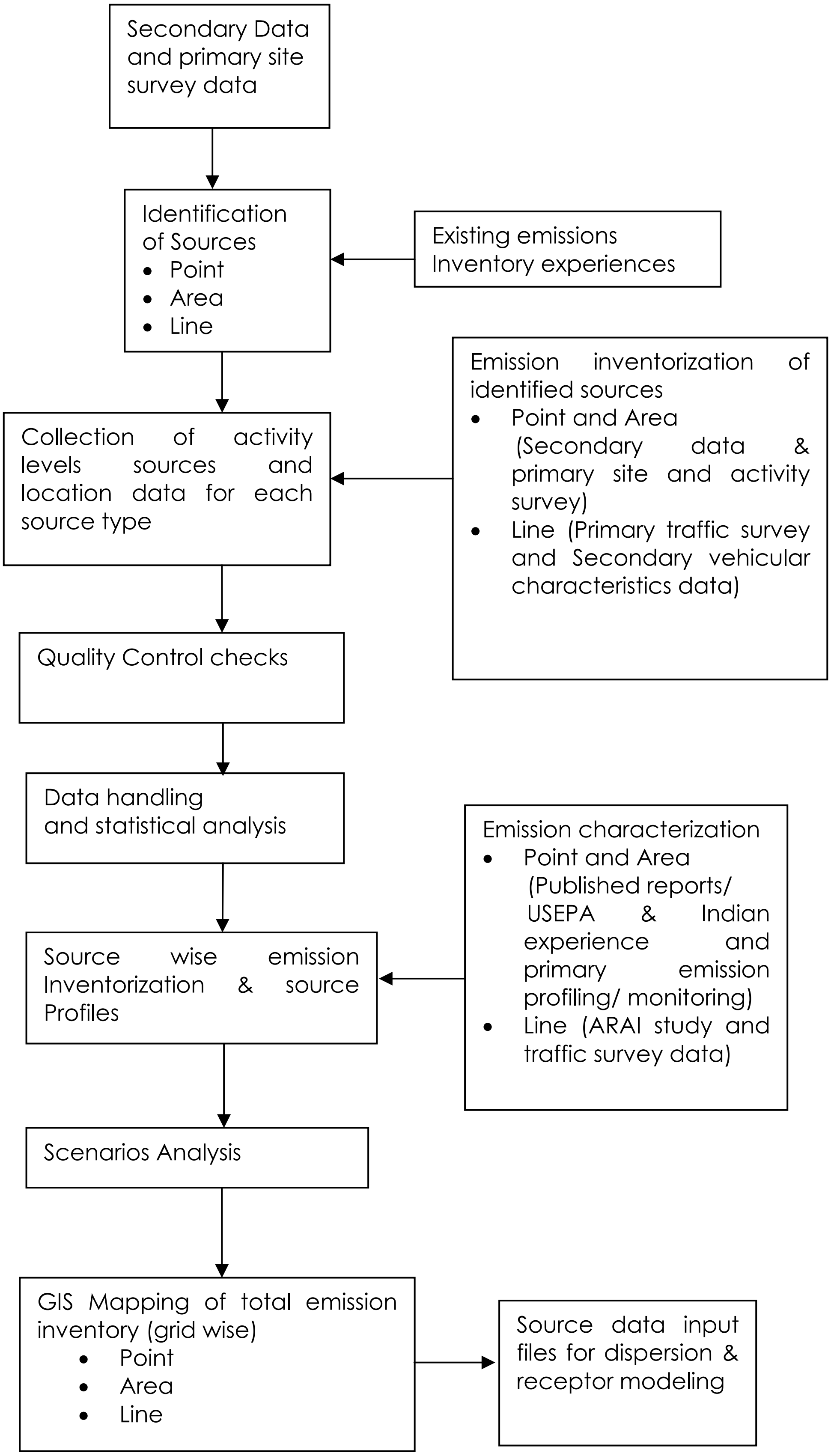


Figure 4.1: Framework on Emission Inventory

4.2 Development of Emission Factors

A properly compiled EI is the key to air quality management in a city. The two essential inputs required for building EI are: activity data; and corresponding EF. While activity data could be generated, non-availability of indigenous EF for a wide range of sources including in-use vehicles was a constraint. Therefore, development/ selection of appropriate EF were an important component of the project, and fundamental requirement for building meaningful EI.

EF for Vehicular Exhaust Emissions

The Automotive Research Association of India (ARAI) was responsible for developing EF for vehicular emissions, based on mass emission tests conducted on limited number of in-use vehicles covering different engine technologies, types of vehicles, vintage, types of fuels, etc.

Study design was discussed with experts and by the Technical Committee for deciding the procedure, methodology, test matrix, fuel matrix, data reporting, etc. Important features of the study are given below:

- In-use vehicles of different vintages (e.g. 1991-96, 1996-2000, Post 2000 and Post 2005 indicating technology shift) were included in the test matrix so that effect of technology on EF gets due representation.
- The study involved mass emission testing of in-use 2-wheelers, 3-wheelers and passenger cars and light & heavy duty commercial vehicles (LCVs and HCVs) on Chassis dynamometer.
- The tests were conducted with commercial fuel. The vehicles, then, were subjected to maintenance at authorized service stations and again tested with commercial fuel. The tests were repeated with varied fuel quality to understand the effect of fuels on emissions.
- It was decided to adopt the Indian Driving cycle for 2-W, 3-W and Pre-2000 4-W vehicles. Modified Indian Driving cycle was used for testing for post-2000 4W. For comparative purpose, post -2000 4-W were also tested on IDC. With regard to HCV, there were no standard test procedures and driving cycle for chassis dynamometer tests as the HCV engines are tested on the engine dynamometer for regulatory purposes. Moreover, there was no correlation between engine test and field emission performance of the vehicle. Therefore, a special cycle developed by ARAI for HCV was used. This overall Bus Driving cycle is based on the average driving pattern of HCV vehicles in the four metro cities (Mumbai, Delhi, Kolkata and Chennai), and was the best

available driving cycle for HCV category of vehicles. Test cycles used in the study are given in Table 4.2

Table 4.2: Test Driving Cycles used for development of EF

Vehicle Category	Test Cycle
2/3 Wheeler vehicles	Indian Driving Cycle (IDC)
Pre 2000 Model year Four Wheeled vehicle with Gross Vehicle Weight (GVW) less than or equal to 3500 kg	Indian Driving Cycle
Post 2000 Model year Four Wheeled vehicle with GVW less than or equal to 3500 kg	Indian Driving Cycle and Modified Indian Driving Cycle
For vehicles with GVW above 3500 kg	Overall Bus Driving Cycle (OBDC)

- Different inertia settings used depending on the vehicle category are as follow:
  - 2-wheelers: ULW (Un-laden Weight) + 75 kg
  - 3-wheelers gasoline: 225 kg (3 passengers x 75)
  - 3-wheeler diesel: GVW
  - Passenger cars: ULW+225 kg (3 passengers x 75 kg)
  - Multi Utility Vehicles: ULW + 450 kg (6 passengers x 75kg)
  - LCV (Bus): ULW + 1500 kg (equivalent to 20 passengers of 75 kg weight each)
  - LCV (Trucks): GVW (as specified by the vehicle manufacturer)
  - HCV (Bus): ULW + 4500 kg (equivalent to 60 passengers of 75 kg each)
  - HCV (Trucks): GVW (to be limited to 20 ton max. for GVW > 20tons. If GVW is less than 20 tons, Inertia was set to the maximum specified GVW).
- Apart from measuring conventional emissions like CO, HC, NO_2, CO_2 and PM, emissions of PAH, Benzene, 1, 3-Butadiene and Aldehydes were also measured and expressed in mg/km.
- The PM was chemically characterized into SOF (Oil and fuel fraction) and IOF (Sulphate, Nitrate, H_2O, Carbon Soot, and Metal Oxides). The particulate size distribution in terms of number, size and mass was also measured by ELPI and MOUDI instruments.
- The idle and constant speed mass emissions were also measured and expressed in g/min.

For EF development, each test vehicle was mounted with its drive wheels on the rollers of the test bed (as depicted in *Figure 4.2*) whose rotational resistance was adjusted to simulate friction and aerodynamic drag. Inertial masses were added to simulate the weight of the test vehicle as per the category of the vehicle. A variable speed vehicle cooling blower, mounted at a short distance in front of the vehicle provided the necessary cooling. The test vehicle was then soaked to ambient temperature conditions; and maintained in that state till the commencement of the test on the chassis dynamometer. This was required to get the vehicle and the engine conditions to the test cell ambient conditions. Before starting the test, the chassis dynamometer was warmed up for 30 minutes with the vehicle mounted on the chassis dynamometer and the engine in OFF condition. After the warm up, chassis dynamometer was calibrated to compensate the frictional losses and then the vehicle was ready to undergo test. The same procedure was followed for all the vehicles. A highly skilled driver was enlisted to drive the test vehicles on the chassis dynamometer. After ensuring the calibration of the test cell, the engine was started and maintained at idling condition for prescribed period as per the applicable regulatory test procedure depending upon the vintage and category of the vehicle. Thereafter, the exhaust sampling was started. The exhaust gases produced by the test vehicle were diluted with fresh air using a DT (dilution tunnel) and a critical-flow venturi-type CVS (constant volume sampler). For gaseous emission measurement, a constant proportion of the diluted exhaust gas was extracted for collection in one sample bag.

The gas analysis of each sample bag was done immediately after each test. The gases in the sampling bag was analyzed for concentrations of CO (carbon monoxide), NO_2 (nitrogen oxides), THC (gasoline) and CO_2 (carbon dioxide), and the emissions were expressed in g/km. For PM measurement, the flow capacity of the CVS and DT system was such that the temperature at the particulate sampling point was below 52°C during the test. The particulate emissions were collected on the primary and back up filters. Before starting the test the primary and secondary particulate filters were conditioned as per the procedure given in EEC directives. They were then weighed and then installed in the particulate sampling system. At the end of the test the filters were removed and again conditioned as per the procedure given by the EEC and weighed.

- A total of 450 emission tests were performed in 89 vehicles.
- The mass emission results of 96 vehicles, conducted under source profiling study, were also used for working out EF.

Figure: Schematic Test Cell Layout

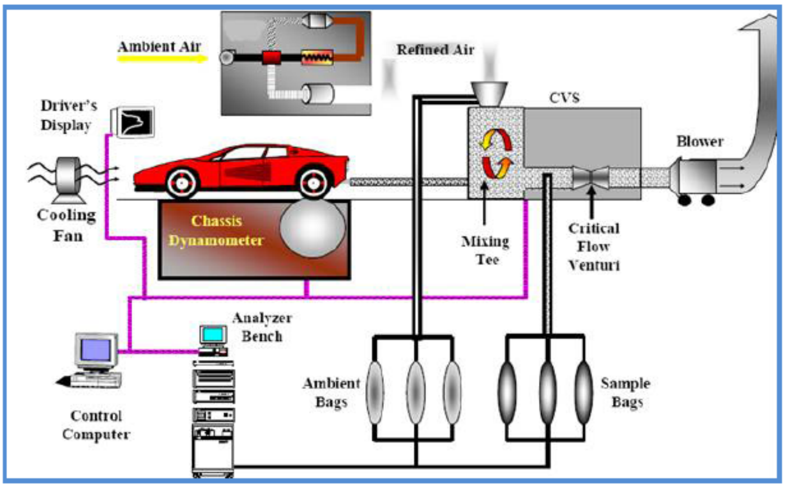


Figure 4.2: Schematic Test Cell Layout

An Expert Group on EF was constituted by CPCB to critically analyze the data, identify and suggest corrective actions for anomalies in the data, if any, and suggest emission factors for different categories. The Group, after numerous debates & deliberations held in its five meetings, agreed on a total of 62 EF. The EF, worked out depending on vehicle categories, vintage and engine cubic capacities, are provided at Annexure – VII, and detailed report is available at (http://cpcb.nic.in/DRAFTREPORT-on-efdiv.pdf).

EF for Non-Vehicular Sources

Besides vehicles, a wide range of other emission sources exits in Indian urban areas. There are a few typical urban sources, which were common to all six project cities. These include different fuel combustions for domestic and commercial use, diesel generator (DG) sets, etc. Some of the sources such as refuse burning paved & unpaved roads, small-scale industries, etc. were city-specific. Institutes, responsible for studies in different cities, reviewed secondary information from local organizations such as State Pollution Control Boards (SPCB), Municipalities, R&D Institutes, Industrial Associations and EF used in different earlier studies. The data available locally, particularly in respect of industries, were preferred. In order to arrive at uniform EF for other sources, an Expert Group reviewed EF available for developing countries as compiled by World Health Organization (WHO), World Bank (WB), Asian Development Bank (ADB), and United State Environment Protection Agency (USEPA). Based on the activity, type of fuel, rate of fuel use, fuel characteristics, level of control, etc., the Group arrived at consensus on best suitable EF. Since, this exercise was based on scientific judgment rather than actual field measurements, possibility of some error cannot be ruled out. However, developing EF for a large number of sources was neither feasible nor desired. A set of uniform EF, recommended by the Expert Group, was used for preparing EI in all the six cities. These EFs are provided at Annexure – VIII.

4.3 Emission Inventory

Emission inventories are for delineating the total mass of pollutants from vehicular, area and industrial sources. In each of these broad categories, further sub-categories have also been detailed and their contributions estimated. All six cities have some major sources that are common such as vehicles, domestic and biomass burning, and re-suspended dust. Other sources are variable and specific to a city, such as emissions from ships in Mumbai, agriculture burning in Pune or leather burning in Kanpur. Emission inventories demonstrate the high variance from city to city due to city specific sources and characteristics. In area source, individual city specific sources are highly variable and show distinct character of the city. Industrial sector contribution is masked by power plant sources, wherever it is present.

It is important to note that high load contribution does not necessarily lead to high ambient contribution of a particular source at the receptor site. This is due to the fact that emission distribution in atmosphere depends upon multitude of factors such as local meteorology, location, height of release, atmospheric removal processes and diurnal variation. Further, it is equally important that the ambient fine particles which constitute higher fractions of toxics are mostly contributed by ground level sources such as vehicles, refuse burning, bakeries-crematoria, road side eateries, etc. Since mass based emission inventories do not provide the complete picture of real contributions at the levels of exposure, it is pertinent to use chemical analysis data with appropriate receptor models such as Chemical Mass Balance Model. Details of EI for the six cities are described below:

Particulate Matter (PM_{10})

The total emissions of PM_{10} show large variations across all cities. Kanpur (9 T/d), Chennai (11 T/d) and Pune (32 T/d) have relatively lower emissions, while Delhi (147 T/d) has the maximum emission load. Bangalore (54 T/d) and Mumbai (73 T/d) lie intermediate within these extremes.

Depending on the profile of each city, the prominent sources vary across the cities. While looking at the relative sectoral share in each of the cities, it is important to address major consideration that in some cases a few prominent sources in the city can mask the contribution of the other sources. Figure 4.3 shows the prominence of sources of PM_{10} in different cities. Kanpur shows equal prominence of industries as well as area sources almost similar to Delhi. However, Delhi, Pune and Chennai show significantly high occurrences of road dust compared to other sources. Bangalore is the only city with highest PM contribution coming from vehicular sector with 41%. Pune with 61 % and Chennai with 72 % show the highest percent contribution from road dust. Pune has the lowest industrial contribution (1-3%) as it has mainly engineering industries and also most of them are outside the city boundary.

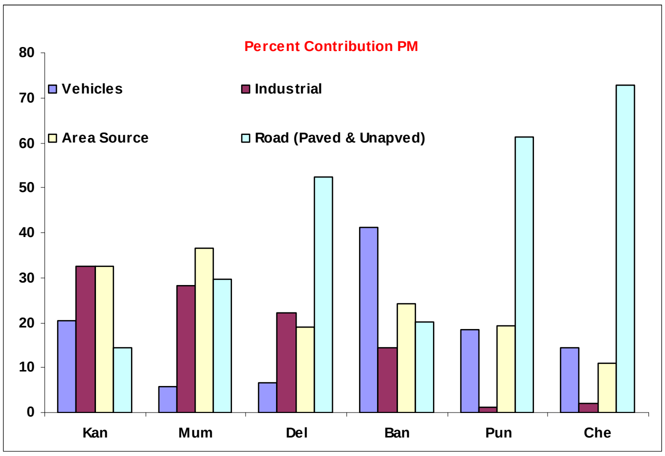
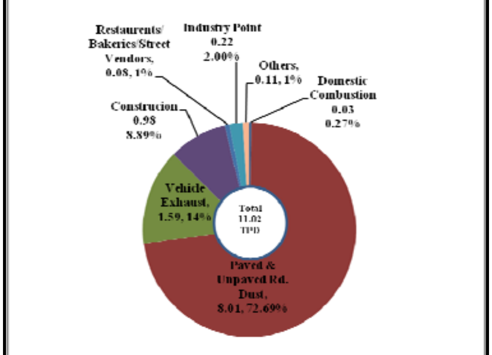


Figure 4.3: Prominence of Sources of PM_{10}

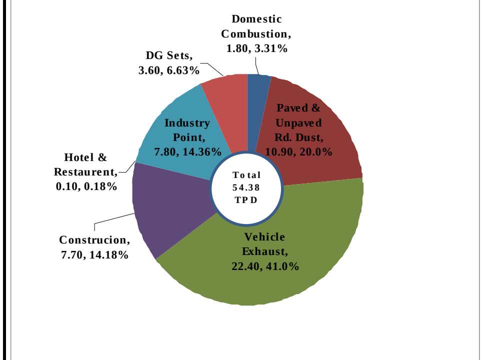
Broadly, the major sources of PM_{10} emissions across these cities are vehicular exhaust emissions, road dust re-suspension, and industrial emissions. The share of vehicular exhaust emissions varies considerably from city to city: 6% in Mumbai, 7% in Delhi, 14% in Chennai, 18% in Pune, 21% in Kanpur, and 41% in Bangalore. Despite the large fleet of vehicles in Delhi, the share is less due to the presence of other significant sources such as power plants, road dust re-suspension, etc. In addition to this fact, due to the whole public transport system being on CNG the contribution is less. It may be noted that road dust re-suspension is dependent on the road conditions and thereby the silt content, as well as on the characteristics of the vehicle fleet. The contribution of industrial sector to PM_{10} pollution load is highest in Kanpur (33%) owing to many small scale industries and Mumbai

(23%) due to a few large industries. Delhi (22%) too has a relatively large industrial sector share, mainly due to the presence of power plants. The share of industries to PM_{10} load in Bangalore is 14% and in Chennai, it is just 2%.

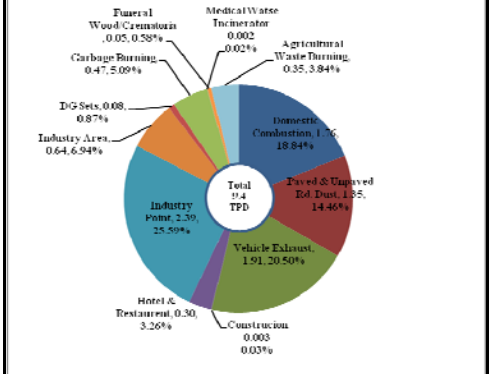
In addition to the above three major sources, there are other contributors that are significant in only some of the cities. For example, domestic sources contribute 19% in Kanpur due to large scale burning of biomass and coal. In Pune, the contribution of domestic sources is about 7%. DG sets contribute 7% in Bangalore but are less than 1% in the other cities, which could be attributed to the variation in number of DG sets and their usage due to power cuts in each city. Other city specific sources include landfill open burning in Mumbai (11%), bakeries in Mumbai (6%) and garbage burning in Kanpur (5%). Construction activities too contribute significantly (8 – 14%) to PM_{10} emission load in Chennai, Mumbai, Delhi and Bangalore. Figure 4.4 presents distribution of source contributions of PM_{10} emissions in six cities.



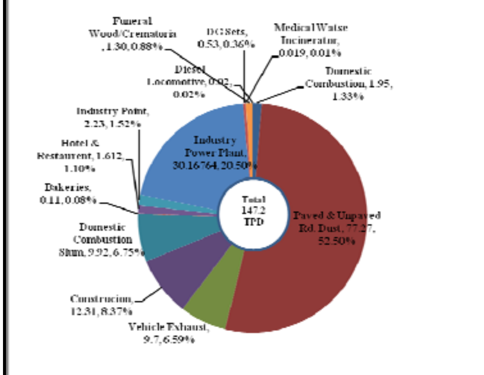
Emission Inventory PM10-Chennai



Emission Inventory PM10-Bangalore



Emission Inventory PM10 Kanpur



Emission Inventory PM10 Delhi

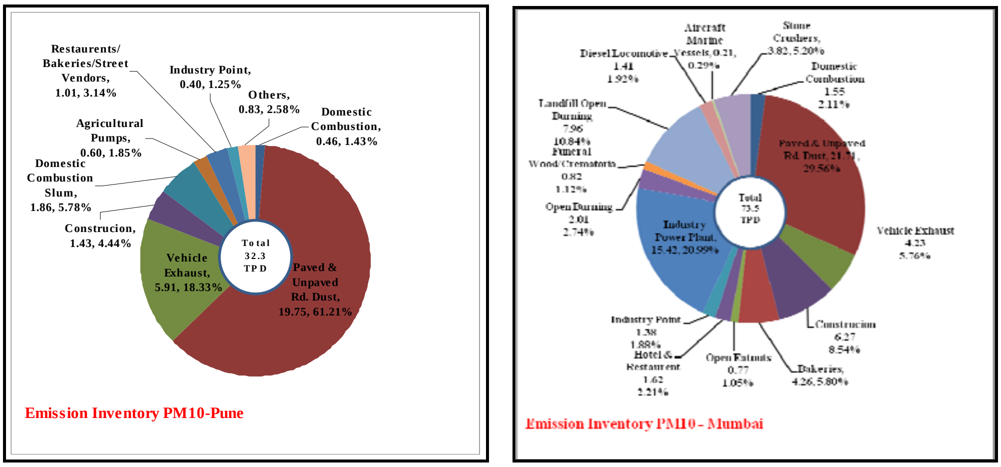


Figure 4.4: Distribution of Source Contributions of PM_{10} Emissions in Six Cities

Oxides of Nitrogen (NO_x)

Nitrogen Oxides is one of the most important gaseous pollutants in almost all the six cities due to its increasing trend. Due to reduction of sulphur content in the automobile fuel, SO_2 values have shown continuous decline and, therefore, after PM, NO_x appears to be next important pollutant. Unlike PM that is also contributed by natural sources and re-suspension, NO_x is mainly contributed by man-made sources such as vehicles, industries and other fuel combustions. The variation in cities NO_x loads is very apparent as evident from the Figure 4.5:

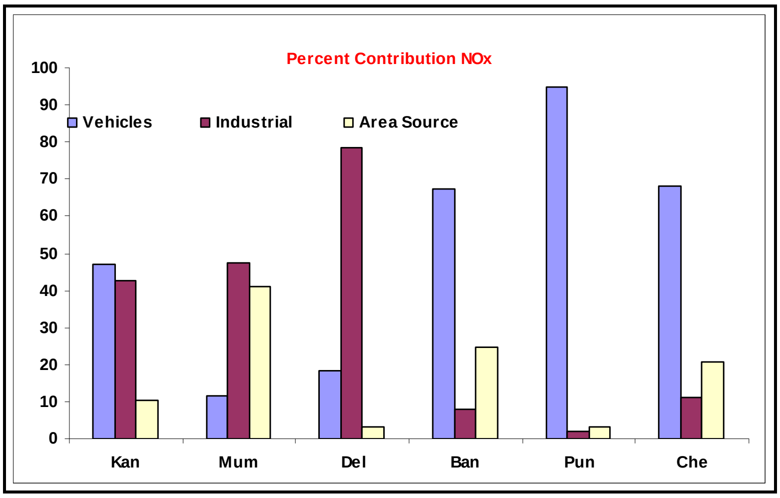
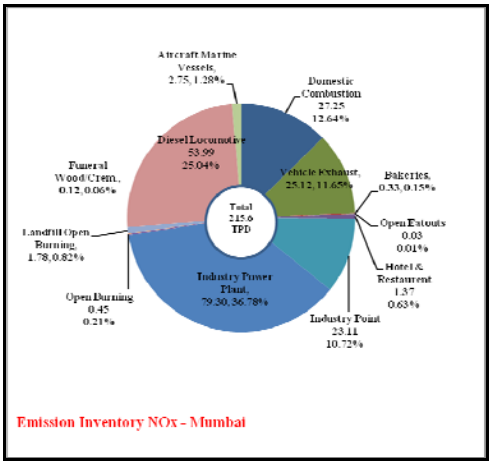


Figure 4.5: Prominence of Sources of NO_x

As can be seen, except Mumbai and Delhi, all cities have maximum contribution from vehicular sources. Mumbai and Delhi exhibit high percentage of NO_x from industries owing to presence of power plants within the city boundary. The industrial contribution excluding power plants is also highest in Delhi (65T/d) followed by Mumbai (23 T/d), Bangalore (17 T/d) and Kanpur (8 T/d). The least industrial contribution of 0.9 T/d is in Pune. Delhi has about 295T/d of NO_x contribution from power plant alone. Contributions from other sources such as hotels, bakeries, open eat outs etc. are much.

It is important to note that though in some cases a source indicates high load within the city boundary, due to elevation of the emission as in the case of power plants with high elevation providing high dilution and dispersion, the exposure impacts due to this source could be lower. Source contributions in respect of NO_x emissions are presented in Figure 4.6.



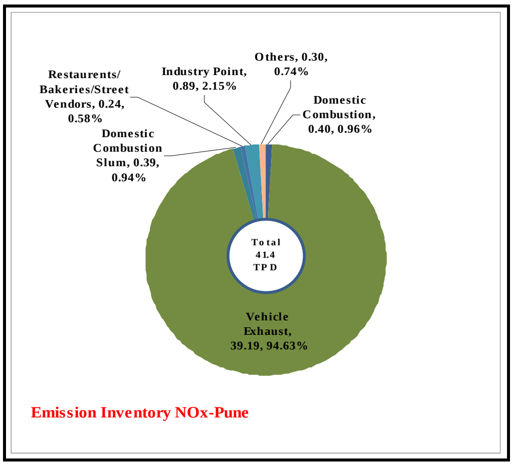


Figure 4.6: Distribution of Source Contributions of NO_x Emissions in Six Cities

Sulphur Dioxide (SO_2)

As explained earlier, SO_2 values have been declining continuously in almost all the six cities due to cleaner fuel being provided for vehicles as also use of low sulphur coal use in power plants. Other fuels, being used in domestic sector and, in some cities for vehicles, are LPG and CNG respectively. Figure 4.7 presents the respective percentage of contribution from three major sources. Delhi, with 255 T/d from power plant and 9T/d from other industries, has the highest load of SO_2 followed by Mumbai with 67T/d from power plant and 78 T/d from other industries. The least contribution is from Chennai (less than 0.1T/d). The DG sets contribution is highest in Bangalore with 3.35 T/d and Delhi about 0.5 T/d.

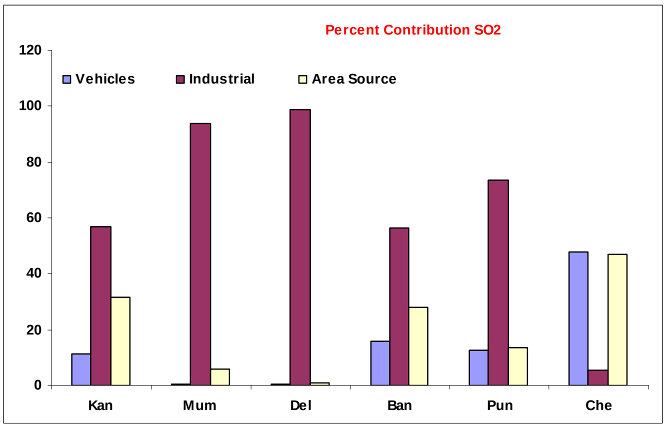


Figure 4.7: Prominence of Sources of SO_2

SO_2 contribution from vehicles is highest in Chennai (48%), followed by much less in Bangalore (16%), Pune (13 %) and Kanpur (less than 12 %).

Industrial source was highest in Delhi (98%), Mumbai (93%) and Pune 73%. Chennai showed the lowest value for SO_2 contribution.

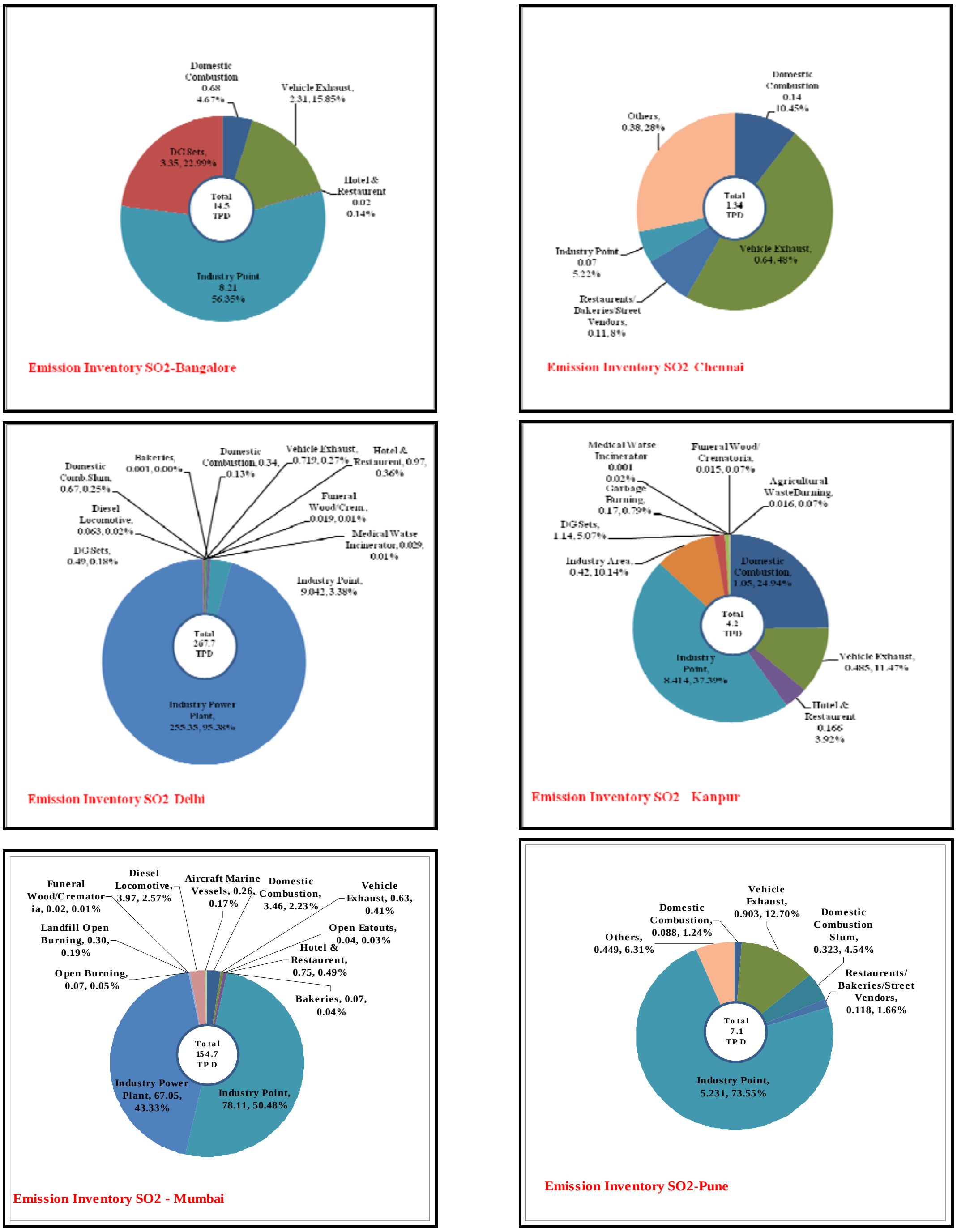
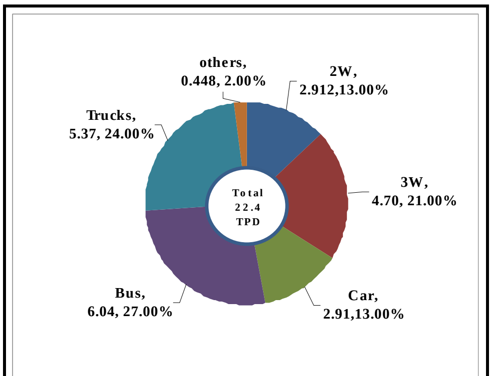


Figure 4.8: Distribution of Source Contributions of SO_2 Emissions in Six Cities

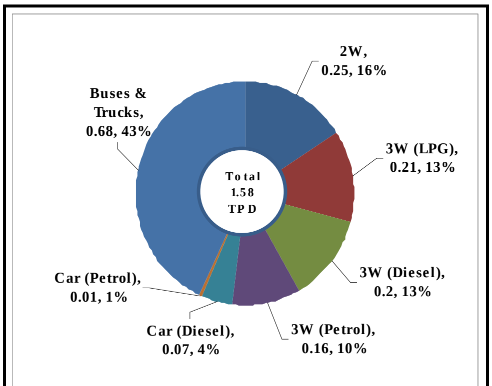
These emission estimates have been used later in the study for projected loads from all these sources for the year 2012 and 2017 without control (Business as usual) and with control (action plan components). These loads have been used in predictive modeling with a view to project future scenario.

Contribution of Different Types of Vehicles in Emissions

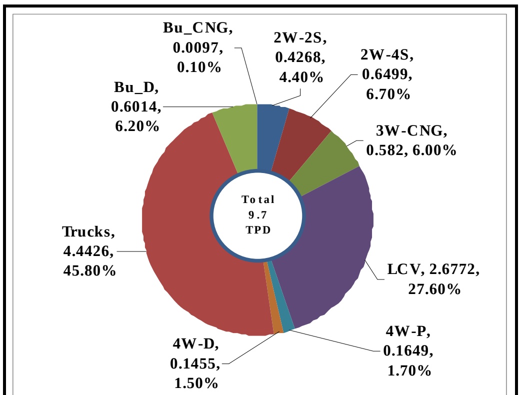
City wise finer distribution of source contribution within transport sector in respect of PM_{10} and NO_x is presented in Figures 4.9 and 4.10 respectively. As can be seen for transport sector, the PM_{10} contribution (40% - 59%) is mainly coming from heavy duty diesel vehicles in almost all the cities. In case of Kanpur, contribution of 3-wheelers is highest (39%), which is followed by heavy duty diesel vehicles (28%). With regard to NO_x, again heavy duty vehicles are major contributors (43 – 75%). It may be pertinent to mention that these contributions depend on share in terms of number of vehicles plying in the city and, therefore, present relative contribution among various vehicle types.



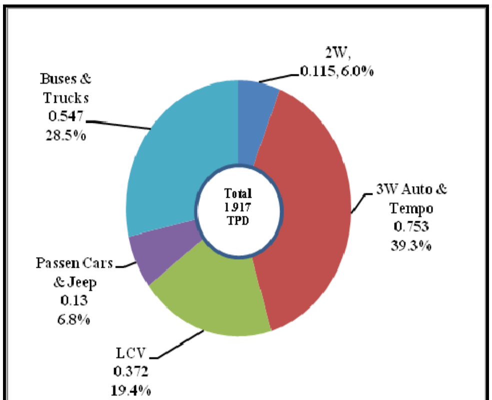
Mobile Source -EI: PM10-Bangalore



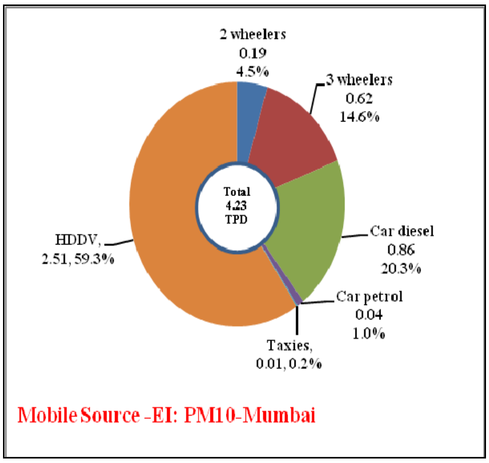
Mobile Source -EI: PM10-Chennai



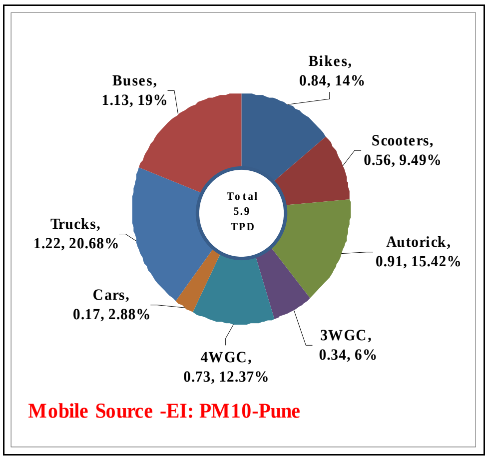
Mobile Source -EI: PM10-Delhi



Mobile Source -EI: PM10-Kanpur

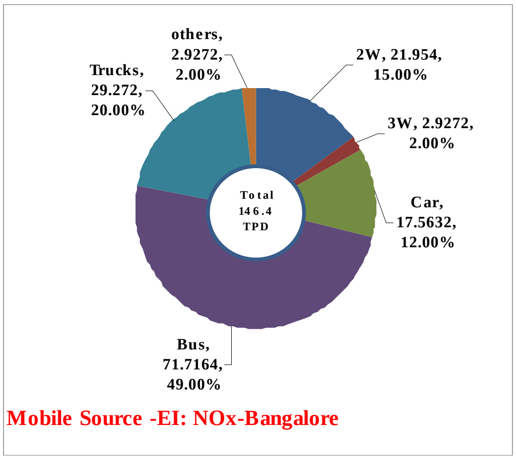


Mobile Source -EI: PM10-Mumbai

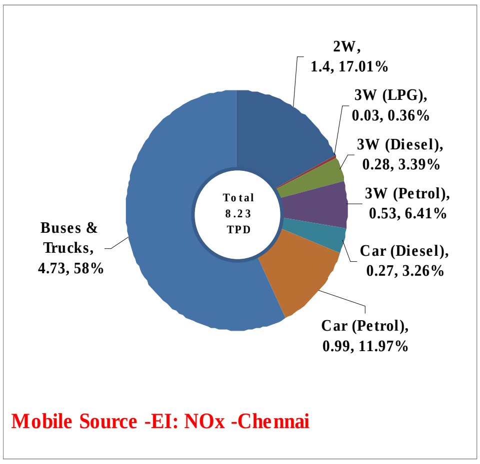


Mobile Source -EI: PM10-Pune

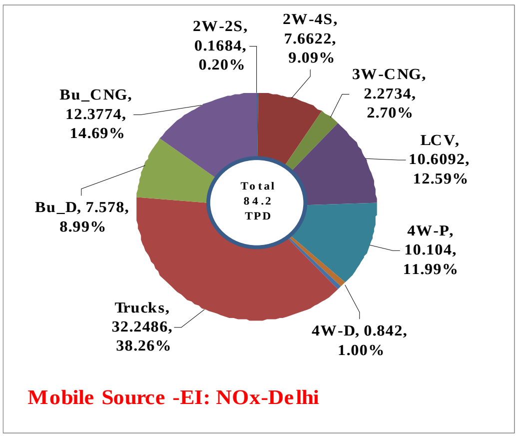
Figure 4.9: Contribution of Different Vehicle Types in PM_{10} Emissions in Six Cities



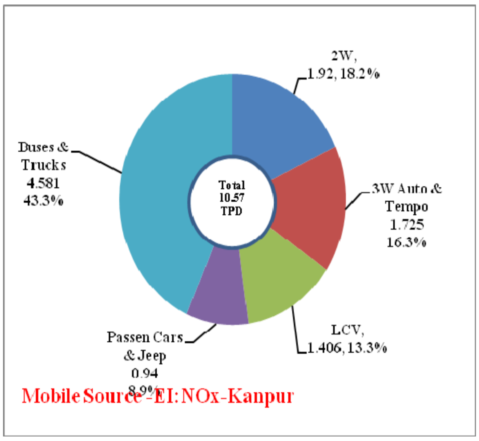
Mobile Source -EI: NOx-Bangalore



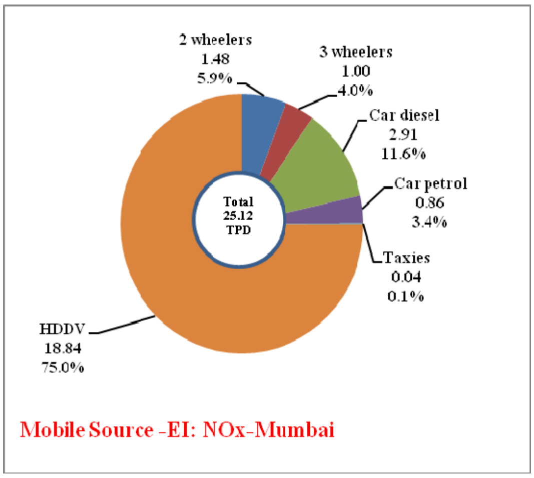
Mobile Source -EI: NOx -Chennai



Mobile Source -EI: NOx-Delhi



Mobile Source -EI: NOx-Kanpur



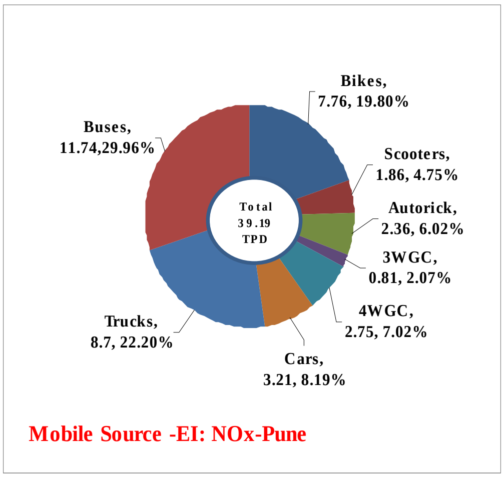


Figure 4.10: Contribution of Different Vehicle Types in NO_x Emissions in Six Cities

5

Receptor Modeling and Source Apportionment

Two approaches were followed for quantifying contributions of pollution sources. First approach is receptor modeling, as summarized earlier, which is based on analyses of PM in the ambient air at a given location and matching their characteristics with those of chemically distinct source types. The second approach is dispersion modeling, which is relatively a traditional approach, wherein emissions from different sources (emissions inventory), geophysical and meteorological conditions are used to calculate ambient concentrations at defined receptors (where ambient concentrations are measured). Dispersion and receptor models are complementary, and applying them to the same situation reveals deficiencies in each one that, when remedied, lead to a better assessment of pollution sources. Therefore, a combination of these two approaches provides a better insight to the contribution of polluting sources to air quality. In this study Factor Analysis and Chemical Mass Balance (CMB 8.2) models were used for receptor modeling. Factor Analysis (varimax rotated Principal Component Analysis) was initially applied to assess dominance of major source groups contributing to receptors. CMB-8.2 model was, then, used to get estimates on contribution of different source groups to the ambient particulate concentrations. Source dispersion modeling formed a vital component of this project. This was used to assess impacts of different control options/ strategies for delineating roadmap for air quality management. Ambient concentrations are used to calibrate the models for running future scenarios.

The fundamental principle of receptor models is that mass conservation can be assumed and a mass balance analysis can be used to identify and apportion sources of airborne particulate matter in the atmosphere. The approach to obtaining a data set for receptor modeling is to determine a large number of chemical constituents such as elemental concentrations in a number of samples. Receptor models use monitored pollutant concentration and some information about the chemical composition of local air pollution sources (profiles) to estimate the relative influence of these sources on pollutant concentrations at any single monitoring location. Receptor models are retrospective i.e. they can only assess the impacts of air pollution source categories on pollutant concentrations that have already been monitored.

5.1 Factor Analysis: Methodology

Factor analysis is a form of exploratory multivariate analysis that is used to either reduce the number of variables in a model or to detect relationships among variables. It replaces a large set of inter-correlated variables with a smaller number of independent variables. Thus, the new variables (Factors) are the linear combinations of original variables used in the analysis. The factor analysis assumes that the total concentration of each constituent is made up of the sum of elemental contributions from each of different pollution source components. All variables involved in the factor analysis need to be interval and are assumed to be normally distributed. The goal of the analysis is to try to identify factors which underlie the variables. There may be fewer factors than variables, but there may not be more factors than variables. The factor analysis method is quick and requires characterization of PM_{10} collected at receptors only without the need of obtaining chemical profiles of all the emission sources. Factor analysis is often used in data analysis to:

- Study the correlations of a large number of variables by grouping the variables into "factors", The variables within each factor are more highly correlated with variables in their factor than with variables in other factors
- Interpret each factor according to the meaning of the variables
- Summarize many variables by a few factors. The scores from the factors can be used as data for tests, regression etc.

In order to reduce the dimensionality in the data set, the new variables i.e. factors must have simple interpretations. But un-rotated principal components are often not readily interpretable since they each attempt to explain all remaining variance in the data set. For this reason, a limited number of components are usually subjected to rotation that constitutes a maximization of the variance of the communality normalized loadings (correlations). Such rotations tend to drive variable loadings toward either zero or one on a given factor.

Based on the above considerations, the Varimax rotated factor analysis technique based on the principal components has been used in the determination of the contribution of respirable particulate matter pollution sources. The components or factors rotated had Eigen values greater than one after rotation. It is widely used technique, because it is a simple, non-parametric method of extracting relevant information from confusing data sets. With minimal additional effort PCA provides a roadmap for how to reduce a complex data set to a lower dimension to reveal the sometimes hidden, simplified structure that often underlie it.

Chemical analysis data of PM_{10} samples collected at each of the sites representing different activity zones used as input to the factor analysis. Principal Component analysis was applied to the chemical speciation data of selected species of all the samples collected at a site in all the seasons.

5.2 CMB Model 8.2: Methodology

A mass balance equation can be written to account for all m chemical species in the n samples as contributions from p independent sources:

$$C_i = \sum_j m_j \, x_{ij} \, a_{ij}$$

Where, C_i is the concentration of species i measured at a receptor site, x_{ij} is the i^{th} elemental concentration measured in the j^{th} sample, and m_j is the airborne mass concentration of material from the j^{th} source contributing to the j^{th} sample. The term a_{ij} is included as an adjustment for any gain or loss of species i between the source and receptor. The term is assumed to be unity for most of the chemical species. CMB model assumptions are:

- Compositions of source emissions are constant over the period of ambient and source sampling;
- Chemical species do not react with each other (i.e., they add linearly);
- All sources with a potential for contributing to the receptor have been identified and have had their emissions characterized;
- The number of sources or source categories is less than or equal to the number of species;
- The source profiles are linearly independent of each other; and
- Measurement uncertainties are random, uncorrelated, and normally distributed.

The following approach was used for CMB modeling:

- Identification of the contributing source types based on primary emission inventory data collected around the monitoring sites in the area of 4 km^2;

- Selection of chemical species to be included in the calculation. Following species were analyzed from the daily PM_{10} samples collected at respective sites for 20 days in three seasons.
    - o Carbon fractions based on temperature (Organic Carbon & Elemental Carbon) using Thermal Optical Reflectance (TOR) Carbon Analyzer,
    - o Ions (Anions- fluoride, chloride, bromide, sulphate, nitrate & phosphate and Cations sodium, ammonium, potassium, magnesium & calcium) using Ion Chromatography
    - o Elements (Na, Mg, Al, Si, P, S, Cl, Ca, Br, V, Mn, Fe, Co, Ni, Cu, Zn, As, Ti, Ga, Rb, Y, Zr, Pd, Ag, In, Sn, La Se, Sr, Mo, Cr, Cd, Sb, Ba, and Pb) using ED-XRF, GT-AAS or ICP-AES or ICP-MS
    - o Molecular Markers (Alkanes, Hopane, Alkanoic acids qualitative analysis using GC-MS & quantitative analysis using GC-FID; PAHs analysis using High Performance Liquid Chromatography (HPLC)). Analysis of organic molecular markers was performed on 20 days composite sample and the species analysed were distributed in proportion to the organic carbon content in the respective samples.
- Selection of representative source profiles with the fraction of each of the chemical species and uncertainty. Source profiles developed for non-vehicular sources and vehicular sources were used.
- Estimation of the both ambient concentrations and uncertainty of selected chemical species from the particulate matter collected at respective sites; and
- Solution of the chemical mass balance equations through CMB-8.2 model run.

Source contribution estimates (SCE) are the main output of the CMB model. The sum of these concentrations approximates the total mass concentrations. When the SCE is less than its standard error, the source contribution is undetectable. Two or three times the standard error may be taken as the upper limit of the SCE in this case. Assuming that the errors are normally distributed, there is about a 66% probability that the true source contribution is within one standard error and about a 95% probability that the true concentration is within two standard errors of the SCE. The reduced chi square (χ^2), R^2, and percent mass are goodness of fit measures for the least-squares calculation. The χ^2 is the weighted sum of squares of the differences between calculated and measured fitting species concentrations divided by the effective variance and the degrees of freedom. The weighting is inversely proportional to the squares of the precision in the source profiles and ambient data for each species. Ideally, there would be no difference between calculated and measured species concentrations and χ^2 would be zero. A value of less than one indicates a very good fit to the data. Values greater than 4 indicate that one or more of the fitting species concentrations are not well-explained by the source contribution estimates. R^2 is determined by the linear regression of the measured versus model-calculated values for the fitting species. R^2 ranges from 0 to 1. The closer the value is to 1.0, the better the SCEs explain the measured concentrations. When R^2 is less than 0.8, the SCEs do not explain the observations very well with the given source profiles. Percent mass is the percent ratio of the sum of model-calculated SCEs to the measured mass concentration. This ratio should equal 100%, though values ranging from 80 to 120% were considered acceptable.

5.3 Source Apportionment of PM_{10} & $PM_{2.5}$

There are a large number of urban anthropogenic as well as background sources of such a high particulate pollution. These sources include large, medium and small-scale industries, household fuel use for cooking and heating, refuse burning, vehicular emissions, re-suspended road dust, construction activities, agricultural activity, naturally occurring dust and trans-boundary migration from other regions, etc. It is accepted that the configuration of possible contributing sources in different cities may vary widely as different potential city-specific sources emit particles of varying composition and sizes. However, respirable size fractions (10 microns and finer) affect public health much more than large particles. For any effective control strategy, it is important to have a good understanding of not only the level of exposure to various ecological receptors, but also the relative contributions from different sources along with the likely impacts and cost-benefit analysis of various control options. Ambient air quality monitoring of PM_{10} and $PM_{2.5}$, though is an important step, has limited role in formulation of strategy, as it can merely signal the existence and extent of problem. Ambient air monitoring at the strategic receptor needs to be supplemented by studies to quantify the contribution made by different sources and to assess the impacts costs (including public health consequences) in order to prioritize the cost-effective mitigation interventions. The receptor modeling studies, as depicted in Fig. 5.1, provided the requisite tool/techniques for the purpose.

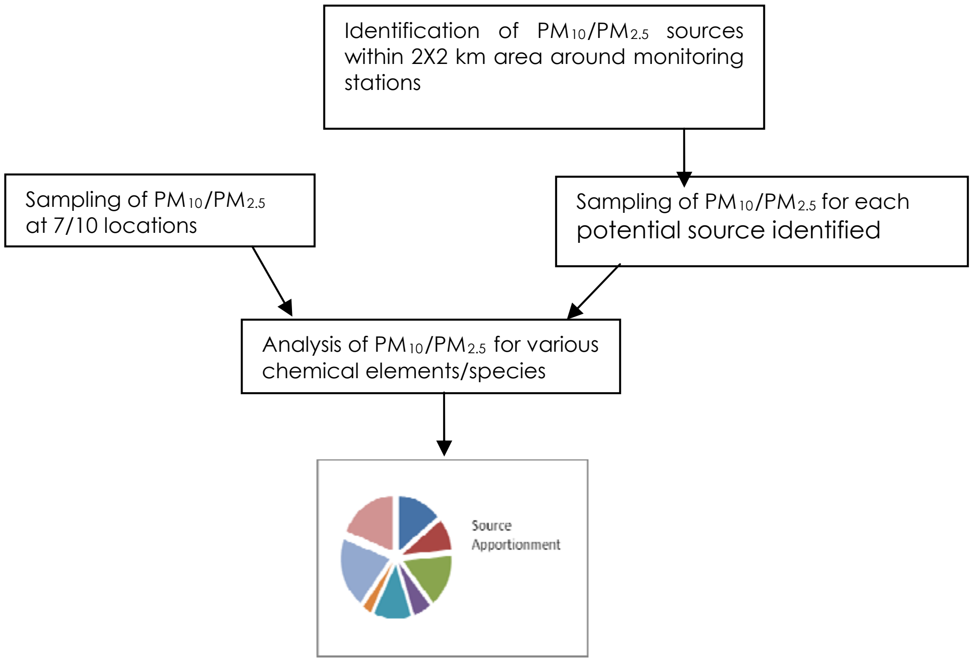


Figure 5.1: Scheme of Source Apportionment

Receptor models use monitored pollutant concentration (PM_{10} and $PM_{2.5}$) at the receptor and apportion it to the contributions of different sources using Chemical Mass Balance. The state-of-the- art model (CMB-8.2) was used for this purpose. Receptor models assess the impact of air pollution source categories on pollutant concentrations that have already been monitored. The most important assumptions for CMB model, relevant to this project are:

- Chemical species do not react with each other (i.e. they add linearly).
- All the sources with a potential to contribute to the receptor have been identified and their emission characterized.
- Measurement uncertainties are random, uncorrelated and normally distributed.
- CMB is intended to complement rather than replace diffusion modeling tool/techniques.

Source apportionment analysis was carried out in all seasons (except rainy season, as it does not represent the actual situation on contribution of different sources due to wash out component) for PM_{10} or $PM_{2.5}$. The CMB-8.2 modeling involves:

- Identification of the contributing sources types;

- Selection of chemical species or other properties to be included in the calculation;
- Estimation of the fraction of each chemical species, which is contained in each source type (Source Profiling of PM_{10} and $PM_{2.5}$ emitted);
- Estimation of the uncertainty in both ambient concentrations and source profiles; and
- Analysis of modeling results.

One of the major requirements of CMB 8.2 is the chemical quantification of different markers (specific to each source type) as fractions of total PM_{10} or $PM_{2.5}$ concentrations monitored at the respective receptors.

5.4 Chemical characterization of PM_{10} and $PM_{2.5}$

PM_{10} and $PM_{2.5}$ samples were subjected to detailed chemical speciation comprising analysis of ions, elements, organic & elemental fractions of carbon, and molecular markers. The sources identified through detailed field visits in each city, were categorized as general and city specific sources. The markers, specific to these sources, were identified based on detailed literature survey and consultations with Experts. Chemical species including molecular markers identified for analysis are given in Table 5.1.

Table 5.1: Target Physical and Chemical components (groups) for Characterization of Particulate Matter

Components	Required filter matrix	Analytical methods
PM_{10}/ $PM_{2.5}$	Teflon or Nylon filter paper. Pre and post exposure conditioning of filter paper is mandatory	Gravimetric
Elements (Na, Mg, Al, Si, P, S, Cl, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Hg, and Pb)	Teflon filter paper	ED-XRF, GT-AAS or ICP-AES or ICP-MS

<table>
<tr><th colspan="2">Components</th><th>Required filter matrix</th><th>Analytical methods</th></tr>
<tr><td colspan="2">Ions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, $SO4^{--}$, K^+, NH_4^+, Na^+, Ca^{++}, Mg^{++})</td><td>Nylon or Teflon filter paper (Same Teflon filter paper can be utilized if ED-XRF is used for elements analysis</td><td>Ion chromatography with conductivity detector</td></tr>
<tr><td colspan="2">Carbon Analysis (OC, EC and Carbonate Carbon)</td><td>Quartz filter. Pre-baking of quartz filter paper at 600 °C is essential</td><td>TOR/TOT method</td></tr>
<tr><td colspan="2">Molecular markers</td><td rowspan="6">The left over quartz filter paper after OC/EC analysis should be taken as composite sample to represent a location and specified duration of exposure</td><td rowspan="6">Extraction, followed by GC-MS analysis with and without derivatization</td></tr>
<tr><td>Alkanes</td><td>n- Hentriacontane
n-Tritriacontane
n- Pentatriacontane</td></tr>
<tr><td>Hopanes</td><td>22, 29, 30 – Trisnorneohopane
17α(H), 21β(H)-29 Norhopane
17α(H),21β(H) norhopane</td></tr>
<tr><td>Alkanoic acid</td><td>Hexadecanamide
Octadecanamide</td></tr>
<tr><td>PAHs</td><td>Benzo[b]fluoranthene
Benzo[k]fluoranthene
Benzo[e]pyrene
Indeno[1,2,3-cd]fluoranthene
Indeno[1,2,3-cd]pyrene
Phenylenepyrene
Picene
Coronene</td></tr>
<tr><td>Others</td><td>Stigmasterol
Levoglucosan</td></tr>
</table>

5.5 Source Profiling of Vehicular and Non-vehicular Emission Sources

Development of chemical profiles of particulate matter for air polluting sources is important for use as input to receptor oriented source apportionment models like Chemical Mass Balance (CMB). The U.S

Environmental Protection Agency's (EPA) SPECIATE database and several studies carried out in other parts of the world provide an extensive collection of source profiles. However, differences in sources, operating conditions, geology and climate may make them unsuitable for the conditions and sources in Indian cities. No database on profiles for sources specific to India was available. Therefore, studies for development of such profiles for Indian conditions, specific to each of the cities, were included as a key component of the project.

The sources were broadly categorized under vehicular and non-vehicular sources. PM emission samples collected from representative sources in all the six cities were subjected to detailed chemical characterization involving analysis of constituents similar to ambient air samples. The methodology adopted is summarized below:

5.6 Vehicular Exhaust Emission Profiles

Chemical speciation of vehicle exhaust particulate matter (source profiles) is required for assessment of contribution from vehicle sources using receptor model. The available international database "SPECIATE-4.0" is the U.S. Environmental Protection Agency's (EPA) repository of total organic compound (TOC) and particulate matter (PM) speciation profiles of air pollution sources(vehicular as well as non-vehicular sources). The vehicle categories available under Speciate for CMB application mostly fall under LCV and HCV category. No data were available on emission profiles for vehicles plying in Indian cities. In view of this and considering the Indian scenario, where traffic composition includes 2-Wheeler (2-Stroke and 4-Stroke), 3-Wheeler (Diesel, Gasoline, LPG and CNG) along with LCV and HCV, indigenous vehicular emission profiles were developed.

To carry out detailed chemical characterization of Particulate Matter, two mass emission tests were carried out on each vehicle - one with Teflon for mass, ions and element analysis and another on Quartz for carbon fractions and molecular markers analysis, following Indian Driving Cycle (IDC) for 2/3 wheelers, Modified IDC for passenger cars and LCVs and Overall Bus Driving Cycle for HCVs on Chassis dynamometer for collection of particulate matter on respective filter papers. The constituents, given in Table 3.2 and similar to analysis of ambient air samples, were analyzed. The observed concentrations of the chemical species were determined as percentage of total PM collected from the vehicle exhaust. Corresponding uncertainties were also found out for the species.

Diesel and gasoline composite: Composite profiles for all gasoline and diesel vehicles including different categories and vintages were generated, which are representative of vehicle fleet including all categories and vintages in gasoline and diesel vehicles. Distribution of exhaust particulate matter in composite profiles for all gasoline and all diesel vehicles in different chemical groups like organic carbon, elemental carbon, ions, elements and other is presented below:

- In all gasoline and diesel composites, organic carbon was found to dominate with 54% and 50% respectively. Elemental carbon fraction was found to be higher in all diesel composite (22%) than in all gasoline composite (7%), which is a major distinguishing factor between gasoline and diesel composite.
- Ions percentage was found to be higher in gasoline composite (19%) as compared to diesel composite (4%). Higher fraction of ions in gasoline exhaust can be attributed to the higher sulphate, chloride, calcium and sodium ions in exhaust due to use of lube oil.
- Elements, mainly wear metal (Fe, Pb & Cu) are found to be higher in gasoline exhaust than diesel exhaust. Although, the absolute quantities of these metals were found to be similar from both the vehicle exhaust, percent contribution in gasoline vehicles is higher due to less overall mass of PM in gasoline exhaust.
- Organic molecular markers fractions were found to be higher in gasoline exhaust composite (~4%) than in diesel exhaust composite (~1.3%). 17 alpha (H), 21 beta (H)-Hopane was found to be marginally higher (2.1%) in gasoline than in diesel exhaust (1.6%). Hopanes are present in lubricating oil used by gasoline and diesel powered engines and hence, are emitted in particle phase from both the engine types.
- Overall mass concentration of all the 16 PAHs is higher in diesel than gasoline exhaust due to higher PM mass in Diesel vehicles. Qualitative interpretation (2, 3, 4 ,5 rings PAH) reveals that mass concentration of 2,3 and 4 ring lighter PAH compounds e.g. Fluorene + Acenaphthene, (3-ring) Fluoranthene and (4-ring) Pyrene is higher in Diesel vehicles as compared to Gasoline vehicles. Whereas, similarly mass concentration of 5-ring heavier PAH compounds (e.g. Benzo(a)Pyrene, Dibenz(a,h)anthracene, Indeno(1,2,3cd) pyrene and Benzo(ghi)perylene) is higher in diesel vehicles as compared to gasoline vehicles. However, overall mass of 2, 3 and 4 ring lighter PAH compounds is high as compared to 5-ring heavier PAH compounds in Diesel as well as Gasoline vehicles.

Co-linearity in data: Co-linearity checks were performed to assess the gasoline and diesel composite profiles for their distinctness. OC % found to be close in gasoline (54%) and diesel (50%). However, diesel and gasoline exhaust EC content was 22% and 7% respectively. Diesel exhaust particles are known to have contained much higher fraction of elemental carbon than gasoline exhaust particles and based on this elemental to organic carbon ratio in gasoline and diesel exhaust, contribution from both engine types can be differentiated. For certain elements % share was found to be very less and similar. PAHs and ions data were not found to be collinear and show higher % in gasoline exhaust.

Category wise distribution of species: Chemical speciation data of vehicle exhaust PM is analyzed and grouped under different categories based on engine technology and fuel types, with following findings:

- Organic carbon was found to vary from 48 to 57 % amongst the composite of different category gasoline vehicles. Similarly, elemental carbon was varied from 3% to 13%. OC and EC in composite of all gasoline vehicles was 52% and 6.6% respectively. Category wise composites for diesel vehicles show variation in organic carbon from 46 % to 52% and variation in EC from 16% to 25%. All diesel vehicles composite shows OC and EC % as 49% and 22% respectively. OC % in CNG vehicles composite varied from 29% to 58% and EC % variation was from 6% to 22%. In case of LPG category wise composite OC % variation was 26% to 49% and EC % variation was from 7% to 14%. All CNG vehicle composite OC and EC % are found to be 43% and 16% respectively, whereas all LPG composite OC and EC % are 38%and 11% respectively.
- Amongst the ions, sulphate, nitrate, chloride and ammonium ions were found to have major share. Gasoline vehicle exhaust was found to have higher % of ions then diesel exhaust, which may be due to lower overall PM mass in gasoline exhaust.
- Elements % were found to be very less in exhaust PM of all vehicle types. Elements from lube oil (Ba, Ca, S, Mg, Zn, P & Mo) and engine wear metals (Fe, Cu & Pb) were found to be comparatively in higher proportion. In terms of % mass gasoline exhaust is found to contain higher % of these metals as compared to diesel exhaust.
- PAHs % distribution shows higher fraction of Pyrene, Fluorine+ Acenaphthene and Acenaphthalene in all vehicle categories. Total PAHs were observed to higher in gasoline vehicle composite (3.96%) than in diesel vehicle composite (1.26%).

Salient features: A comprehensive data base on source profiles generated on Indian vehicles' exhaust includes:

- Total 192 mass emission tests on 96 vehicles (2 tests on each vehicle). The emission factors generated in this study were supplementary to the emission factors generated in emission factor study on in use Indian vehicles.
- Vehicles selected/tested with respect to fuel type, category and vintage are as follow:
  - Gasoline, Diesel, LPG (OE/Retrofit) and CNG (OE/Retrofit)
  - 2S-2W, 4S-2W, 2S-3W, 4S-3W, Cars, LCV, HCV
  - 1991-96, 1996-2000, 2000-2005+ vintage
- Total of 96 nos. of Individual profiles and 44 nos. of composite profiles were developed for different vintage, category and fuel.
- The profiles are reported as percentage abundances of measured species with their corresponding uncertainties of the PM mass collected. These source profiles were prepared in a CMB receptor model input-file format.
- Carbonaceous material accounted for a majority of the PM mass. Of the total carbon, OC represented on average between 54 & 50% of the mass in gasoline and diesel vehicle exhaust PM.
- Higher fraction of EC was observed in Diesel Vehicles (22%) than in Gasoline vehicle exhaust (7%).
- Organic molecular markers were found to be higher in percentage in gasoline exhaust composite (~4%) than in diesel exhaust composite (~1.3%). 17 alpha (H), 21 beta (H)-Hopane was found to be marginally higher (2.1%) in gasoline than in diesel exhaust (1.6%). Overall mass concentration of all the 16 PAHs is higher in diesel than gasoline exhaust due to higher PM mass in Diesel vehicles. Overall mass of 2, 3 and 4 ring lighter PAH compounds is high as compared to 5-ring heavier PAH compounds in Diesel as well as Gasoline vehicles.
- Ions fraction in gasoline vehicles were found to be higher than Diesel vehicles. Gasoline exhaust composite was found to contain high percentage of sulphate (~4.5%), chloride (~3.5%) calcium (~3%) ions and sodium (~2%). In diesel exhaust composite ions percentage was found to be below 1% for all the ions.
- Calcium, barium, sodium, magnesium, zinc and iron were found to be higher as compared to other metals in gasoline and diesel exhaust. The Zn, P, Mg, and Ca are attributed to compounds in the lubricant while the Fe is an indication of engine wear.

- Unidentified percentage varied from 3 to 30 % in all the vehicle categories.
- Mass fractions (%) of carbon, ions, elements, and PAH are given in Table 5.2 and 5.3.

Table 5.2: Percentage distribution of Carbon, Ions and Elements in PM_{10} for different categories of vehicles

Vehicle Category	Carbon Fraction (%)		Ions (%)				Elements (%)										
	OC	EC	Chloride (Cl)	Nitrate (NO_3^-)	Sulphate (SO_4)	Ammonium (NH_4)	Barium (Ba)	Calcium (Ca)	Copper (Cu)	Iron (Fe)	Magnesium (Mg)	Molybdenum (Mo)	Sodium (Na)	Phosphorus (P)	Lead (Pb)	Sulphur (S)	Zinc (Zn)
2-stroke, 2-wheeler (Gasoline)	57.34	3.10	4.37	0.86	4.24	0.56	0.813	3.163	0.006	0.056	0.000	0.008	1.295	0.000	0.037	0.035	0.292
4-stroke, 2-wheeler (Gasoline)	48.63	5.08	5.07	0.39	5.94	0.00	3.263	1.792	0.036	0.082	0.000	0.000	0.398	0.031	0.319	0.000	1.229
3-Wheeler(Gasoline)	54.24	4.70	2.62	0.76	4.80	0.01	2.057	0.739	0.003	0.114	0.000	0.011	0.000	0.005	0.010	0.072	1.201
Passenger Car(Gasoline)	47.98	13.42	2.44	1.40	3.20	0.50	0.000	2.373	0.018	0.347	0.081	0.004	0.461	0.066	0.082	0.414	0.000
3-Wheeler(Diesel)	48.73	16.20	0.95	0.04	0.56	0.00	0.539	0.148	0.006	0.003	0.000	0.000	0.389	0.008	0.010	0.021	0.120
Passenger Car(Diesel)	50.26	18.59	0.10	0.17	0.74	0.01	0.573	0.507	0.014	0.026	0.000	0.000	0.000	0.016	0.021	0.324	0.303
LCV(Diesel)	46.16	26.86	0.12	0.23	0.98	0.08	0.782	0.210	0.008	0.008	0.000	0.001	0.000	0.000	0.014	0.415	0.532
HCV(Diesel)	51.93	24.62	0.20	0.28	1.06	0.00	0.782	0.210	0.008	0.008	0.000	0.001	0.000	0.000	0.014	0.415	0.532
3 Wheeler (CNG)	58.38	6.46	3.27	0.08	2.34	0.00	0.000	2.147	0.000	0.242	0.000	0.003	2.941	0.015	0.152	0.000	0.000
4 Wheeler (CNG)	28.71	18.56	3.42	2.02	3.77	0.96	0.490	1.083	0.035	0.301	0.607	0.000	0.228	0.069	0.035	0.282	0.156
HCV (CNG)	41.97	22.01	2.19	0.00	0.67	1.21	0.000	0.000	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3 Wheeler (LPG)	49.04	7.17	2.74	0.06	1.68	0.00	0.245	1.383	0.029	0.072	0.000	0.000	0.937	0.002	0.201	0.000	0.026
4 Wheeler (LPG)	26.41	14.36	2.84	1.18	4.97	1.14	0.134	2.736	0.009	1.246	0.737	0.003	2.396	0.060	0.035	0.325	0.000
All Gasoline Composite	52.05	6.58	3.63	0.85	4.54	0.27	1.53	2.02	0.02	0.15	0.02	0.01	0.54	0.03	0.11	0.13	0.68
All Diesel Composite	49.27	21.57	0.34	0.18	0.83	0.02	0.58	0.27	0.01	0.02	0.00	0.00	0.10	0.01	0.01	0.23	0.25
CNG Composite	43.02	15.68	2.96	0.70	2.26	0.72	0.16	1.08	0.03	0.18	0.20	0.00	1.06	0.03	0.06	0.09	0.05
LPG Composite	37.72	10.77	2.79	0.62	3.32	0.57	0.19	2.06	0.02	0.66	0.37	0.00	1.67	0.03	0.12	0.16	0.01

Table 5.3: Percentage distribution of PAHs in PM_{10} for different categories of vehicles

	PAHs (%)										
	Acenapthalene	Fluorene + Acenapthene	Fluoroanthene	Pyrene	Benzo(a) Anthracene	Chrysene	Benzo(b) Fluoroanthene	Dibenz(a,h) anthracene	Benzo(ghi) Pyrene	Indenol(1,2,3) Pyrene	Total PAHs
2-stroke, 2-wheeler (Gasoline)	0.683	0.652	0.101	0.066	0.002	0.001	0.165	0.000	0.000	0.000	1.900
4-stroke, 2-wheeler (Gasoline)	0.382	1.637	0.532	1.933	0.045	0.041	0.111	0.125	0.427	0.751	8.572
3-Wheeler(Gasoline)	0.331	0.252	0.147	0.878	0.056	0.011	0.024	0.046	0.349	0.017	2.910
Passenger Car(Gasoline)	0.078	0.251	0.062	0.503	0.510	0.034	0.478	0.006	0.048	0.009	2.414
3-Wheeler(Diesel)	0.080	0.122	0.028	0.079	0.004	0.006	0.011	0.012	0.010	0.006	0.511
Passenger Car(Diesel)	0.024	0.036	0.007	0.037	0.000	0.001	0.005	0.005	0.001	0.001	0.130
LCV(Diesel)	0.020	0.056	0.013	0.056	0.004	0.000	0.002	0.006	0.002	0.001	0.181
HCV(Diesel)	0.345	0.951	0.654	0.352	0.066	0.083	0.100	0.290	0.171	0.225	4.235
3 Wheeler (CNG)	0.333	2.340	0.396	1.124	0.029	0.040	0.052	0.128	0.000	0.000	6.642
4 Wheeler (CNG)	0.092	0.324	0.060	0.109	0.002	0.001	0.001	0.000	0.000	0.000	0.666
HCV (CNG)	0.016	0.072	0.132	0.154	0.012	0.008	0.014	0.033	0.002	0.011	0.533
3 Wheeler (LPG)	0.225	1.343	0.199	0.835	0.027	0.015	0.001	0.018	0.001	0.001	3.605
4 Wheeler (LPG)	0.163	0.270	0.057	0.334	0.003	0.006	0.007	0.012	0.026	0.035	1.253
All Gasoline Composite	0.37	0.70	0.21	0.84	0.15	0.02	0.19	0.27	0.04	0.21	3.96
All Diesel Composite	0.12	0.29	0.18	0.13	0.02	0.02	0.03	0.08	0.05	0.06	1.26
CNG Composite	0.15	0.91	0.20	0.46	0.01	0.02	0.02	0.05	0.00	0.00	2.61
LPG Composite	0.19	0.81	0.13	0.58	0.01	0.01	0.00	0.01	0.01	0.02	2.43

5.7 Non-Vehicular Sources Emission Profiles

The stationary sources to be profiled in each city were identified based on a list of major contributing sources compiled from the emission inventories of respective partner institutes carrying out city-specific studies. The overall participation framework of the present study is shown in Figure 5.2. Sources were categorized based on their nature (combustion or non-combustion) and occurrence (city specific or common to all cities). These categories were combustion common (CC), combustion city specific (CCS), non-combustion common (NCC) and non-combustion city specific (NCS). The city specific sources were sampled in the respective city for developing source profiles specific to that city. The common sources were sampled either in any one of the city or in laboratory to develop source profiles. A total of 58 PM_{10} profiles and 21 $PM_{2.5}$ profiles were developed for 58 sources in the present study. A summary of the sources and corresponding profiles is presented in Table 5.4.

Based on the nature of sources, different methodologies were adopted for source sampling. Sampling strategies for different sources are depicted in Figure 5.3. Three sampling methodologies adopted in the present study include dilution sampling for combustion sources, re-suspension sampling for dust sources, and source dominated sampling for area sources. Combustion sources were sampled using an iso- kinetic two stage dilution sampler designed at IIT Bombay. Dilution sampling allowed representative sampling of combustion sources by simulating the atmospheric dilution of exhaust gas**.** Dilution ratio was varied from source to source depending upon the source gas temperatures and the particulate matter (PM) concentrations. The iso-kinetic sampling probe in the sampler ensured minimum particle loss during sampling.

The re-suspended geological dust sources in each city included paved road dust, unpaved road dust and soil dust. These dust samples were collected from each of these cities following internationally accepted protocols and they were sampled using a well known re-suspension chamber approach. The sampling duration was determined based on the characteristics of dust samples and the PM fraction. The re-suspension chamber approach was also used for sampling other dust sources such as cement, sand, aggregate dust and rock phosphate dust from a fertilizer plant.

The sampling of sources such as marine aerosols, solid waste burning, paint spray booth and tar melting was carried out by placing the sampling probe directly into the source dominated volume. The source dominated sampling of solid waste burning, paint spray booth and tar melting was carried out under controlled laboratory conditions to ensure that these samples are not contaminated by other sources. Marine aerosol sampling was carried out at a beach which was far away from Mumbai city in order to avoid influence of city pollution.

Table 5.4 List of Source Profiles Developed

No.	Name of Sources (in alphabetical order)	Source Code	Class	PM_{10}	$PM_{2.5}$	F	L
1	Aggregate Dust	6004	NCC	1	0	0	1
2	Agricultural Waste Burning	15	CC	1	0	0	1
3	Asphalt Paving Operations	24	NCC	1	0	1	0
4	Bagasse Combustion	5	CC	1	0	0	1
5	Bricks and Related Clay Products	40	CS	1	0	1	0
6	Cement	6002	NCC	1	0	0	1
7	Chulah (Wood)-Chennai	9	CC	1	0	0	1
8	Chulah (Wood)-Kanpur	9	CC	1	0	0	1
9	Chulah (Wood)-Mumbai	9	CC	1	1	0	1
10	Coal Combustion - Domestic-Kanpur	8	CC	1	0	0	1
11	Coal Combustion - Domestic -Mumbai	8	CC	1	1	0	1
12	Coal Combustion Power Plant-Delhi	12	CS	1	0	1	0
13	Coal Combustion Power Plant-Kanpur	12	CS	1	0	1	0
14	Construction and Aggregate Processing	43	NCC	1	0	1	0
15	Diesel Industrial Generators	21	CC	1	1	1	0
16	Electric Arc Furnace	45	CC	1	1	1	0
17	Fertilizer Plant Stack	6007	CC	1	0	1	0
18	Fuel Oil combustion	2	CC	1	1	1	0
19	Fugitive Rock Phosphate Emission from Fertilizer Plant	6005	NCC	1	0	0	1
20	Garden Waste Combustion	5001	CC	1	0	0	1
21	Kerosene Combustion-Domestic	7	CC	1	1	0	1
22	Kerosene Generators- 80 % Load	20	CC	1	1	0	1
23	Kerosene Generators- Full Load	20	CC	1	1	0	1
24	Kerosene Generators-No Load	20	CC	1	1	0	1

No.	Name of Sources (in alphabetical order)	Source Code	Class	PM_{10}	$PM_{2.5}$	F	L
25	Leather Waste Burning	13	CS	1	0	0	1
26	Liquefied Petroleum Gas Combustion	4	CC	1	0	0	1
27	Low Sulphur Heavy Stock-Power Plant	6000	CS	1	1	1	0
28	Marine Aerosols	26	NCS	1	0	1	0
29	Medical Waste Incineration (Controlled)	17	CC	1	0	1	0
30	Medical Waste Incineration (Uncontrolled)	17	CC	1	0	1	0
31	Paint Spray Booth	31	NCS	1	0	0	1
32	Paved Road Dust-Bangalore	52	NCS	1	0	0	1
33	Paved Road Dust- Chennai	52	NCS	1	0	0	1
34	Paved Road Dust- Delhi	52	NCS	1	0	0	1
35	Paved Road Dust- Kanpur	52	NCS	1	0	0	1
36	Paved Road Dust- Mumbai	52	NCS	1	1	0	1
37	Paved Road Dust- Pune	52	NCS	1	1	0	1
38	Petroleum Refining-Combustion	27	CC	1	0	1	0
39	Petroleum Refining-Non-Combustion	28	NCC	1	0	1	0
40	Power Plant Natural Gas based	5002	CS	1	0	1	0
41	Sand	6003	NCC	1	0	0	1
42	Secondary Metal (Lead) Smelting and other operations-Bangalore	46	CC	1	1	1	0
43	Secondary Metal (Lead) Smelting and other operations-Kanpur	46	CC	1	0	1	0
44	Soil Dust-Bangalore	54	NCS	1	0	0	1
45	Soil Dust-Chennai	54	NCS	1	0	0	1
46	Soil Dust-Delhi	54	NCS	1	0	0	1
47	Soil Dust-Kanpur	54	NCS	1	0	0	1
48	Soil Dust-Mumbai	54	NCS	1	1	0	1
49	Soil Dust-Pune	54	NCS	1	1	0	1
50	Solid Waste Open Burning-Commercial Area	18	CC	1	1	0	1
51	Solid Waste Open Burning-Residential Area	18	CC	1	1	0	1
52	Steel Rolling Mills	6001	CC	1	1	1	0
53	Tar Melting	6006	CC	1	1	0	1

No.	Name of Sources (in alphabetical order)	Source Code	Class	PM_{10}	$PM_{2.5}$	F	L
54	Unpaved Road Dust-Bangalore	53	NCS	1	0	0	1
55	Unpaved Road Dust-Delhi	53	NCS	1	0	0	1
56	Unpaved Road Dust-Kanpur	53	NCS	1	0	0	1
57	Unpaved Road Dust-Pune	53	NCS	1	1	0	1
58	Wood Residue Combustion in Boilers	11	CS	1	1	1	0
			TOTAL	58	21	20	38

F Field Sampling: 20 1 – available SPECIATE database

L Lab Sampling: 38 0 – not in SPECIATE database

CC Combustion common sources NCC Non-combustion common sources

CS Combustion city specific sources NCS Non-combustion city specific sources

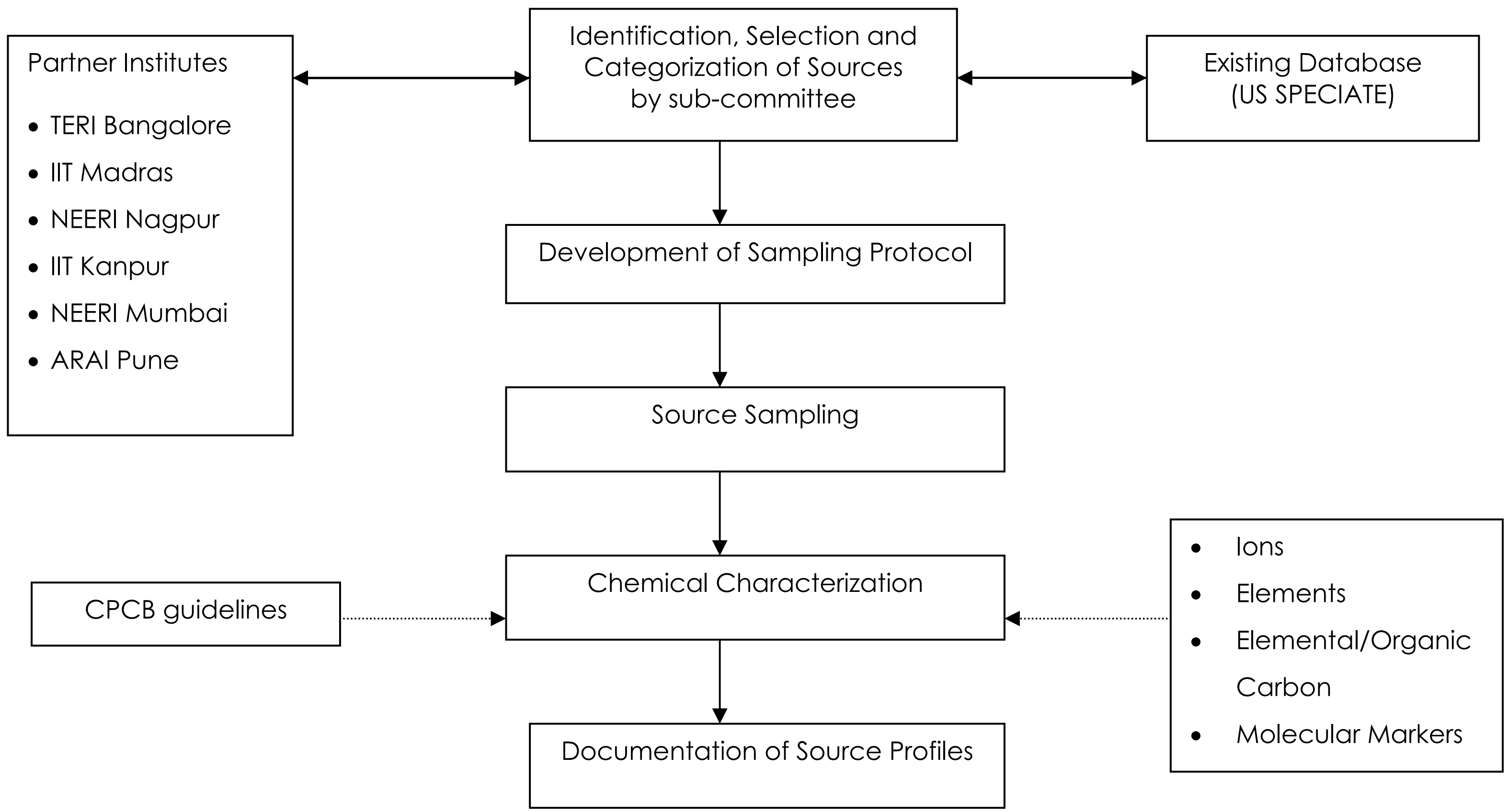


Figure 5.2: Overall Framework for the Work Elements in the Development of Stationary Source Profiles carried out at IIT-Bombay

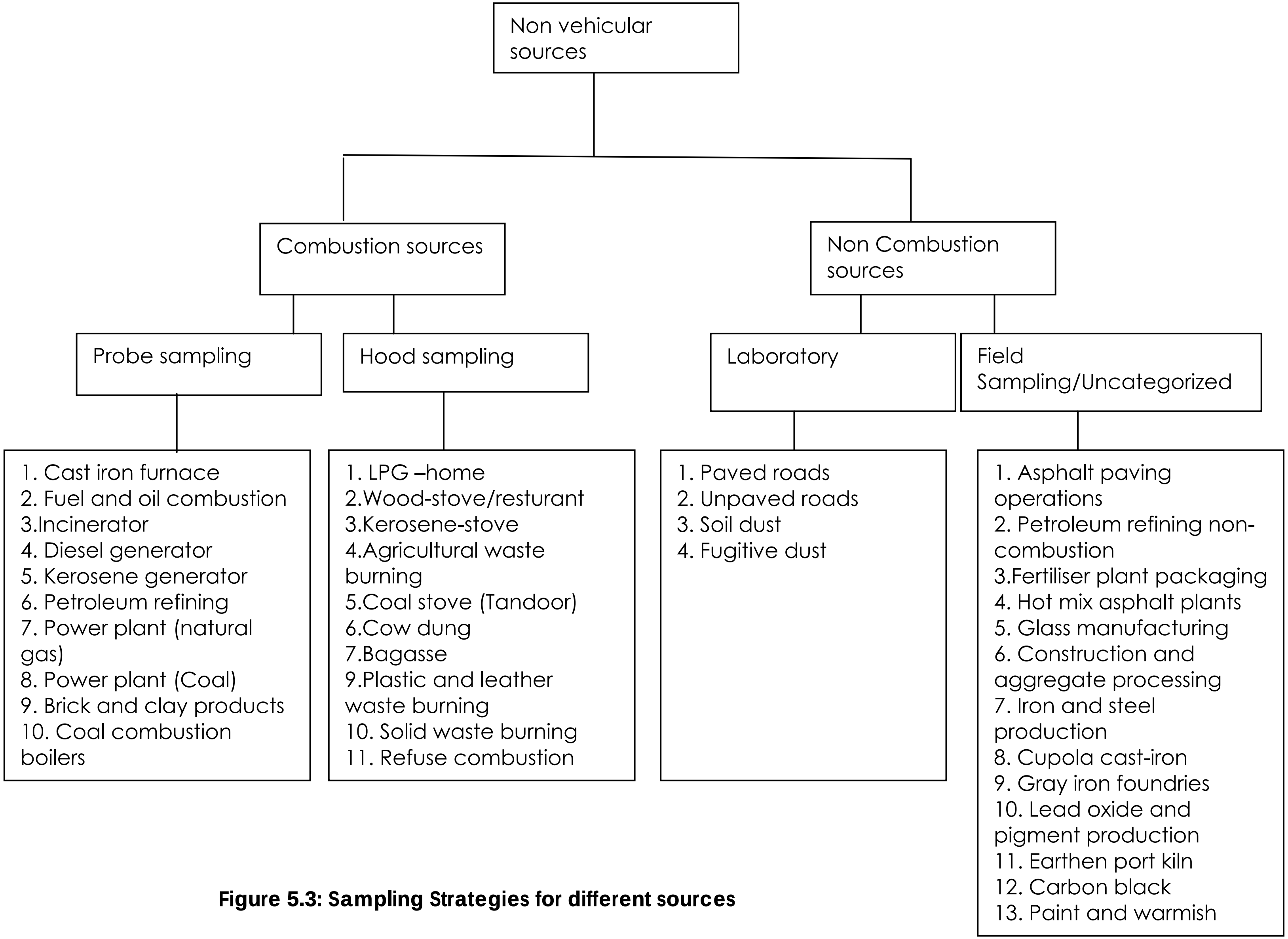


Figure 5.3: Sampling Strategies for different sources

Adequate PM deposition on the filters was ensured during all samplings. Quartz and Teflon filters were used to collect PM for chemical analyses. Each sample consisted one Quartz and two Teflon filters for both PM_{10} and $PM_{2.5}$. Quartz filter was used for EC/OC and molecular marker analyses, and Teflon filters were used for ionic and elemental analyses. All gravimetrical analyses of filters were carried out using a microbalance having a least count of 1 μg. Filter handling procedures were in accordance with the conceptual guidelines and common methodology, developed for the project.

The reported source profiles contain 39 elemental species analyzed by ICP-AES, 12 water soluble ions analyzed by Ion Chromatography (IC), organic carbon (OC) and elemental carbon (EC) analyzed by Thermal Optical Reflectance (TOR) method and 12 molecular marker compounds analyzed by GC-FID. The analysis of molecular marker compounds were limited to the qualitative identification of these compounds in the source samples. All chemical and gravimetrical analyses were as per CPCB described protocols and have been reported together with the detailed QA/QC documentation.

The measured concentrations of these chemical species were normalized to PM gravimetric mass to produce source profiles as percentage abundances and reported with their corresponding uncertainties. Figure 5.4 gives a graphical representation of a typical source profile developed in the present study. These source profiles were submitted in a format suitable for input in to CMB receptor model as a soft file, and also documented as a report in two volumes (http://www.cpcb.nic.in/). Volume 1 comprises the background development work and Volume 2 comprises of all the source profiles data.

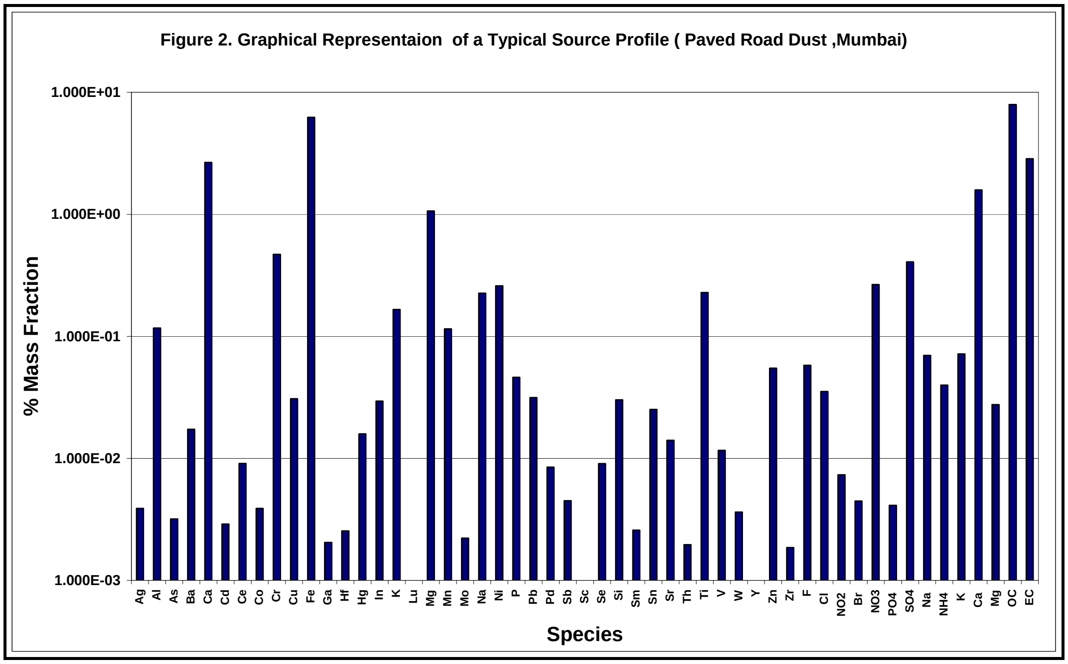


Figure 5.4: A Typical Source Profile (Paved Road Dust, Mumbai)

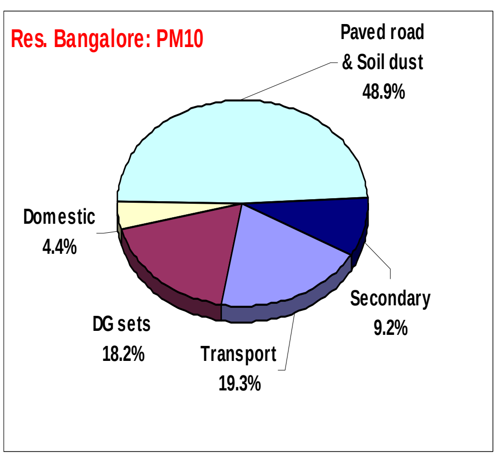
5.8 Contributing Sources based on Receptor Modeling

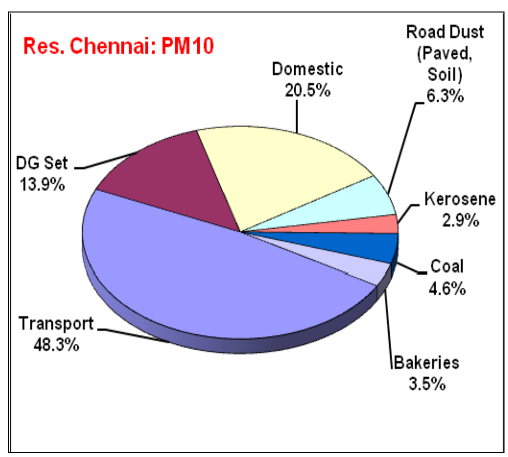
Factor analysis and Chemical mass balance (CMB8.2) models were used to apportion contribution of source groups in ambient particulate matter (PM_{10} & $PM_{2.5}$). The Varimax rotated factor analysis technique based on the principal components was initially used to determine the dominance of sources contributing to various receptors. The information on indicative source dominance along with data on chemical speciation of PM_{10} & $PM_{2.5}$ were subsequently, used in CMB8.2 model to get quantitative contribution of sources. The CMB model was run for each day of sampling (at the location) for each location and in all the three seasons. There have been seasonal as well as day-to-day variations in the prominent sources that contribute to PM_{10} and $PM_{2.5}$. Therefore, the source contribution estimates of all the seasons were averaged for locations of similar land use (e.g. data for two residential locations were pooled together). This helped in preparing overall source - receptor linkages. The overall results of source – receptor impact relationship in terms of percent contribution (excluding unidentified sources, which are explained in the mass closure plots – Figures 3.25 – 3.30) of various sources at residential, kerbside, industrial locations in all the six cities in respect of PM_{10} are presented in Figures 5.5 – 5.7.

In residential locations, re-suspension of road dust & soil dust emerged as prominent sources of PM_{10} in the cities of Pune (57%), Bangalore (49%), Mumbai (47%) and Delhi (15%). Vehicular sources (15 – 48%) contribute significantly in Bangalore, Chennai, Delhi and Kanpur. Other prominent sources include DG sets in Bangalore, Chennai and Delhi; and Garbage burning in Delhi, Kanpur and Mumbai. Construction activities (22%) are another major source contributing to higher PM_{10} levels in Delhi.

The kerbside locations in all the cities, except Kanpur, show resuspension of road/soil dust as the most prominent source (27- 75%). Higher contributions at these locations clearly indicate that the dust on paved/unpaved roads get airborne due to movements of vehicles. Transport sector, as expected, is a major contributor in almost all the cities. Other sources show city specific dominance (domestic – Chennai & Kanpur; garbage burning – Delhi & Kanpur; secondary particulate (SO_4^{--}, NO_3^- and NH_4^+) – Bangalore & Kanpur; and construction – Delhi).

In case of industrial locations, contributions of industries are reflected in Bangalore (27%), Kanpur (19%) and Delhi (9%). Dominance of other sources like re-suspension of road dust, transport, garbage burning, etc. exhibit trends more or less similar to residential and kerbside locations.





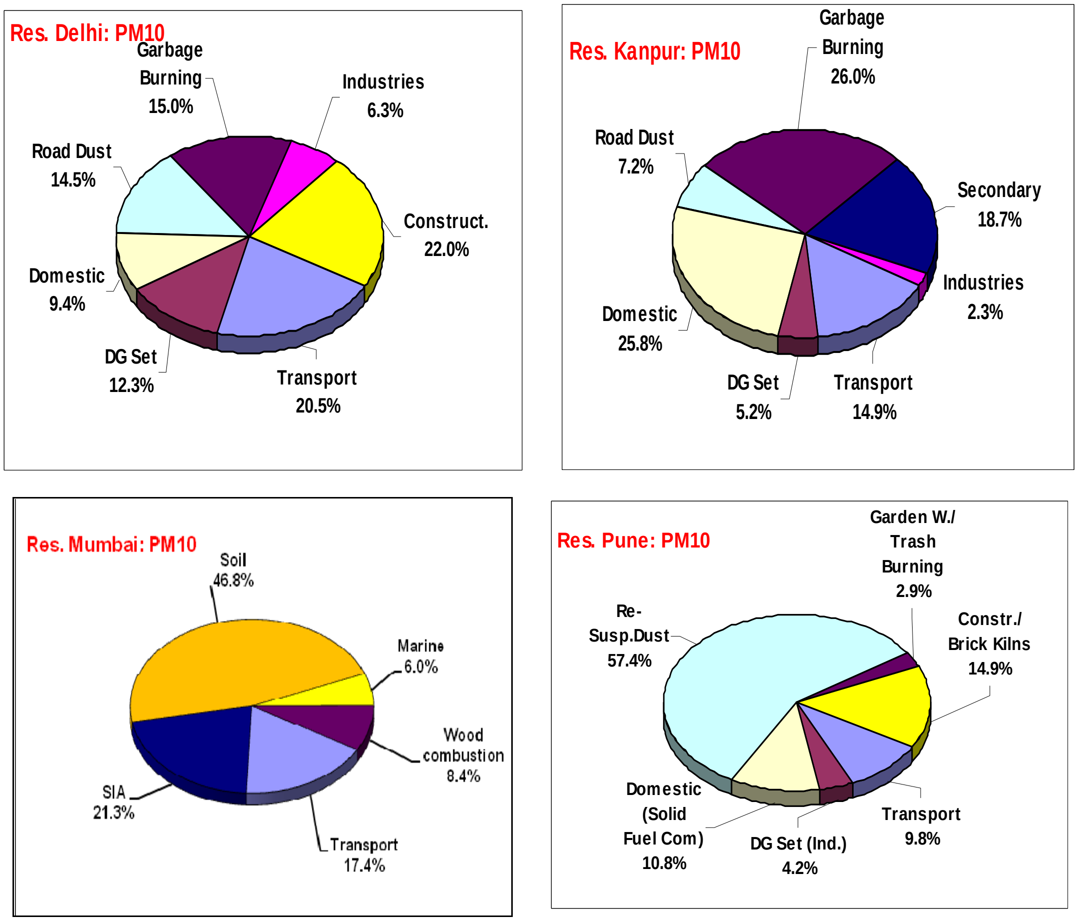
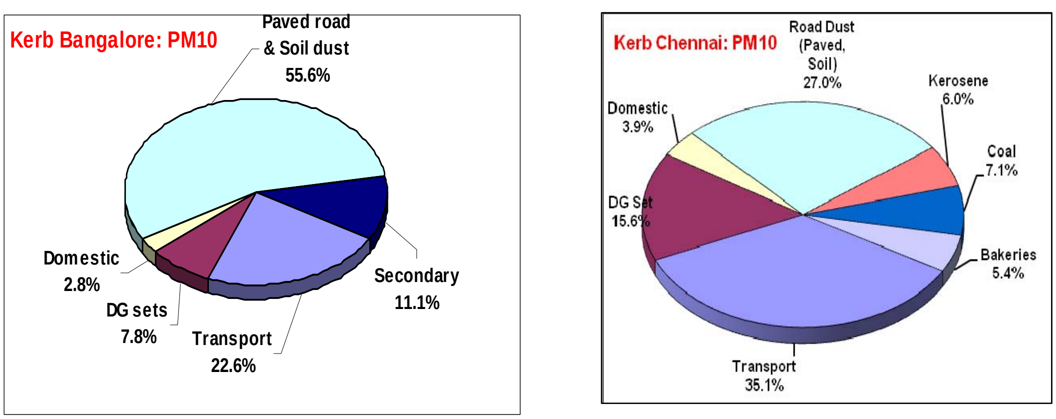


Figure 5.5: Contribution of Sources in PM_{10} in Residential Locations



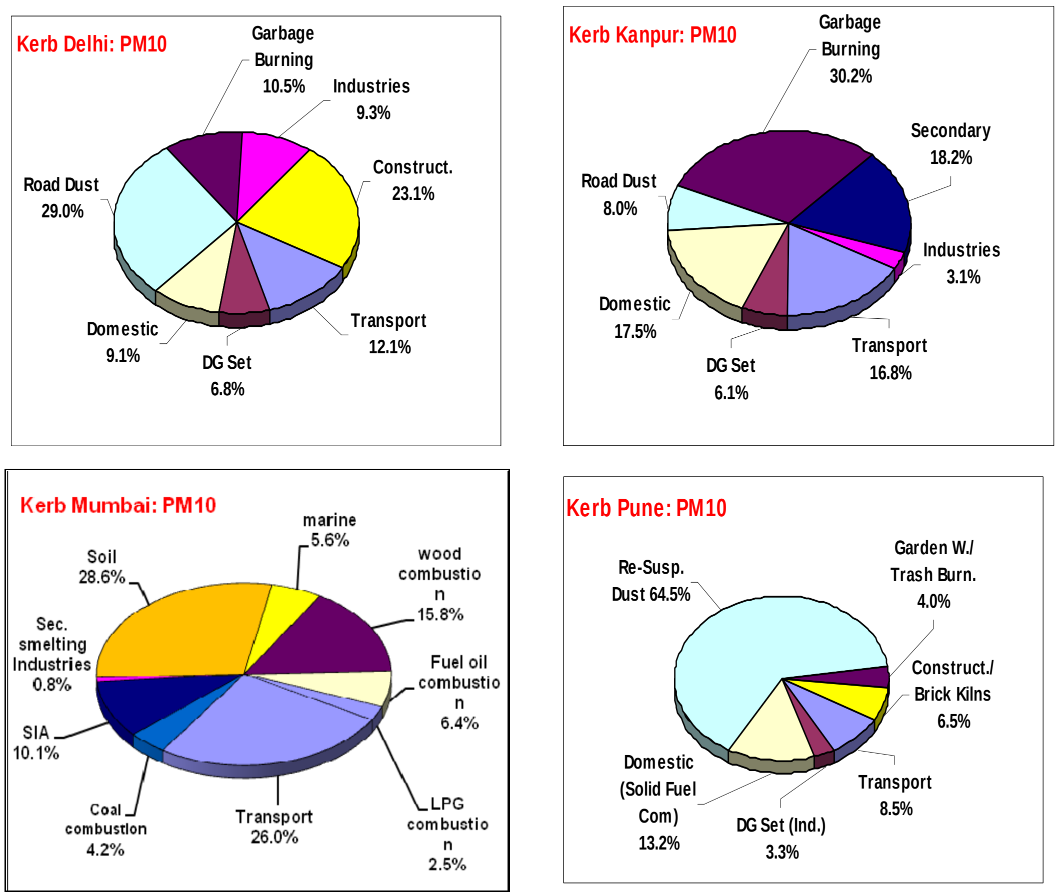
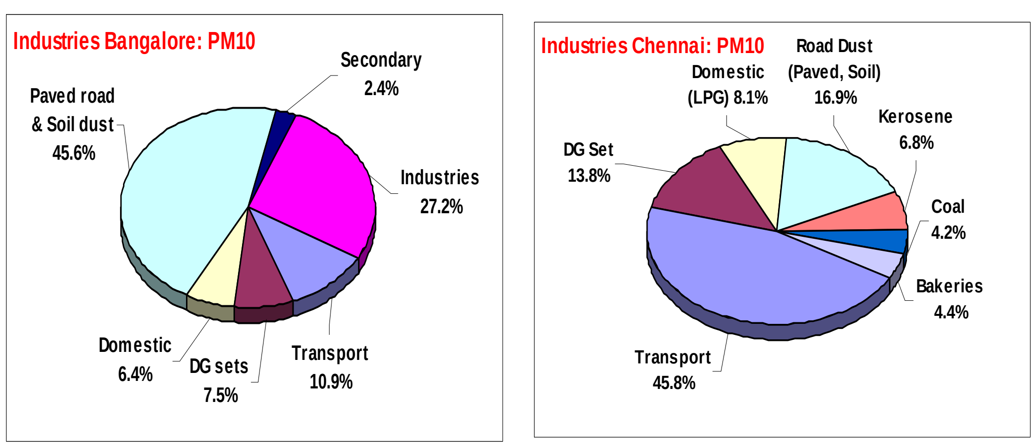


Figure 5.6: Contribution of Sources in PM_{10} in Kerbside Locations



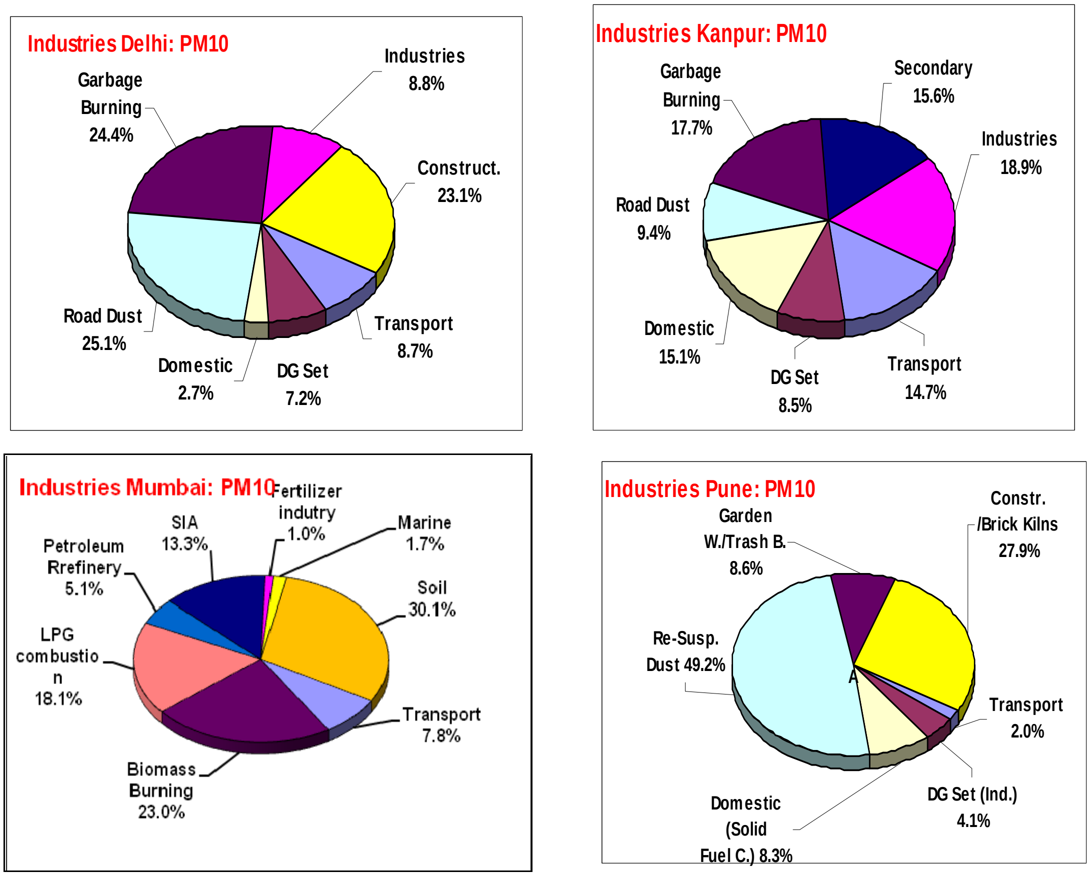


Figure 5.7: Contribution of Sources in PM_{10} in Industrial Locations

CMB8.2 results of $PM_{2.5}$ are presented in Figures 5.8 – 5.10. CMB 8 could not be applied for $PM_{2.5}$ in Mumbai. The following emerge from analysis of data:

- Contribution of resuspension/soil dust (mostly in coarser fraction range i.e. $PM_{2.5-10}$) drops down (about 5% against 15 – 60% in PM_{10}) drastically at all the locations in all the cities.
- The contribution of combustion sources including transport (20 – 60%), DG sets (8 – 28%) is much higher as compared to their contribution in PM_{10}. Domestic source contribution is quite high in Delhi (48 – 89%), Kanpur (21 – 27%) and Pune (about 15%).
- Secondary particulates, which are not directly emitted but formed through atmospheric processes, have significant contributions (14 – 60%).
- While vehicles contribute significantly at all the locations, their contributions at kerbside locations are much higher (e.g. Bangalore has 61% contribution from vehicles at kerbside locations against 48% at residential location).

- Other city-specific sources include industries (at industrial monitoring sites in Bangalore and Kanpur), Coal (Chennai) and domestic fuel combustion Delhi).
- The contribution of transport sector was observed in Delhi at residential sites more than the kerb sites. This indicates that road network and vehicular sources are widespread and dense, and do not exhibit typical land use based variations. Besides, presence of molecular markers such as hopanes and Steranes at all the locations confirm contribution of vehicular sources.

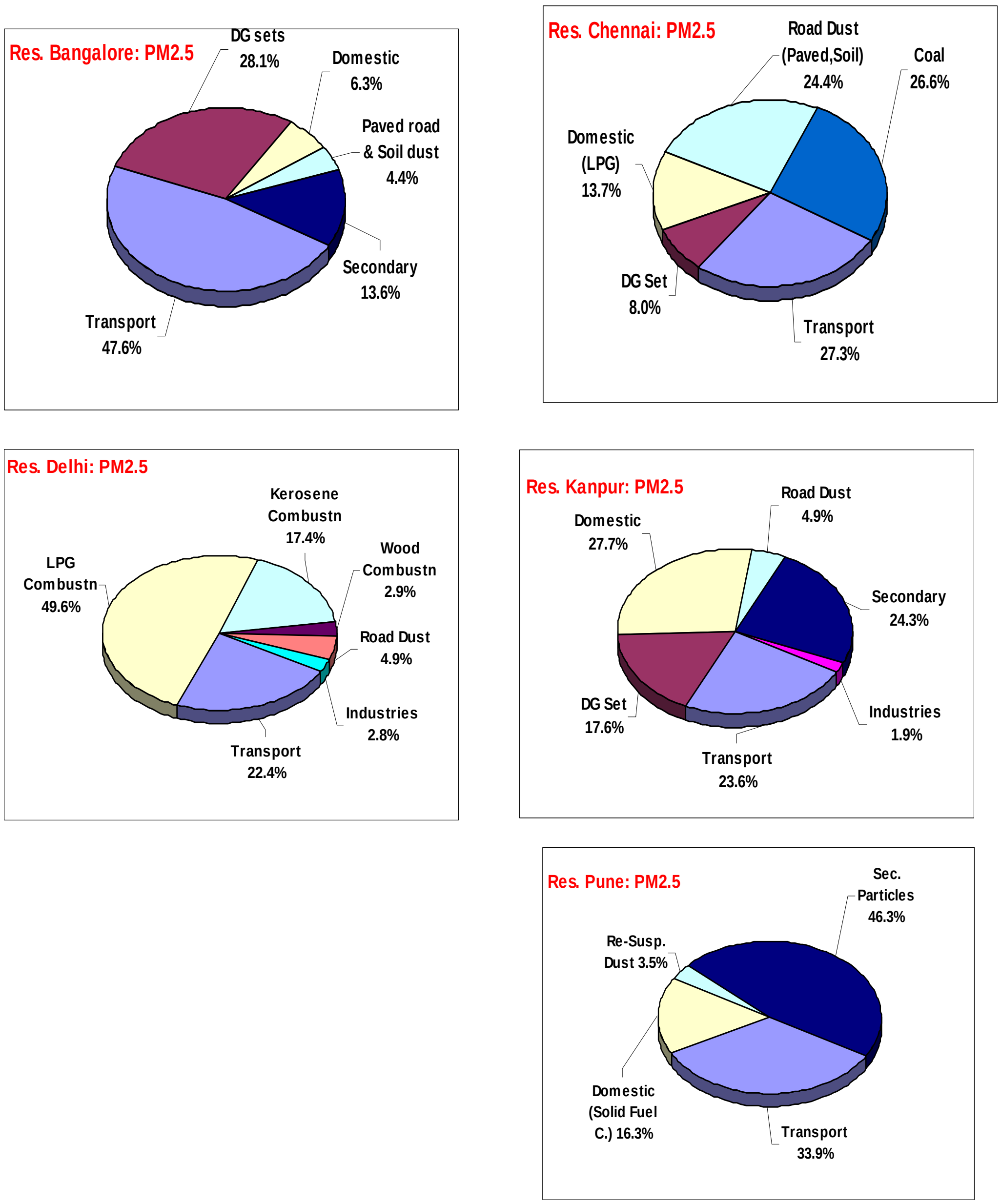


Figure 5.8: Contribution of Sources in $PM_{2.5}$ in Residential Locations

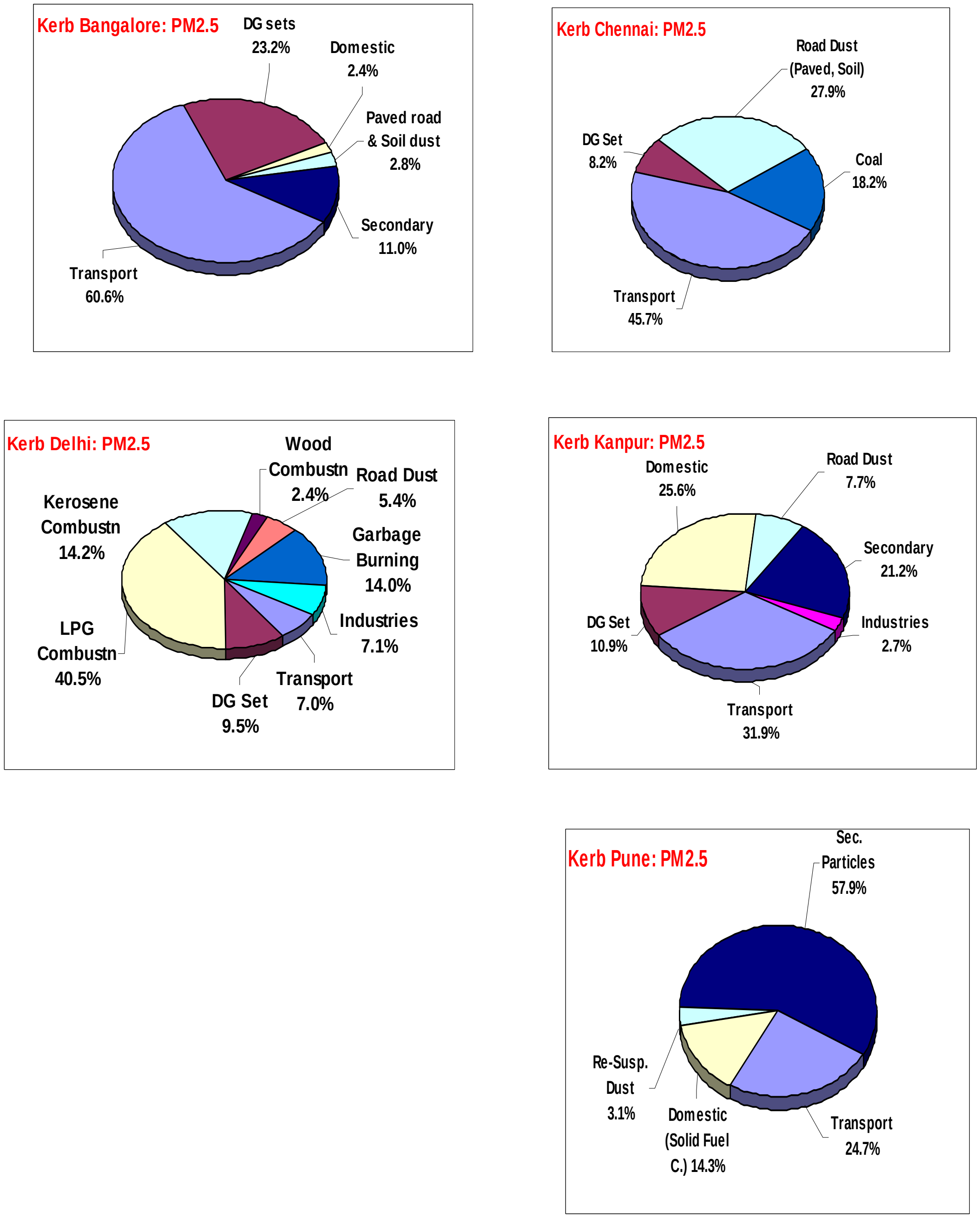


Figure 5.9: Contribution of Sources in $PM_{2.5}$ in Kerbside Locations

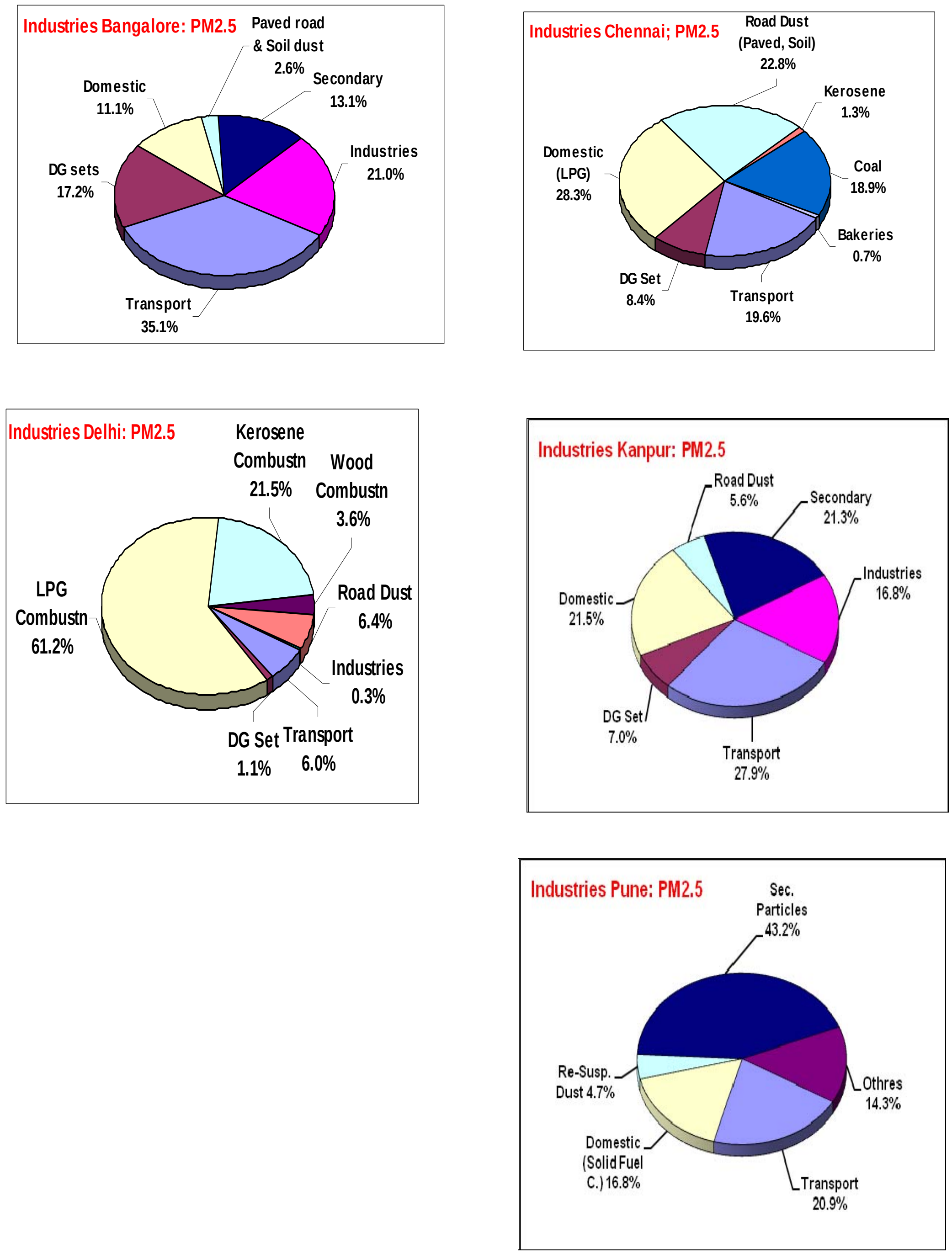


Figure 5.10: Contribution of Sources in $PM_{2.5}$ in Industrial Locations

The contribution of various source categories in respect of PM_{10} and $PM_{2.5}$ are summarized in Table 5.5.

Table 5.5 Percent contribution of various sources at residential, kerbside, industrial locations in all the six cities in respect of PM_{10} and $PM_{2.5}$

		LPG	Garbage	Soil	Road Dust	Secondary Aerosol	Construction	Transport	DG	Domestic/ wood combustion	Coal	Kerosene	Bakery	Industrial
Residential														
Bangalore	PM_{10}	0	0	0	49	9	0	19	18	4	0	0	0	0
	$PM_{2.5}$	0	0	0	4	14	0	48	28	6	0	0	0	0
Chennai	PM_{10}	0	0	0	6	0	0	48	14	21	5	3	4	0
	$PM_{2.5}$	0	0	0	24	0	0	27	8	14	27	0	0	0
Delhi	PM_{10}	0	15	0	15	0	22	21	12	9	0	0	0	6
	$PM_{2.5}$	50	0	0	5	0	0	22	0	3	0	17	0	3
Kanpur	PM_{10}	0	26	0	7	19	0	15	5	26	0	0	0	2
	$PM_{2.5}$	0	0	0	5	24	0	24	18	28	0	0	0	2
Mumbai	PM_{10}	0	0	47	0	21	0	17	0	8	0	0	0	0
	$PM_{2.5}$													
Pune	PM_{10}	0	3	0	57	0	15	10	4	11	0	0	0	0
	$PM_{2.5}$	0	0	0	3	46	0	34	0	16	0	0	0	0
Kerbside														
Bangalore	PM_{10}	0	0	0	56	11	0	23	8	3	0	0	0	0
	$PM_{2.5}$	0	0	0	3	11	0	61	23	2	0	0	0	0
Chennai	PM_{10}	0	0	0	27	0	0	35	16	4	7	6	5	0
	$PM_{2.5}$	0	0	0	28	0	0	46	8	0	18	0	0	0
Delhi	PM_{10}	0	11	0	29	0	23	12	7	9	0	0	0	9
	$PM_{2.5}$	41	14	0	5	0	0	7	9	2	0	14	0	7
Kanpur	PM_{10}	0	30	0	8	18	0	17	6	18	0	0	0	3
	$PM_{2.5}$	0	0	0	8	21	0	32	11	26	0	0	0	3
Mumbai	PM_{10}	2	0	29	0	10	0	26	0	16	4	0	0	1
	$PM_{2.5}$													
Pune	PM_{10}	0	4	0	64	0	6	8	3	13	0	0	0	0
	$PM_{2.5}$	0	0	0	3	58	0	25		14	0	0	0	0
Industrial														
Bangalore	PM_{10}	0	0	0	46	2	0	11	8	6	0	0	0	27
	$PM_{2.5}$	0	0	0	3	13	0	35	17	11	0	0	0	21
Chennai	PM_{10}	0	0	0	17	0	0	46	14	8	4	7	4	0
	$PM_{2.5}$	0	0	0	23	0	0	20	8	28	19	1	1	
Delhi	PM_{10}	0	24	0	25	0	23	9	7	3	0	0	0	9
	$PM_{2.5}$	61	0	0	6	0	0	6	1	4	0	21	0	1
Kanpur	PM_{10}	0	18	0	9	16	0	15	9	15	0	0	0	19
	$PM_{2.5}$	0	0	0	6	21	0	28	7	21	0	0	0	17
Mumbai	PM_{10}	18	23	30	0	13	0	8	0	0	0	0	0	6
	$PM_{2.5}$													
Pune	PM_{10}	0	9	0	49	0	28	2	4	8	0	0	0	0
	$PM_{2.5}$	0	0	0	5	43	0	21	0	17	0	0	0	0

6

Dispersion Modeling

Dispersion modeling is an important component of the study that was used for projecting air quality profiles (iso-concentration plots) of the city, under different scenarios viz. business as usual, future projections with implementation of control options, etc. It was also used to evaluate efficacy of various control options for evolving city-specific action plans for air quality improvements.

6.1 Approach and Methodology

The broad approach and methodology followed for source dispersion modeling are summarized in Table 6.1 and given below:

- With regard to choice of the model, AERMOD and ISC-3 models were considered. It was decided to use ISC-3 due to lower meteorological data requirement, extensive hands on experience available, general acceptability in terms of prediction quality, etc.
- A detailed and relatively reliable emission inventory is incorporated for better prediction. Source locations and receptors were marked on GIS based map of 02 x 02 sq. km grids. Grid wise emission rates for different source groups were worked out for PM_{10} and NO_x from baseline emission inventory of the year 2007.
- In-situ micrometeorological data were collected at all sampling locations during monitoring period. Meteorological stations were installed at monitoring sites to capture data on wind direction, wind velocity, ambient temperature and percent relative humidity. Relevant data for the monitoring period were converted into daily mean hourly parameters and used for prediction at respective sites. These site specific data provided better predictions. Predominant meteorological data/IMD data were used at city level, as sources from far locations are unaffected by the local meteorology and their impact can best be evaluated by broad meteorology for the city. Regarding mixing height and diurnal stability pattern, the secondary data sources and/or established calculation procedure were adopted uniformly for all cities. For the Model calibration exercise, the correlation curves for observed and predicted concentrations for ambient PM_{10} were analyzed for different seasons.

- Model runs were made at grid (02 x 02 sq km around each monitoring location) as well as city levels. Receptors were selected in Cartesian coordinate system wherein multiple receptor networks were defined.
- Predictions were made for three seasons viz. summer, post/pre monsoon and winter.
- Model performance was also examined for seasonal averages. For each season, observed and predicted concentrations were plotted and R-square values were determined for each of the locations.
- With city-level EI (baseline 2007) and future projections of emission growths (BAU 2012 and 2017), the Iso-concentration plots were developed to generate air quality profiles. Plots for grid-wise emission load projections are given in Annexure – IX.
- Dispersion modeling was also carried out to determine the efficacy of control/management options. This has led to long and short term city specific action plans.

Table 6.1: Salient Features of Modeling Exercise at Each Grid and City level for all Project Cities

Parameter	Grid level modeling within zone of influence (2kmx2km)	City level modeling
Sources Considered	Area, Industrial, Vehicular, Road dust, and all sources together	Area, Industrial, Vehicular, Road dust, and all sources together
Pollutants Monitored	PM_{10}, NO_x	PM_{10}, NO_x
Emission rate	Hourly variations	Hourly variations
Sources Grids	0.5x0.5 km	2 x2 km
Surface Met data	Site specific	IMD/predominant data measured at sites
Upper air Met data	CPCB document on mixing height	CPCB document on mixing height
Seasons	Summer, Post monsoon, Winter	Summer, Post monsoon, Winter
Model used	ISCST3	ISCST3
Receptors Grids	500m x 500m	2000m x 2000m
Model Output	24 hrly average concentration	24 hrly average concentration
Ground Level Concentration (GLC) prediction at	Center of grids	Center of grids
Ranked GLCs	First 10 highest values	First 10/15 grids with highest values
Iso- concentrations plots	---	For each pollutant in each season using Surfer graphical software

6.2 Modeling Results

The salient observations on grid-based modeling (predictions within 02x02 sq. km grid around monitoring locations) are as follow:

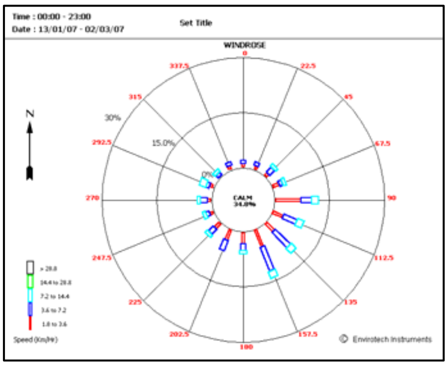
- The impact of PM_{10} emissions on its GLC was found maximum due to re-suspended road side dust. It mainly depends on silt load as well as traffic density of the respective roads. The silt loads used for the different roads in the six cities were based on in-situ observations.
- The GLCs were maximum during critical season, which is winter for Bangalore, Kanpur, Mumbai, Pune; and Post monsoon for Chennai and Delhi.
- Wide variations in the local meteorology were observed in different grids depending on the geographical location and land use characteristics (building heights, terrain, etc.). The impacts on GLC varied in the grids of same cities because of such variations. However, in certain cities like Bangalore, where land use and terrain are more or less uniform, such variations were less.
- The impacts of PM_{10} and NO_x emissions on GLC were maximum in the grids located within the traffic dominated zones. Whereas impact of SO_2 emissions was maximum in industrial zones.
- The impacts of transport sector emissions were maximum on both sides of heavy traffic major roads depending on the wind direction. For the health impacts on population exposure, such locations emerge as hot spots.

Air quality profiles, in terms of iso-concentration plots, for each of the six cities are given in Figures 6.1 – 6.18. In order to facilitate better understanding of emissions, meteorology and resultant air quality, grid-wise emission loads, wind rose and iso-concentration plots are provided together in the figures. The figures provide results for the base year 2007 in respect of PM_{10} & NO_x for all the three seasons. While results of grid and city level modeling are discussed briefly in this report, the details are provided in the main reports of the cities.

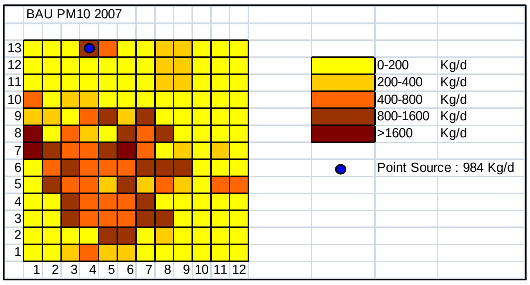
Bangalore: Modeling results for Bangalore are presented in Figures 6.1 – 6.3. The pockets of highest concentration of PM_{10} are well captured by the contours at the city level whereby they correspond to high industrial (Peenya industrial area) and major traffic activities close to the central hub of the city. Likewise, the contours at the city level for predicted 24-hourly average NO_x concentration again capture well the pockets of high concentration in terms of activity levels corresponding to high traffic and

DG set usage. The maximum spread of pollution in winter and least in pre-monsoon clearly indicate that the winter is the worst season in terms of air quality concentration. During the winter season, the contribution of different sectors to predicted PM_{10} air quality at the 6 monitoring locations within the city indicates maximum contribution by the transport sector (average 44%; range 13-54%) followed by road dust re-suspension (average 22%; range 7-29%), other area sources, including domestic, construction activities, hotels and DG sets(average 20%; range 6-35%), and industries(average 14%; range 1-74%). Likewise, in the case of NOx, the contribution of different sectors at the 6 monitoring locations indicates maximum contribution by transport sector (average 50%; range 23-73%), followed by other area sources (average 46%; range 26-77%) and industries (average 4%; range 0-19%).

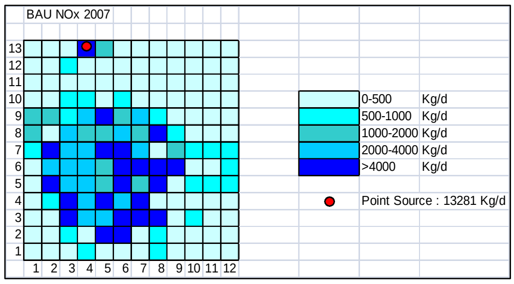
Chennai: Modeling results for Chennai are presented in Figures 6.4 – 6.6. In industrial sites, PM_{10} as well as NO_x levels are higher as compared to other sites. City specific modeling shows that there are four hotspots – (i) Ambattur industrial area in the western zone; (ii) region comprising Royapuram, Tondaiarpet, Washermanpet and Korrukupet area (which is close to the Manali industrial area) in eastern zone; (iii) Alwarpet; and (iv) K.K. Nagar area (both in southern zone). In these locations, the predicted values are relatively high, but are within the specified limits. With regard to $PM_{10,}$ it was found that resuspension of unpaved and paved road dust contributed close to 68%, while vehicles contributed 12% to the pollution levels in Chennai. As far as NOx levels are concerned the contributions from vehicles was close to 65% while the area sources (bakeries, domestic cooking etc.) contribute around 20%.



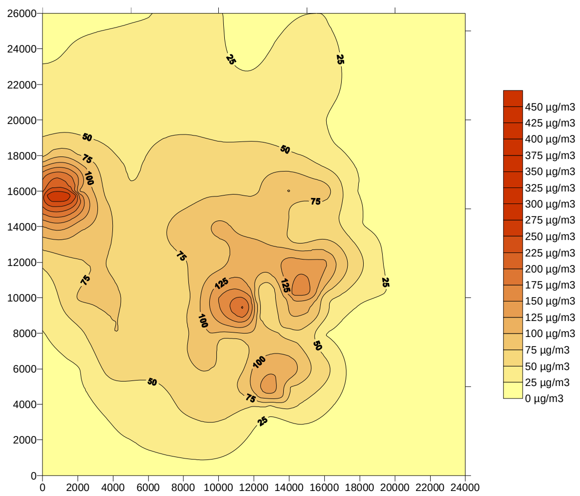
Wind Rose

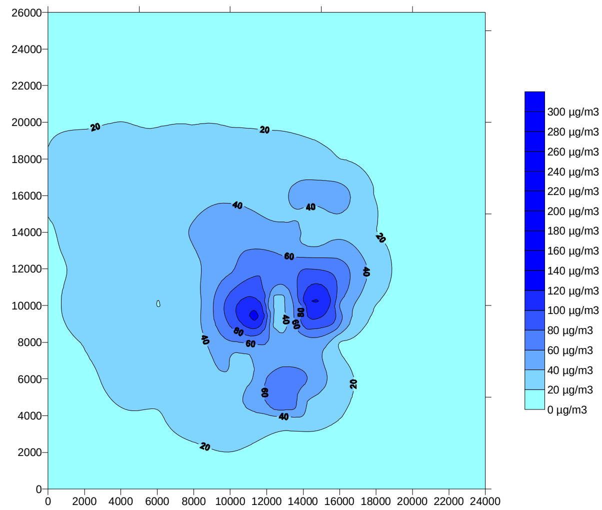


PM_{10} Emission Load (Kg/day) – BAU-2007



NO_x Emission Load (Kg/day) – BAU-2007

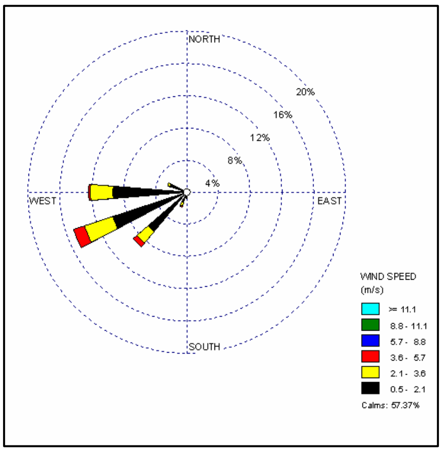




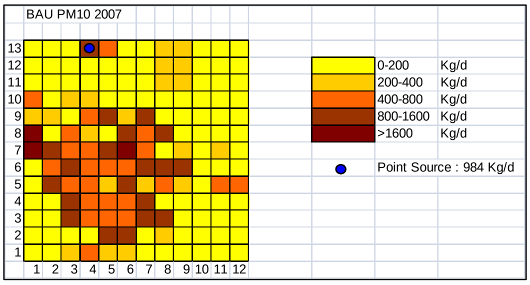
Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (µg/m^3) **NOx concentration (µg/m^3)**

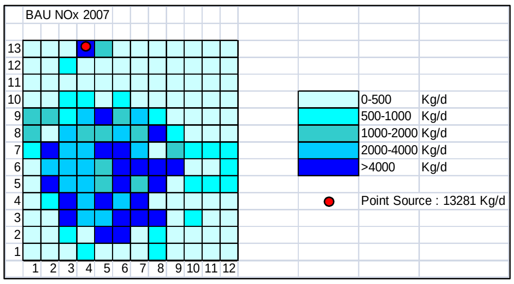
Figure 6.1: Modeling results for Bangalore (Base year 2007; PM_{10}, NO_x; Winter)



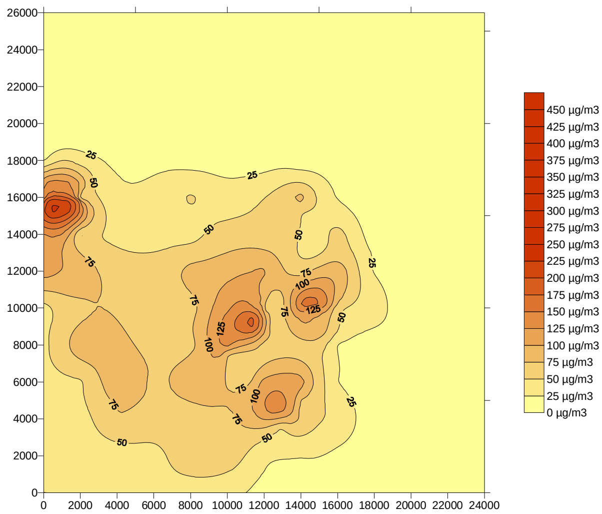
Wind Rose

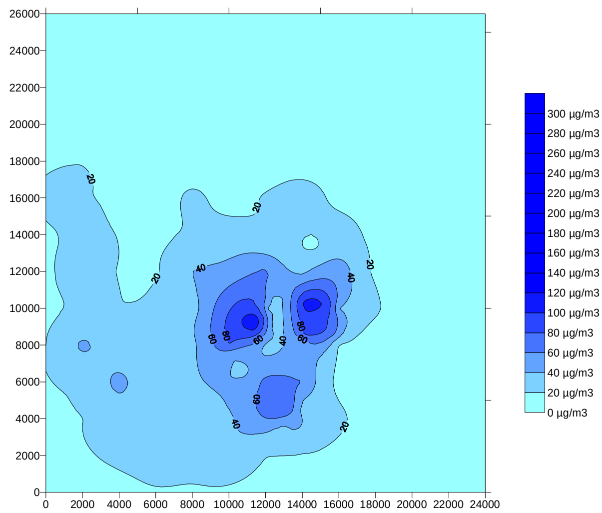


PM$_{10}$ Emission Load (Kg/day) – BAU-2007



NO$_x$ Emission Load (Kg/day) – BAU-2007

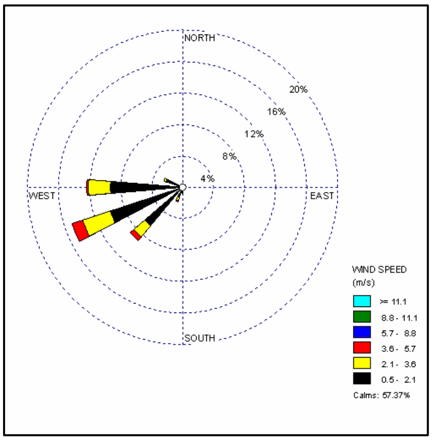




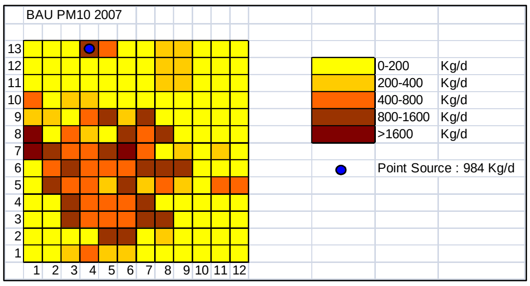
Isopleths for 24-hourly average– BAU-2007

PM$_{10}$ concentration (µg/m^3) **NO$_x$ concentration (µg/m^3)**

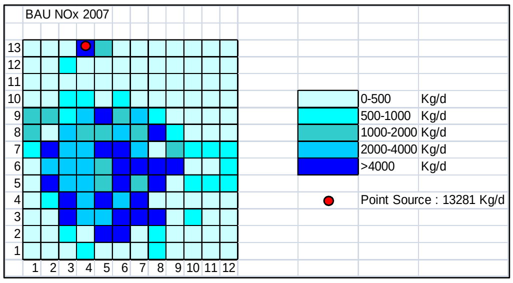
Figure 6.2: Modeling results for Bangalore (Base year 2007; PM$_{10}$, NO$_x$; Summer)



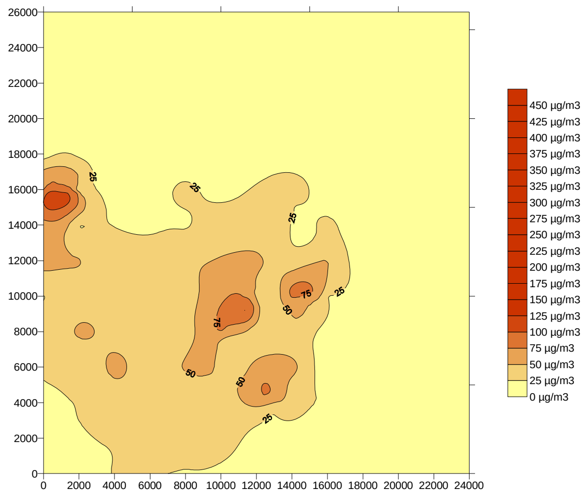
Wind Rose

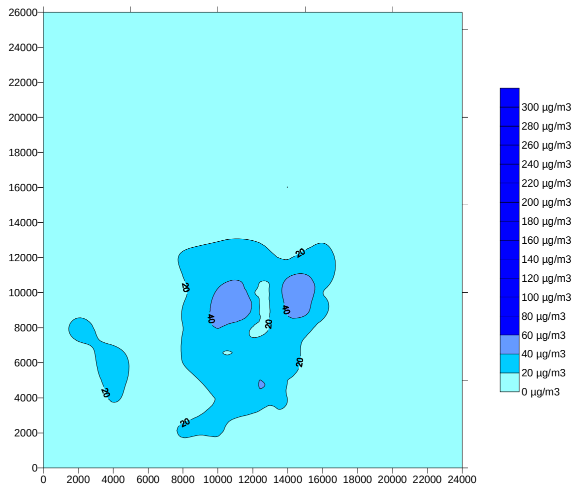


PM$_{10}$ Emission Load (Kg/day) – BAU-2007



NO$_x$ Emission Load (Kg/day) – BAU-2007

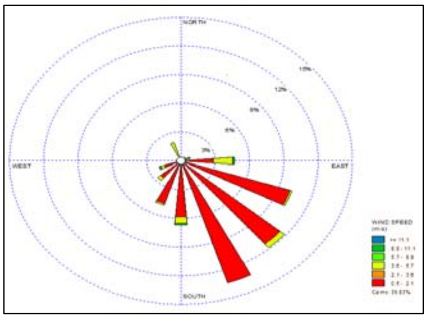




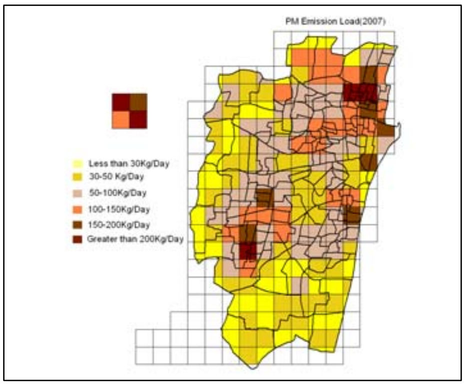
Isopleths for 24-hourly average– BAU-2007

PM$_{10}$ concentration (µg/m^3) **NOx concentration (µg/m^3)**

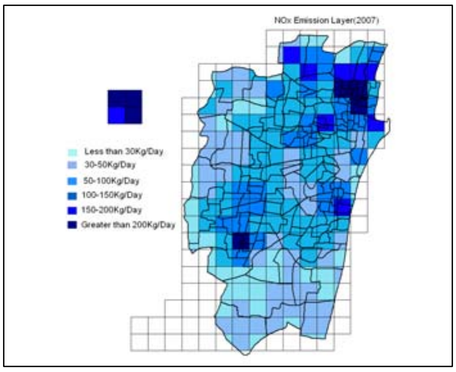
Figure 6.3: Modeling results for Bangalore (Base year 2007; PM$_{10}$, NO$_x$; Pre-Monsoon)



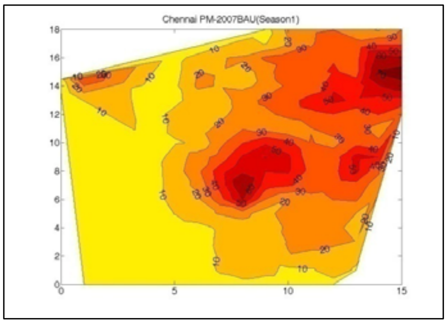
Wind Rose

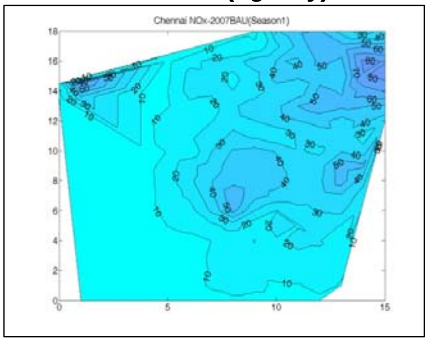


PM_{10} Emission Load (Kg/day) – BAU-2007



NO_x Emission Load (Kg/day) – BAU-2007

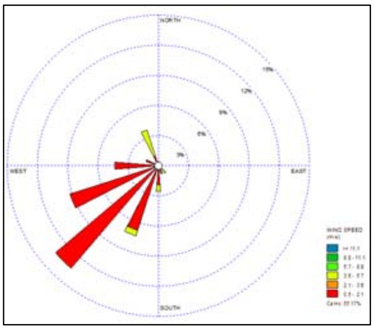




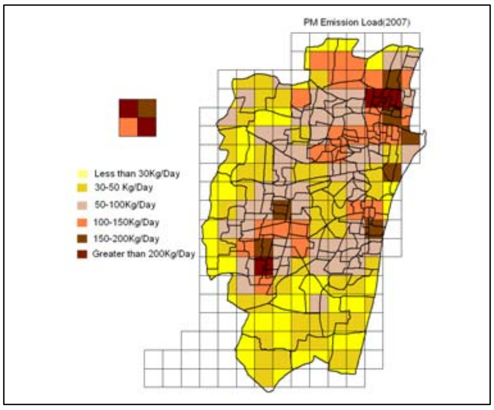
Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (µg/m³) **NO_x concentration (µg/m³)**

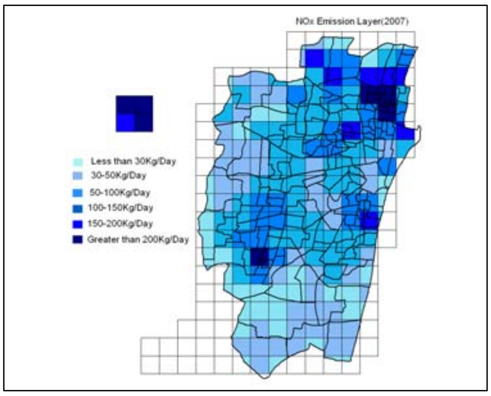
Figure 6.4: Modeling results for Chennai (Base year 2007; PM_{10}, NO_x; Winter)



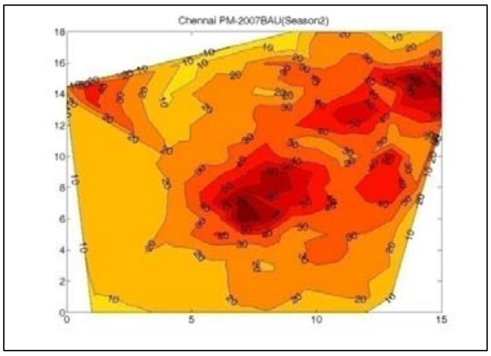
Wind Rose

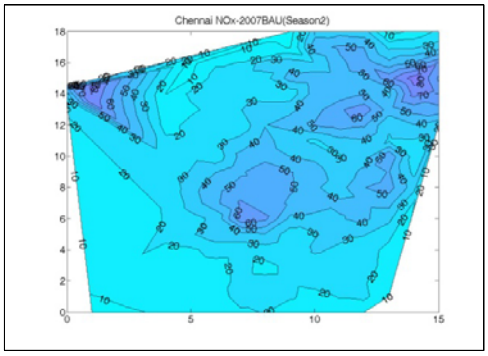


PM_{10} Emission Load (Kg/day) – BAU-2007



NO_x Emission Load (Kg/day) – BAU-2007

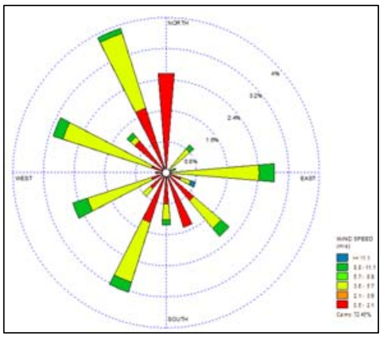




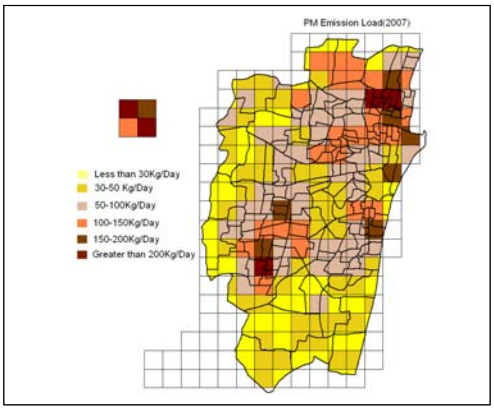
Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (µg/m³) **NO_x concentration (µg/m³)**

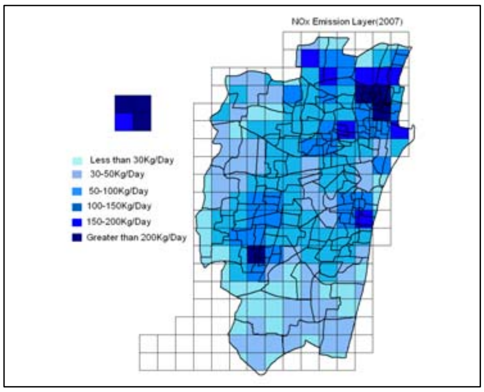
Figure 6.5: Modeling results for Chennai (Base year 2007; PM_{10}, NO_x; Post monsoon)



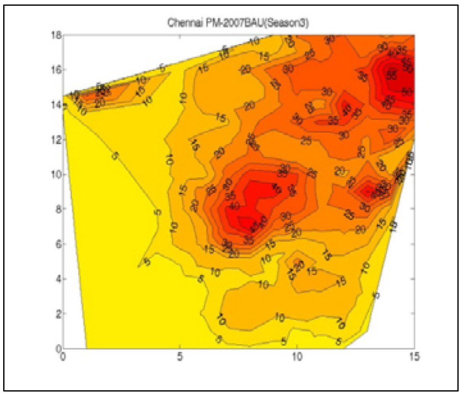
Wind Rose

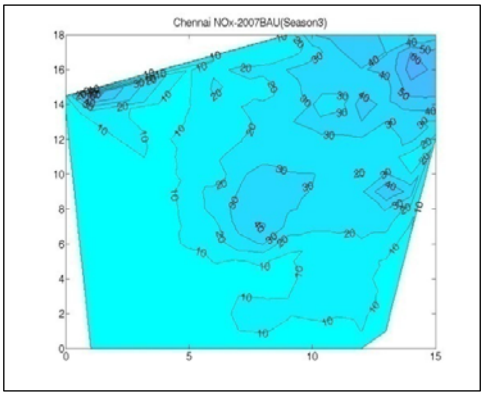


PM_{10} Emission Load (Kg/day) – BAU-2007



NO_x Emission Load (Kg/day) – BAU-2007





Isopleths for 24-hourly average– BAU-2007

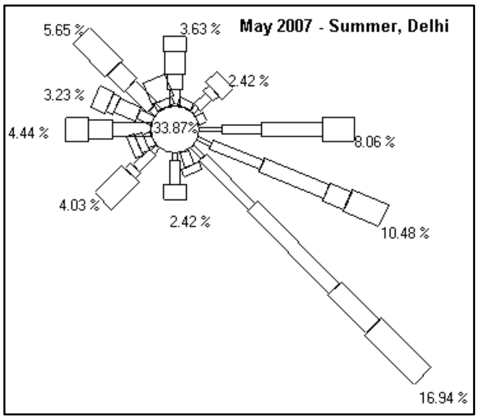
PM_{10} concentration (µg/m³) **NOx concentration (µg/m³)**

Figure 6.6: Modeling results for Chennai (Base year 2007; PM_{10}, NOx; Summer)

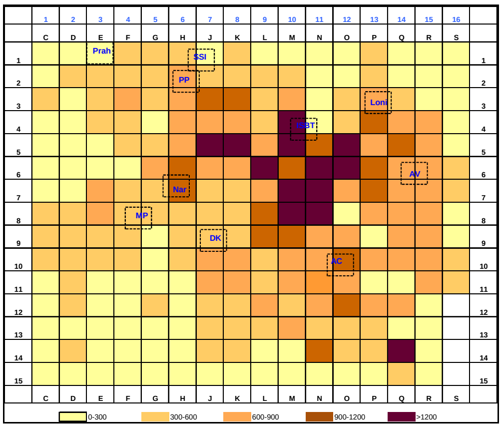
Delhi: Air quality dispersion modeling results for Delhi are presented in Figures 6.7 – 6.9. Maximum GLCs of PM_{10} (total of all sources) during summer, post-monsoon and winter are observed in Connaught Place-India Gate-ITO area. Higher PM_{10} concentration levels are due to the fact that contribution of road dust is also included in the total PM_{10}. Maximum

GLCs of NOx during summer, post-monsoon occurred in Chandni Chowk-Chawri Bazar area (during summer) and in Mayur Vihar-Patparganj area (during post monsoon and winter). Iso-concentration plots drawn for PM_{10} and NOx for summer, post-monsoon and winter seasons indicate high concentrations of PM through out Delhi, with higher levels confining to the area between ISBT and Ashram Chowk. A good spread of high levels of NOx (40 $\mu g/m^3$) was observed in all the three seasons, but highest levels are following the trend of dispersion from point sources, mainly power plants.

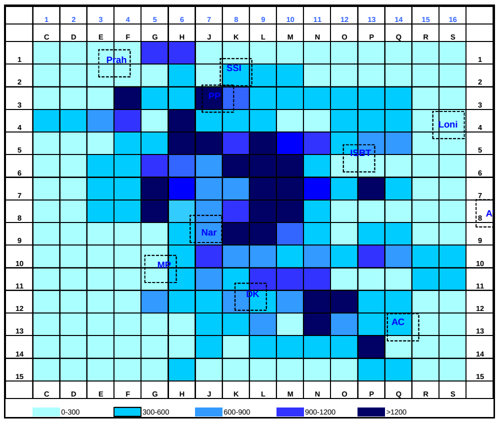
Kanpur: Modeling results for Kanpur are presented in Figures 6.10 – 6.12. For PM_{10}, the industrial site (Dadanagar) showed the highest concentration and the industries appear to contribute a significant pollution at this site (~ 40 percent). There are three prominent and probably equally important sources of PM_{10} (vehicles, road dust and domestic fuel burning) that contribute to about 80 percent of PM_{10} at all sampling sites (except for the industrial location). For NOx , 50-70 percent contribution is from vehicles at all sampling sites. It is only at industrial area (i.e. Dadanagar), where contribution of industries is seen and on a few occasions, the point source (power plant) also contributes to NOx at this site. At the kerbside and commercial sites, almost entire NOx is from vehicles. Overall city specific modeling results follow the meteorology and emissions in each grid and there are clear hotspots. These hotspots vary depending on the season. PM_{10} hotspot in summer is in the industrial area and in winter season there are two equally important hotspots – industrial area and city centre. NOx levels show two consistent hotspots, where concentrations can really be very high: (i) industrial area; and (ii) the city centre. It is seen that emission are also high in these two areas.



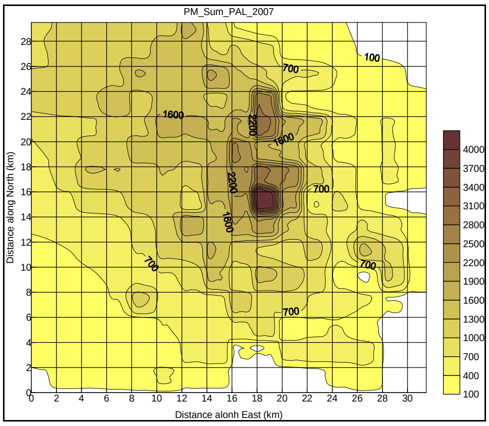
Wind Rose

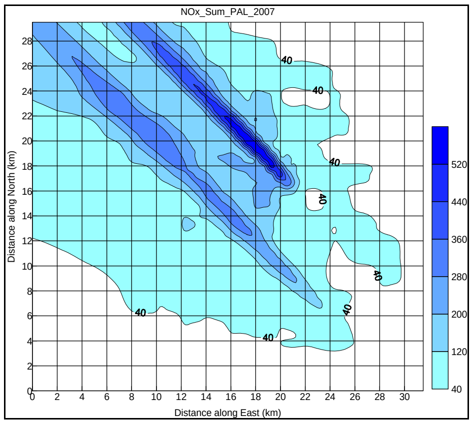


PM_{10} Emission Load (Kg/day) – BAU-2007



NOx Emission Load (Kg/day) – BAU-2007

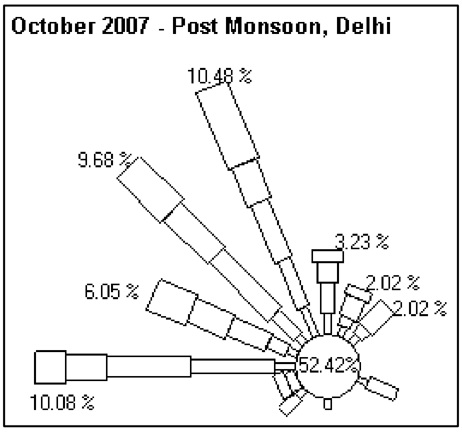




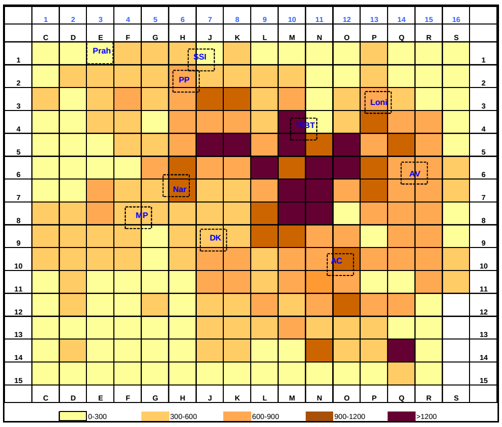
Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (µg/m³) **NOx concentration (µg/m³)**

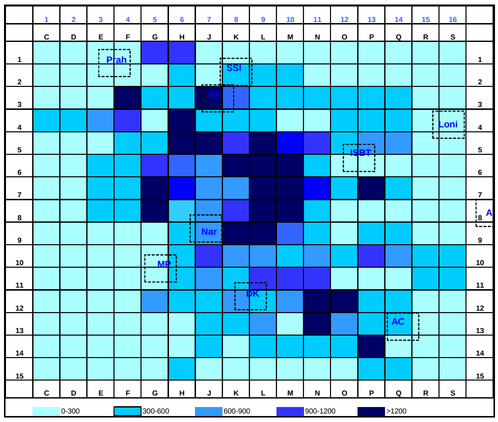
Figure 6.7: Modeling results for Delhi (Base year 2007; PM_{10}, NOx; Summer)



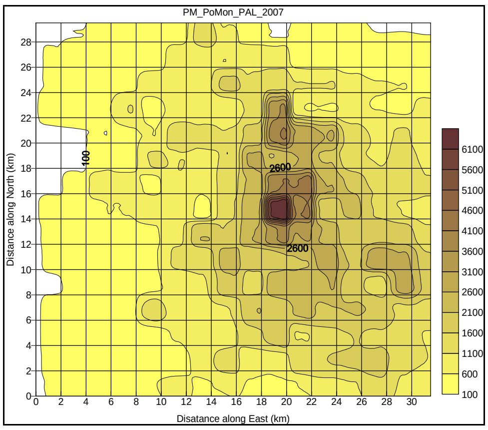
Wind Rose

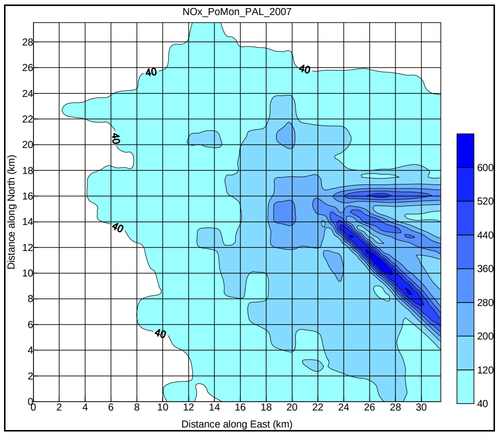


PM_{10} Emission Load (Kg/day) – BAU-2007



NOx Emission Load (Kg/day) – BAU-2007

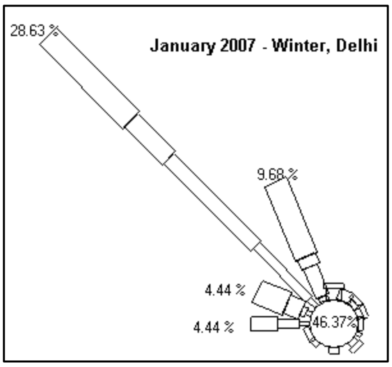




Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (µg/m^3) **NOx concentration (µg/m^3)**

Figure 6.8: Modeling results for Delhi (Base year 2007; PM_{10}, NOx; Post monsoon)



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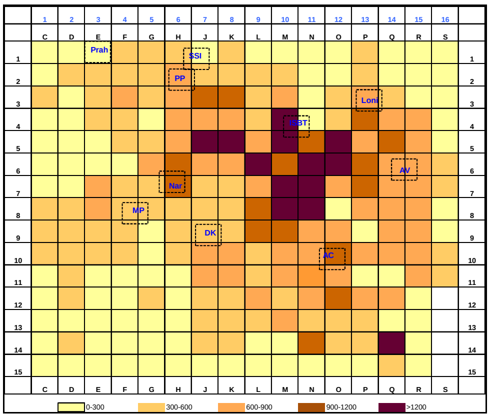
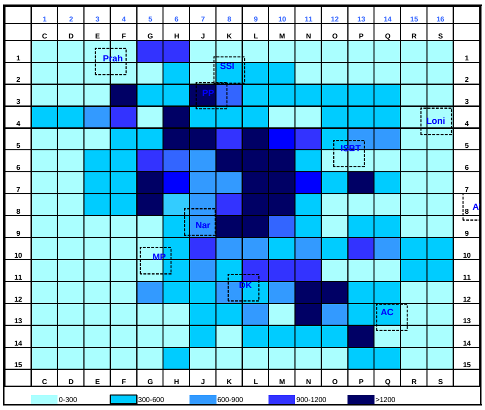
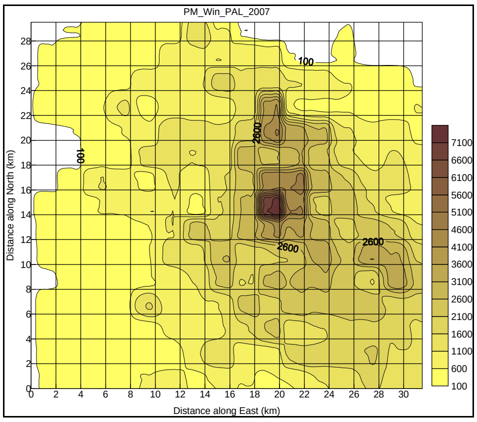
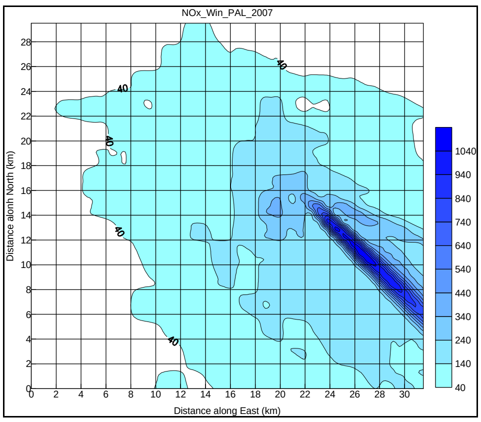


PM_{10} Emission Load (Kg/day) – BAU-2007



NOx Emission Load (Kg/day) – BAU-2007

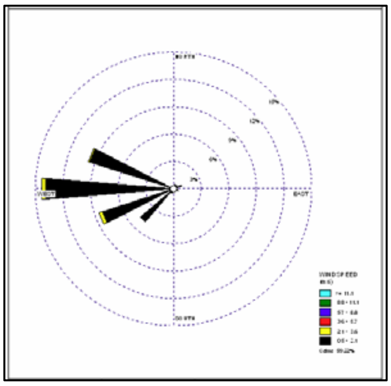




Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (µg/m³) **NOx concentration (µg/m³)**

Figure 6.9: Modeling results for Delhi (Base year 2007; PM_{10}, NOx; Winter)



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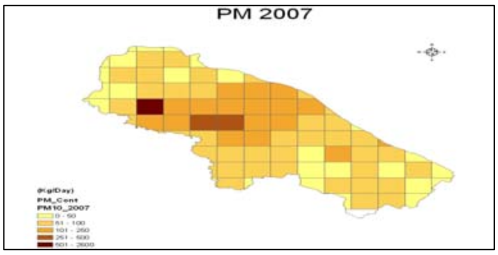
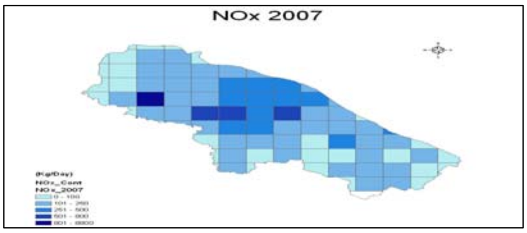
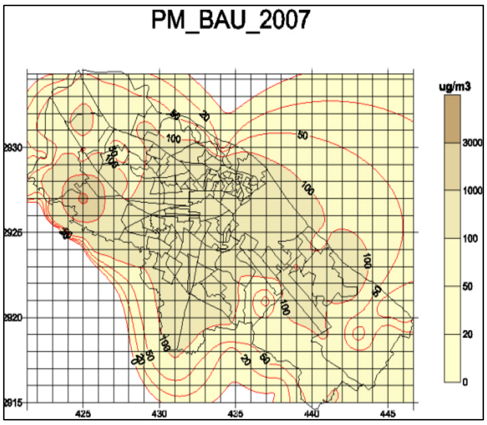
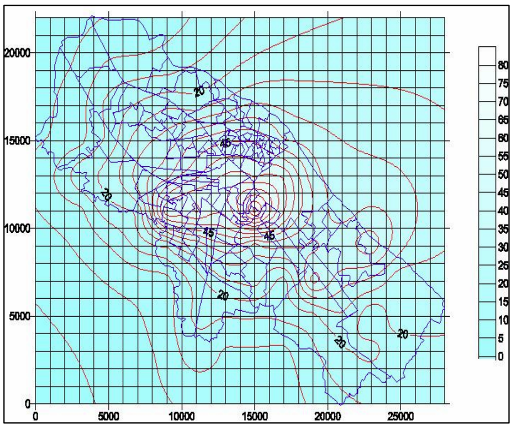




PM$_{10}$ Emission Load (Kg/day) – BAU-2007

NOx Emission Load (Kg/day) – BAU-2007



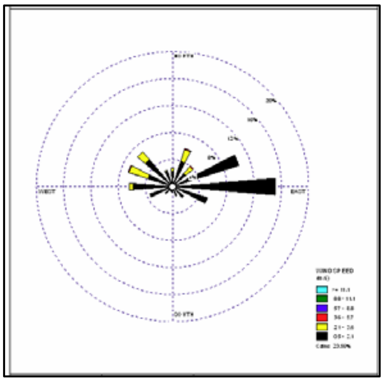


Isopleths for 24-hourly average– BAU-2007

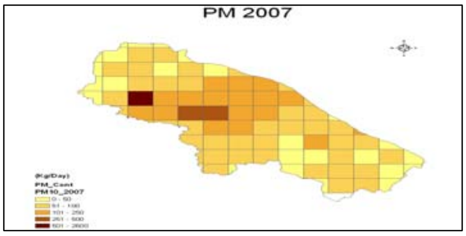
PM$_{10}$ concentration (µg/m^3)

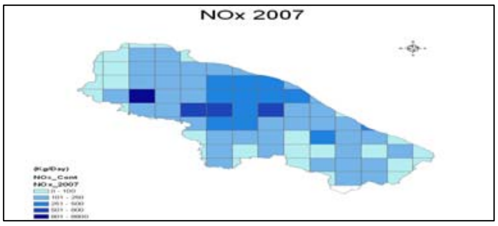
NOx concentration (µg/m^3)

Figure 6.10: Modeling results for Kanpur (Base year 2007; PM$_{10}$, NOx; Winter)



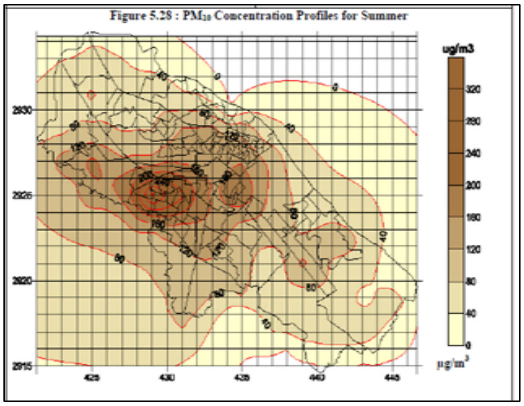
Wind Rose

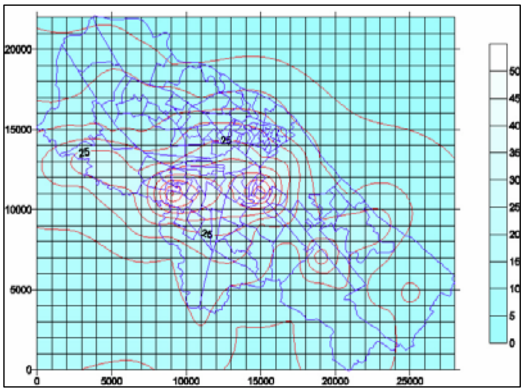




PM_{10} Emission Load (Kg/day) – BAU-2007

NOx Emission Load (Kg/day) – BAU-2007



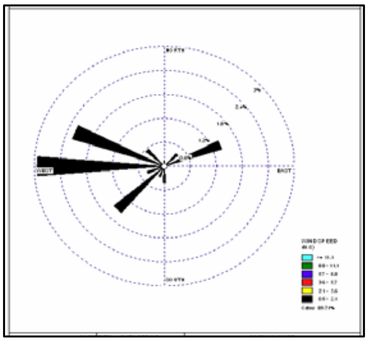


Isopleths for 24-hourly average– BAU-2007

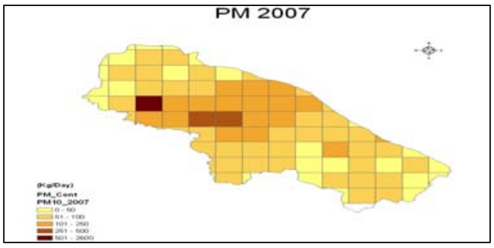
PM_{10} concentration (µg/m³)

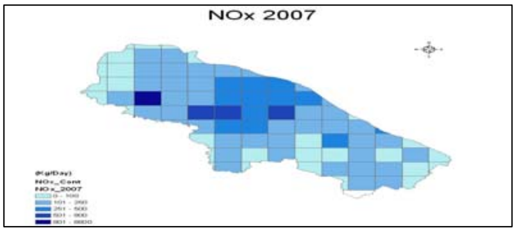
NOx concentration (µg/m³)

Figure 6.11: Modeling results for Kanpur (Base year 2007; PM_{10}, NOx; Summer)



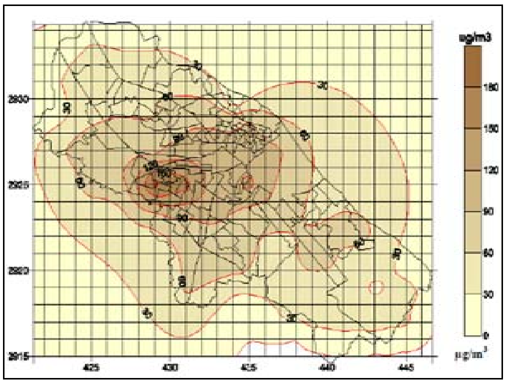
Wind Rose

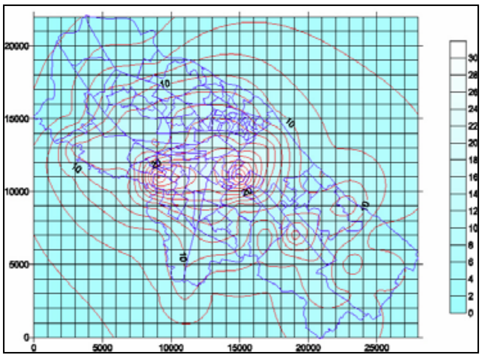




PM_{10}

Emission Load (Kg/day) – BAU-2007 **NOx Emission Load (Kg/day) – BAU-2007**





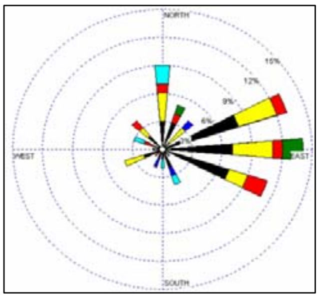
Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (μg/m^3) **NOx concentration (μg/m^3)**

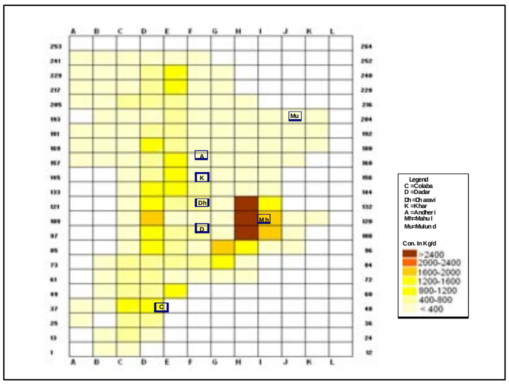
Figure 6.12: Modeling results for Kanpur (Base year 2007; PM_{10}, NOx; post monsoon)

Mumbai: The results of modeling for Mumbai are given in Fig 6.13 to 6.15. Seasonal changes in Mumbai are not significant, except in monsoon, when due to high precipitation; the air pollutants levels are very low. The critical winter season for a limited period can be considered important. The PM dispersion modeling for the whole city shows that PM_{10} hot spots are around Dharavi, Dadar and Mahul. The measured PM_{10} concentrations are highest at Dharavi followed by Mulund and Mahul. The model results for average of ten highest concentrations in different grids in the city indicate that percent contribution of PM_{10} is 5% for vehicles, 16% for industries, 1% for area sources and rest from the re-suspended dust. With regard to NOx, industries contribute the highest, with 53% followed by 46% for vehicles and rest from area sources. The model results are dominated by few industrial sources, however, they are located in a very limited area of the city.

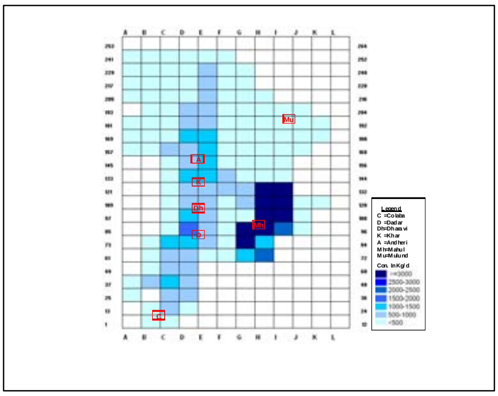
Pune: Modeling results for Pune are given in Figures 6.13 – 6.15. Winter season was found to be critical with respect to ambient concentration levels. Re-suspended dust was found to be the major source with a contribution of around 58%. Mobile source and other area sources contribute around 22% and 19% respectively. Average contribution of all the grids in Pune of Industrial sources was found to be very less (0.1%). Site-specific dispersion modeling results show higher contribution of about 30-40% from mobile sources at all sites, especially kerbside locations. However, re-suspended dust was found to be the highest contributor at all sites with contribution ranging from 40 to 60%. Other area sources contributed in the range from 8 to 19%. Mobile source was found to be largest contributor towards the NOx concentration with average contribution more than 95% from dispersion modeling for Pune city and at various sites. Area sources, including hotels, bakeries, residential fuels, contributed for about 3% of the NOx concentrations. Contribution from industry was about 1%. Hot-spots are found to be present at the central part of Pune with higher population as well as road densities.



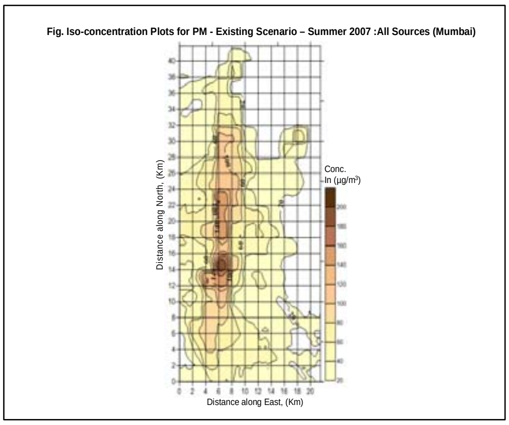
Wind Rose

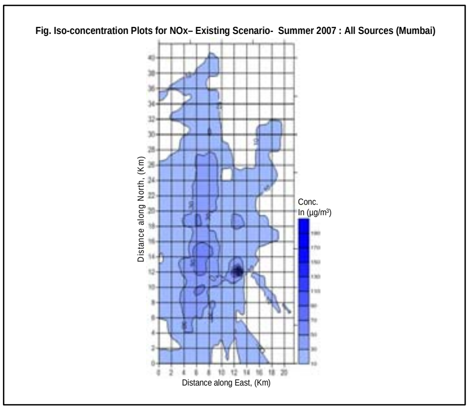


PM$_{10}$ Emission Load (Kg/day) – BAU-2007



NOx Emission Load (Kg/day) – BAU-2007

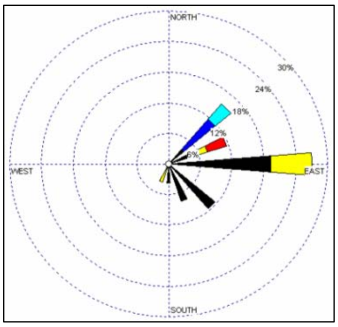




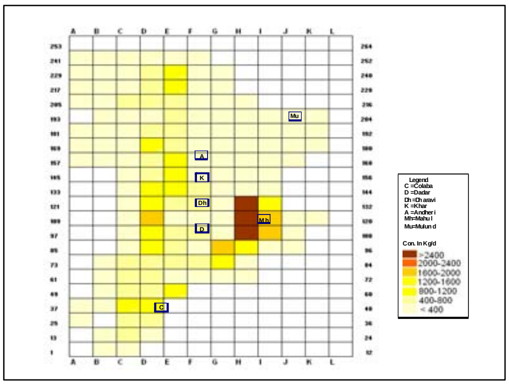
Isopleths for 24-hourly average– BAU-2007

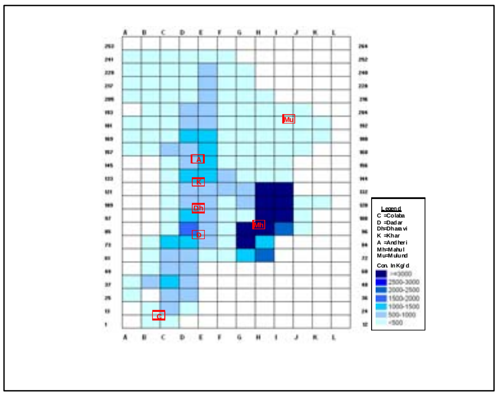
PM$_{10}$ concentration (µg/m^3) **NOx concentration (µg/m^3)**

Figure 6.13: Modeling results for Mumbai (Base year 2007; PM$_{10}$, NOx; Summer)



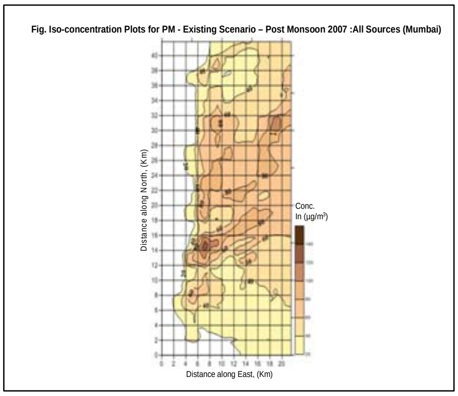
Wind Rose

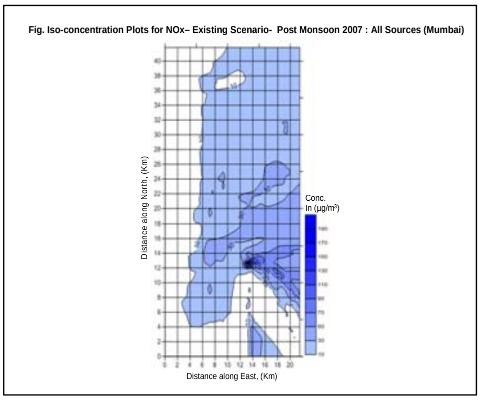




PM_{10} Emission Load (Kg/day) – BAU-2007

NOx Emission Load (Kg/day) – BAU-2007



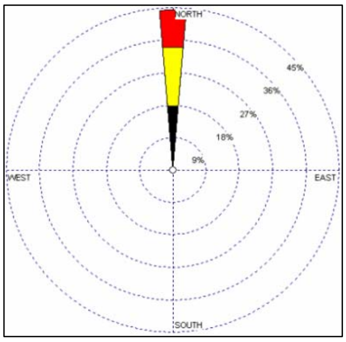


Isopleths for 24-hourly average– BAU-2007

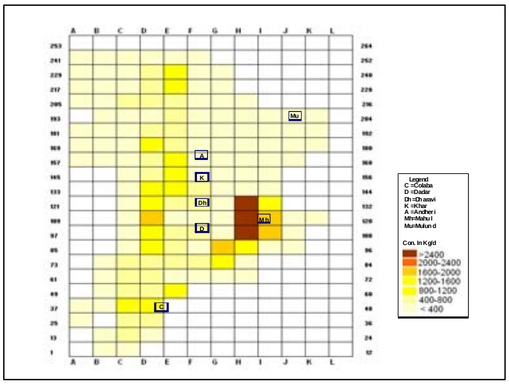
PM_{10} concentration (µg/m³)

NOx concentration (µg/m³)

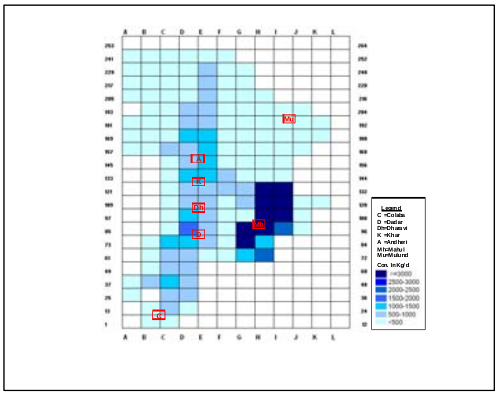
Figure 6.14: Modeling results for Mumbai (Base year 2007; PM_{10}, NOx; Post monsoon)



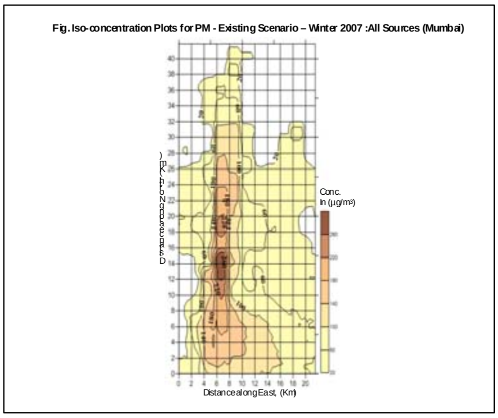
Wind Rose

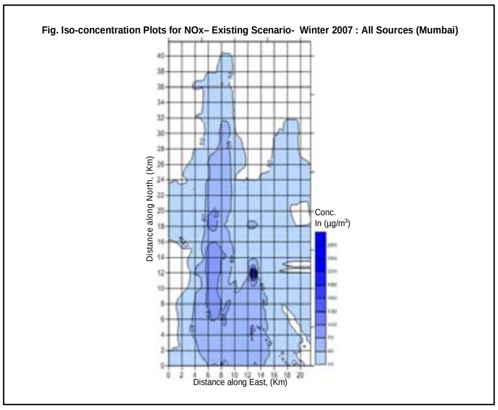


PM$_{10}$ Emission Load (Kg/day) – BAU-2007



NOx Emission Load (Kg/day) – BAU-2007

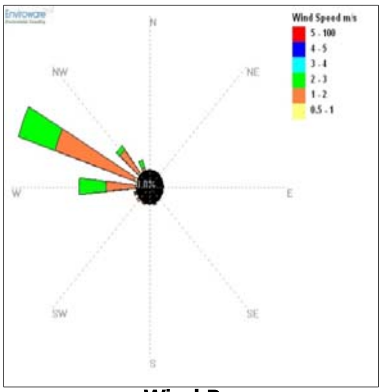




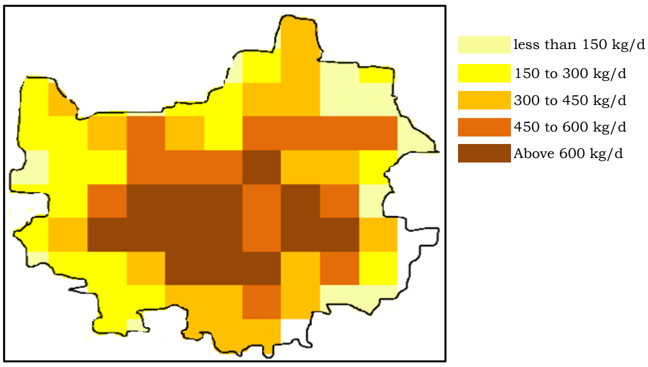
Isopleths for 24-hourly average– BAU-2007

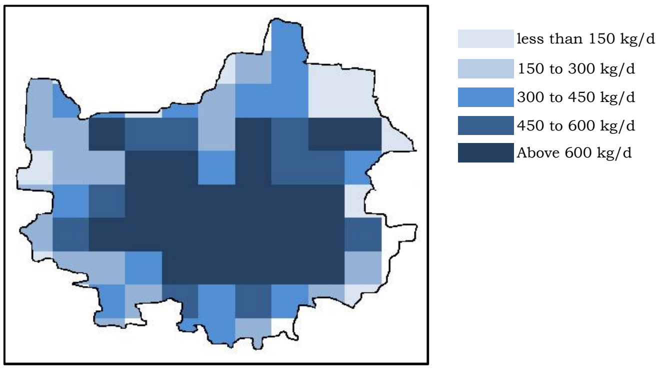
PM$_{10}$ concentration (µg/m^3) **NOx concentration (µg/m^3)**

Figure 6.15: Modeling results for Mumbai (Base year 2007; PM$_{10}$, NOx; Winter)

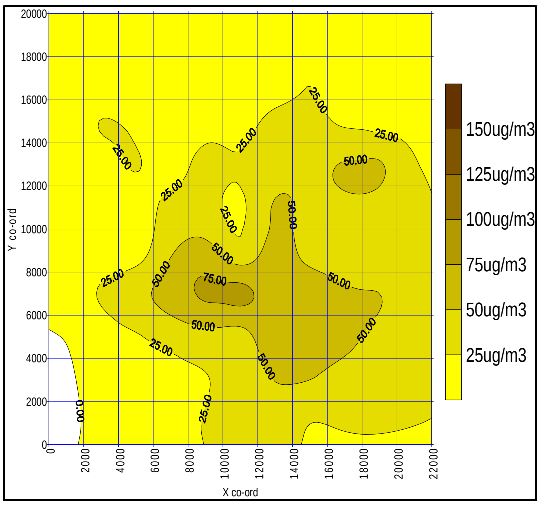


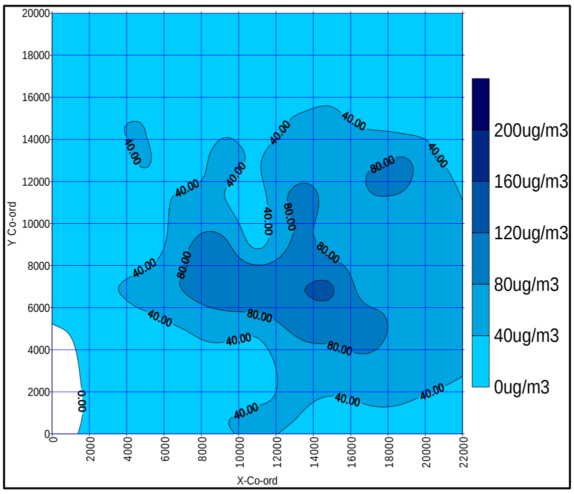
Wind Rose





PM_{10} Emission Load (Kg/day) – BAU-2007 **NOx Emission Load (Kg/day) – BAU-2007**

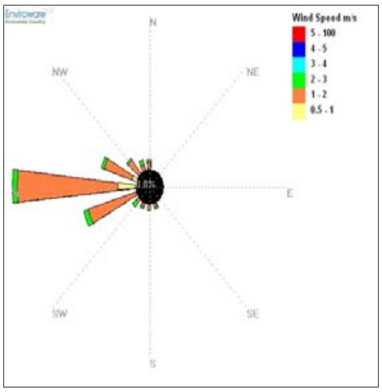




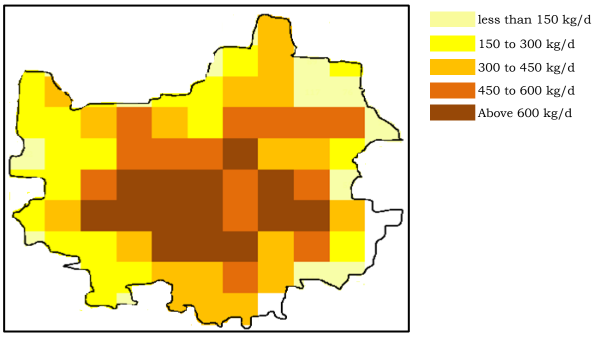
Isopleths for 24-hourly average– BAU-2007

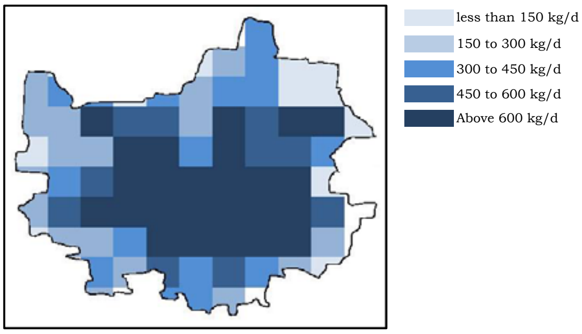
PM_{10} concentration (μg/m³) **NOx concentration (μg/m³)**

Figure 6.16: Modeling results for Pune (Base year 2007; PM_{10}, NOx; Summer)

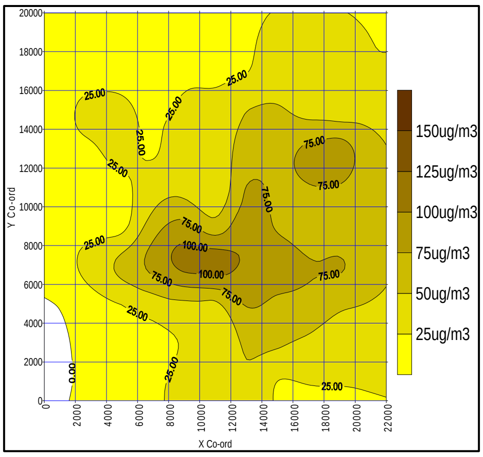


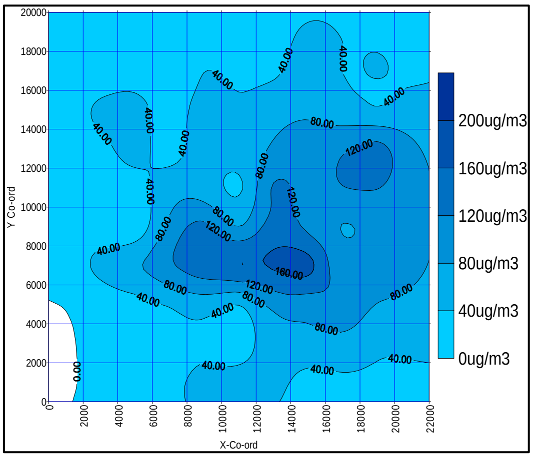
Wind Rose





PM_{10} Emission Load (Kg/day) – BAU-2007 **NOx Emission Load (Kg/day) – BAU-2007**

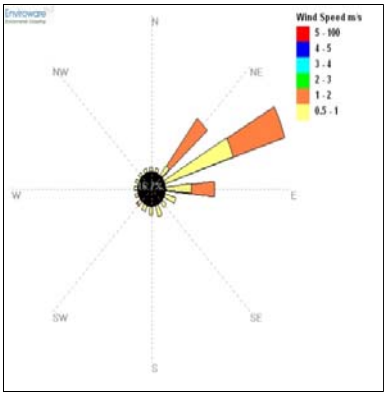




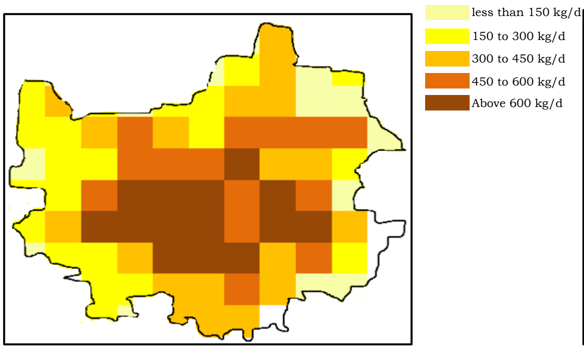
Isopleths for 24-hourly average– BAU-2007

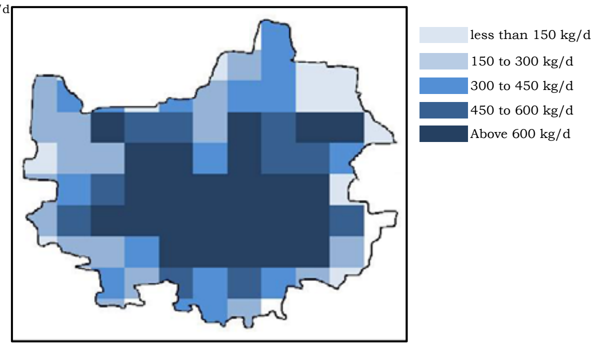
PM_{10} concentration (µg/m^3) **NOx concentration (µg/m^3)**

Figure 6.17: Modeling results for Pune (Base year 2007; PM_{10}, NOx; Post monsoon)

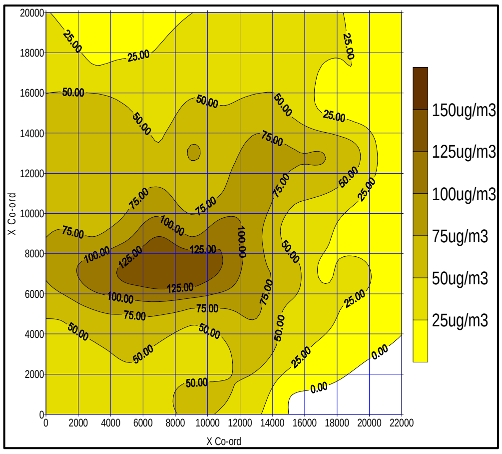


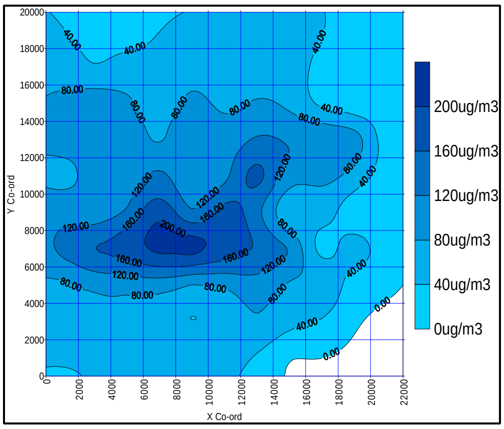
Wind Rose





PM_{10} Emission Load (Kg/day) – BAU-2007 **NOx Emission Load (Kg/day) – BAU-2007**





Isopleths for 24-hourly average– BAU-2007

PM_{10} concentration (µg/m³) **NOx concentration (µg/m³)**

Figure 6.18: Modeling results for Pune (Base year 2007; PM_{10}, NOx; Winter)

6.3 Model Performance and Calibration

The predicted and observed concentrations were compared to assess the performance of the model. For PM, the predicted values, at times, do not fall within the acceptable modeling criteria because of extraneous factors (e.g. background sources) not accounted while modeling. It is recognized that the term 'NO_x' at the source is largely NO (about 90%) and at receptor location (far from sources), the major component of NO_x is NO_2. As the Gaussian model does not account for chemical reactions, it is not reconcilable that the model estimated NO_x be compared with observed NO_2 in an absolute sense. However, it remains a fact that model computed NO_x and observed NO_2 will be linearly associated. Therefore, the model interpretation in terms of source-specific contribution of NO_x remains valid. In general the model performance was found to be reasonably good and adequate (within a factor of 2 for NO_x), though there have been variations across the cities. The city specific observations are given below:

Bangalore: Dispersion modeling of PM_{10} and NOx at city level using calibrated model suggests that in general the predicted concentrations lie within a factor of 2 as compared against observed concentrations.

Chennai: There is a general match between the concentrations predicted in the 2x2 km and the concentration measured for PM_{10} and NOx, i.e. the concentration measured falls within the minimum and maximum concentrations predicted within the 2x2 km grid. However, there is no one-to-one correspondence between the values predicted exactly at the monitoring site and the values measured. There is no consistent over prediction or under prediction of the concentrations for PM_{10} or NOx.

Delhi: It is observed that the predicted values of PM_{10} are much lower as compared to the measured levels, at all the sites and during all seasons. Very high levels of PM are prevalent, which can be attributed to windblown dust, which are not accounted in emission inventory and many other unaccounted infrequent sources prevailing in the study zones. Analysis of measured and predicted PM concentration levels reveal dominance of non-anthropogenic sources almost at all the study zones. The predicted NOx values are either lower or equal to the observed values. However, concentrations are over-predicted at kerbside locations. This can be attributed to the fact that the vehicular emission factors are for NO_x giving emission rates in terms of NO_x, whereas the monitored observations confined to NO_2. Due to higher vehicular activities, the difference between measured and modeled values becomes much prominent at kerside locations.

Kanpur: Model performance was found adequate (R-square 0.88 – 0.44 for observed and predicted values). Observed levels are generally higher than predicted levels both for PM_{10} and NO_x. For PM_{10}, there is a significant part as background level.

Mumbai: Comparison of measured and predicted concentrations shows that site specific average concentrations predicted using primary survey based emission inventory are close to measured values to a large extent. NOx values across the city in both cases are much closer to measured values.

Pune: The model was found to under predict the PM_{10} concentrations. The ratio of observed to predicted concentrations at different sites revealed the variation in the range of 1.1 to 2.3. Average ratio, of all sites, of observed and predicted ground level concentrations was found to be 1.7. In case of NOx, variation in ratio of observed to predicted ground level concentrations at different sites was found in the range 0.3 to 0.8 with overall average ratio of observed to predicted concentrations of 0.6. Thus the model was found to over predict the concentrations to some extent, which may be attributed to the fact that the observed concentrations are representative of NO_2 while the emission inventory data used for predictions include all oxides of nitrogen. However, comparisons between observed and predicted values are within the factor of 2 and considered reasonably good.

7

Evaluation of Control/Management Options and City Specific Action Plans

The results of air quality measurements, emission inventory, source apportionment based on receptor modeling, and dispersion modeling provide vital information in terms of status of air quality and sources contributing to it, in each of the six project cities. List of prioritized sources based on EI, receptor modeling (factor analysis and CMB8) is given in Table 7.1. The levels of PM_{10} are high, and there are multiple contributing sources. Therefore, controlling a single source type may not yield desired results, and it is necessary to evolve a comprehensive action plan comprising a combination of control/management options. These options would vary from city to city depending on extent of problem and source configuration in the city.

There is no single method which provides the complete idea about the urban air pollution sources, their strength, exposure assessment at the receptor, probability of high concentrations, seasonal variations, predicted values etc. In view of such high probable variation in large data sets about the air pollution levels that city has to grapple with, dispersion models are needed for evaluating effectiveness of action plans. In order to evaluate various control options and suggest an appropriate action plan, the following approach and methodology were adopted:

7.1 Approach and Methodology

The broad approach included identification of critical season from air quality perspective, EI projections for BAU for the years 2012 and 2017, preparation of comprehensive list of possible control/management options under each source category (e.g. vehicle, industries, fugitive area sources, etc.), analysis of their efficacies, development of alternate scenarios with different combination of options using dispersion modeling, and selecting most preferred scenario as action plan. A schematic view of approach for developing action plan is given in Figure 7.1, and broad methodology adopted is summarized below:

- The results of dispersion modeling for existing scenario (please refer Figures 6.1 – 6.18 in Chapter 6) indicated that PM_{10} and NOx levels were of major concerns requiring priority attention. Besides, levels during winter (post monsoon, in case of Chennai & Delhi) were higher as in other seasons. Therefore, detailed analysis was carried out for PM_{10} and NOx for the critical season in respective cities.

- Baseline EI for 2007 was used to estimate emission loads for BAU scenarios for the years 2012 and 2017. While working out future projections for a city, growth pattern of the city including growth in population, vehicles, industries, construction activities, Diesel Generator (DG) sets, etc. as well as proposed future land use/urban development plans was considered. BAU does not account for any intervention to abate air pollution levels. However, the roadmap already planned is considered as BAU e.g. BS-III regulations for 2&3 wheeler vehicles and BS-IV regulations for all other categories of vehicles from the year 2010. Grid based emission rates were worked out.
- A comprehensive list of various control options was compiled for different source groups (Table 7.2). This included technological as well as management based interventions. In order to assess (wherever possible) effectiveness of each of these options, the dispersion model was run twice with and without the control option (keeping other sources being absent). By this, it was possible to determine impact of each control option for improving air quality from vehicles, industries, and area sources. While the model simulations were performed for the whole city, the greater focus was on improving the air quality in the city specific hot spots. The air quality in other grids will automatically improve concurrently along with critical grids.
- Based on the potential impacts of each of these options, three or four alternate plans with different combination of options were evaluated. While deciding a set of options, other factors like ease in implementation from administrative point of view, technical feasibility, financial viability, short & long term impacts, co-benefits in terms of reduction in other pollutants, etc. were considered. Analysis of these factors for various control options is given in Table 7.3.
- The most preferred scenario was determined to formulate action plan, which can result in GLC of PM_{10} and NOx within the permissible levels as per National Ambient Air Quality Standards in 2012 as well as 2017.

Table 7.1: List of Prioritized Sources

Contributing sources	Factor Analysis	Emission Inventory	Receptor Modeling/CMB PM_{10}	Receptor Modeling/CMB $PM_{2.5}$
Bangalore	Vehicle exhaust, road dust, secondary particulates, construction activities	Vehicle exhaust, road dust, construction activities, industries	Road & soil dust, vehicle exhaust, DG sets, secondary particulate	Vehicle exhaust, DG sets, Secondary particulate, domestic combustion, road dust, industries
Chennai	Vehicle exhaust, construction, DG sets, bakeries	Road dust, vehicle exhaust, construction, industries	Domestic, vehicle exhaust, road dust, DG sets	Vehicle exhaust, road dust, domestic, DG sets
Delhi	Combustion, road & soil dust, vehicle exhaust, industries	Road dust, power plant, construction, domestic combustion, vehicle exhaust	Road dust, construction, vehicle exhaust, garbage burning	Domestic, vehicle exhaust, road dust, industries, garbage burning
Kanpur	Road dust, secondary particulates, oil burning (e.g. diesel or heavy oil), biomass burning	Industry, vehicle exhaust, domestic combustion, road dust	Garbage burning, domestic combustion, secondary particulate, vehicle exhaust	Vehicle exhaust, domestic combustion, secondary particulate, DG sets, road dust, industries.
Mumbai	Road & soil dust, vehicle exhaust, coal combustion, kerosene combustion	Road dust, power plant, landfill open burning, construction	Domestic, Soil & road dust, garbage burning, industries, vehicle exhaust	Not done
Pune	Road dust, construction, combustion/vehicles, secondary particulates	Road dust, vehicle exhaust, domestic combustion, construction	Road dust, construction/brick kilns, domestic combustion, vehicle exhaust	Secondary particulates, vehicle exhaust, domestic combustion, road dust

Table 7.2: List of Potential Control Options

Source Category	Control Options	Expected % Reduction in Emissions (Factor)	Scenario for 2012	Scenario for 2017	Remarks
Vehicles	**Technology based**				
	1.Implementation of BS – IV norms	Difference between BS – III and BS – IV (as currently BS – III is in use): Gasoline – NOx: 47% Diesel – PM: 45%, NOx: 50%	BS – IV from 2010 (adopt progressive increment)	BS – IV from 2010 (adopt progressive increment)	Technically feasible, involves huge investments
	2. Implementation of BS – V norms	Difference between BS – IV and BS – V: Gasoline – NOx: 25% Diesel – PM: 90%, NOx: 28%	BS – IV from 2010 (adopt progressive increment)	BS – IV from 2010 (adopt progressive increment) BS – V from 2015 (adopt progressive increment)	Technically feasible, involves huge investments
	3. Implementation of BS – VI norms	Difference between BS – V and BS – VI: Diesel – NOx: 55%	BS – IV from 2010 (adopt progressive increment)	BS – IV from 2010 (adopt progressive increment) BS – VI from 2015 (adopt progressive increment)	Technically feasible, involves huge investments
	4. Electric Vehicles	NOx and PM: 100% (Zero emissions)	Share of Electric vehicles in total city fleet – Two wheeler: 1%,	Share of Electric vehicles in total city fleet – Two wheeler: 2%,	Technically feasible, Infrastructure and power requirement

Source Category	Control Options	Expected % Reduction in Emissions (Factor)	Scenario for 2012	Scenario for 2017	Remarks
			Auto Riksha and Taxi: 5% Public buses: 5%	Auto Riksha and Taxi: 10% Public buses: 10%	to be assessed. With regard to public utility vehicles, % share of electric vehicles may be city-specific and changed, if required.
	5. Hybrid vehicles	NOx: 50%	Share of Hybrid vehicles in total city fleet (Gasoline powered four-wheelers only) – 1%	Share of Hybrid vehicles in total city fleet (Gasoline powered four-wheelers only) – 2%	
	6. CNG/LPG to commercial (all 3 and 4-wheelers)	Public Transport (Buses) – PM: 75% NOx: 12.5% (as compared to BS – II and BS – III vehicles)	25% conversion	100% conversion	Technically feasible, Supply of CNG/LPG and required infrastructure to be assessed
	7. Ethanol blending (E10 – 10% blend)	NOx: 5%	Share of Ethanol blended fuel – 10%	Share of Ethanol blended fuel – 10%	Technically feasible, Availability of Ethanol to be assessed
	8. Bio-diesel (B5/B10: 5 – 10% blend)	PM: 10% NOx: + 2.5% (increase)	Share of Bio-diesel fuel – 5%	Share of Bio-diesel fuel – 10%	Estimation, as no data

Source Category	Control Options	Expected % Reduction in Emissions (Factor)	Scenario for 2012	Scenario for 2017	Remarks
					(current) available on B5/B10
	9. Hydrogen – CNG blend (H10/H20: 10 – 20% blend)	NOx: 10%		Share of Hydrogen blended (H%)fuel - 10% (for vehicles on CNG)	Techno-economic feasibility to be established.
	9. Retrofitment of Diesel Oxidation Catalyst (DOC) in 4-wheeler public transport (BS – II)	PM: 22.5 % (as compared to BS – II vehicles)	50% conversion	100% conversion	Technically feasible but compliance to be ensured
	10. Retrofitment of Diesel Particulate Filter in 4-wheeler public transport(BS – III city buses)	PM: 70 % (as compared to BS – III vehicles)	50% conversion	100% conversion	Technically feasible but compliance to be ensured
	Management based				
	1. Inspection/ maintenance	BS – II & BS – III public transport vehicles – PM: 12.5% NOx: 12.5% 2 and 3-wheelers (gasoline) – NOx: 10% 3-wheelers (diesel) – NOx: 5%, PM: 12.5% 4-wheelers (gasoline) – NOx: 7.5% 4-wheelers (diesel) – NOx:	New I&M regulation introduced and compliance by 50% anticipated	Strict compliance by 100%	Strict compliance mechanisms to be worked out

Source Category	Control Options	Expected % Reduction in Emissions (Factor)	Scenario for 2012	Scenario for 2017	Remarks
		7.5%, PM: 7.5%			
	2. Banning of 10 year old commercial vehicles	100% reduction of off-road vehicles	Old vehicles (10 years +): nos. to be worked out	Old vehicles (10 years +): nos. to be worked out	Regulatory provision required
	3. Banning of 15 year old private vehicle	100% reduction of off-road vehicles	Old vehicles (10 years +): nos. to be worked out	Old vehicles (10 years +): nos. to be worked out	
	4. Synchronization of traffic signals	20% reduction in pollution load for the roads on which it is implemented.	Effective synchronization on all major roads (or about 10% of the prime roads)	Effective synchronization on all major & minor roads, excluding feeder roads (or about 20% of the prime roads)	
	5(a). Improvement of public transport: as per existing plan for the city	Refer DPR or EIA reports or any other suitable document for percentage shift in VKT and off road personal transport vehicles for calculating reduction in PM & NOx emissions.	Incorporate city specific proposals on public transport with respect to Metro/mono rail, BRT, large buses contingent etc	Incorporate city specific proposals on public transport with respect to Metro/mono rail, BRT, large buses contingent etc.	
	5(b). Improvement of public transport: % share (VKT of cars, 2-wheelers and buses)	For percentage shift in VKT calculate off-road personal transport vehicles for calculating reduction in PM and NOx emissions.	10% shift in VKT	20% shift in VKT	
	6. Fiscal incentives/disincentives like increased parking				Quantification may be difficult but

Source Category	Control Options	Expected % Reduction in Emissions (Factor)	Scenario for 2012	Scenario for 2017	Remarks
	fee, proper fuel pricing policy, incentives for car pool, etc				could be a good option
	7. Scattered business timings				Quantification may be difficult but could be a good option
	8. Banning odd/even vehicles on particular roads	Zero emissions from the vehicles off the roads			
Industries					
	1. Fuel change	Appropriate EF to be used Zero PM emissions in case of NG	All solid fuel fired combustion converted to LSHS	All solid fuel or HSD fired combustion converted to NG	Strict compliance required
	2. Cleaner technology change	Based on data on type of industrial units and possible conversion to cleaner technology and information on expected emission reduction due to use of cleaner technology	Clean production option implemented in all feasible industries	Clean production option implemented in all feasible industries	Incentives are necessary and need to be defined
	3. Fugitive emission control	80% PM reduction in fugitive emissions for the industries in which implemented.	50% of the industries having effective control implementations	100% of the industries having effective control implementations	Will also improve occupational health
	4. Particulate control system (cyclone, BF etc)	Bag Filters to have 95% collection efficiency of PM	Bag Filters adopted for combustion emissions	Bag Filters adopted for combustion emissions	
	5. Shifting of air	Deduct emission load from	50% air polluting	100% air	

Source Category	Control Options	Expected % Reduction in Emissions (Factor)	Scenario for 2012	Scenario for 2017	Remarks
	polluting industries	shifted industries	industries shifted out	polluting industries shifted out	
	6. Ban of new industries in existing city limit		No addition of industries	No addition of industries	
	7. Voluntary measures like ISO 14000, ISO 18000	Quantification of impact may not be possible. Could make some assumption	-	100% industries with ISO 14000	
	8. Compliance monitoring	Quantification of impact may not be possible. Could make some assumption	100% compliance	100% compliance	
Area sources (Combustion - Domestic, Bakeries, Open Eat outs, Hotels, etc.)	1. Use of Natural Gas/LPG	Appropriate EF to be used Zero PM emissions in case of NG	50% of solid fuel, kerosene for domestic use to be shifted to LPG/NG 100% of other sources to NG/LPG	75% of solid fuel, kerosene for domestic use to be shifted to LPG/NG 100% of other sources to NG/LPG	
DG sets	1. Inspection & Maintenance of large DG sets				Data required for quantification of impact is not available but this could be a good option. Some assumptions (e.g. 15% change or improvement similar to vehicle I & M) could be

Source Category	Control Options	Expected % Reduction in Emissions (Factor)	Scenario for 2012	Scenario for 2017	Remarks
					made.
	2. Adequate supply of grid power	Zero emissions from DG sets	No use of DG sets	No use of DG sets	
Construction	1. Better construction practices including proper loading /unloading, transportation of material, water spraying, etc.	PM: 50%	50% reduction from construction activities in the BAU 2012	50% reduction from construction activities in the BAU 2017	
Road side dust	1. Converting unpaved roads to paved roads	Use appropriate EF for emissions from respective roads	50% of all unpaved roads to paved	100% of all unpaved roads to paved	
	2. Wall to wall paving (brick)	Use appropriate EF [leads to 15% reduction on paved roads, 40% on unpaved roads for SPM]	All major roads	All major roads; and minor roads with heavy traffic excluding feeder roads	Use of bricks or tiles that do not restrict ground water percolation
	3. Sweeping and watering (mechanized)	Use appropriate EF	All major roads	All major roads; and minor roads with heavy traffic excluding feeder roads	
Open Burning	Strict compliance to ban of open burning		50% compliance	100% compliance	
All sources in hotspots	1. Zero polluting activities in hotspots				Certain areas in the city with high pollution levels could be declared zero polluting activity/no

Source Category	Control Options	Expected % Reduction in Emissions (Factor)		Scenario for 2012	Scenario for 2017	Remarks
						vehicles zone

Table 7.3: Factors considered in formulating control strategies

A) Framework for Selecting Measures to Address Urban Air Pollution – Vehicles

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
(1) Strategy: Reducing Emissions per Unit of Fuel			
Fuel Quality Improvement	Sulphur Reduction	Delineating tighter diesel fuel standards	Phasing out fuel subsidies, uniform pricing all over the state followed by country
Installation of after treatment devices	Fitment of Diesel Oxidation Catalyst, catalytic converter in older vehicles	Tighter diesel fuel standards particularly for Sulphur to bring down its level up to 50 ppm. Emission test frequency to be more for those without the after treatment devices	Differential taxation to those with and without after treatment device
Tackle fuel adulteration	Markers for detection	Better specification of fuel quality for detection as well as booking the offenders. Monitoring fuel quality in a specified laboratory, making companies accountable	Oil companies to finance the setting up of a laboratory, Fines and cancellation of license
Use of alternative fuels	CNG,-LPG and Bio fuels	Promote its use in private sector as well as organized sector through administrative orders	Differential taxation for older vehicles changing to CNG/LPG, Incentive for new owners to buy CNG/LPG vehicles. Low cost bio fuels
Renewal of vehicle fleet	Phase out vehicles above a certain age	Scraping of older vehicles	Older vehicles to remain on road if it passes the fitness test as well as emission test, however higher tax to be paid as the vehicle gets older
Improve traffic flow	Synchronized signal corridors	Coordination with other institutions to check indiscriminate parking , and enforce one way system at peak hours	Congestion pricing Higher parking fees
(2) Strategy: Reducing Fuel Consumption per unit Distance			
Change to better	4 stroke engines for two	Standards for fuel economy need to be	Tax break for older vehicles changing to

technology engines	–three wheelers, Bharat stage III engines with DOC for older diesel vehicles, All new diesel vehicles to be Bharat stage III and above	specified Useful age of the vehicles to be specified by the manufacturer	new engine with DOC or DPF
Improve vehicle I&M	I&M programs that are difficult to cheat; computerized data capture and control of tests	Strict enforcement	Better infrastructure, manpower augmentation, Strict fines
Better road maintenance	Investment in better road maintenance technology to avoid frequent relaying	Standards for road construction specified in terms of guaranteed life of the road	Financial incentives for contractors using better technology for road construction
(3) Strategy: Reduce Vehicle Distance Traveled			
Increase private vehicle occupancy		Encourage car pooling	Congestion pricing
Promote better and more public transport	Dedicated bus lanes; user friendly MRTS	Reform of public transport – competition, privatization etc	Subsidize public transport by taxing private car users
Demand management		1. Limit parking 2. Limit the use of vehicles in congested areas 3. Allow odd /even no. private vehicles on specified days.	- High one time tax on purchase of a new vehicle - High parking fees - Road user charges - Allow to ply a vehicle (odd/even) with charges
Encourage non motorized transport	Pedestrian friendly walkways / subways	Protection of pedestrian facilities	Financial incentives for pedestrian friendly design
Reduce dust re-suspension	Road paving /cleaning	Coordination with all institution working in the area of road and pavement maintenance, digging for utilities etc. One agency to monitor the working practices.	Steep fines to agencies leaving the debris-dust on the roads after the completion of jobs.

B) Framework for Selecting Measures to Address Urban Air Pollution – Industries

Fuel change	For power plant the fuel change leads to technology change as well. However, newer technologies are more efficient and long term cost effective. Other industries may experience lower level of technology issues.	SPCB can make the rule stringent and link with City Action Plan	High cost initially. However, in longer run more cost effective
Industrial Policy	• Specifying technology needs policy review. • Area specific location policy	Detail feasibility study for technology as well as land use based policy issues.	Financial incentive to burn cleaner fuel or use of cleaner technology

C) Framework for Selecting Measures to Address Urban Air Pollution – Area Sources

Action Category	**(a) Technical**	**(b) Administrative / Regulatory**	**(c) Economic / fiscal**
Fuel change - Domestic	No major technical issue	Adequate administrative measures in place	No major cost involved. Facilitation for awareness needed. Low cost fuel to slums
Fuel change - Bakeries/Crematoria	Need for technical evaluation	Standards to be specified to drive technical changes	Medium cost
Resuspended dust	• Pavement to be wall to wall • Better sweeping system • Better road paving technology issue	Regulatory push and enforcement required for better road paving technologies.	• Minor cost • Fines for poor road surfaces
Construction	Improved construction practices, no technology issue	Regulatory push and surveillance needed for better compliance	Minor costs of regulation and surveillance
DG Sets	• Revision of emission standards • Inspection & maintenance	Revision of emission standards have been initiated by CPCB; and I&M needs to be taken up. As such, technical/administrative/economic issues need evaluation. Issue of non-emission/industrial engines being delivered for DG sets is an issue which needs to be taken.	

7.2 Evaluation of Efficacy of Control Options and Development of City-Specific Action Plans

In each of the cities, depending on dominance of source contributions, local situations, various options were short listed. Efficacy of each of these options was worked out using dispersion model. Alternate scenarios with combination of selected options were developed. These scenarios were developed for the year 2012 and 2017 for PM_{10} as well as NOx. The best scenario, in terms of air quality improvement, was chosen as appropriate Action Plan. While details of alternate scenarios including analysis of expected improvement in air quality are given in the base reports of the cities, best scenario that led to formulation of Action Plan is presented in this report. Model predictions were made considering implementation of the suggested Action Plan, to assess the expected improvement in the air quality. The expected emission reductions expected after implementation of Action Plan are given in Table 7.4.

Table 7.4: Emission Reductions with Implementation of Action Plan

Pollutants		Emission Load (T/day)					% increase over Baseline 2007		% reduction w.r.t. BAU	
		Baseline-2007	BAU-2012	BAU-2017	Action Plan 2012	Action Plan 2017	BAU-2012	BAU-2017	Action Plan 2012	Action Plan 2017
PM_{10}	Bangalore	54	72	96	33	35	32%	76%	54%	64%
	Chennai	11	17	26	10	9	16%	25%	41%	66%
	Delhi	147	175	203	101	146	19%	38%	42%	28%
	Kanpur	9	11.	14	7	7	22%	48%	40%	51%
	Mumbai	73	105	132	37	22	43.%	79%	65%	83%

	Pune	32.	48	78	25	39	50%	140%	49%	50%
NOx	Bangalore	217	321	460	131	122	48%	112%	59%	73%
	Chennai	12	17	25	11	12	41%	108%	34%	53%
	Delhi	460	489	611	83	202	6%	32%	83%	67%
	Kanpur	22	33	44	20	30	49%	97%	40%	33%
	Mumbai	215	278	341	185	212	29%	58%	33%	37%
	Pune	41	71	112	39	49	71%	170%	45%	56%

City-wise details are given below:

Bangalore:

Based on emission inventory and receptor modeling approach, the major common sources of PM_{10} are transport and road dust re-suspension. DG sets and industry show significant contributions in different approaches. In addition, due to major construction activities ongoing in Bangalore, construction sector also contributes to the emission load. Therefore, in the case of Bangalore, control strategies need to be devised for transport, road dust re-suspension, industry, DG sets, and soil dust/construction. In addition, CMB8.2 quantification shows secondary particulates as an additional source. The control strategies for primary pollutant like SO_2 and NOx would results in the reduction of the secondary particulates as well.

For prioritizing the list of management/control options, an analysis is made of the percentage reduction in the overall emission load as compared to the BAU total emission load in the respective years i.e. 2012 and 2017. Four alternate scenarios were generated that were a mix of different control strategies and management options. The prioritized list of key individual interventions/control measures that were considered under different alternate scenarios in terms of percent reduction in the PM_{10} emission load in 2017 as compared to the respective BAU emission load; and the best scenario for air quality improvement (alternate IV) is discussed below:

- By-passing of trucks through the proposed peripheral ring road around Bangalore (14%); Installation of DOC and DPF devices in all pre-2010 diesel vehicles (13%);No power cuts leading to zero usage of DG sets (13%);Ban on 10 year old commercial vehicles in 2012 and 2017 (12%); Ban on any new industries in city limits(6%) and fuel shift towards cleaner fuel CNG (5%) in existing industries (11%); Installation of DOC and DPF devices in DG sets (8%); Wall to wall paving for reduction of road dust (6%); Better construction practices (5%);Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017)(4%); Improvement in inspection and maintenance for vehicles (2%); Inspection and maintenance for DG sets (2%); Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017) (2%);Enhancement of public transport system based on diesel (shift of PKT from private vehicles to public transport i.e. 10% in 2012 and 20% in 2017) (1%).

- Besides the above strategies, introduction of electric vehicles and synchronization of traffic signal also lead to reduction in emission loads. Other options such as staggered business timings and no vehicle zones in hot spots would also be helpful in improving the air quality. Fiscal measures such as congestion charges, enhanced parking charges, etc. would be helpful in reducing the usage of private vehicles. More importantly, rationalization of excise duty on vehicles and appropriate fuel pricing policies could play an important role in curbing the growth of more polluting private vehicles. Other measures such as appropriate land use planning to curb travel demand, enhancing virtual mobility, car pooling, etc would contribute to air quality improvements. However, in order to implement many of these strategies, the basic requirement is to have an efficient mass public transport system in place.

- Selection of various control options shows an impact in terms of reduction in emission loads eventually translating into reduction of PM_{10} ambient concentrations. The benefits are anticipated in terms of improvements in the ambient air quality at the six ambient air quality stations as well as at the city level thereby leading to improved health and ecological benefits.

- The suggested Action Plan for Bangalore is given in Table 7.5. Air quality profiles (isopleths) of the city for BAU 2012 and 2017 as well as expected after implementation of proposed Action Plan in respect of PM_{10} and NOx are given in Figures 7.1 and 7.2 (yellow plots for PM_{10} and Blue plots for NO_x).

Table 7.5: Action Plan for Bangalore

S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
1	Transport	Strengthening of Public transport system • Metro implementation on schedule • Enhance share of public mass transport system on diesel • Conversion/ enhancement of public transport to CNG	High	Govt of India, State Government, BMRCL (Bangalore Metro rail Corporation Ltd.), Transport Department-Bangalore, BMTC (Bangalore Metropolitan Transport Corporation), GAIL	Medium term	Leveraging the JNNURM funding mechanism for public transportation improvement Public-private partnership models to be explored The metro network needs to be progressively expanded. Bangalore currently does not have a CNG network. There are plans to set up such a network in future. ULSD would also be available by April 2010 in Bangalore. Retro-fitted 2-stroke three wheelers on LPG in Bangalore have higher PM emissions compared to OE 2-stroke/ 4-stroke LPG/Petrol. Thus retro-fitment of 2-stroke 3-wheelers is not an effective control option.
		Ban on old commercial vehicles (10 year) in the city	High	Transport department - Bangalore	Short-term	Fiscal incentives/ subsidies for new vehicle buyers A plan should be devised for gradual phase out with due advance notice. Careful evaluation of socio-economic impact of banning required. In the long run, a ban/ higher tax on private vehicles (> 15 years) could be looked into.
		By-passing of trucks through the proposed peripheral ring road around Bangalore	High	Traffic Police, Transport department	Short-term	Has high potential in reducing the pollutant load in the city
		Progressive improvement of vehicular emissions norms (BS-V, BS-VI)	Low	MoRTH, MoPNG, Ministry of Heavy Industry and Public Enterprises, MoEF, Oil companies,	Medium to Long term	Auto-fuel road map should be developed well in advance to plan the progressive improvement of emissions norms and corresponding fuel quality

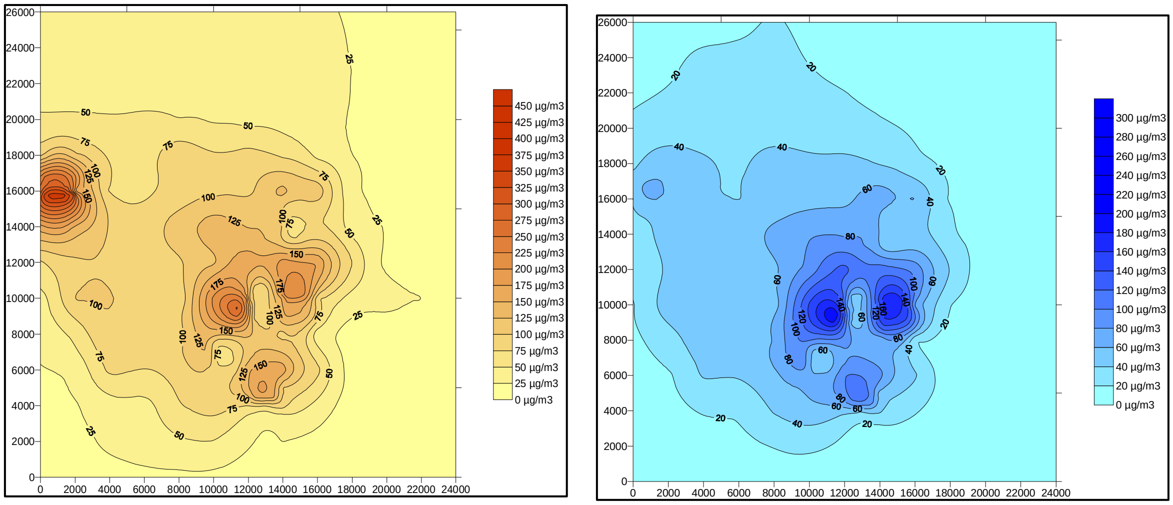
S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
				Automobile manufacturers		norms. Though the impact is low, its potential is high in the long term when gradually fleet renewal takes place.
		Installation of pollution control devices (DOC/DPF) in all pre-2010 diesel vehicles	High	Transport department	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction. Retro-fitment of DOC in BS-II buses and DPF in BS-III buses is technically feasible.
		Introduction of fuel efficiency standards	Low	BEE, Ministry of Power, Ministry of Heavy Industry and Public Enterprises, Automobile manufacturers, Ministry of Road Transport	Medium	Impact is low since it is applied only to new vehicles registered after 2012. However, its potential is high in the long term when gradually fleet renewal takes place.
		Introduction of hybrid vehicles/ electric vehicles	Low - medium	Ministry of Finance, Ministry of Heavy Industry and Public Enterprises, Automobile manufacturers, State government,	Short-Medium	Appropriate fiscal incentives need to be provided; Electric vehicles would be especially effective in high pollution zones. Impact determined by the extent of switchover to hybrid/ electric vehicles.
		Effective Inspection and maintenance regime for vehicles	Medium	Transport Department, Traffic police	Short to Medium	Initial focus could be on commercial vehicles; Capacity development in terms of infrastructure for fully computerized testing/certification and training of personnel. Linkage of all PUC centers for better data capture.
		Alternative fuels such as ethanol, bio-diesel	Low	MNRE, MoRD, MoPNG, MoA, Oil companies,	ongoing	There are operational issues regarding availability and pricing that need to be sorted.
		Reduction in private vehicle usage/ ownership		Min. of Finance, State Government NGOs General public	Medium term	A pre-requisite for curbing the growth of private vehicles is the provision of an effective mass based transport system. Strategies such as costlier parking, higher excise duties/sales tax on private vehicles, car pooling would be helpful.
		Improve traffic flow	Medium	Traffic police, Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara	Short	Synchronization of signals, one way roads, flyovers, widening of roads, removal of encroachments, staggering of office timings to reduce peak flow and congestion. Application of IT tools for

S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
				Palike (BBMP),		traffic management (Intelligent transport system)
		Fuel adulteration	NA	Govt. of India, Oil companies, Food and civil supplies department- Bangalore	Short	Re-assess subsidy on kerosene, strict vigilance and surveillance actions, better infrastructure in terms of testing laboratories
2	Road dust	• Construction of better quality roads • Regular maintenance and cleaning/sweeping of roads • Reduction in vehicular fleet and trips	NA	Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP), NHAI	Short - Medium term	Effective enforcement of road quality norms is required. Landscaping/ greening of areas adjacent to roads
		Wall to wall paving for reduction of road dust	High	Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP)	Short term	Interlocking tiles may be used so that water percolation takes place.
3	Industries	Fuel shift towards cleaner fuels	High	KSPCB, Directorate of Industries and Commerce, Industry associations, GAIL, Oil companies	Short-Medium term	Shift from solid fuels to liquid fuels (LSHS) and subsequently to gaseous fuels (CNG)
		Ban on any new air polluting industry in city limits	High	KSPCB, Department of Forest, Ecology and Environment, Department of Industries and Commerce, Karnataka Industrial Area Development Board	Short term	Industrial estates/zones may be developed well outside the city
		Strengthening of enforcement mechanism for pollution control	NA	KSPCB, Industry associations,	Short term	This would ensure greater compliance with standards. In addition, cleaner technology options need to be promoted and appropriate incentives to be defined. Voluntary measures such as ISO certifications to be encouraged.

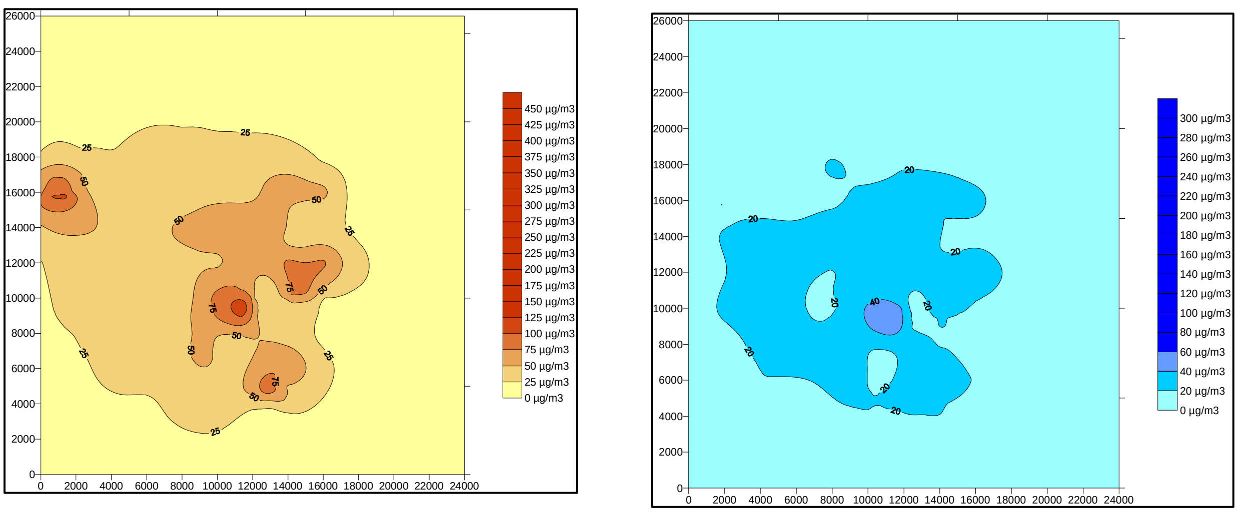
S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
4	Power/ DG sets	No power cuts leading to zero usage of DG sets	High	Bangalore Electricity Supply Company, Karnataka Power Corporation Ltd.	Medium term	Adequate tie-ups need to be ensured
		Installation of pollution control devices (DOC/DPF) in DG sets	High	KSPCB, DG set manufacturers	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction
		Effective Inspection and maintenance regime for large DG sets	Medium	KSPCB, Chief Electrical inspectorate	Short to Medium	
5	Construction	Better enforcement of construction guidelines (which should reflect Green Building concepts)	High	KSPCB, SEAC (State expert appraisal committee), Bruhat Bengaluru Mahanagara Palike (BBMP),	Short term	
6	Other sectors	Integrated land-use development of Bangalore taking environmental factors into consideration	NA	Bangalore Metropolitan Region Development Authority, Bangalore Development Authority, Bruhat Bengaluru Mahanagara Palike (BBMP)	Medium term	Holistic development of the entire region including peripheral areas.
		Open burning/ Waste burning to be discouraged	NA	Bruhat Bengaluru Mahanagara Palike (BBMP), KSPCB	Short term	Organic matter could be used for compost formation and methane gas generation
		Domestic sector – biomass burning to be reduced	Low	Food and civil supplies department, Oil companies	Medium	Rural areas should be encouraged to shift to cleaner fuels
		Virtual mobility- using ICT information and communication technology	NA	Department of Information Technology& Biotechnology, Government of Karnataka;	Short-Medium term	Reduced number of trips.
		Strengthening of	NA	KSPCB	Short	Good quality data is an important input

S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
		air quality monitoring mechanism in terms of number of stations as well as pollutants monitored. Capacity building of KSPCB staff.				in assessing the change in air quality and the impact of policy interventions. Continuous monitoring stations to be promoted.
		Environmental education and awareness activities	NA	Education department, Schools/Colleges, CBOs, NGOs	Short	Also, sensitization programmes for policy makers.

* Impact is determined in terms of percent reduction in total emission load for PM_{10} for the study period up to 2017 subject to the assumptions listed in chapter 6 (High impact > 5% reduction; medium impact 1-5% reduction; low impact < 1% reduction; NA = not quantified or not quantifiable). Time frame: Short (up to 2012), Medium (2012-2017)

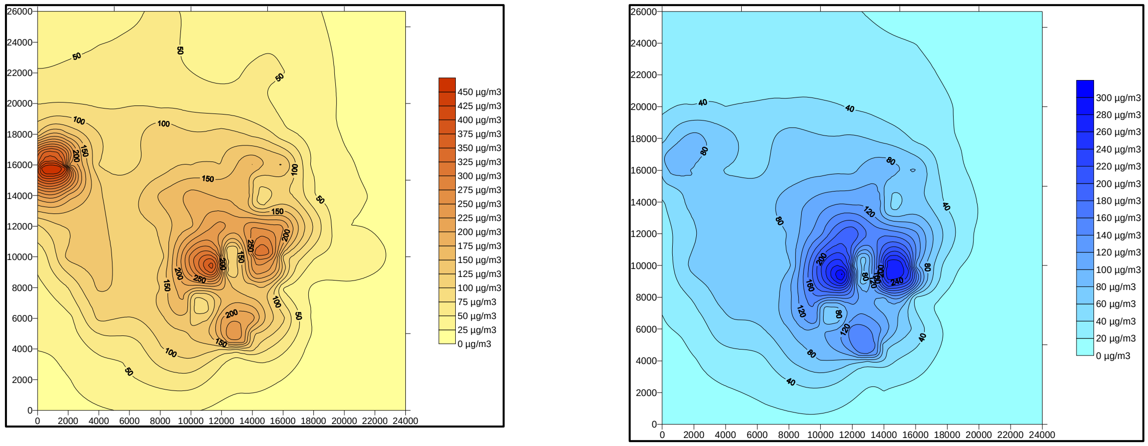


Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3) for winter: 2012 BAU

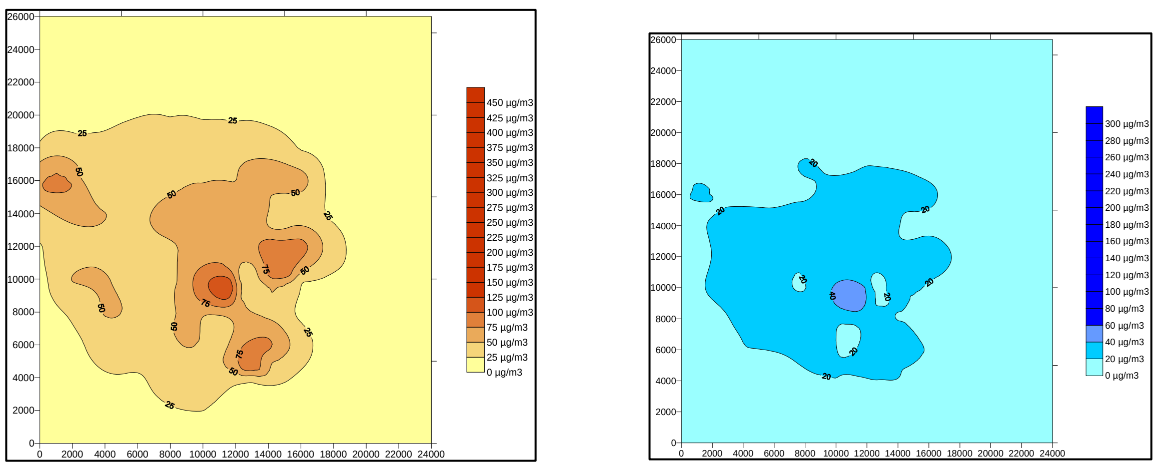


Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3) respectively for winter:
Control Scenario 2012

Figure 7.1: Air Quality Profiles for BAU 2012 and with Implementation of Action Plan in Bangalore



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m³) for winter: 2017 BAU



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m³) respectively for winter:
Control Scenario 2017

Figure 7.2: Air Quality Profiles for BAU 2017 and with Implementation of Action Plan in Bangalore

Chennai:

The primary conclusions are that the PM can be abated by reducing the silt loading and that the NOx can be abated by controlling the vehicular emissions. Improving public transport would help control both to a significant extent. However, the effectiveness of the individual options was different. Implementing silt loading reduction would reduce the PM by 23% in 2012 and by 48% in 2017. Improving public transport would reduce the PM by 9% in 2012 and by 19% in 2017. Implementation of BS IV option would decrease the NOx load by 6% in 2012 and by 20% in 2012. Implementation of BS V would decrease the NOx by 22% in 2012 and the implementation of BS VI norms would decrease NOx by 24% in 2012. Banning 10 year old commercial vehicles would reduce the NOx by 13% in 2012 and by 14% in 2017. Banning 15 year old private vehicles would reduce the NOx by 15% in 2012 and by 17% in 2017. Improving public transport would reduce the NOx by 8% in 2012 and by 17% in 2017. Thus it is clear that a judicious combination of these options have to be exercised to control the pollution level in the future.

The control options which resulted in significant reduction in the PM_{10} and NOx concentrations would be of higher priority for implementation. Combinations of these control options were considered to determine the total effect. On the basis of the effect on emission loads as well as on the concentration levels of PM_{10} and NOx, the control options which are most effective are:

- Control of emissions from road dust by reducing silt loading. This has a significant impact on the emissions and concentration levels of PM_{10}. This however does not include the effect on NOx levels.

- Control of emissions from vehicles has significant improvement on NOx emissions and NOx levels, but not much influence on emissions and ambient levels of PM.

- Improving public transport has significant reduction in both PM and NOx.

- Other control options such as action on point sources and open burning have a more local impact since their contribution to the air quality in the city level is low.

- The banning of commercial vehicles and private vehicles of a critical age has a significant impact on the NOx emission load and pollution levels.

- The suggested Action Plan for Chennai is given in Table 7.6. Air quality profiles (isopleths) of the city for BAU 2012 and 2017 as well as expected after implementation of proposed Action Plan in respect of PM_{10} and NOx are given in Figures 7.3 and 7.4.

Table 7.6: Action Plan for Chennai

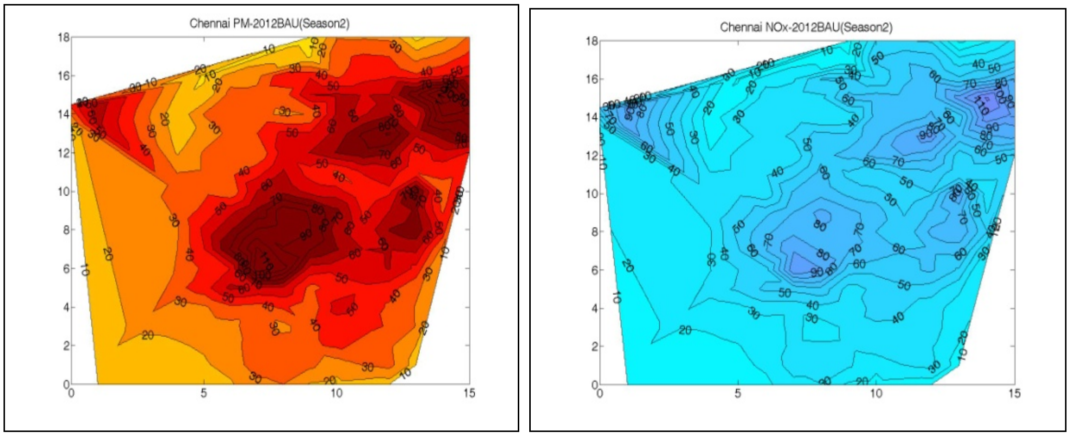
S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
1	Transport	Strengthening of Public transport system • Metro implementation on schedule • Enhance share of public mass transport system • Conversion of public transport to CNG	High	Govt of India, State Government, CMRL (Chennai Metro Rail Limited), Transport Department- Chennai, , MTC (Metropolitan Transportation Corporation Chennai), GAIL	Medium term	The metro network is being expanded. On Jan 2009, GOI approved plans for two phase expansion, with first phase expected to complete by 2014-15. Chennai does not have a CNG network and has a limited LPG network. There are plans to set up CNG network in future, but no timeframe is available. ULSD would also be available by April 2010 in Chennai. Retro-fitted 2-stroke three wheelers on LPG have higher PM emissions compared to OE 2-stroke/ 4-stroke LPG/Petrol. Thus retro-fitment of 2-stroke 3-wheelers is not an effective control option.
		Ban on old commercial vehicles (10 year) and private vehicles (15 years) in the city	High	Transport department - Chennai	Short-term	Fiscal incentives/ subsidies for new vehicle buyers A plan should be devised for gradual phase out with due advance notice. Careful evaluation of socio-economic impact of banning required.
		Progressive improvement of vehicular emissions norms (BS-V, BS-VI)	High	MoRTH, MoPNG, Ministry of Heavy Industry and Public Enterprises, MoEF, Oil companies, Automobile manufacturers	Medium to Long term	Auto-fuel road map should be developed well in advance to plan the progressive improvement of emissions norms and corresponding fuel quality norms. Though the impact is low, its potential is high in the long term when gradually fleet

S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
						renewal takes place.
		Installation of pollution control devices (DOC/DPF) in all pre-2010 diesel vehicles	Low	Transport department	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction. Retro-fitment of DOC in BS-II buses and DPF in BS-III buses is technically feasible.
		Effective Inspection and maintenance regime for vehicles	Medium	Transport Department, Traffic police	Short to Medium	Initial focus could be on commercial vehicles; Capacity development in terms of infrastructure for fully computerized testing/certification and training of personnel. Linkage of all PUC centers for better data capture.
		Improve traffic flow	Low	Traffic police, CMDA (Chennai Metropolitan Development Authority)	Short	Synchronization of signals, one way roads, flyovers, widening of roads, removal of encroachments, staggering of office timings to reduce peak flow and congestion. Application of IT tools for traffic management (Intelligent transport system)
2	Road dust	• Construction of better quality roads • Regular maintenance and cleaning/sweeping of roads • Reduction in vehicular fleet and trips	High	CMDA, NHAI	Short - Medium term	Effective enforcement of road quality norms is required. Landscaping/ greening of areas adjacent to roads
		Wall to wall paving for reduction of road dust	High	CMDA	Short term	Interlocking tiles may be used so that water percolation takes place.
3	Industries	Fuel shift towards cleaner fuels	Low	TNPCB, Directorate of Industries and	Short-Medium	Shift from solid fuels to liquid fuels (LSHS) and subsequently

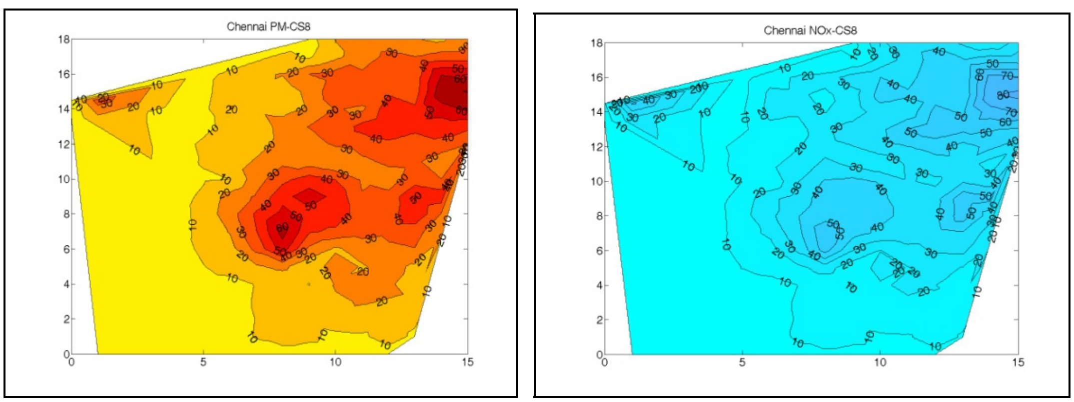
S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
				Commerce, Industry associations, GAIL, Oil companies	term	to gaseous fuels (CNG). Local pollution load will decrease significantly. However, impact on overall level in the city will be low
		Ban on any new air polluting industry in city limits	Low	TNPCB, Department of Forest, Ecology and Environment, Department of Industries and Commerce, Tamil Nadu Industrial Development Corporation	Short term	Real estate prices will inhibit growth of new large scale industry within city limits and hence the impact is low. Industrial estates/zones may be developed well outside the city
		Strengthening of enforcement mechanism for pollution control	Low	TNPCB, Industry associations,	Short term	This would ensure greater compliance with standards. In addition, cleaner technology options need to be promoted and appropriate incentives to be defined. Voluntary measures such as ISO certifications to be encouraged.
4	Power/ DG sets	No power cuts leading to zero usage of DG sets	Medium	TNEB (Tamil Nadu Electricity Board)	Medium term	Adequate tie-ups need to be ensured
		Installation of pollution control devices (DOC/DPF) in DG sets	Medium	TNPCB, DG set manufacturers	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction
		Effective Inspection and maintenance regime for large DG sets	Medium	TNPCB, Electrical inspectorate	Short to Medium	
5	Construction	Strict enforcement of construction guidelines (which should reflect Green Building concepts)	Low	TNPCB, CMDA	Short term	Pollution load due to construction is limited to short time and small locality.
6	Other sectors	Integrated land-use development of Chennai taking environmental factors into consideration	Low	CMDA	Medium term	Holistic development of the entire region including peripheral areas.

S. No.	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
		Open burning/ Waste burning to be discouraged	Low	CMDA, TNPCB	Short term	Sorting solid waste is important. Organic matter could be used for compost formation and methane gas generation
		Strengthening of air quality monitoring mechanism in terms of number of stations as well as pollutants monitored. Capacity building of TNPCB staff.	Low	TNPCB, CPCB	Short	Good quality data is an important input in assessing the change in air quality and the impact of policy interventions. Continuous monitoring stations to be promoted.
		Environmental education and awareness activities	Medium	Education department, Schools/Colleges, CBOs, NGOs	Medium/ Long Term	Sensitization programmes for policy makers.

* Impact is determined in terms of percent reduction in total emission load for PM_{10} for the study period up to 2017 subject to the assumptions listed in chapter 6 (High impact > 5% reduction; medium impact 1-5% reduction; low impact < 1% reduction; NA = not quantified or not quantifiable). Time frame: Short (up to 2012), Medium (2012-2017)

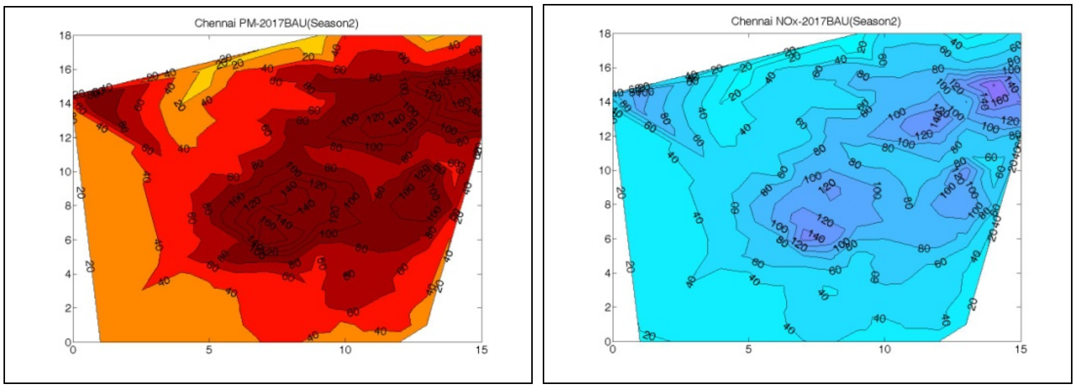


Isopleths for 24-hourly avg. PM_{10} and NOx concentration ($\mu g/m^3$) respectively for Post Monsoon: 2012 BAU

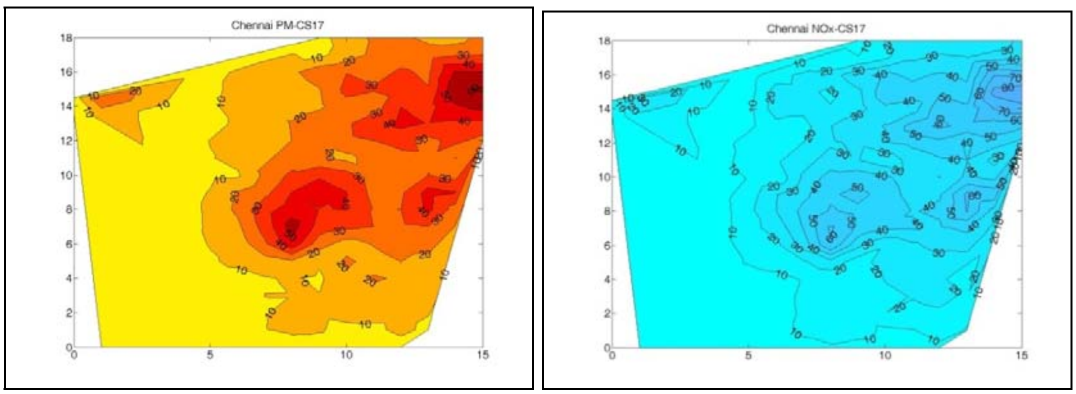


Isopleths for 24-hourly avg. PM_{10} and NOx concentration ($\mu g/m^3$) respectively for Post Monsoon:
Control Scenario 2012

Figure 7.3: Air Quality Profiles for BAU 2012and with Implementation of Action Plan in Chennai



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3)
respectively for Post Monsoon: 2017 BAU



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3)
respectively for Post Monsoon:
Control Scenario 2017

Figure 7.4: Air Quality Profiles for BAU 2017 and with Implementation of Action Plan in Chennai

Delhi:

Analysis of various technology and management based options indicated that implementation of any one of the above strategies would not be able to achieve significant reduction Significant reductions are not observed because several vehicular pollution control measures like introduction of BS-II for 2 Wheelers and BS-III for all other vehicles, introduction of CNG for 3 Wheelers, taxis and buses, less sulfur content in diesel, ban on more than 8 years old buses, etc. have already been implemented in Delhi during the last decade. To get further incremental reductions, the efforts required would be much more, whereas the expected benefits would not be commensurate with the efforts towards technology based pollution control systems. Therefore, the control scenario of vehicular sector particularly must look at managerial options, which can provide the right reductions.

The control scenario for vehicular emissions includes implementation of next stage emission norms for new vehicles, retro-fitment of diesel particulate filter for in-use commercial diesel vehicles, mandatory inspection and maintenance in automobile manufacture company owned service centers, improvement in public transport system, synchronization of traffic signals, introduction of hybrid vehicles with improvement in fuel quality (no adulteration) is expected to yield about 47% reduction by 2012 and 82% reduction in PM emissions by 2017 as compared to estimated emissions under BAU for those years. Reduction in NOx emissions is expected to the tune of 30% by 2012 and 43% by 2017, as compared to respective years BAU scenario emission levels.

Preferred scenario delineation involves critical examination of the constraints (technical, fiscal, administrative and others) with a view to understand the applicability of the solution for the city. It also examines the benefits and co-benefits of each of the actions. Impact of control options in the improvement of air quality was assessed using three types of scenario generation. The first scenario is for only PM emissions reduction, whereas the second scenario is formulated for NOx emissions reduction. However, the final scenario considered is for the reduction of both PM and NOx emissions.

Percentage reductions in emissions of PM, SO_2 and NOx have been estimated for different control options with respect to the corresponding year BAUs (2012 and 2017) emission loads. Area coverage for PM and NOx reduces substantially by 2012 and continues till 2017 as compared to the respective year BAU scenarios. With the suggested management plans, road dust re-suspension is expected to be reduced to a large extent by 2012 and 2017. Based on series of evaluation aiming at emission load reduction leading to better air quality, a list of most important options have been prepared as Action Plan and the same is given in Table 7.7. The resultant air quality is given in Figure 7.5 – 7.6.

Table 7.7: Action Plan for Delhi

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
1	Transport	Augmentation of city public transport system	High	Govt of Delhi, MCD, NCR Board, Metro Rail and public transport companies DTC etc.	Medium	• Dedicated bus lane, better buses, low cost of travel, faster travel etc. • Finances for better buses. • Measures to reduce the cost of travel by way of cross subsidizing. • Dedicated funds for public transport
		Traffic restrain, and congestion related taxes – Financial aid to public transport	Moderate	SIAM, MORTH,CPCB Delhi Government, MCD, NCR Board, Transport police, other utilities.	Medium	• Improvement of roads, new roads, scientifically planned traffic management, mass transit systems, parking on roads • Concretization of road may be the solution. New road planning and Traffic management are being taken as integral part of the road and flyovers construction. • Better planning and training in traffic management. Mass Rapid Transit System (Metro and High Capacity Bus system) • It will reduce traffic junction hotspot of all the pollutants • It will also reduce continuous source of dust
	Transport	Development of fuel based	Moderate	Vehicle manufacturer,	Medium	• No technical issue with new vehicles.

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
		emission norms for all category of vehicles	(Marginal improvement from newer vehicles except when implementation is for Euro V & VI In-use vehicles emission reduction can be substantial)	GoI, CPCB, SIAM		• For in use old vehicles, technical feasibility needs to be established • The process of in-use vehicles standards may take time as they need to be revised at central level. Inadequate infrastructure and manpower at local; levels could other major barriers. • After the legislation is in place, provision of strict penalty leading to cancellation of vehicle registration. • As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types
		Fuel Quality Improvement (S reduction in Diesel)	Moderate (Reduction in S leads to 2.5 – 13 % reduction in PM #)	Oil companies, GoI, Vehicle Manufacturer, Ministry of Petroleum,	Medium	• The S reduction will not only reduce the PM but also lead to correspondingly lower SO_2 emission leading to lower ambient SO_2 and sulphate. • High cost. Being planned by Refineries as per the Auto Fuel Policy. • Improvement in emission standards as well as legislation for stringent fuel standards for S • Phasing out the subsidies on diesel. Bringing diesel cost at par in a state/centre

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
		Stringent system for checking for adulteration in fuels	Moderate Reduced PM emissions (difficult to quantify). Effectiveness is moderate as marker system has not been seen as a primary means to reduce PM	Oil Companies, Anti Adulteration Cell, Vehicle owners	Medium	• One of biggest advantage of non-adulteration shall be longer engine life besides the emission reduction for PM as well as CO and HC. The catalytic converter shall be active for its lifetime. Better quality fuel by adopting stricter fuel supply and dispensing system (e.g. Pure for Sure etc.) • Chemical marker system • Present system of Anti Adulteration cell function needs major improvement in terms of higher manpower and spread. • Finer fuel specifications are needed for implementation.
		Alternative fuels * Technical infrastructure in Mumbai for dispensing CNG/LPG is fairly good and is improving * Biofuels can be used up to 5-10% without any	High *More than 90 % reduction in PM can be achieved compared to diesel # * Similar to diesel but low SO_2 and low PM	GOI, SIAM, Oil Companies	Medium	• Will lead to substantial reduction in CO and HC emission, however, NOx values may go up • Can be applicable mainly for vehicles, which are supposed to ply within the city. Applicable to only local public transport, taxies etc. * Low SO_2 emission

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
		major technical issue				
		Inspection and Maintenance (I&M) System for all category of vehicles in Automobile Manufacture Company Owned Service Centers (AMCOSC)	High (May lead to 5-10% reduction of emission).	DPCC, CPCB MCD, GoD, Transport Dept, Other institutions involved in awareness campaign	Medium	• On use of alternative fuel, Inspection and certification, adulteration of fuels, use of public transport, less usage of private vehicles • Resources for awareness and training, bringing the different groups together • Savings by way of improved vehicle maintenance and operation
		Introduction of new technology vehicles	High	Vehicle Companies, Transport Office GoD, , MNRE	Medium	• New technology based vehicles emit less per unit distance travelled • Electric vehicles for grossly polluting high VKT vehicles are a good option. It needs regulatory push • It will lead to better compliance from on-road emission test and overall improvement in emission of all the pollutants.
		Retro-fitment of DPF in LCVs, Trucks and Diesel-Buses	Moderate (Engine replacement could lead to major reduction of PM. Emission	DPCC, SIAM Govt. of Delhi, Vehicle Manufacturer, Vehicle Fleet Owners	Medium	• Experience of other countries suggests that it can be feasible. However, in Indian scenario, a pilot retrofit programme to evaluate the efficacy needs to be undertaken. A small pilot project is on in Pune with USEPA, USTDA and NEERI

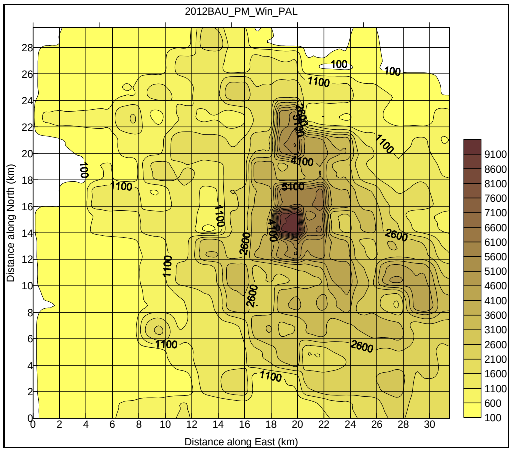
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
			control devices available (DPF, DOC) can remove PM upto 90%			• Availability of new engines for retrofit. Vehicle manufacturers need to come forward. • For Emission control devices, there are innumerable agencies. • Presently no legislation • Short time frame, high levels of compliance expected for all the in-use older vehicles.
		Phase out of older grossly polluting vehicles	High (Estimate suggest 25% of these vehicle may contribute 75% of total emission)	MORTH, DPCC, CPCB, Transport Commissioner office,	Medium	• New legislation may require changes in Motor Vehicles Act • Poor Inspection system both for emission as well as vehicle. • Better compliance will lead to reduction of other pollutants as well. It will also lead to less pressure on complying vehicles
2	Industries	Alternate Fuel Power Plants (Fuel shift - coal to NG) Medium Scale industries (Fuel shift)	High	DPCC, Govt of India, Power companies,	Medium	• Large no of industries are using NG and LPG • More allocation of NG/LPG to the industrial sector by Govt. of India • Better air quality in terms of SO_2, CO and HC will be achieved.
		Combustion Processes	Moderate	DPCC, Power companies and Industries, CPCB	Medium	• Change in combustion technology will be needed for shifting from coal/oil to natural gas • Finances to change the process

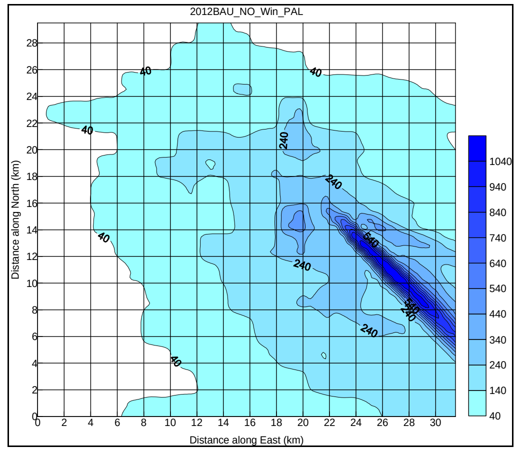
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
						technology • It will lead to lower emission of CO and HC
		Promoting Cleaner Industries	Moderate (Large scale shift shall result in major PM /NOx reduction)	CII, MoEF, CPCB	Medium	• MoEF can provide incentives to carry out the necessary change • It will lead to sustainable existence of industries within the city. It will also lead to other pollutants reduction
		Location Specific emission Reduction	Medium	Govt of Delhi, DPCC CPCB and GoI	Medium	• State as well as central government can provide the necessary incentive on use of advance technology by the power plant and other industries • Lower NOx and other emissions
		Fugitive Emission control	Moderate	DPCC, Industries, CPCB	Medium	• Monitored data is scarce and therefore how and where to undertake the action will be limited • Local area air quality improvement could be highly effective.
3	Area Source	Improve fuel used for domestic purposes	Moderate	State Govt., Central Govt and MoPNG	Medium	• LPG/PNG major domestic fuel, however kerosene is still a major source in low income group/ better stoves or change in fuel to LPG • Lack of finance to low income group, particularly in slums • It would alleviate large section of population with high indoor pollution of other sources leading to

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
						lower disease burden and better quality of life
		Bakeries /crematoria	High Local grid based PM can be reduced.	MCD, DPCC	Medium	• Electric/LPG source based bakeries needing changes in design • Awareness to bakeries that the quality can still be maintained with electric or LPG ovens. • Many crematoria have electric system, but need to convert all the other into electric system • Similarly, despite electric crematoria being available, people prefer using wood based pyres • Reduction in PM as well as odour will take place and is likely to improve the local air quality
		Biomass/trash burning, landfill waste burning	Moderate (Local area can have substantial reduction in PM. Very high effectiveness to adjoining grids)	MCD, DPCC	Medium	• Better control on collection and disposal at the respective sites. Landfill waste burning needs proper technology driven site management • Awareness and local control. Apathy to take urgent action. No burning day vow to be taken by BMC • High level improvement in local area ambient air quality not only for PM but other pollutants
		Resuspension	Moderate	MCD, DPCC	Medium	• Vehicle movement related

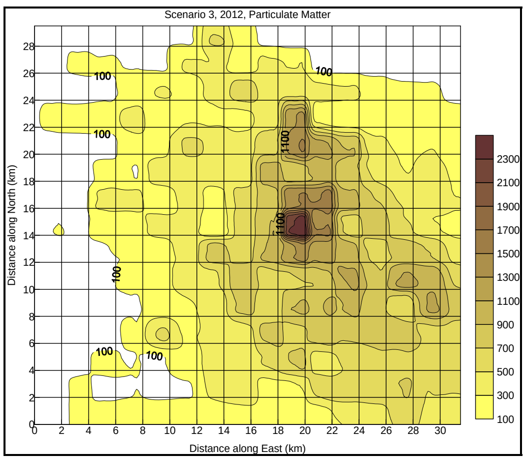
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
			(Highly effective for kerb-side air quality)			resuspension can be reduced by having better paved roads, regular sweeping and spray of water. • Norms for road construction to be framed and implemented • Roadside as well population within the distance of about 200-300 m from the road will have low exposure of PM leading to better sense of well being
		Illegal SSI	Moderate (Local area improvement can be moderately good)	MCD, DPCC, DIC	Medium	• Level of problem not well known. Need to understand what are the levels of operation and their contribution in each of the grids in the city • Need for strict rules of such units and identification by DPCC/DIC and MCD • It will lead to large scale reduction of fire accidents as well as minimization of wastewater problem
		Construction	Moderate (Large scale improvement in local area is expected.)	MCD, DPCC, Builders Association	Short Term	• Construction activities which involve demolition, digging, construction, vehicle movement etc. • Emphasis on better construction practices and management plan for air emission and its control by the implementing agencies

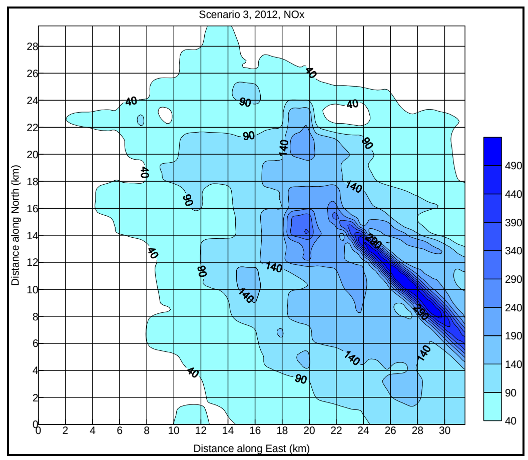
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
						• Spillage on road and further re-suspension of dust can be minimized





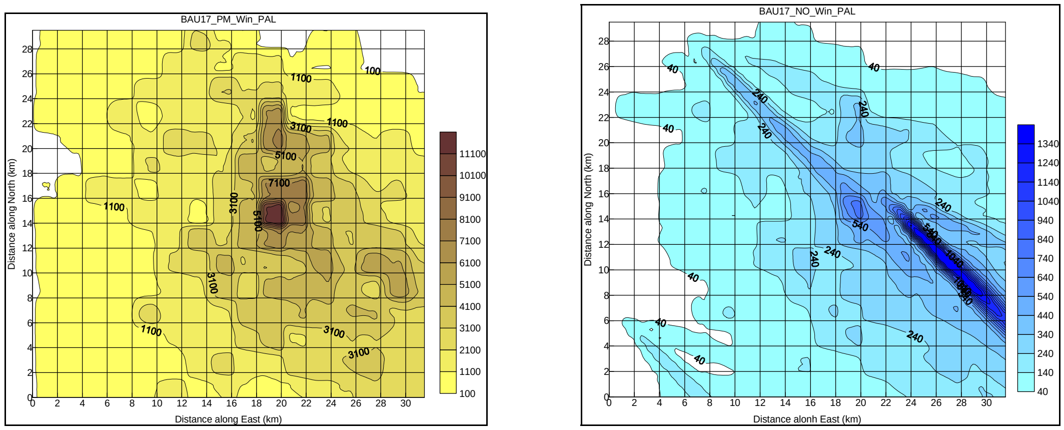
Isopleths for 24-hourly avg. PM_{10} and NOx concentration ($\mu g/m^3$) respectively for Post Monsoon: 2012 BAU



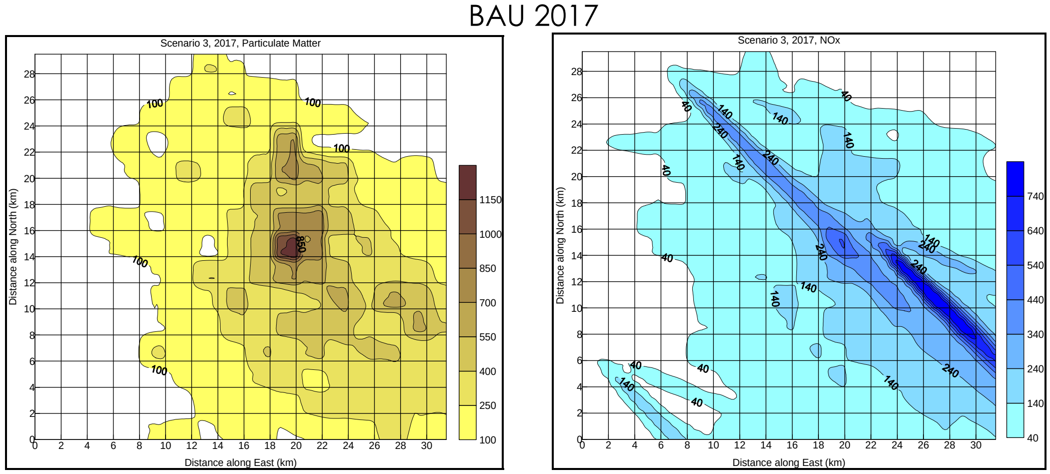


Isopleths for 24-hourly avg. PM_{10} and NOx concentration ($\mu g/m^3$) for respectively Post Monsoon:
Control Scenario 2012

Figure 7.5: Air Quality Profiles for BAU 2012 and with Implementation of Action Plan in Delhi



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3)
respectively for Post Monsoon:
BAU 2017



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3) for
respectively Post Monsoon:
Control Scenario 2017

Figure 7.6: Air Quality Profiles for BAU 2017, and with Implementation of Action Plan in Delhi

Kanpur:

Some 24 control options were considered and evaluated for their impact in terms of emission reduction and air quality improvements for PM_{10} and NOx using ISCST3 modeling. Table 3 presents ten most promising options those showed the significant average air quality improvements in all critical grids. Further, scenarios were developed as a combination of various control options to examine as to which control options, if implemented as a group, will give the best improvements in air quality.

If no action is taken to reduce PM_{10} and NOx emissions, in 2012, entire city will totter under high air pollution when standards for PM_{10} will exceed over the entire city with very high concentration of over 500 μg/m^3 (max 24-hour) in 16 km^2 area. If no action is taken up to 2017 and city will have unbridled growth, not only the entire city will exceed the air quality standards, nearly 50 km^2 (nearly 1 /5th of city) areas may have air quality much above 500 μg/m^3 (max 24- hour) for PM_{10}. NOx standard will be met in the year 2012 with control options however about 1/5th of the area will still exceed air quality standard for NOx.

It is recommended that the following control options, found most effective in improving the air quality, must be implemented in a progressive manner: (i) Implementation of BS – VI norms; (ii) CNG/LPG for commercial Vehicles; (iii) Banning of 15 year old private vehicles; (iv) Particulate control systems in industry; (v) Domestic-Use of Natural Gas/LPG; (vi) Converting unpaved roads to paved roads; (vii) Sweeping and watering (mechanized); and (ix) Strict compliance to ban of open burning.

By implementing the above options, air quality will improve dramatically but will fall short of achieving 24-hour air quality standards for PM_{10} in 1/4 the part of the city and by the year 2017, almost 2/3 area will still be below the desired air quality; this represents worst case scenario by considering that standard should be attained on each day. It is necessary that emissions in certain grids (area) should reduce to 40 percent of controlled emission of 2012 and 2017 (as recommended above). This will require additional efforts to reduce the emission. Vehicles, road dust and domestic cooking are the important sources both in 2012 and 2017. It may be noted that that if vehicular pollution is reduced further by 50 percent which can best be done by restricting entry of vehicles in critical areas by 50 percent of projected number of vehicles (e.g. by allowing odd number of vehicles the first day and the next day even number and the repeating the cycle). This needs to be done during winter months (November to January) only. The reduction in vehicles will also reduce the road dust by 50 percent. In addition, there should be a total ban on any refuse or garbage burning from 2012.

The decision to restrict the public transport can put the general public to inconvenience. It is emphasized that a network of public transport in terms of metro or elevated railway needs to be planned. Further, construction of flyovers at all railway intersections (15 Nos.) will help in about 20 percent time saving that will result in 20 percent lowering of vehicular emissions and corresponding improvements in air quality. The overall action plan that will ensure compliance with air quality standards both for PM_{10} and NOx is presented in Table 7.8. The resultant air quality is given in Figures 7. 7 – 7.8.

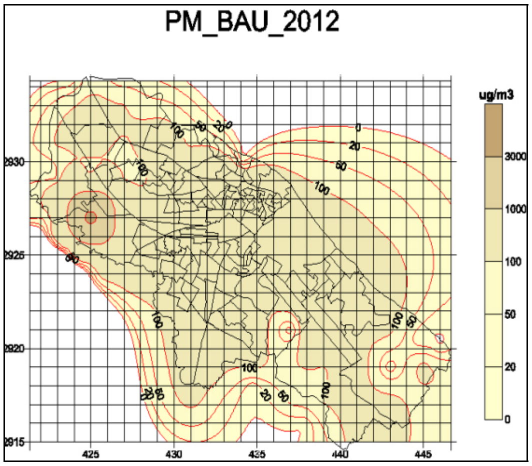
Table 7.8: Action Plan for Kanpur

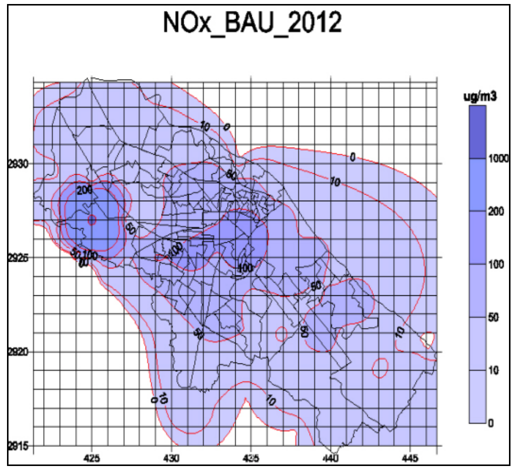
S. No	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
1	Transport	Strengthening of Public transport system • Metro implementation on schedule • Enhance share of public mass transport system • Conversion of public transport to CNG	High	Govt of India, State Government, KMC (Kanpur Municipal Corporation0 and KDA (Kanpur Development Authority), GAIL	Medium term	The metro network is being expanded. On Jan 2009, GOI approved plans for two phase expansion, with first phase expected to complete by 2014-15. Kanpur does not have a CNG network and has a limited LPG network. There are plans to set up CNG network in future, but no timeframe is available. ULSD would also be available by April 2010 in Chennai. Retro-fitted 2-stroke three wheelers on LPG have higher PM emissions compared to OE 2-stroke/ 4-stroke LPG/Petrol. Thus retro-fitment of 2-stroke 3-wheelers is not an effective control option.
		Ban on old commercial vehicles (10 year) and private vehicles (15 years) in the city	High	Transport department - Kanpur	Short-term	Fiscal incentives/ subsidies for new vehicle buyers A plan should be devised for gradual phase out with due advance notice. Careful evaluation of socio-economic impact of banning required.
		Progressive improvement of vehicular emissions norms (BS-V, BS-VI)	High	MoRTH, MoPNG, Ministry of Heavy Industry and Public Enterprises, MoEF, Oil companies, Automobile manufacturers	Medium to Long term	Auto-fuel road map should be developed well in advance to plan the progressive improvement of emissions norms and corresponding fuel quality

S. No	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
						norms. Though the impact is low, its potential is high in the long term when gradually fleet renewal takes place.
		Installation of pollution control devices (DOC/DPF) in all pre-2010 diesel vehicles	Low	Transport department	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction. Retro-fitment of DOC in BS-II buses and DPF in BS-III buses is technically feasible.
		Effective Inspection and maintenance regime for vehicles	Medium	Transport Department, Traffic police	Short to Medium	Initial focus could be on commercial vehicles; Capacity development in terms of infrastructure for fully computerized testing/certification and training of personnel. Linkage of all PUC centers for better data capture.
		Improve traffic flow	Low	Traffic police, KMC and KDA	Short	Synchronization of signals, one way roads, flyovers, widening of roads, removal of encroachments, staggering of office timings to reduce peak flow and congestion. Application of IT tools for traffic management (Intelligent transport system)
2	Road dust	• Construction of better quality roads • Regular maintenance and cleaning/sweeping of roads • Reduction in vehicular fleet and trips	High	KMC, KDA, NHAI	Short - Medium term	Effective enforcement of road quality norms is required. Landscaping/ greening of areas adjacent to roads

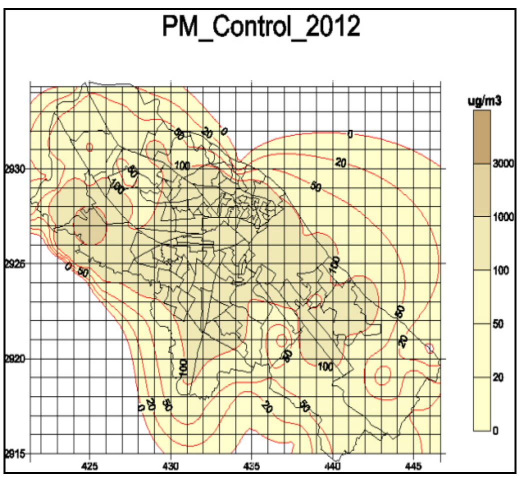
S. No	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
		Wall to wall paving for reduction of road dust	High	KMC, KDA	Short term	Interlocking tiles may be used so that water percolation takes place.
3	Industries	Fuel shift towards cleaner fuels	Low	UP PCB, Directorate of Industries and Commerce, Industry associations, GAIL, Oil companies	Short-Medium term	Shift from solid fuels to liquid fuels (LSHS) and subsequently to gaseous fuels (CNG). Local pollution load will decrease significantly. However, impact on overall level in the city will be low
		Ban on any new air polluting industry in city limits	Low	UP PCB, Department of Forest, Ecology and Environment, Department of Industries and Commerce, UP Industrial Development Corporation	Short term	Real estate prices will inhibit growth of new large scale industry within city limits and hence the impact is low. Industrial estates/zones may be developed well outside the city
		Strengthening of enforcement mechanism for pollution control	Low	UPPCB, Industry associations,	Short term	This would ensure greater compliance with standards. In addition, cleaner technology options need to be promoted and appropriate incentives to be defined. Voluntary measures such as ISO certifications to be encouraged.
4	Power/ DG sets	No power cuts leading to zero usage of DG sets	Medium	UPSEB (UP State Electricity Board)	Medium term	Adequate tie-ups need to be ensured
		Installation of pollution control devices (DOC/DPF) in DG sets	Medium	UPPCB, DG set manufacturers	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction
		Effective Inspection and maintenance regime for large DG sets	Medium	UP PCB	Short to Medium	
5	Construction	Strict enforcement of construction guidelines	Low	UPPCB, KMC, KDA	Short term	Pollution load due to construction is limited to short

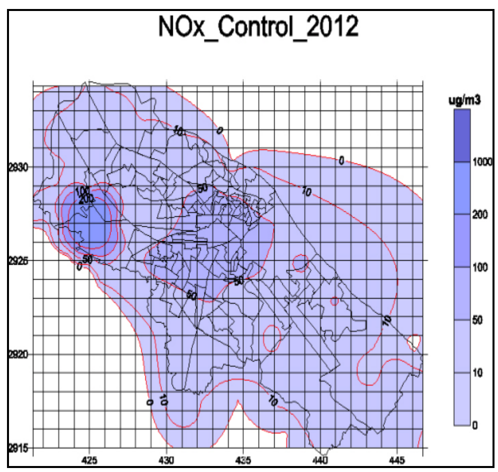
S. No	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
		(which should reflect Green Building concepts)				time and small locality.
6	Other sectors	Integrated land-use development of Chennai taking environmental factors into consideration	Low	KMC and KDA	Medium term	Holistic development of the entire region including peripheral areas.
		Open burning/ Waste burning to be discouraged	Low	KMC, UPPCB	Short term	Sorting solid waste is important. Organic matter could be used for compost formation and methane gas generation
		Strengthening of air quality monitoring mechanism in terms of number of stations as well as pollutants monitored. Capacity building of TNPCB staff.	Low	CPCB, UPPCB	Short	Good quality data is an important input in assessing the change in air quality and the impact of policy interventions. Continuous monitoring stations to be promoted.
		Environmental education and awareness activities	Medium	Education department, Schools/Colleges, CBOs, NGOs	Medium/ Long Term	Sensitization programmes for policy makers.





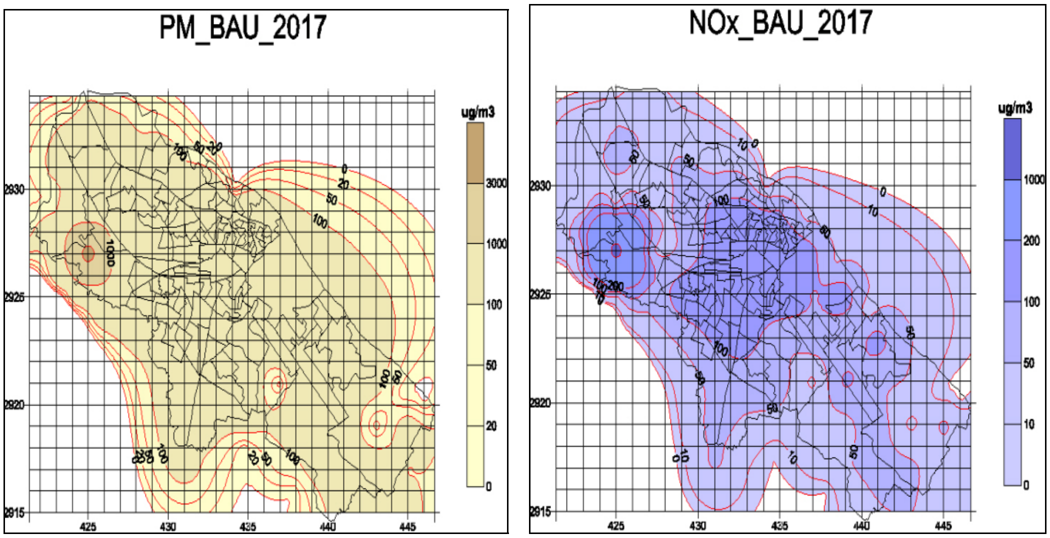
Isopleths for 24-hourly avg. PM_{10} and NOx concentration (μg/m^3) respectively for winter: 2012 BAU



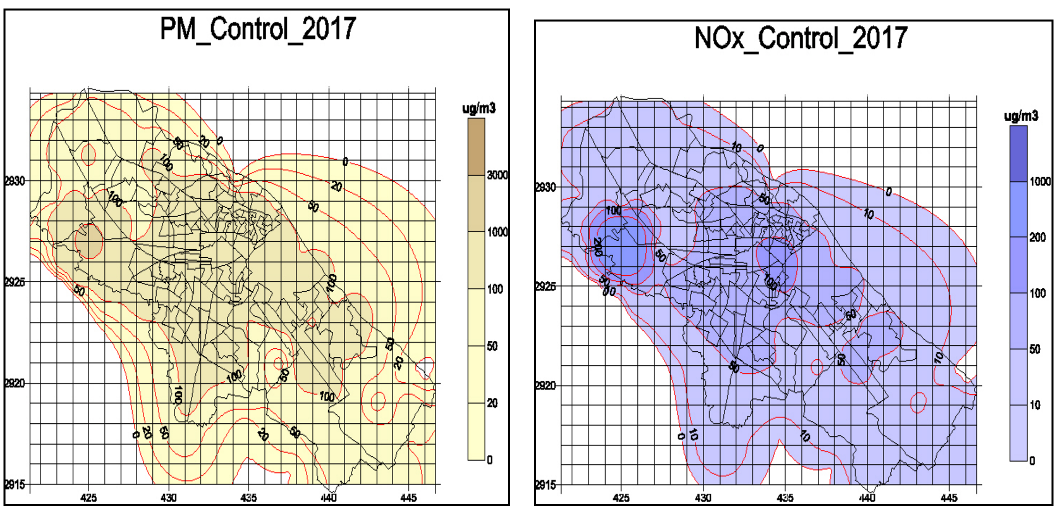


Isopleths for 24-hourly avg. PM_{10} and NOx concentration (μg/m^3) for respectively winter: Control Scenario 2012

Figure 7.7: Air Quality Profiles for BAU 2012, and with Implementation of Action Plan in Kanpur



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (μg/m^3) respectively for winter: 2017 BAU



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (μg/m^3) for winter: Control Scenario 2017

Figure 7.8: Air Quality Profiles for BAU 2017 and with Implementation of Action Plan in Kanpur

Mumbai:

Management options for each sector need to be prioritized with a view to understand the issue of implementation. Implementations are highly influenced not only by the idea of the improvement alone but also by the nature of the recommendations, fiscal and administrative barriers, effectiveness, implementing agencies and acceptance from large group of stakeholders. The Prioritization also takes into account the earlier recommendations made by Lal Committee under the order of Hon'ble High Court, Mumbai, 2000. Many of the recommendations have been implemented; however few which are still relevant and applicable in current scenario have been included in the recommendations made for control options. Prioritization issues are also driven by the comparative account of short term and long term implementation dilemma. Low cost with high effectiveness and low cost with shorter implementation period shall be a better option, when compared with high effectiveness with high costs or long implementation period. Though some of the options were selected on the basis of PM reduction potential, their possible co-benefits in reducing NOx and other pollutants were also considered during the process of prioritizing. The prioritized control options are based on high effectiveness in pollution load reduction leading to improvement in ambient air quality.

The predicted ground level concentrations show improvement all across the city. Results shown for the seven sampling locations indicate that though NOx levels would be met most of the time, PM levels will exceed at many locations, except at Mahul and Mulund. The levels would become highly un-acceptable with regard to the PM and NOx especially if no control scenario continues till 2012 and 2017.

The suggested Action Plan is given in Table 7.9 and expected air quality is given in Figures 7.9 – 7.10.

Table 7.9: Action Plan for Mumbai

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
1	Transport	S reduction in diesel	Medium (Reduction in S leads to 2.5–13 % reduction in PM)	Oil companies, Ministry of Petroleum, Vehicle manufacturer	Medium	• Improvement in emission standards as well as legislation for stringent fuel standards for S, • Phasing out the subsidies on diesel. bringing diesel cost at par in a state/centre • The S reduction will not only reduce the PM but also lead to correspondingly lower SO_2 emission leading to lower ambient SO_2 and sulphate •
		Reduce fuel adulteration	Low (Reduced adulteration will lead to reduced PM (difficult to quantify). Effectiveness is moderate as marker system has not been seen as a primary means to reduce PM)	Anti-Adulteration cell, Oil Companies, Vehicle owners	Medium	• One of biggest advantage of non-adulteration shall be longer engine life besides the emission reduction for PM as well as CO and HC. The catalytic converter shall be active for its entire lifetime. • Better quality fuel by adopting stricter fuel supply and dispensing system (e.g. Pure for Sure etc.) • Chemical marker system • Finer fuel specifications are needed for implementation. • Present system of Anti Adulteration cell function needs major improvement in terms of higher manpower and spread.
		Alternative fuels				• Will lead to substantial reduction in

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
		-- Technical infrastructure in Mumbai for dispensing CNG/LPG is fairly good and is improving * Biofuels can be used upto 5-10% without any major technical issue.	-- High, more than 90 % reduction in PM can be achieved compared to diesel # * High Similar to diesel , low SO_2 and low PM	--Local Government Mahanagar Gas, Oil Companies marketing LPG, * Ministry of Petroleum	--Medium * Medium	CO and HC emission, however, NOx values may go up • Can be applicable mainly for vehicles, which are supposed to ply within the city. • Applicable to only local public transport, taxies etc. - Similar to diesel but low SO_2 and low PM - Can be easily implemented
		Phase out of grossly polluting vehicles	High (No major technical problem)	Ministry of Road Transport and Highway Transport Commissioner office,	Medium	• High, Estimate suggest 25% of these vehicle may contribute 75% of total emission $ • Poor Inspection system both for emission as well as vehicle. • Need for improved inspection certification system, better testing facility. • New legislation may require changes in Motor Vehicles Act • Better compliance will lead to reduction of other pollutants as well. It will also lead to less pressure on complying vehicles
		Congestion reduction	- High (Improvement of roads, new roads, scientifically	State Govt, BMC, MMRDA, Transport police, other utilities.	Medium	• High emission due to fuel burning at idle or slow moving traffic • Road quality improvement is a matter of technology and quality of work carried out.

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
			planned traffic management)			• Concretization of road may be the solution. New road planning and Traffic management are being taken as integral part of the MUTP. • It will reduce traffic junction hotspot of all the pollutants • It will also reduce continuous source of dust
		Standards for new and In-use vehicles	- Medium (Marginal improvement from newer vehicles except when implementation is for Euro V & VI. In-use vehicles emission reduction can be substantial)	Transport Office Govt. Maharashtra MoRTH,	Medium	• No technical issue with new vehicles. • For inuse old vehicles, technical feasibility needs to be established • The process of in-use vehicles standards may take time as they need to be revised at central level. • Inadequate infrastructure and manpower at local levels could be other major barriers. • After the legislation is in place, provision of strict penalty leading to cancellation of vehicle registration. • As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types
		Introduction of new technology vehicles	High (Moderate with respect to in use vehicles)	Transport Office Govt. Maharashtra, MNRE MoRTH,	Medium	• New technology based vehicles emit less per unit distance travelled Electric vehicles • Emphasis to allow only a type of technology to be permitted may meet with resistance from manufacturer as well as buyer. (e.g.

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
						rule to allow only 4 stroke vehicle to be registered) • Proper legislation else charge higher registration fee or subject them to carry out more frequent I&C test. Electric vehicles for grossly polluting high VKT vehicles are a good option. It needs regulatory push • It will lead to better compliance from on-road emission test and overall improvement in emission of all the pollutants. Electric vehicles provide localized benefits of no air pollution
		Retrofitment of new engine/ Emission control device	High (Engine replacement could lead to major reduction of PM. Emission control devices available (DPF, DOC) can remove PM upto 90%)	Transport Office Govt. Maharashtra, vehicle manufacturer, vehicle fleet owners Short time frame, high levels of compliance expected for all the in-use older vehicles.	Medium	• Experience of other countries suggests that it can be feasible. However, in Indian scenario, a pilot retrofit programme to evaluate the efficacy needs to be undertaken. A small pilot project is on in Pune with USEPA, USTDA and NEERI • Availability of new engines for retrofit. Vehicle manufacturers need to come forward. • Presently no legislation. Need to frame one including a mechanism by which the system can be evaluated by an appropriate agency.
		Higher usage of Public Transport	High (Effectiveness is	BMC, MMRDA, MSRDC,	Medium	• Dedicated bus lane, better buses, low cost of travel, faster travel etc.

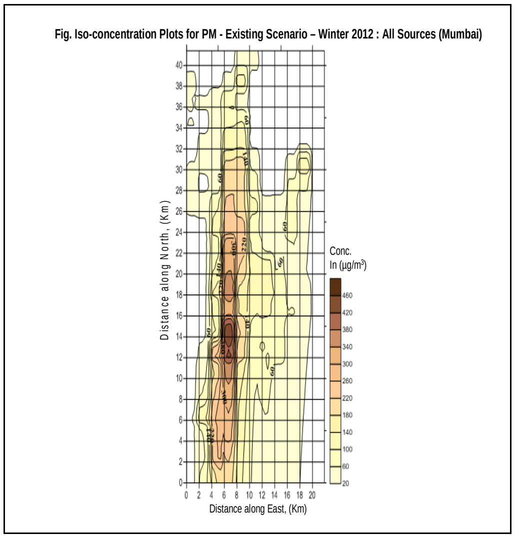
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
			high as less and less road space will be occupied by private vehicles, faster movement of public transport in comfort shall lead to low emissions)	BEST,		• Feasibility to be established for bus lane. Finances for better buses • Local level planning in coordination with all the authorities involved in MUTP. • Future growth of the city will entirely depend upon the levels of public transport availability. Cheaper and faster mode of public transport will lead to higher per capita efficiency.
		Decrease Private vehicles on Road	Low	Private vehicles owners should must own their own garages, less parking on the roads, less congestion BMC, MMRDA, RTO,	Medium	• Awareness matched with better public transport. • Higher parking charges, high registration fees, higher car user charges, sale linked with parking availability • Less private vehicles on road, high road space utilization
		Training and Awareness programme for car owners, public transport operators, drivers and mechanics	Medium (May lead to 5-10% reduction of emission).	Savings by way of improved vehicle maintenance and operation MMRDA, Transport Department, Other institutions involved in awareness campaign	Short Term	• On use of alternative fuel, Inspection and certification, adulteration of fuels, use of public transport, less usage of private vehicles • Resources for awareness and training, bringing the different groups together • Structure for such programme should be developed and integrated into legislation.
2	Industry	S reduction in fuel	Moderate (Many industries in Mumbai region	MPCB, Industries	Medium	• This process is currently on, however, the fuel S reduction is mainly for vehicular sector

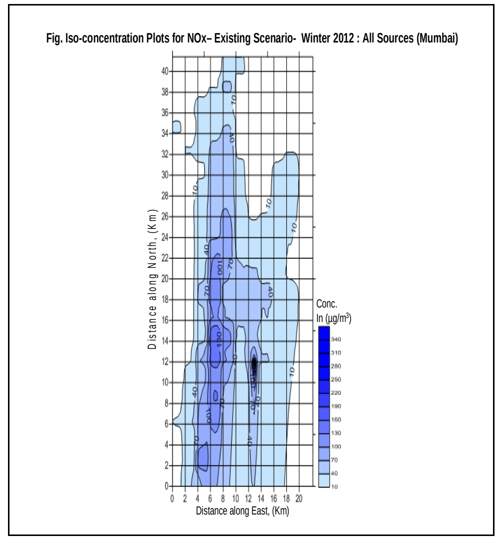
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
			use coal, HSD, LSHS, and FO)			• As the industrial growth is negative in Mumbai, the need of S reduction in conventional fuel is not being pressed upon • S levels in fuel have been very strictly controlled for Tata Power. An example of this can be extended to other industries
		Combustion Processes	Moderate	MPCB	Medium	• It will lead to lower emission of CO and HC • Change in combustion technology will be needed for shifting from coal/oil to natural gas • Finances to change the process technology
		Alternate Fuel	High Use of cleaner fuel has already resulted in better air quality in the city	Mahanagar Gas, MPCB	Medium	• Large no of industries are using NG and LPG • More allocation of NG/LPG to the industrial sector through MGL/GAIL/ Govt. of India • Better air quality in terms of SO_2, CO and HC will be achieved.
		Promoting Cleaner Industries	High Large scale shift shall result in major PM reduction	MPCB, BCCI, CII, MoEF, CPCB	Medium	• Use of cleaner production processes • Finances to carry out these changes • It will lead to sustainable existence of industries within the city. Also lead to other pollutants reduction
		Location Specific emission Reduction	High	GoM, MPCB, GoI, CPCB	Medium	• Specification of site specific emission standards • Higher allocation of NG/LNG at

S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
						lower cost is needed • High level emission shall have lower PM and other gaseous pollutants
		Fugitive Emission control	Moderate	MPCB, Industries, CPCB	Medium	• Industrial process improvement better operation and maintenance • Monitored data is scarce and therefore how and where to undertake the action will be limited • MPCB can work on the standards for fugitive emission and develop compliance system • Local area air quality improvement could be highly effective.
3	Area Source	Improve fuel used for domestic purposes	Moderate	State Govt., Central Govt MoPNG	Medium	• LPG/PNG major domestic fuel, however kerosene is still a major source in low income group/ better stoves or change in fuel to LPG • Lack of finance to low income group, particularly in slums • It would alleviate large section of population with high indoor pollution of other sources leading to lower disease burden and better quality of life
		Bakeries /crematoria	High (Local grid based PM can be reduced)	MMRDA, BMC and MPCB	Short Term to Long Term	• Electric/LPG source based bakeries needing changes in design. • Many crematoria have electric system, but need to convert all the other into electric system • Awareness to bakeries that the quality can still be maintained with electric or LPG ovens. Similarly,

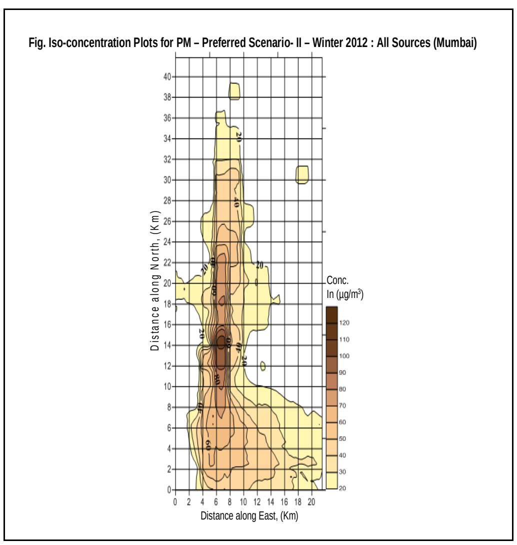
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
						despite electric crematoria being available, people prefer using wood based pyres • Reduction in PM as well as odour will take place and is likely to improve the local air quality
		Biomass/trash burning, landfill waste burning	High (Local area can have substantial reduction in PM. Very high effectiveness to adjoining grids)	BMC, MMRDA MPCB	Medium	• Better control on collection and disposal at the respective sites. Landfill waste burning needs proper technology driven site management • Awareness and local control. • MPCB needs to address this issues • High level improvement in local area ambient air quality not only for PM but other pollutants
		Resuspension	Moderate (Highly effective for kerb-side air quality)	BMC, MMRDA	Long Term	• Vehicle movement related resuspension can be reduced by having better paved roads, regular sweeping and spray of water. • Awareness and will to implement • Norms for road construction to be framed and implemented • Roadside as well population within the distance of about 200-300 m from the road will have low exposure of PM leading to better sense of well being
		Illegal SSI	High (Local area improvement can be moderately	MPCB, BMC, DIC	Medium	• Level of problem not well known. Need to understand what are the levels of operation and their contribution in each of the grids in the city

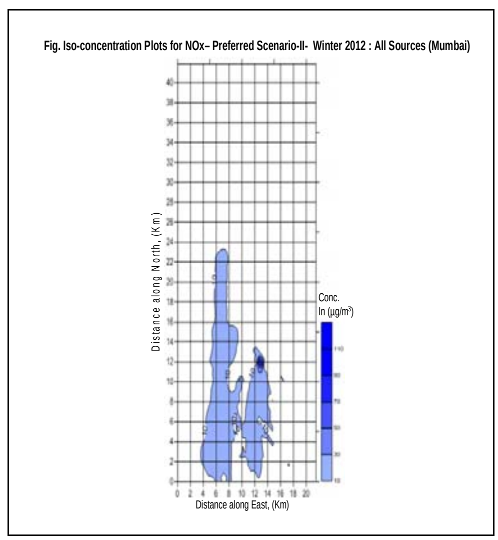
S. No.	Sector	Strategy	Impact	Responsible Agency/ Agencies	Time Frame	Remarks
			good)			• Poor rules and guidelines of such units and it will lead to large scale reduction of fire accidents as well as minimization of wastewater problem
		Construction	Moderate Large scale improvement in local area is expected.	BMC, MMRDA, Builders Association	Short Term	• Construction activities which involve demolition, digging, construction, vehicle movement etc. need information on how to minimize the dust • Use best construction practices • Spillage on road and further re-suspension of dust can be minimized
		Railways Emissions	Moderate Low, as the extent of problem is not in large areas.	CR, WR, MRVC	Medium	• All trains are being change to electric. Limited use of diesel locomotive. Resuspension due to train can be minimize by platform cleaning. • Awareness to railways • Practices and norms to be framed • Exposure to population will reduce





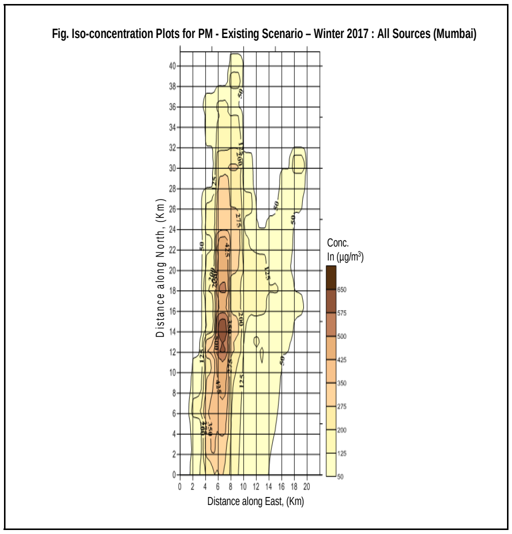
Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3) respectively for winter: 2012 BAU

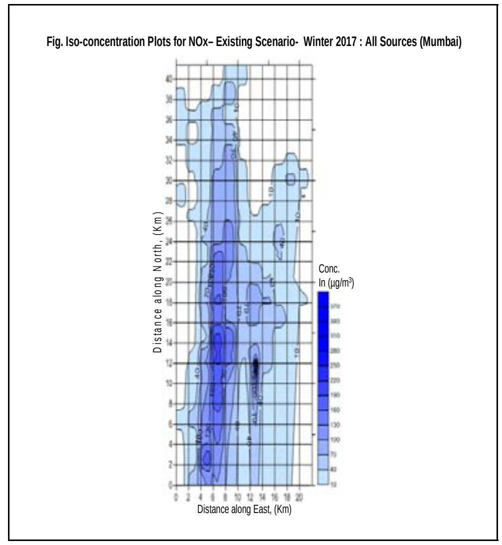




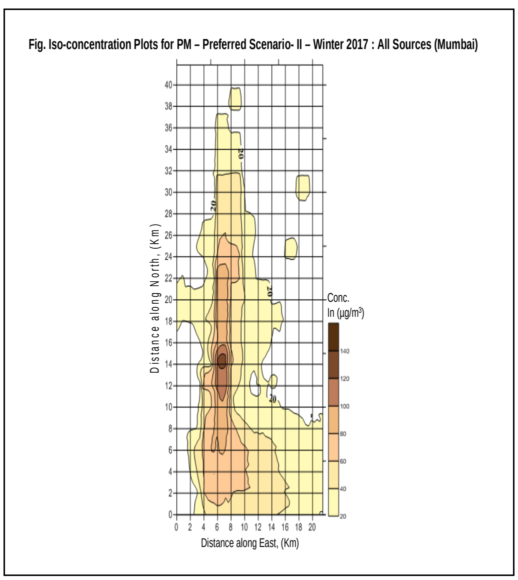
Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3) respectively for winter: Control Scenario 2012

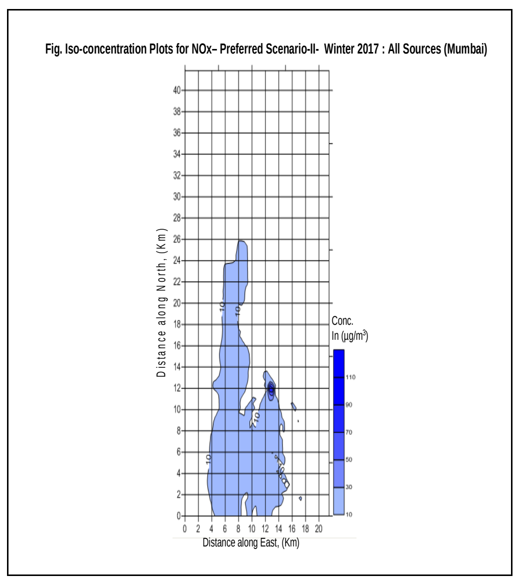
Figure 7.9: Air Quality Profiles for BAU 2012, and with Implementation of Action Plan in Mumbai





Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m³) respectively for winter: 2017 BAU





Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m³) respectively for winter:
Control Scenario 2017

Figure 7.10: Air Quality Profiles for BAU 2017 and with Implementation of Action Plan in Mumbai

Pune:

Based on the evaluation of the impact of various individual control options and their feasibility in implementation for both management and technology based options, a list of control options considered is prepared for generating controlled scenarios. Percent reduction in PM_{10} and NOx concentration levels with respect to BAU scenario, were worked out using ISCST3 dispersion modeling. The top10 grids were found to be present at the central part of Pune where population and road densities are higher.

In case of PM_{10} control scenario, the ambient concentrations were found to be reduced by 30- 50% in the year 2012 and 2017 with respect to BAU scenario in that year. Similarly, NOx concentrations were found to be reduced by 40-50% in top 10 grids with respect to BAU scenario.

As the major source of PM_{10} was found to be re-suspended road dust from paved roads (48%), benefits for PM_{10} control options could be higher if only the silt-loading of the road is reduced i. e. if the road quality itself is improved. It is, therefore, evident that, road conditions need to be improved. With the reduction in silt loading factor by 50% of the existing value, total PM_{10} reduction benefit of about 35% can be achieved. However, silt loading improvements will depend upon the methods used for road quality improvement and subsequent reduction in silt loading. Though Mechanized sweeping and watering shows higher benefits, the implementation is difficult. Wall to wall pavement can yield around 10% and 16 % benefits if implemented on all major roads and all major and minor roads respectively. Therefore, road infrastructure needs to be set up and maintained as per national/inter-national standards. Guidelines should be made available for the quality of the roads based on traffic patterns.

In Pune, public transportation system is inadequate and not in pace with the transportation requirement. This also increases the use of personalized vehicles which intern contributes to road dust as well as vehicle tail pipe emissions. Effective Mass transport system must be established to reduce the rising tendency of owning personal vehicles. In Pune, the average occupancy of 2 Wheelers is 1 and for cars around 1.3. The 10% & 20% shift of 2W & cars to public transport in 2012 & 2017 respectively, gives benefit of upto 3 % for PM_{10} & NOx. However, the reduction in VKT also reduces the road dust by 3.5 % and 12% respectively for year 2012 &2017.

Progressive tightening of emission norms must be implemented and vehicle emission regulation road map should be ready for next 10 years, which need to be updated on continuous basis. Progressive tightening of emission regulations since 1991 to BS-III regulations for 2& 3 wheelers and BS-IV regulations for all other categories of vehicles (in line EURO-IV) scheduled to be implemented in 2010; have given an edge, by curbing the emission to some extent, over the multifold growth of cities and Mega cities of India and in turn the increase in number of vehicles. The cities like Pune have been showing the growth of vehicles around 10% continuously for more than last 10 years.

Continuous power supply must be ensured to avoid use of non-industrial generators, as it has remarkable benefits in terms of emission reduction. Reduction in use of non-industrial generators by ensuring continuous power supply can give benefits as reduction in PM and NOx emissions by 6% and 83% respectively in year 2012 and by 6% and 83% respectively in year 2017.

Banning of 10 years old commercial vehicles yields highest benefits in terms of emission reduction. However, the socio economic impacts of banning of older vehicles need to be evaluated. Entry of these vehicles in the city area must be restricted as an immediate measure to curb major portion of vehicle pollution. Higher NOx reduction benefits, 45% and 56% for year 2012 and 2017 respectively, are observed mainly due to banning of old vehicles. Table 7.10 provides list of control options required for improving air quality in Pune. Expected benefits, in terms of predicted air quality, are given in Figures 7.11 – 12.

Table 7.10: Action Plan for Pune

Technology based control options for line sources

Control Option Considered	Scenario 2012	Scenario 2017	Remarks
Implementation of BS – V norms	Same as BAU. BS-III for 2-3 W, BS-IV for rest all from 2010 onwards.	BS-III for 2-3 W, BS-IV for rest all from 2010 to 2015	Progressive tightening of emission regulations for new vehicles

	--	BS-IV for 2-3 W, BS-V for rest all from 2015	
Electric / Hybrid Vehicles	Share of Electric vehicles in total city fleet – Two wheeler: 1%, Auto-Rickshaw and Taxi: 5%, Public buses: 5%	Share of Electric vehicles in total city fleet – Two wheeler: 2%, Auto-Rickshaw and Taxi:10%, Public buses: 10%	Though electric / hybrid vehicles are very effective in city pollution curbing, the infrastructure and initial cost may limit the penetration.
OE-CNG for new Public transport buses	47.5% fleet	90% of fleet	Retro fitment has may issues like effectiveness and durability along with safety related problems
Ethanol blending (E10 – 10% blend)	E-10 all petrol vehicles	E-10 all petrol vehicles	Considering proposed implementation in near future
Bio-diesel (B5/B10: 5 – 10% blend)	--	B-10 all diesel vehicles	Effective in vehicle PM reduction, but availability by 2012 is questionable.
Retro-fitment of Diesel Oxidation Catalyst (DOC) in 4-wheeler public transport (BS–II and BS-III)	BS-II & III buses retro-fitment - 20%	BS-II & III buses retro-fitment 50%	Feasibility and effectiveness along with durability issues, will limit the penetration.
Retro-fitment of Diesel Particulate Filter in 4-wheeler public transport(BS – III city buses)	BS-III buses retro- 10%	BS-III buses retro-20%	Feasibility, effectiveness, regeneration and durability issues will limit the penetration.

Management based control options for line sources

Control Option Considered	Scenario 2012	Scenario 2017	Remarks
Banning of 10 year old commercial vehicles	100% compliance –pre 2002 3W, GC, buses and trucks	100% compliance – pre 2007 3W, GC, buses and trucks	Most effective control option.
Inspection/ maintenance to all BSII & BSIII commercial vehicles	50% compliance	100% compliance	I&M is the option for identifying and controlling emissions from high polluters.
Improvement of public transport: % share	10% shift in VKT	30% shift in VKT	Mass transportation like metro, etc. is feasible by next 10 years. % shift will

			depend upon the option considered and its capacity and connectivity.
Synchronization of traffic signals	All highways & major roads	All major & minor roads excluding feeder roads	Very effective and relatively simpler for implementation.
Restrict commercial vehicles entering city by having ring roads	50% Trucks & 20% LCVs -diversion	70% Trucks & 30% LCVs -diversion	Expected to have ring roads in place from 2012-2015.

Area source control options

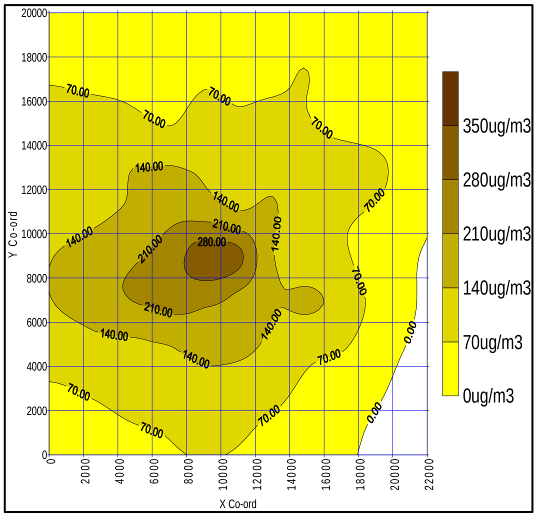
Control Option Considered	Scenario 2012	Scenario 2017
Shift to LPG from solid fuel &kerosene for domestic applications	50% compliance	100% compliance
Shift to LPG from solid fuel &kerosene for commercial applications (bakeries, open eat outs etc)	100% compliance	100% compliance
Better construction practices with PM reduction of 50%	50% compliance	100% compliance
Banning of operation of brick kilns in city area	100% compliance	100% compliance
Strict compliance of ban on open burning, including open eat outs	50% compliance	100% compliance
Reduction in DG set operation/ Un-interrupted power supply	50% reduction in power cut	100% reduction in power cut

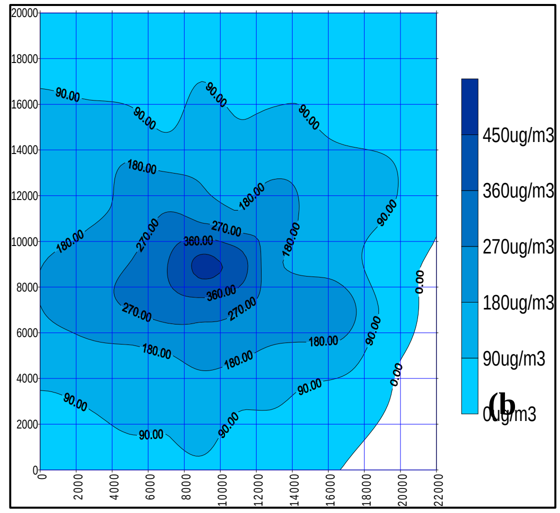
Control options for road dust

Control Option Considered	Scenario 2012	Scenario 2017
Wall to wall paving (brick)	All major roads	All major & minor roads excluding feeder roads

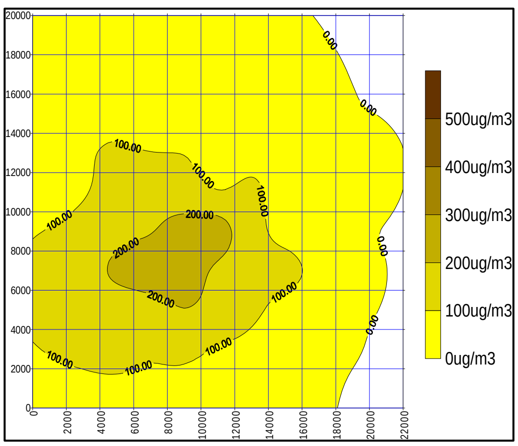
Point source control options

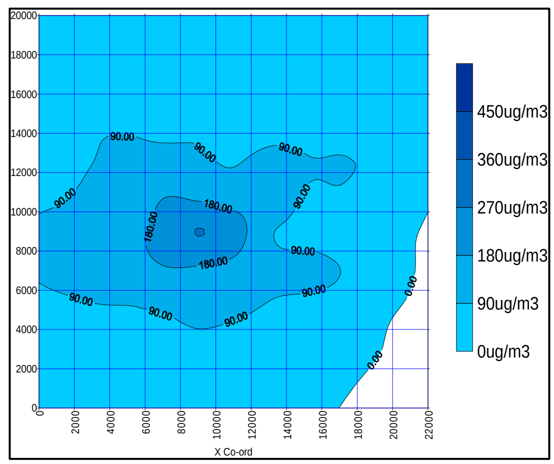
Control Option Considered	Scenario 2012	Scenario 2017
Banning of new industries in existing city limit	100% compliance	100% compliance





Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3) respectively for winter: 2012BAU

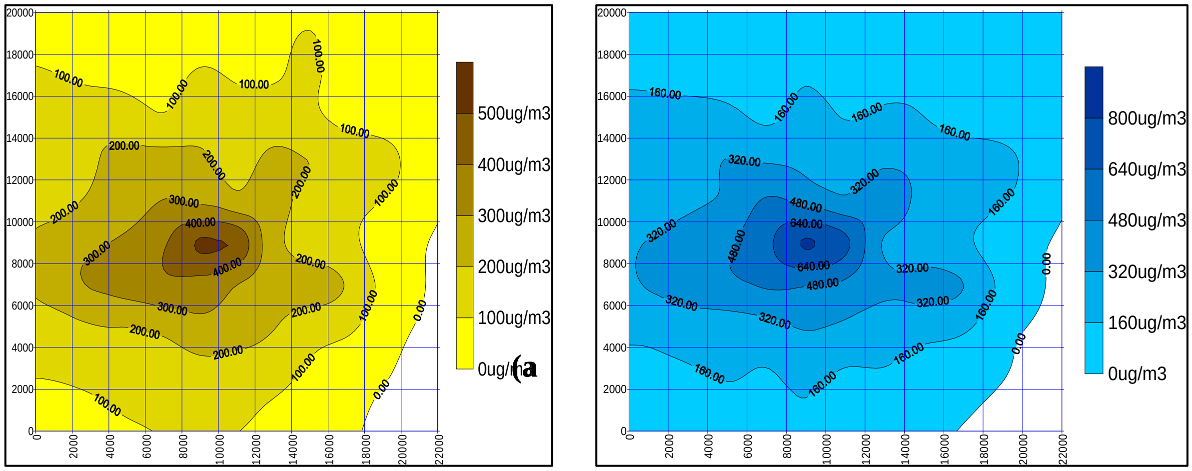




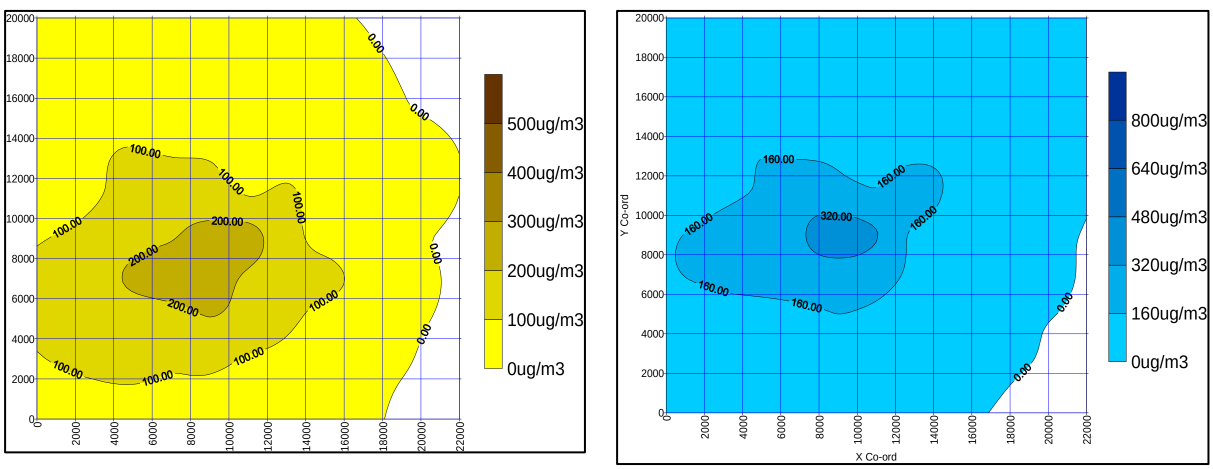
Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m^3) respectively for winter:

Control Scenario 2012

Figure 7.11: Air Quality Profiles for BAU 2012 and with Implementation of Action Plan in Pune



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m³) respectively for winter: 2017 BAU



Isopleths for 24-hourly avg. PM_{10} and NOx concentration (µg/m³) for winter: Control Scenario 2017

Figure 7.12: Air Quality Profiles for BAU 2017 and with Implementation of Action Plan in Pune

8

Conclusion

Based on the Source Apportionment Studies carried out in six cities, the following broad conclusions emerge, which provide guidance, with adequate scientific evidence, to plan strategies for improving air quality in urban areas:

1. Levels of PM_{10} and $PM_{2.5}$ in the ambient air are significantly high irrespective of the type of locations. Even background locations indicate presence of considerable levels of particulates, which could be occurring naturally and/or due to transport of finer dust from other settlements surrounding the cities. The concentrations of these pollutants are relatively higher at kerbside/roadside locations. While vehicles contribute significantly at all the locations, their contributions at kerbside locations are comparatively higher.

2. Winter and post monsoon seasons had been found most critical when standard exceedence rates are higher than in the summer months.

3. PM pollution problem is severe and NO_2 is the emerging pollutant. These two pollutants require immediate attention to control their emissions.

4. O_3 concentrations in all cities did not exceed the proposed hourly standard of 180 µg/m^3 at any of the locations, where sampling was done. However, in case of Mumbai and Pune, the peak hourly concentration observed is very close to 180 µg/m3 (90 ppb). Although higher ozone concentrations are expected around 1 – 3 pm, but it appears that good dilution and high speed winds (in afternoon) bring the concentration down. As such, O_3 does not seem to be of much concern. Similarly, CO levels may exceed marginally the hourly standard of 4000 µg/m^3 in at a few kerbside locations. In all cities, there are morning and evening peaks in CO levels corresponding to vehicular movement.

5. With regard to air toxics, Benzene levels are higher in Bangalore, Pune and Kanpur. The values of formaldehyde are also matter of concern in Mumbai, Pune and Bangalore.

6. High Elemental Carbon (EC) to Organic Carbon (OC) ratio (EC/OC) represents freshly contributed diesel/coal combustion particles biomass and garbage burning. Many cities have shown this ratio to be high at kerbside and industrial locations. EC and OC contribution to $PM_{2.5}$ is even more than what it is to PM_{10}; and have high (25 – 75%) values in all the cities. It signifies an important point that $PM_{2.5}$ has much higher component of toxic EC and OC that mostly come from combustion sources like vehicles and others.

7. Higher fraction of $PM_{2.5}$ in PM_{10}, and higher values of EC and OC (which have more severe health impacts) at kerbside locations indicate that control of vehicular exhaust would be an important element of any strategy or action plan for improving air quality and minimizing adverse effects on the health of people.

8. Elemental and ion analysis show abundance of soil constituents (e.g. Si, Fe, Ca, Na). This clearly suggests that there could be significant sources of particulate pollution from soil, and road dust. The soil related fraction drops down drastically (about 5% against 15 – 60% in PM_{10}) in $PM_{2.5}$. The re-suspension of road dust due to vehicular movements on paved/unpaved roads and construction activities, emerging as prominent sources, would largely be contributing to coarser fraction of PM_{10} and combustion sources including vehicles, DG sets, refuse burning, etc. would emit particles in the finer size (< $PM_{2.5}$). Hence, strategies for reduction of PM_{10} and $PM_{2.5}$ would involve different categories of sources.

9. There are significant quantities of SO_4^{2-} and NO_3^-, (10-15% in most cities and 20-30% in Kanpur) in PM_{10} indicating an important contribution of secondary particles. These contributions are even high at the background upwind direction in all cities. It signifies long-range transport of particles in the city as well as formation of secondary particles in the city. Any control strategy for reduction of particulate will have to consider control of SO_2, NO_2 and NH_3.

10. The presence of molecular markers like hopanes and steranes in much higher quantities compared to background location indicates that effect of vehicles is prevalent. Higher concentration of levoglucosan confirms contribution from biomass burning.

11. Within the transport sector, the PM_{10} contribution in terms of emission load is mainly from heavy duty diesel vehicles (40 – 59%) in almost all the cities. With regard to NO_x emissions, again heavy duty vehicles are major contributors (43 – 75%).

12. Though, there are city-specific variations among the dominance of sources, re-suspension of road dust and combustion sources including vehicles, refuse burning & DG sets; emerge as prominent sources in all the cities for PM.

13. Several epidemiological studies have linked PM_{10} and especially $PM_{2.5}$ with significant health problems. $PM_{2.5}$ is of specific concern because it contains a high proportion of toxins, and aerodynamically it can penetrate deeper into the lungs. Therefore, while planning control strategies greater emphasis is to be given on reduction of $PM_{2.5}$ and toxic constitutes of particulates.

14. An effective control strategy would require combination of engineering as well as non-engineering solutions. Prioritization of these solutions, in addition to their effectiveness, should also be driven by the comparative account of short and long term implementation dilemma. Low cost with high effectiveness and low cost with shorter implementation period shall be a better option, when compared with high effectiveness with high costs or long implementation period.

15. Based on the findings of the study, some of the important steps required for improving the air quality in urban areas are given below.

    (i) Better maintenance of roads, paving of unpaved roads, footpaths or low-elevation concreting of unpaved surfaces along major roads with high traffic. Use of fly ash bricks could be considered as an option for pavement that would also help in utilization of fly ash.

    (ii) Agencies responsible for road construction & maintenance (MoRTH, City Development Authority) should prepare guidelines for reducing silt load on roads.

    (iii) With regard to minimizing vehicular emissions, following actions are required:

- **Implementation of progressive norms:**

  - Progressive tightening of emission regulations since 1991 to BS-III regulations for 2& 3 wheelers and BS-IV regulations for all other categories of vehicles (in line EURO-IV) implemented in 2010; have given an edge over the multifold growth of cities and Mega cities of India and in turn the number of vehicles.

  - The implementation roadmap for emission regulations for all categories of vehicles in the short and medium run need to be prepared and has to be updated on the continuous basis.

  - Progressive tightening of emission regulations may be implemented. As a next stage universalization of BS IV norms throughout the country and subsequently introduction of BS – V regulations, taking into account environmental and economic factors may be considered.

  - New vehicles to be introduced in future also have to be compliant to the auto fuel norms that may be prescribed.

- **Road map for fuel quality improvement**

  - Since year 2000, differential norms are implemented in metros and rest of the country due to non-availability of uniform quality fuel across the country. Due to non-availability of appropriate quality fuel, the vehicles of advance technology registered in metros and major cities are deteriorating fast defeating the purpose.

  - BS-III regulations except for 2&3 wheelers are implemented in 12 cities of India since 2005. However, there will be vehicles plying in these cities which are not registered in these cities and such numbers are also high due to local tax structures. Similarly, BS-III fuel is available only in the city and not even 20-30km away from city boundary. Considering the circumferential growth of these cities, the number of city vehicles traveling out of the city boundary is much higher and tend to refuel the vehicles outside the city because of the lesser cost of the fuel. Thus not using the required fuel, particularly low sulfur content fuel, deteriorates the emission performance of these vehicles and in turn increases the in-use vehicle emissions.

- Ensuring nationwide same quality of fuel will definitely improve the conditions of in-use vehicle pollution noticeably due to the fact that the after-treatment devices and other newer technologies are very susceptible to the quality of fuel used. Very short distance exposure to low grade fuel quality may damage these devices permanently and thus making newer generation of in-use vehicles not effective or even worse than those of earlier generation vehicles due to the failures of emission control devices. With this background, it is desirable to have the policy of 'One country One fuel quality and One regulation'.

- Restricting entry of polluting trucks and heavy duty goods vehicles, and banning of old commercial vehicles in the cities.
- As old vehicles emit more, a comprehensive vehicle scarp policy needs to be evolved.
- In place of existing PUC scheme, mandatory periodical inspection and maintenance requirements may be considered. Authorized service stations may issue certificates, after servicing of the vehicles, with details of inspections/maintenance jobs carried out.
- Management options like synchronizing traffic signals, staggering business hours, restricting vehicular movements in certain areas with high pollution levels (particularly during peak hours and/or critical season), fiscal incentives/disincentives (e.g. increased parking fee, proper fuel pricing policy), banning odd/even vehicles on major roads, etc. may be considered.
- Development of mass rapid transportation system. This will reduce traffic congestion, smaller personalized VKT, and reduce soil and road dust re-suspension.
- Financial incentives on non-polluting vehicles like electric- hybrid will also increase the penetration of these vehicles in public as well as in personal vehicles category.

(iv) Certain highly polluting areas (hotspots) can be identified as low emission zone and very specific norms are applied including restrictions on certain activities.

(v) Guidelines to be prepared for better construction practices and strict compliance of the same is to be ensured.

(vi) Garbage/refuse burning should be strictly banned and efforts should be made to minimize biomass use for domestic purposes.

(vii) A time-bound action plan for reduction in use of biomass for cooking may be prepared.

(viii) Reduction in use of DG sets by ensuring adequate power supply, and have stricter norms for DG set emissions.

(ix) Use of cleaner fuels, stricter emission norms for industries located in and around the cities.

As multiple agencies are involved, a high power Inter-ministerial Committee may be set up to implement recommendations of the report. The Committee, considering various factors, may decide and monitor implementation plan.

9

Major Accomplishments

The source apportionment study with integrated approach has been a milestone work in air quality management in India. The study of this nature and extent has probably been done for the first time in the world. Some of the major accomplishments of the study are as follow:

- A standard methodology for dealing with air quality management in Indian cities was established.
- It provided the most needed scientific basis, evidence and insight into urban air quality issues.
- Useful database on various air quality parameters including some of air toxics has been developed.
- Technical competence, experience and capacity building in terms of infrastructure as well as trained manpower to conduct comprehensive air quality studies are now available in the country.
- Refined Emission Factors (EF) for vehicular exhaust emissions, based on mass emission tests of in-use vehicles, was evolved that provide better assessment of vehicular pollution.
- More reliable emission inventories were built up for the six cities on the basis of primary data.
- Source emission profiles for vehicular as well as non-vehicular sources were developed. This would provide more reliable inputs to receptor modeling based source apportionment studies in future.

10

Way Forward

Source apportionment study in six cities was a comprehensive set of works involving all major factors influencing urban air quality management viz. air quality measurements, meteorological measurements, building up emission inventories, receptor modeling for apportioning the source contribution, dispersion modeling to evaluate efficacies of various interventions, and delineating appropriate action plans for improving air quality to desired levels. Based on the experiences gained and outcomes of the study, following are suggested as future course of action:

1. At national level, different working groups may be set up to deal with the sectoral recommendations of the study. These may be housed in the respective thematic Ministries:

   (i) Group for working on road quality improvement and minimizing re-suspension of road dust – can take up studies on silt load measurements in different cities; and prepare guidelines for quality of road, silt content, paving of unpaved roads, concreting of unpaved surface along road side for various traffic volume and road types.

   (ii) Group on improvement of fuel quality & vehicle exhaust norms – roadmap beyond 2010 for progressive implementation of BS – IV/V norms.

   (iii) Group to deal with old vehicles – retrofitment of pollution control devices, scrap policy, inspection & maintenance issues, etc.

   (iv) Group on traffic management – use of IT in traffic management, guidelines for minimizing/synchronization traffic signals, providing adequate parking, parking fee structure, etc.

   (v) Group on construction activities – prepare and supervise implementation of guidelines on cleaner construction practices.

(vi) Group on industrial activities: industrial action plan implementation.

2. In case of six cities, local Implementation Committee comprising various stakeholders viz. municipal corporation, development authorities, RTO, SPCB, etc. may be set up to oversee implementation of city-specific action plans. Wherever such Committees or Authorities are functional, the study findings could supplement their efforts. The local Committees may also address biomass. garbage/refuse burning and other city-specific sources.

3. Since a comprehensive source apportionment is resource intensive, a simpler and quicker methodology may be worked out for application in other cities (e.g. measurement for critical season, chemical speciation with regard to limited key constituents, etc.).

4. With regard to dispersion modeling, better available models such as AERMOD can be used with new met processor, which can convert IMD data into a usable met input file for AEROMOD.

5. Technical competence, experience and capacity (infrastructure and human resources) built through the project should be gainfully utilized. The institutes participated in the project should become focal point in the respective region, and help in expanding the institutional network by providing necessary training to other institutes through partnership in the future work.

6. Stock taking of air quality trends in major cities needs to be continued. In all the six cities, air quality measurements including chemical speciation of PM_{10} and $PM_{2.5}$ (only key parameters) should continue for at least next five years. This would not only help in building database on key air quality measurements but also provide scientific means to assess the effect of implementation and take mid-term corrections on action plan.

7. Emission inventory, which is an important constituent of air quality management, has been a weak link. More reliable inventories need to be developed in all major cities, particularly for non-attainment cities. A computerized database would be essential for updating inventories at regular intervals.

8. Molecular markers analysis is a highly skilled task that needs to be strengthened. The project institutes should focus on developing necessary expertise in such analysis.

9. The emission factors for vehicles need to be improved at regular intervals, as automotive industry in Indian is expanding at a very rapid rate and more and more numbers of vehicle models are introduced. More number of tests on in-use vehicles should be carried out in future. Similarly, city-specific driving cycles need to be evolved/updated, as there is continuous change in the road traffic pattern such as synchronization of traffic signals, construction of flyovers, one way traffic, restriction of entries of HCV in city areas and continuous increase in density of vehicles. These steps will lead to more refined EF and subsequently, better estimation of vehicular exhaust. More comprehensive work on non exhaust emission for vehicles may be undertaken.

10. Developing source profiles for non-vehicular sources should be extended to cover a few more sources. Similarly, more research, for vehicular and non-vehicular sources, to deal with issues on co-linearity of sources, molecular markers analysis, etc. need to be taken up.

11. Source apportionment of $PM_{2.5}$ was on limited measurements. $PM_{2.5}$ being more critical from health point of view, more focus should be given on this parameter in future.

12. As and when new studies are commissioned, other emerging parameters like NO_2, $PM_{2.5}$ and Benzene may be looked at apart from PM_{10}.

13. Public health impact and related issues should also be studied in future. This would help in better understanding of linkages between air Quality and exposure assessment and health impacts

14. More scientific studies should be planned to understand formation of secondary particles in Indian condition with presence of high OH radical concentration and moisture. This will require modeling efforts and scientific measurements of SO_2, NO_x, HNO_3, SO_4^{--}, NO_3^- , NH_3 and NH_4^+ in the atmosphere. This exercise can also look into long range transport of pollutants and formation of haze in winter months.

15. A series of Guidebooks drawing on the work done may be developed. Some of the titles include Planning and Operating Urban Air Quality Monitoring Networks, Statistical Analyses, Presentation and Interpretation of Air Quality Data, Approaches to Conduct Source Apportionment, Preparation of Urban Emission Inventories, Urban Air Quality Dispersion Modeling, and Development of City Level Air Quality Action Plans.

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ANNEXURE – I

Steering Committee

1. Secretary, MoEF – Chairman
2. Additional Secretary (PA Division), MoEF – Vice-Chairman
3. Joint Secretary (PA), MoEF – Member
4. Chairman, CPCB – Member
5. Representative of Oil Companies (Dir. Level) – Member
6. Representative of SIAM – Member
7. Representative of MoP&NG (JS level) – Member
8. Representative of MoRT&HW (JS level) – Member
9. Representatives of Project executing agencies – Member
10. Member-Secretary, CPCB – Member
11. Director (PA), MoEF – Member Secretary

Technical Committee

1. Chairman, CPCB – Chairman
2. Dr. (Mrs.) Nalini Bhat, Adviser/Shri R. N. Jindal, Additional Director, MoEF – Member
3. Member Secretary, CPCB – Member
4. Prof. H.B. Mathur, Retd. Professor, IIT, Delhi – Member
5. Shri G. K. Acharya, Chief Manager, IOC (R&D) (representative of oil companies) – Member
6. Shri M. Kannan, Head (Env), RIL, (representative of oil companies) – Member
7. Shri K. K. Gandhi, Executive Director, SIAM (representative of SIAM) – Member
8. Shri M. K. Chaudhari, Senior Deputy Director, ARAI – Member
9. Prof. Mukesh Sharma, IIT, Kanpur – Member
10. Dr. Rakesh Kumar, Head, NEERI, ZO, Mumbai – Member
11. Dr. T. S. Panwar, Senior Fellow, TERI – Member
12. Dr. C. V. Chalapati Rao, Deputy Director, NEERI – Member
13. Prof. S. Pushpavanam, IIT, Chennai – Member
14. Prof. Virendra Sethi/Prof. (Mrs.) R. S. Patil, IIT, Mumbai – Member
15. Dr. S. A. Dutta, Tata Motors Ltd., Pune – Member
16. Dr. B. Mukhopadhyay, Director, IMD – Member
17. Representative of concerned SPCBs – Member
18. Dr. Prashant Gargava, SEE, CPCB – Member Secretary

Finance Sub-Committee

1. Director (CP), MoEF – Chairperson
2. Dr. R. K. Malhotra, Executive Director, IOC (R&D) – Member
3. Member Secretary, CPCB – Member
4. Shri Nainsingh, Accounts Officer, CPCB – Member
5. Dr. Prashant Gargava, SEE, CPCB – Member Convener

Expert Group on Emission Factors

1. Prof. H. B. Mathur, Rtd. Professor, IITD – Chairman
2. Prof. B. P. Pundir, Professor, IIT, Kanpur
3. Dr. R. K. Malhotra, Executive Director/ Shri G. K. Acharya, Chief Manager, IOC (R&D)
4. Dr. A. L. Aggarwal, Consultant, ASEM-GTZ
5. Dr. S. A. Dutta, Divisional Manager, Tata Motors Ltd., Pune
6. Shri K. K. Gandhi, Executive Director, SIAM
7. Shri. M. K. Chaudhari, Sr. Deputy Director, ARAI
8. Dr. Prashant Gargava, SEE, CPCB

Expert Group on QA/QC

1. Dr. V. K. Kondawar, Retd. Scientist, NEERI, Nagpur
2. Dr. A. L. Aggarwal, Consultant, ASEM-GTZ
3. Dr. D.P. Mukherjee, Scientist C, CPCB, ZO Kolkata
4. Dr. Prashant Gargava, SEE, CPCB
5. Shri Abhijeet Pathak, Scientist B, CPCB

National Ambient Air Quality Standards, prevailing in 2007

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

ANNEXURE – III

Revised National Ambient Air Quality Standards

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
(1)	(2)	(3)	(4)	(5)	(6)
1	Sulphur Dioxide (SO_2), µg/m³	Annual* 24 hours**	50 80	20 80	- Improved West and Gaeke - Ultraviolet fluorescence
2	Nitrogen Dioxide (NO_2), µg/m³	Annual* 24 hours**	40 80	30 80	- Modified Jacob & Hochheiser (Na-Arsenite) - Chemiluminescence
3	Particulate Matter (size less than 10µm) or PM_{10} µg/m³	Annual* 24 hours**	60 100	60 100	- Gravimetric - TOEM - Beta attenuation
4	Particulate Matter (size less than 2.5µm) or $PM_{2.5}$ µg/m³	Annual* 24 hours**	40 60	40 60	- Gravimetric - TOEM - Beta attenuation
5	Ozone (O_3) µg/m³	8 hours** 1 hour**	100 180	100 180	- UV photometric - Chemilminescence - Chemical Method
6	Lead (Pb) µg/m³	Annual* 24 hours**	0.50 1.0	0.50 1.0	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper - ED-XRF using Teflon filter
7	Carbon Monoxide (CO) mg/m³	8 hours** 1 hour**	02 04	02 04	- Non Dispersive Infra Red (NDIR) spectroscopy
8	Ammonia (NH_3) µg/m³	Annual* 24 hours**	100 400	100 400	- Chemiluminescence - Indophenol blue method
9	Benzene (C_6H_6) µg/m³	Annual*	05	05	- Gas chromatography based continuous analyzer - Adsorption and Desorption followed by GC analysis
10	Benzo(a)Pyrene (BaP) - particulate phase only, ng/m³	Annual*	01	01	- Solvent extraction followed by HPLC/GC analysis
11	Arsenic (As), ng/m³	Annual*	06	06	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
(1)	(2)	(3)	(4)	(5)	(6)
12	Nickel (Ni), ng/m^3	Annual*	20	20	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper

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

** 24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note. — Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigation.

Description of Monitoring Sites

S. No.	Monitoring Stations	Type	Site Description
Bangalore			
1	Kanamangala	Background	Bio fuel usage for cooking, movement of very few public transport buses and HDD vehicles.
2	Domlur	Residential1	DG sets, light vehicles, construction
3	Kammanhalli	Residential2	DG sets, light vehicles, heavy construction activities
4	Peenya	Industrial1	DG sets, heavy vehicles, few construction activities
5	Victoria	Kerbside1	DG sets, vehicles, heavy construction activities
6	CSB	Kerbside2	DG sets, vehicles, heavy construction activities
7	Other	Hospital	DG sets, vehicles, few construction activities
Chennai			
1	IIT Madras (IITM)	Background area	Forest area, residential, minor roads
2	Mylapore	Residential	Residential, minor roads, minor commercial
3	Triplicane	Residential	Residential, minor roads, commercial
4	Adyar	Kerbside Site	Commercial, major roads, residential
5	Saidapet	Kerbside Site	Commercial, major roads, residential
6	R K Nagar	Industrial	Industries, roads, commercial.
7	Ambattur	Industrial	Industries, roads, commercial.
Delhi			
1	Prahladpur	Background	Close to agricultural field, Main Bawana road about 800m from the site.
2	Pitampura	Residential	Residential area, commercial activity, Ring road at 600m distance from station
3	Naraina	Mixed Use	SSI units like electrical, electronics, hospital equipments, plastics, garments, printing press, engineering machinery etc. Fly over construction in progress, residential area, commercial activity, slum population
4	SSI- GTK Road	Industrial	National Highway and outer Ring Road, Jahangirpur Industrial area, High traffic volume, Slum population, construction work for Metro Rail

S. No.	Monitoring Stations	Type	Site Description
5	Ashram Chowk	Kerb Side	High traffic volume, Ring roads, National Highway, Residential, commercial activity
6	Dhaula kuan (DK)	Kerb Side	High traffic volume, Ring road and two National Highways, Cantonment area, Relatively less commercial and residential activity
7	Mayapuri	Kerb Side	Industries, Heavy traffic on Ring Road, Limited residential area, Tihar Jail area
8	Anand Vihar (Road No. 56)	Kerb Side	Proximity to ISBT, Sahibabad and Patparganj Industrial area, commercial activity
9	ISBT Ring Road	Kerb Side	Traffic connecting to Northern States, River Yamuna on east side, Metro rail station, Road side eateries and moderate commercial activities
10	Loni Road	Kerb Side	National and State highway, High traffic volume, residential and commercial activities
Kanpur			
1.	IIT Kanpur (IITK)	Background area	Domestic cooking, light vehicles
2	Vikash nagar (VN)	Commercial cum residential area	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
3	Govind nagar (GN)	Residential area	Domestic cooking, vehicles, road dust
4	Dada nagar (DN)	Industrial area	Industries, Domestic cooking, DG sets, vehicles, road dust, garbage burning
5	Colonel ganj (CG)	Kerb site	Vehicles, Domestic cooking, DG sets, road dust, garbage burning
6	A.H.M. Hospital (AHM)	Commercial area	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
7	Ramadevi Square (RD)	Traffic site, away from kerb	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
Mumbai			
1	Colaba	Control	Protected area under Indian Navy, minimum traffic, one side surrounded by sea, residential area

S. No.	Monitoring Stations	Type	Site Description
2	Dharavi	Residential, Slum	Slums, poor sanitations, small scale industries viz. Glassworks, Leathers, Plastic /Pellets Recycling, Earthenware, Eat outs, Small scale Food Industries, welding operations, truck terminal, bakeries, Unpaved roads, refuse and biomass burning
3	Khar	Residential, upper income group	Residential area, vehicles , Hotels/ Restaurants, public transport & Pvt. Buses, Auto rickshaw, construction activity
4	Mahul	Industrial	Refineries, Thermal power plant, Unpaved roads, fertilizer/ chemical industries, Heavy duty vehicles, tankers, residential areas, sea coast, salt pans
5	Dadar	Commercial	Commercial activity, open eatouts, flyovers, petrol pump, inter city bus terminals, railway cart shed, traffic junction, Multiple lane with traffic
6	Andheri	Kerb	Western Express Highway, MIDC (Industries), Hotels/ Restaurants, Airport, BEST & Pvt. Buses, Auto rickshaw, trucks, construction activity
7	Mulund	Kerb	Heavy traffic, industries, buses, trucks, Auto rickshaw, city limit- toll naka,
Pune			
1	CWPRS Guest House, Khadakwasla	Background Site	Away from the main city area, very low vehicle traffic activity, 40% of the land is agricultural land, about 20% bare land, 16 % forest and hilly area and about 11% residential area.
2	Shantiban, Kothrud	Residential site-1	Residential site with the residential bungalows around the monitoring sites. Considerable vehicular traffic activity and new constructions. Around the site, 40% of the area is residential area, 20% of bare land and 15% of hilly area.
3	Sahakarnagar Colony, Sahakarnagar	Residential site-2	Mixed residential and commercial site with many street-vendors near the site. Construction activity and solid fuel burning is observed around the site. Surrounded by residential area 40%, Slum 8%, bare land 25% and Hilly area 11%.

S. No.	Monitoring Stations	Type	Site Description
4	College of Engineering Ground, Shivajinagar	Kerbside site-1	This site is along a major road with continuous traffic flow from the old Mumbai highway. Residential area (31%) with commercial activities (17%), slum (12%) and 16% agricultural land.
5	Hadapsar square, Hadapsar	Kerbside site-2	Alongside a state-highway with continuous traffic flow and heavy commercial activities. Surrounded by 27% agricultural land, 21 % bare land, 23% residential area, 14% slum area. Significant construction activities were around the site.
6	SAJ Test Plant Pvt. Ltd., Mundhwa	Industrial Site	Major industries nearby include metal industries like Bharat Forge Ltd., Kalyani Carpenter, etc.; ceramic and clay products industries like Siporex India Ltd., B G Shirke Construction Tech Ltd. Surrounded by 37% agricultural land, 13% bare land and about 10% residential area.
7	Geography Dept., University of Pune	Other (Institute) site	No major air pollution sources in the impact zone other than the vehicular activity. Surrounded by Forest plantation (59%), bare land (16%), Residential area (10%) and commercial (9%).

ANNEXURE – V

Air Quality Monitoring: Sampling Period

S. No.	City	Sampling Period		
		Winter	Pre/Post monsoon	Summer
1	Bangalore	Dec. 2006 – March 2007	July 2007 – Sep. 2007	April 2007 – July 2007
2	Chennai	Oct. 2007 – Jan. 2008; March 2008	May 2007 – Oct. 2007	Feb 2007 – Aug. 2007
3	Delhi	Dec. 2007 – Feb. 2008	Sep. 2007 – Dec. 2007	April 2007 – June 2007
4	Kanpur	Dec. 2006 – Feb 2008.	Oct. 2007 – Dec. 2007	April 2007 – June 2007
5	Mumbai	Dec. 2007 – March 2008	Oct. 2007 – Dec. 2007	March 2007 - June 2007
6	Pune	Dec. 2007 – Feb 2008	Sep. 2007 – Oct 2007	April 2007 – June 2007

ANNEXURE – VI

Seasonal Variation in Concentration of Different Pollutants

		SPM									PM_{10}									$PM_{2.5}$								
		Winter			Post Monsoon*			Summer			Winter			Post Monsoon			Summer			Winter			Post Monsoon			Summer		
City	**Site Type**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
Bangalore	**Background (Kanamangala)**	36	183	110	30	146	83	42	160	82	16	91	47	17	227	66	54	255	105	15	45	27	22	33	27	15	34	23
	Residential1 (Domlur)	68	192	126	38	107	71	81	345	152	22	108	69	28	126	63	32	211	93	24	26	25	16	22	19	16	31	25
	Residential2 (Kammanhalli)	207	387	294	79	304	177	211	443	301	79	211	133	28	107	53	25	242	92	23	42	34	15	48	29	9	81	41
	Industrial (Peenyal)	167	331	262	76	410	171	168	315	245	131	212	171	23	228	69	86	346	171	21	46	30	15	32	22	20	22	21
	Kerbside1 (Victoria)	217	394	306	263	505	369	191	423	287	111	257	199	33	221	109	33	566	184	48	83	64	22	40	27	17	78	43
	Kerbside2 (CSB)	94	259	181	256	537	411	54	431	191	52	171	98	34	113	73	40	184	96	38	85	62	33	46	38	29	34	31
	Hospital	143	272	197	35	125	79	32	74	52	47	134	85	16	178	69	16	74	34	31	44	36	18	25	22	11	19	15
Chennai	**Background (IIT Madras)**	40	411	117	29	200	75	49	1200	178	7	87	56	37	138	88	2	143	70	17	71	35	24	49	38	15	82	34
	Residential1 (Mylopore)	60	642	164	56	372	147	66	544	174	29	168	77	40	295	122	14	131	73	19	61	39	18	34	28	27	48	34
	Residential2 (Triplicate)	39	594	106	45	986	173	34	1221	168	30	166	82	15	953	200	12	416	86	49	110	78	31	36	34	13	32	22
	Industrial1 (R.K. Nagar)	95	572	311	51	554	298	80	524	319	39	246	108	37	191	113	26	736	117	38	77	57	26	64	41	35	218	79
	Industrial2 (Ambattur))	99	668	297	124	971	348	91	716	295	59	365	138	25	326	147	52	469	141	48	87	67	21	65	40	49	81	67
	Kerbside1 (Saidapet)	92	661	241	65	748	242	24	342	161	36	261	111	37	212	128	13	622	144	29	94	64	29	54	44	36	49	42
	Kerbside2 (Adyar)	115	1587	350	79	638	207	49	971	211	48	158	87	7	299	127	2	1172	271	41	110	73	37	94	56	30	66	51
Delhi	**Background (Prahladpur)**	284	888	574	400	833	558	251	967	558	156	571	333	249	515	365	108	479	253	163	194	183	170	205	188	87	233	143
	Residential (Pritampura)	654	1133	839	640	1427	990	174	358	289	284	901	527	308	1119	719	25	230	92	297	304	300	NA	NA	NA	30	30	30
	Industrial1 (Naraina)	710	1463	990	268	824	481	385	972	637	279	725	446	172	492	268	124	359	216	186	209	198	56	89	75	50	53	51
	Industrial2 (SSI-GTK)	692	1359	929	762	1776	1263	169	685	423	397	726	553	389	1425	815	94	418	251	74	320	212	146	699	383	6	46	20
	Kerbside1 (Ashram Chowk)	501	861	682	678	1097	890	577	985	800	262	585	393	138	798	453	153	383	297	104	203	166	148	226	182	56	102	80
	Kerbside2 (Dhaulakuan)	364	971	566	179	444	306	409	764	529	188	536	347	96	353	195	NA	NA	NA	137	143	140	43	55	49	NA	NA	NA
	Kerbside3 (Mayapuri)	656	1464	1111	258	697	422	338	922.	604	233	688	453	84	499	251	137	518	344	129	327	209	112	176	141	54	55	54
	Kerbside4 (Anand Vihar)	429	988	628	459	1285	878	717	1944	1272	198	678	380	177	842	508	163	486	307	176	224	198	146	268	208	56	102	80
	Kerbside5 (ISBT)	681	1382	984	670	1569	1264	311	650	460	212	838	487	240	1053	675	92	218	149	122	160	137	103	199	149	102	114	107
	Kerbside6 (Loni Road)	654	1903	1123	1058	3877	2765	541	2568	1339	243	895	456	341	2023	1051	131	868	375	276	350	307	347	375	361	46	47	46

		SPM									PM_{10}									$PM_{2.5}$								
		Winter			Post Monsoon*			Summer			Winter			Post Monsoon			Summer			Winter			Post Monsoon			Summer		
City	**Site Type**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
Kanpur	**Background (IITK)**	269	506	362	164	555	329	180	664	342	90	313	205	91	285	169	89	400	187	97	236	172	104	173	132	104	178	136
	Residential1 (Vikas Nagar)	210	781	429	197	657	373	217	812	422	135	365	226	143	283	195	106	478	216	135	299	207	106	221	161	87	294	190
	Residential2 (Govind Nagar)	217	688	445	185	636	417	237	595	437	122	349	240	114	346	212	111	471	234	153	269	185	108	204	154	105	206	159
	Commercial (AHM Hospital)	298	894	550	250	823	511	233	779	537	142	444	276	115	423	239	114	468	255	165	247	198	123	209	169	121	223	172
	Industrial (Dada Nagar)	345	857	603	288	782	576	258	891	591	220	631	396	167	629	371	183	614	388	220	471	305	103	391	273	151	356	232
	Kerbside1 (Colonelganj)	339	928	564	326	884	532	198	941	561	152	476	291	137	400	260	139	514	272	160	303	216	153	278	226	145	310	218
	Kerbside2 (Ramadevi)	360	700	515	315	871	508	330	773	507	106	377	234	139	367	221	108	334	190	149	345	207	127	284	197	108	274	170
Mumbai	**Background (Colaba)**	115	512	246	125	343	205	77	438	159	45	382	174	64	225	140	50	151	91	54	113	92	52	71	60	16	41	29
	Residential1 (Dharvi)	289	859	552	304	642	501	186	698	401	143	468	272	186	321	245	91	299	177	67	122	92	84	96	91	43	120	74
	Residential2 (Kher)	288	812	495	276	588	400	85	204	146	151	440	263	119	306	229	41	94	62	91	110	102	66	107	83	14	15	14
	Industrial (Mahul)	241	502	395	237	497	392	116	640	239	178	400	271	100	374	226	55	181	98	116	134	127	85	89	87	13	23	17
	Commercial (Dadar)	177	423	291	204	503	351	197	758	335	116	388	248	105	417	212	49	204	116	75	137	106	98	134	112	27	47	37
	Kerbside1 (Andheri)	208	570	396	253	742	399	116	676	255	103	433	237	173	287	223	48	144	84	103	140	121	84	113	99	25	29	28
	Kerbside2 (Mulund)	310	689	463	269	566	391	230	626	352	143	549	279	158	361	234	90	254	163	89	165	131	159	220	189	60	64	62
Pune	**Background (Khadakwasla)**	123	333	225	41	119	76	90	210	142	44	200	100	25	85	60	37	108	78	29	34	32	17	26	23	22	22	22
	Residential1 (Kothrud)	160	567	328	48	285	107	157	304	210	27	286	130	20	202	64	72	162	106	51	63	58	23	28	26	26	31	28
	Residential2 (Sahakarnagar)	383	821	511	135	728	384	121	200	173	99	373	178	80	261	137	34	116	67	38	55	48	26	42	35	19	26	22
	Institutional (Shivajinagar)	200	361	259	89	285	212	47	197	121	75	225	133	18	165	71	11	117	59	43	48	45	26	39	32	13	17	14
	Industrial (Mundhwa)	272	567	412	83	393	188	196	321	272	91	498	237	22	316	86	91	167	124	48	84	64	21	31	26	29	44	37
	Kerbside1 (Shivajinagar)	279	670	466	136	457	282	375	714	517	112	413	266	71	290	140	86	262	143	113	136	124	29	55	45	42	48	46
	Kerbside2 (Pune-Solapur Highway, Hadapsar)	439	888	663	362	878	599	178	503	321	111	506	237	59	484	212	44	184	103	106	143	120	59	65	62	27	32	30

* In case of Bangalore – Pre-monsoon

		NO_2									SO_2								
		Winter			Post Monsoon*			Summer			Winter			Post Monsoon			Summer		
City	**Site Type**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
Bangalore	**Background (Kanamangala)**	7	60	18	BDL	280	91	BDL	151	45	BDL	10	6	BDL	23	9	5	42	14
	Residential1 (Domlur)	17	63	46	7	38	22	10	53	29	5	13	9	BDL	37	15	5	30	15
	Residential2 (Kammanhalli)	15	32	26	24	163	49	8	31	19	BDL	12	5	3	19	11	10	12	10
	Industrial1 (Peenya)	22	156	53	7	234	89	6	75	30	BDL	21	9	6	14	10	6	22	10
	Kerbside1 (Victoria)	42	78	60	15	125	66	30	242	105	BDL	12	7	BDL	37	12	4	39	19
	Kerbside2 (CSB)	29	182	94	23	72	47	8	178	58	5	17	10	4	33	10	3	26	14
	Hospital	15	37	23	10	191	90	4	48	18	4	11	6	3	15	8	4	31	13
Chennai	**Background (IIT Madras)**	9	41	27	BDL	15	8	5	27	14	BDL	10	3	BDL	BDL	BDL	BDL	9	5
	Residential1 (Mylapore)	12	42	28	BDL	28	13	5	32	12	BDL	8	3	BDL	7	3	BDL	9	5
	Residential2 (Triplicane)	13	58	32	7	34	17	3	60	28	BDL	36	4	BDL	5	3	BDL	13	3
	Industrial1 (R.K. Nagar)	20	71	39	12	37	20	19	63	36	BDL	22	5	BDL	3	BDL	BDL	13	3
	Industrial2 (Ambattur)	25	70	45	6	47	17	22	60	42	BDL	14	6	BDL	6	4	BDL	18	6
	Kerbside1 (Saidapet)	2	73	42	20	50	33	28	71	43	BDL	7	3	BDL	6	BDL	BDL	5	3
	Kerbside2 (Adyar)	24	61	45	13	46	25	8	43	25	BDL	24	6	BDL	4	BDL	BDL	10	4
Delhi	**Background (Prahladpur)**	14	54	35	14	53	33	15	43	26	6	32	17	5	20	9	5	21	9
	Residential (Pitampura)	57	94	74	59	120	90	19	44	30	3	24	15	10	34	19	3	11	8
	Industrial1 (Naraina)	36	97	60	13	43	31	23	62	41	5	21	12	3	12	6	4	23	10
	Industrial2 (SSI-GTK)	98	228	162	81	216	146	34	93	63	48	134	90	34	144	83	4	20	12

	Kerbside1 (Ashram Chowk)	52	150	94	67	172	114	27	61	48	10	20	15	7	25	14	3	13	6
	Kerbside2 (Dhaulakuan)	42	98	75	22	60	40	41	93	68	6	35	15	6	9	7	6	13	8
	Kerbside3 Mayapuri	38	90	65	26	46	33	31	76	47	5	16	10	4	7	5	4	10	7
	Kerbside4 Anand Vihar	44	102	72	41	125	85	18	67	37	8	33	16	7	49	23	6	34	14
	Kerbside5 (ISBT)	60	149	112	69	183	124	35	61	48	6	28	18	7	32	19	3	14	7
	Kerbside6 (Loni Road)	47	93	74	36	67	44	9	57	33	11	33	21	6	9	7	4	22	10
Kanpur	**Background (IITK)**	12	28	23	8	58	20	8	38	20	3	22	8	3	19	8	BDL	13	4
	Residential1 (Vikas Nagar)	19	77	49	12	55	32	6	37	19	5	29	14	4	23	8	BDL	14	4
	Residential2 (Govind Nagar)	14	60	40	8	61	36	20	72	37	5	24	9	4	26	10	BDL	36	6
	Commercial (AHM Hospital)	14	74	38	16	50	32	10	60	32	4	25	12	3	17	8	BDL	29	7
	Industrial (Dada Nagar)	22	66	35	10	37	24	7	70	27	9	68	26	10	30	19	BDL	31	15
	Kerbside1 (Colonelganj)	13	79.9	45	16	98	42	16	76	37	7	25	15	3	27	9	BDL	17	8
	Kerbside2 (Ramadevi)	25	54	39	14	58	35	14	56	30	7	58	17	4	37	15	BDL	27	12
Mumbai	**Background** (Colaba)	14	113	53	13	76	38	9	94	18	5	45	15	4	27	13	4	9	5
	Residential1 (Dharvi)	28	119	70	33	75	53	12	76	36	7	21	13	5	53	16	4	24	6
	Residential2 (Kher)	39	129	75	31	94	66	6	34	14	6	41	12	4	23	11	4	8	5
	Industrial (Mahul)	29	97	72	35	100	57	10	38	20	7	35	18	4	25	15	4	28	7
	Commercial (Dadar)	47	148	99	32	92	63	11	60	31	6	31	16	5	30	15	4	15	6
	Kerbside1 (Andheri)	29	130	79	57	97	79	9	39	17	5	26	11	5	34	14	4	57	8
	Kerbside2 (Mulund)	38	139	71	30	100	53	24	155	51	5	33	15	4	41	17	4	10	5

Pune	**Background (Khadakwasla)**	6	33	17	9	20	10	9	14	10	4	39	14	4	17	9	4	14	5.6
	Residential1 (Kothrud)	8	65	27	9	16	10	9	30	15	5	60	14	4	17	9	4	19	7.2
	Residential2 (Sahakarnagar)	9	90	45	27	74	45	9	14	10	9	30	19	5	31	12	4	11	5.1
	Institutional (Shivajinagar)	21	61	38	23	52	35	9	19	10	17	36	24	6	17	10	4	14	6.0
	Industrial (Mundhwa)	27	90	57	7	38	18	10	47	23	11	103	47	9	34	18	7	49	24.5
	Kerbside1 (Shivajinagar)	22	96	74	9	75	33	30	133	65	7	80	21	4	44	13	4	16	72
	Kerbside2 (Pune-Solapur Highway, Hadapsar)	37	99	68	25	66	44	9	43	26	18	99	41	8	40	13	4	11	6

* In case of Bangalore – Pre-monsoon

Emission Factors for Vehicular Exhaust

Vehicle Type	Model Year	PM g/km	CO g/km	HC g/km	NO_2 g/km
Scooters-2s	1991-1995	0.073	6	3.68	0.02
Scooters-2s	1996-2000	0.073	5.1	2.46	0.01
Scooters-2s	2001-2005	0.049	2.37	2.05	0.03
Scooters-4s	2001-2005	0.015	0.93	0.65	0.35
Scooters-4s	2006-2010	0.015	0.4	0.15	0.25
(4 Stroke) Motorcycles	1991-1995	0.01	3.12	0.78	0.23
(4 Stroke) Motorcycles	1996-2000	0.015	1.58	0.74	0.3
(4 Stroke) Motorcycles	2001-2005	0.035	1.65	0.61	0.27
(4 Stroke) Motorcycles	2006-2010	0.013	0.72	0.52	0.15
3-Wheeler - CNG- 4S OEM	2006-2010	0.015	1	0.26	0.5
3-Wheeler - Auto rickshaw-Petrol 2S	Post 2000	0.045	1.37	2.53	0.2
3-Wheeler - Auto rickshaw-LPG 2S	Ret-pre 2000	0.721	4.39	3.6	0.08
	Ret-post-2000	0.13	1.7	1.03	0.04
3-Wheeler - Auto rickshaw-D	Post 2000	0.347	2.09	0.16	0.69
	Post 2005	0.091	0.41	0.14	0.51
4 Wheeler - Petrol	1991-1995	0.008	4.75	0.84	0.95
4 Wheeler - Petrol	1996-2000	0.008	4.53	0.66	0.75
4 Wheeler - Petrol	2001-2005	0.004	1.3	0.24	0.2
4 Wheeler - Petrol	2006-2010	0.002	0.84	0.12	0.09
4 Wheeler - Diesel	1996-2000	0.145	0.87	0.22	0.45
4 Wheeler - Diesel	2001-2003	0.19	0.72	0.14	0.84
4 Wheeler - Diesel	2003-05	0.06	0.3	0.26	0.49
4 Wheeler - Diesel	2006-2010	0.015	0.06	0.08	0.28
4 Wheeler - LPG	1996-2000	0.001	6.46	1.78	0.44
	2001-2005	0.002	2.72	0.23	0.2
	2006-2010	0.002	2.72	0.23	0.2
4 Wheeler - CNG	2006-2010	0.006	0.06	0.46	0.74
LCVs	1991-1995	0.998	3.07	2.28	3.03
(Light Commercial Vehicles) 4 Wheeler GC	1996-2000	0.655	3	1.28	2.48
	2001-2005	0.475	3.66	1.35	2.12
	2006-2010	0.475	3.66	1.35	2.12

Vehicle Type	Model Year	PM g/km	CO g/km	HC g/km	NO_2 g/km
Large Trucks + MAV	1991-1995	1.965	19.3	2.63	13.84
	1996-2000	1.965	19.3	2.63	13.84
	2001-2005	1.24	6	0.37	9.3
	2006-2010	0.42	4.13	0.28	8.63
Buses-Diesel	1991-1995	2.013	13.06	2.4	11.24
	1996-2000	1.213	4.48	1.46	15.25
	2001-2005	1.075	3.97	0.26	6.77
	2006-2010	0.3	3.92	0.16	6.53
Buses - CNG	2001-2005	N A	3.72	3.75	6.21
	2006-2010	-	3.72	3.75	6.21

Emission Factors for Vehicle Exhaust Future Scenario Generation

Vehicle Type	Model Year	PM (g/km)	% red.	Remarks	NO_2 (g/km)	% red.	Remarks
2 Wheelers-2S	2006-2010	0.057		20% reduction assumed with technology changes(Direct Injection etc)	0.02		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.0456	20.0%		0.0134	33.0%	0.333
	2015-2017	0.0365	20.0%		0.0107	20.0%	In absence of road map, 20% reduction assumed
2 Wheelers (4-Stroke) Scooters	2006-2010	0.015		20% reduction assumed with technology changes(Fuel Injection etc)	0.25		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.012	20.0%		0.1675	33.0%	0.333
	2015-2017	0.0096	20.0%		0.134	20.0%	In absence of road map, 20% reduction assumed
2 Wheelers (4 Stroke) Motorcycles	2006-2010	0.013		20% reduction assumed with technology changes(Fuel Injection etc)	0.15		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.0104	20.0%		0.1005	33.0%	0.333
	2015-2017	0.0083	20.0%		0.0804	20.0%	In absence of road map, 20% reduction assumed
3-Wheeler-OE - 4S CNG/ LPG/ Petrol	2006-2010	0.015		20% reduction assumed with technology changes(	0.5		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.012	20.0%		0.3125	37.5%	0.375

	2015-2017	0.0096	20.0%	Injection etc)	0.2500	20.0%	In absence of road map, 20% reduction assumed
3-Wheeler - Diesel	2006-2010	0.091		BS-II to BSIII	0.51		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.0455	50.0%	0.5	0.4202	17.6%	0.176
	2015-2017	0.0364	20.0%	In absence of road map, 20% reduction assumed	0.3362	20.0%	In absence of road map, 20% reduction assumed
3-Wheeler-OE - 2S CNG/ LPG/ Petrol	2006-2010	0.045		20% reduction assumed with technology changes(Injection etc)	0.2		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.0360	20.0%		0.125	37.5%	0.375
	2015-2017	0.0288	20.0%		0.100	20.0%	In absence of road map, 20% reduction assumed
3-Wheeler - LPG 2S- retro	2006-2010	0.13		20% reduction assumed with technology changes(Injection etc)	0.04		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.104	20.0%		0.025	37.5%	0.375
	2015-2017	0.0832	20.0%		0.02	20.0%	In absence of road map, 20% reduction assumed
3-Wheeler - CNG 2S-retro	2006-2010	0.118		20% reduction assumed with technology changes(Injection etc)	0.19		BS-II to BSIII: HC+ NOx limit
	2011-2015	0.0944	20.0%		0.1188	37.50%	0.375
	2015-2017	0.0755	20.0%		0.095	20.0%	In absence of road map, 20% reduction assumed
4 Wheeler - Petrol	2006-2010	0.002			0.09		
	2011-2015	0.0016	20.0%		0.0477	47.0%	
	2015-2017	0.0013	20.0%	EURO-V, PM norm instruction in line with diesel values	0.0358	25.0%	EURO-V
	2015-2017	0.0013	0.0%	EURO-VI, no change in norms from EURO-V to VI	0.0358	0.0%	EURO-VI, no change in norms from EURO-V to VI
4 Wheeler -	2006-2010	0.0150			0.28		

Diesel	2011-2015	0.0083	45.0%		0.14	50.0%	
	2015-2017	0.0008	90.0%	EURO-V	0.1008	28.00%	EURO-V
	2015-2017	0.0008	0.0%	EURO-VI	0.0454	55.0%	EURO-VI
4 Wheeler - CNG	2006-2010	0.006			0.74		
	2011-2015	0.0048	20.0%		0.3922	47.0%	In line with petrol
	2015-2017	0.0038	20.00%		0.2942	25.00%	
	2015-2017	0.0038	0.0%		0.2942	0.0%	
4 Wheeler - LPG	2006-2010	0.002			0.2		
	2011-2015	0.0016	20.0%		0.106	47.0%	In line with petrol
	2015-2017	0.0013	20.0%		0.0795	25.0%	
	2015-2017	0.0013	0.0%		0.0795	0.0%	
LCVs (Light Commercial Vehicles)-diesel	2006-2010	0.475			2.12		
	2011-2015	0.0808	83.0%		1.484	30.0%	
	2015-2017	0.0808	0.0%	EURO-V	0.8459	43.0%	EURO-V
	2015-2017	0.0339	58.0%	EURO-VI	0.1692	80.0%	EURO-VI
LCVs (Light Commercial Vehicles) - CNG	2006-2010	0.058		data taken from vehicle emissions source profile	5.7		data taken from vehicle emissions source profile
	2011-2015	0.0464	20.0%		3.99	30.0%	In line with diesel
	2015-2017	0.0371	20.0%		2.2743	43.0%	
	2015-2017	0.0297	20.0%		0.4549	80.0%	
Large Trucks + MAV	2006-2010	0.42		data taken from vehicle emissions source profile	8.63		
	2011-2015	0.0714	83.0%		6.041	30.0%	
	2015-2017	0.0714	0.0%	EURO-V	3.4434	43.0%	EURO-V
	2015-2017	0.03	58.0%	EURO-VI	0.6887	80.0%	EURO-VI
Large Trucks + MAV CNG	2006-2010	0.032		data taken from vehicle emissions source profile	3.92		
	2011-2015	0.0256	20.0%		2.744	30.0%	In line with diesel
	2015-2017	0.0205	20.0%		1.5641	43.0%	
	2015-2017	0.0164	20.0%		0.3128	80.0%	

Buses-Diesel	2006-2010	0.3			6.53		
	2011-2015	0.051	83.0%		4.5710	30.0%	
	2015-2017	0.051	0.0%	EURO-V	2.6055	43.0%	EURO-V
	2015-2017	0.0214	58.0%	EURO-VI	0.5211	80.0%	EURO-VI
Buses - CNG-OE	2006-2010	0.044		taken from TERI-ARAI report	6.21		
	2011-2015	0.0352	20.0%		4.347	30.0%	In line with diesel
	2015-2017	0.0282	20.0%		2.4778	43.0%	
	2015-2017	0.0225	20.0%		0.4956	80.0%	
Buses - CNG-Retro	2006-2010	0.032		data taken from vehicle emissions source profile	3.92		
	2011-2015	0.0256	20.0%		2.744	30.0%	In line with diesel
	2015-2017	0.0205	20.0%		1.5641	43.0%	

Non-Vehicular Emission Factors

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
1	Fuel Oil Combustion	TSP = {9.19(S) + 3.22} * 0.120 SO_2 = 18.84S NOx = 6.6 CO = 0.6 CH_4 = 0.0336 TOC = 0.1248 NMTOC = 0.091 **(Unit: kg/10^3 L)**	TSP may be considered PM_{10}. TOC is Total Organic Compound including VOC. EPA-42: Table 1.3 – 1 And Table 1.3 – 3; S – Sulphur Content In Fuel (For 1% Sulphur S=1); Gm/Lit Oil, Fuel Oil Combustion, Normal Firing.
2	Natural Gas Combustion	TSP = 121.6 SO_2 = 9.6 NOx = 1600 CO = 1344 CO2 =1,920,000 CH4 = 36.8 VOC =88 TOC = 176 NMTOC = 0.091 **(Unit: kg/10^6 M^3)**	TSP may be considered PM_{10}. http://www.epa.gov/ttn/chief/ap42/ch01/Final/C01s04.Pdf
3	Liquefied Petroleum Gas Combustion	PM= 2.1 SO_2 = 0.4 **(Unit: Gm/kg)** NO_x = 1.8 CO = 0.252	Reddy And Venkatraman Http://www.Epa.Gov/Ttn/Chief/Ap42/Ch01/Final/CO1s05.Pdf (Commercial Boilers)

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		CO_2 =1716 CH4 = 0.024 VOC =88 TOC = 0.072 NMTOC = 0.091 **(Unit: kg/10^6 M^3)**	
4	Bagasse Combustion	TSP = 7.8 NO_x = 0.6 CO_2 = 780 **(Unit: kg/Ton)**	EPA-AP42: Table 1.8-1, Uncontrolled Emission Factors
5	Residential Wood Stoves/Restaurants	PM_{10}=15.3 CO=115.4 NOx=1.4 SOx= 0.2 TOC=41.5 CH_4=15 TNMOC=26.5 **(Unit: kg/Mg)**	Table 1.10-1 Conventional AP-42
6	Kerosene Combustion Domestic	PM=1.95 SO_2=4 **(Unit: G/Lit)** TSP=0.61 CO=62 NOx=2.5	PM & SO_2 – Reddy And Venkatraman TSP May Be Considered as PM_{10}. USEPA 2000

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		CH_4=1 TNMOC=19 **(Unit: G/kg)**	
7	Coal Combustion - Tandoor / Domestic	TSP=20 CO=24.92 NOx=3.99 SO_2= 13.3 **(Unit: kg/Mg)**	TERI Report Uncontrolled wherever controlled use efficiency.
8	Coal Combustion Boilers	**Stoker Fired Boilers** CO=0.3 CO_2=2840 SOx=19.5S NOx=4.5 PM=0.04 A **FBC Boilers** CO=0.3 CO_2=ND SOx=1.45 NOx=0.9 **Pulverized Coal Boilers** SOx=19.5S NOx=9.0 **(Unit: kg/Mg)**	S= Weight Percent Sulphur A= Ash content (weight %) AP-42 1.2-1,2,3 Use suitable EF pertinent to the city & 2x2 grid

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
9	Chulha (Dung, Wood)	PM=6.3 PM_{10}=5.04 SO_2= 0.48 **(Unit: G/kg)** TSP=1.9 CO=31 NOx=1.4 TNMOC=29.8 CH_4=3 **(Unit: G/kg)**	Reddy And Venkatraman - (PM_{10}, SO_2, PM) TSP may be Considered as PM_{10}. USEPA 2000 Use suitable EF pertinent to the city & 2x2 grid
10	Agricultural Waste (From Pune And Kanpur)	PM=11 PM_{10}=11 CO=58 CO_2=207 SO_2=0.12 NO_X=0.49 **(Unit: kg/Ton)**	EPA-AP42: Table 2.5-5 Emission Factors For Open Burning Of Agricultural Materials, kg/Ton; Unspecified Field Crop Burning Emission Factor Is Considered. Particulate Matter From Most Agricultural Refuse Burning Has Been Found To Be In The Sub micrometer Size Range. For SO_2 And NO_2: M. S. Reddy And C. Venkatraman (2002), Inventory Of Aerosol And Sulphur Dioxide Emissions From India. Part II - Biomass Combustion, Atm. Envt., Vol 36, Issue 4, Pp 699-712 Manish Shrivastava, Gazala Habib, Venkatraman C, Jeffery W. Sterh, Russell R. Dickerson(Sept.8 2003) Emissions From Biomass Burning In India : II - Sulfur Dioxide And Nitrogen Dioxide, Global Biogeochemical Cycles, Pp15
11	Garden Waste Combustion	(Same as under 10)	
12	Medical Waste Incineration	PM=2.33 SO_2=1.09	EPA-AP42: Table 2.3.2; Apply Emission Factors for uncontrolled Emission

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		CO=2.95 NOx=1.78 **(Unit: kg/Ton)**	
13	Solid Waste Burning (Landfill Sites)	PM_{10} = 8 $PM_{2.5}$ =5.44 CO=42 SOx=0.5000 NOx=3 VOC= 21.5 **(Unit: kg/MT)**	*A Guide To Rapid Source Inventory Techniques And Their Use In Formulating Environmental Control Strategies – Part One – Rapid Inventory Techniques In Environmental Pollution By A.P. Economopolous, WHO, Geneva, 1993*
14	Kerosene Generators Domestic	Apply same EF as for item no. 6: domestic Kerosene combustions	
15	Diesel Industrial Generators Large Stationary Diesel And All Stationary Dual - Fuel Engines(Film Shooting)	PM_{10} = 1.33 10^{-3} CO_2= 0.69 CO=4.06 10^{-3} SOx= 1.24 10^{-3} NOx=0.0188 Aldehydes= 2.81 10^{-4} TOC Exhaust = 1.50 10^{-3} Evaporative =0 Crankcase = 2.68 10^{-3} Refueling =0 **(Unit: kg/Kw-Hr)**	AP-42 (Table 3.3-1) EF For Uncontrolled Gasoline & Diesel Industrial Engines.

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
16	Petroleum Refining	**Boilers & Process Heaters** Fuel Oil – EF Used For Fuel Oil Combustion (Sec 1.3 AP-42) Natural Gas - EF Used For Natural Gas Combustion (Sec 1.4 AP-42) **Fluid Catalytic Cracking Units** **Uncontrolled** PM=0.695 SO_2=1.413 CO=39.2 Total Hydrocarbons=0.630 NO_2=0.204 Aldehydes=0.054 Ammonia=0.155 **Electrostatic Precipitator and CO Boiler** PM=0.128 SO_2=1.413 CO=Negligible Total Hydrocarbons= Negligible NO_2=0.204 Aldehydes= Negligible Ammonia= Negligible	AP-42 (Table 5.1-1 To 5.1-3). Calculate EF inclusive for all the processes for each ton of product.

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Moving Bed Catalytic Cracking Units PM=0.049 SO_2=0.171 CO=10.8 Total Hydrocarbons=0.250 NO_2=0.014 Aldehydes=0.034 Ammonia=0.017 **Fluid Coking Units** **Uncontrolled** PM=1.50 SO_2=ND CO= ND Total Hydrocarbons= ND NO_2= ND Aldehydes= ND Ammonia= ND **Electrostatic Precipitatorand CO Boiler** PM=0.0196 SO_2=ND CO= Negligible Total Hydrocarbons= Negligible NO_2=ND Aldehydes= Negligible	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Ammonia= Negligible **(Unit: kg/10³ L Fresh Feed)** **Vapor Recovery System and Flaring** PM= Negligible SO_2=0.077 CO=0.012 Total Hydrocarbons=0.002 NO_2=0.054 Aldehydes= Negligible Ammonia= Negligible **(Unit: kg/10³ L Refinery Feed)** **Vacuum Distillation Column Condensers** **Uncontrolled** PM=Negligible SO_2=Negligible CO=Negligible Total Hydrocarbons=0.14 NO_2=Negligible Aldehydes=Negligible Ammonia=Negligible Controlled (Vented To	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Heater Or Incinerator) PM=Negligible SO_2=Negligible CO=Negligible Total Hydrocarbons=Negligible NO_2=Negligible Aldehydes=Negligible Ammonia=Negligible **(Unit: kg/10^3 L Refinery Feed)** **Claus Plant And Tail Gas Treatment** (See Sec 8.13- "Sulphur Recovery" AP-42) **Cooling Towers (Uncontrolled Emissions)** PM=0.7 **(Unit: kg/10^6 L Cooling Water)** Oil Water Separators (Uncontrolled Emissions) PM=0.6	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		(Unit: kg/10^3 L Waste Water) Storage (Uncontrolled Emissions) (See Chapter 7-Liquid Storage Tanks AP-42) Loading (Uncontrolled Emissions) (See Section 5.2 – Transportation And Marketing Of Petroleum Liquids AP-42) **Fugitive VOC Emissions (Uncontrolled Oil Refinery Of 52,500 M^3/Day)** Total =20,500 **(Unit: kg/Day)**	
17	Electric Arc Welding	TSP=6.3 SO_2=ND NO_x=0.16 CO=9.75 VOC=0.09 **(Unit: kg/Ton**)	WHO 1993, Rapid Techniques In Environmental Pollution Part 1 By Alexander P. Economopoulos EF Are Cited Without Control Equipments
18	Secondary Metal Smelting (Lead)	**Lead** **Sweating**	AP-42 12.11 For Lead; 12.13 For Steel Foundries; 12.4 For Zinc

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
	And Other Operations (Foundries)	PM=16-35 Pb=4-8 SO_2=ND **Reverberatory Smelting** PM=162 Pb=32 SO_2=40 **Blast Smelting Cupola** PM=153 Pb=52 SO_2=27 **Kettle Refining** PM=0.02 Pb=0.006 SO_2=ND **Kettle Oxidation** PM=$\leq$ 20 Pb=ND SO_2=ND Casting PM=0.02 Pb=0.007 SO_2=ND	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		(Unit: kg/Mg) **Steel Foundries** **Melting** **3 Electric Arc** TSP=6.5 (2 To 20) NOx=0.1 PM_{10}=ND **Open Hearth** TSP =5.5 (1 To 10) NOx=0.005 PM_{10}=ND **Open Hearth Oxygen Lanced** TSP =5.5 (1 To 10) NOx=0.005 PM_{10}=ND **Electric Induction** TSP =0.05 NOx=ND PM_{10}=0.045 Sand Grinding/Handling In **Mold And Core Making** TSP =ND NOx=NA PM_{10}=0.27 3.0	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Core Ovens TSP =ND NOx=ND PM_{10}=1.11 0.45 **Pouring and Casting** TSP =ND NOx=NA PM_{10}=1.4 **Casting Cleaning** TSP =ND NOx=NA PM_{10}=0.85 **Charge Handling** TSP =ND NOx=NA PM_{10}=0.18 **Casting Cooling** TSP =ND NOx=NA PM_{10}=0.7 **(Unit: kg/Mg)** **Zinc** Reverberatory Sweating Clean Metallic Scrap PM= Negligible **General Metallic Scrap**	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		PM=6.5 **Residual Scrap** PM=16 **(Unit: Mg/Mg Of Feed)** **Rotary Sweating** PM=5.5-12.5 **Muffle Seating** PM=5.4-16 **Kettle Sweating** **Clean Metallic Scrap** PM= Negligible **General Metallic Scrap** PM=5.5 **Residual Scrap** PM=12.5 **Electric Resistance Sweating** PM=<5 **Sodium Carbonate Leaching Calcining** PM=44.5 **(Unit: kg/Mg Of Zinc Used)** **Kettle Pot** PM=0.05	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		(Unit: Mg/Mg) **Crucible Melting** PM=ND **Reverberatory Melting** PM=ND Electric Induction Melting PM=ND **Alloying** PM=ND **Retort and Muffle Distillation** **Pouring** PM=0.2 – 0.4 **Casting** PM=0.1-0.2 **Muffle Distillation** PM=22.5 **(Unit: kg/Mg Of Product)** **Graphite Rod Distillation** PM-Negligible **Retort Distillation/Oxidation** PM=10-20 **Muffle Distillation/Oxidation** PM=10-20	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Retort Reduction PM=23.5 **Galvanizing** PM=2.5 **(Unit: kg/Mg Of Zinc Used)**	
19	Cast Iron Furnace	Cupola Uncontrolled PM=6.9 Electric Arc Furnace Uncontrolled PM=6.3 **(Unit: kg Of Pollutant/Mg Of Grey Iron Produced)**	AP-42 (Table 12.10-2) Use suitable EF pertinent to the city & 2x2 grid
20	Power Plant - Natural Gas	CO_2=1920000 Pb=0.008 PM(Total)=121.6 NOx=4480 CO=1344 SO_2=9.6 TOC=176 CH_4= 36.8 VOC=88 **(Unit: kg /10^6 M^3)**	AP-42 Table (1.4-1-2) Use suitable EF pertinent to the city & 2x2 grid
21	Wood Residue Combustion In	PM_{10}=17.3 CO=126.3	*AP42 (Sec. 1.9, Pp. 1.10.4, Table 1.9.1)* Use suitable EF pertinent to the city & 2x2 grid

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
	Boilers / Bakeries	SOx=0.2 NOx=1.3 CO_2=1700 Total VOC=114.5 **(Unit: kg /Mg)**	
22	Coal Combustion - Power Plant	PC, Dry Bottom, Wall-Fired, Sub-Bituminous Pre-NSPS SOx=19S NOx=11 (5.5 With Low NOx Burners) CO=0.25 Filterable PM=5A Filterable PM_{10}=1.15 **(Unit: kg /Mg)**	AP-42 (Table 1.1-3-4) Use suitable EF pertinent to the city & 2x2 grid Particulate Is Expressed In Terms Of Coal Ash Content, A, Factor Is Determined By Multiplying Weight % Ash Content of Coal (as Fired) By The Numerical Value Preceding The A.
23	Plastic And Leather Waste Burning	SO_2=0.5 NOx=3 CO=42 CH_4=6.5 TSP=8 **(Unit: kg /Mg Of Waste)**	AP 42/(Table 2.4-7)
24	Bricks And Related Clay Products (Earthen Pot Kiln)	TSP=0.9 PM_{10}=0.7 SO_2=0.6 NOx=0.255 CO=0.4 CO_2=150	EPA-AP42 (Table: 11.3-2) Apply for uncontrolled Emissions for Coal Fired Kiln unless a different fuel is used.

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		(Unit: kg /Tons Of Bricks)	
25	Cupola Cast Iron	TSP=6.9 SO_2=0.6S NOx=ND CO=73 VOC=ND Pb=0.32 **(Unit: kg /Tons)**	WHO 1993, Rapid Techniques In Environmental Pollution Part 1 By Alexander P. Economopoulos
26	Municipal Solid Waste Landfills	PM_{10} = 8 $PM_{2.5}$ =5.44 CO=42 SOx=0.5000 NOx=3 VOC= 21.5 **(Unit: kg/MT)**	A Guide To Rapid Source Inventory Techniques And Their Use In Formulating Environmental Control Strategies – Part One – Rapid Inventory Techniques In Environmental Pollution By A.P. Economopolous, WHO, Geneva, 1993 Divide under different types of emissions such as vehicular movement on unpaved roads, combustion of organic content, loading and unloading etc. Determine the activity levels for each category and apply suitable factors given.
27	Manufacture Of Rubber Products / Plastics Small Scale	PM=17.5 **(Unit: kg /Mg)**	AP-42 (Table 6.6.1-1) Use suitable EF pertinent to the city & 2x2 grid
28	Fertilizer And Inorganic Chemical Industry	**Solution Formation and Concentration** PM=0.0105 NH_4=9.23 Non Fluidized Bed Prilling Agricultural Grade PM=1.9	AP-42 8.2-1 – Chapter – 8 Use suitable EF pertinent to the city & 2x2 grid

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		NH_4=0.43 **Feed Grade** PM=1.8 NH_4=ND Fluidized Bed Prilling **Agricultural Grade** PM=3.1 NH_4=1.46 **Feed Grade** PM=1.8 NH_4=2.07 **Drum Granulation** PM=120 NH_4=1.07 **Rotary Drum Cooler** PM=3.89 NH_4=0.0256 **Bagging** PM=0.095 NH_4=NA **(Unit: kg /Mg Of Product)**	
29	Hot Mix Asphalt Plants	**Batch HMP** PM=16 PM_{10}=2.25 CO=0.2(Natural Gas-Fired Dryer, Hot Screens and Mixer) 0.2 (Fuel Oil-Fired	AP-42 11.1-1, 5 & 6 Use suitable EF pertinent to the city & 2x2 grid

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Dryer, Hot Screens and Mixer) 0.2 (Waste Oil-Fired Dryer, Hot Screens and Mixer) CO_2=18.5(For All Type O Process) NOx=0.0125(Natural Gas-Fired Dryer, Hot Screens And Mixer) 0.06 (Fuel Oil-Fired Dryer And Waste Oil-Fired Dryer, Hot Screens And Mixer) SO_2=0.0023(Natural Gas-Fired Dryer ,Hot Screens And Mixer) 0.044(Fuel Oil-Fired Dryer, And Waste Oil-	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Fired Dryer Hot Screens And Mixer) 0.0215 (Coal-Fired Dryer, Hot Screens And Mixer) TOC =0.0075 (Natural Gas-Fired Dryer, Hot Screens And Mixer) 0.0075 (No.2 Fuel Oil-Fired Dryer, Hot Screens And Mixer) 0.0215(No.6 Fuel Oil-Fired Dryer, Hot Screens And Mixer) CH_4= 0.0037(For All Type O Process) VOC=0.0041(Natural Gas-Fired Dryer, Hot Screens	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		And Mixer) 0.0041(No.2 Fuel Oil-Fired Dryer, Hot Screens And Mixer) 0.018(No.6 Fuel Oil-Fired Dryer, Hot Screens And Mixer) **(Unit: kg /Mg)** **Drum Mix HMP** PM=14 PM_{10}=3.25 CO=0.065 (For All Process Type) CO_2= 16.5(For All Process Type) NOx=0.013 (Natural Gas Fired Dryer) 0.0275(No.2 Fuel Oil And Waste Oil Fired Boiler)	

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		TOC=0.022 (For All Process Type) CH_4=0.006(For All Process Type) VOC=0.016(For All Process Type) **(Unit: kg /Mg)**	
30	Glass Manufacturing	TSP=0.7 SO_2=1.7 NO_X=3.1 CO=0.1 VOC=0.1 **(Unit: kg /Ton)**	WHO 1993, Rapid Techniques In Environmental Pollution Part 1 By Alexander P. Economopoulos
31	Lead Oxide And Pigment Production	TSP=7 SO_2=NA NO_X= NA CO= NA VOC= NA Pb=7 **(Unit: kg /Ton)**	WHO 1993, Rapid Techniques In Environmental Pollution Part 1 By Alexander P. Economopoulos
32	Construction (Building)	TSP=1.2 **(Unit: Tons/Acre/ Month Of Activity)**	For Details Refer AP-42 Section 13.2.3.3 Use suitable EF pertinent to the city & 2x2 grid depending upon construction activity
33	Construction Roads (A)	TSP=1.2 **(Unit: Tons/Acre/ Month Of**	For Details Refer AP-42 Section 13.2.3.3 Use suitable EF pertinent to the city & 2x2 grid depending upon construction

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
	Aggregate Laying And (B) Asphalt	**Activity)**	activity
34	Construction Of Flyovers	TSP=1.2 **(Unit: Tons/Acre/ Month Of Activity)**	For Details Refer AP-42 Section 13.2.3.3 Use suitable EF pertinent to the city & 2x2 grid depending upon construction activity
35	Carbon Black	**Oil Furnace Process** **Main Process Vent** PM=3.27 CO=1400 NO=0.28 SO=0 CH_4=25 Non CH_4 VOC=50 **Flare** PM=1.35 CO=122 NO=ND SO=25 Non CH_4 VOC=1.85 **CO Boiler And Incinerator** PM=1.04 CO=0.88 NO=4.65 SO=17.5 Non CH_4 VOC=0.99 **Oil Storage Tank Vent** Non CH_4 VOC=0.72	AP 42 Table 6.1-3 Use suitable EF pertinent to the city & 2x2 grid

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Fugitive Emissions PM=0.10 **(Unit: Weight Of Emissions /Weight Of Carbon Black Produced)**	
36	Paint Applications (Auto)	Prime Coat (Solventborne Spray) 6.61 Guide Coat (Solventborne Spray) 1.89 Top Coat (Enamel) 7.08 **(Unit: Automobile kg Of VOC/Vehicle)**	AP 42 Table 4.2.2.8-1 Based on the number of vehicles being painted in each location
37	Paved Roads	Refer Section 13.2.1.3 Of AP-42	AP 42 (13.2.1.3) Given equation has to be used and respective parameters shall vary for each city and/or grid
38	Unpaved Roads	Refer Section 13.2.2 Of AP-42	AP 42 (13.2.2) Given equation has to be used and respective parameters shall vary for each city and/or grid
39	Soil Dust (Wind Erosion)	PM=0.263 PM_{10}=0.1315	Pune EI Study Conducted By ARB, In kg/Acre/Year, 1. Emission Factor For TSP Is 0.001052 Tons Per Acre Per Year, Which Is The

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		(Unit: kg/Acre/Year)	Default Emission Factor For Default San Joaquin Valley, California, Averaged Over All The Counties. Multiplication Factor Of 0.5 For Deriving PM10 Is Used. 2. Assumed A Longer Vegetative Coverage In India After The Harvest, Hence Multiply The Above Emission Factor By A Factor Of 1/4.
40	Stone Pulverization Industry, Quarries	**Primary And Secondary Crushing** Total PM=ND Total PM_{10}= ND Total $PM_{2.5}$= ND <u>Tertiary Cushing</u> Total PM=0.0027 Total PM_{10}= 0.0012 Total $PM_{2.5}$= ND **Fines Crushing** Total PM=0.0195 Total PM_{10}= 0.0075 Total $PM_{2.5}$= ND **Screening** Total PM=0.0125 Total PM_{10}= 0.0043 Total $PM_{2.5}$= ND **Fines Screening** Total PM=0.15 Total PM_{10}= 0.036 Total $PM_{2.5}$= ND **Conveyor Or Transfer Point** Total PM=0.0015	AP 42 Table (11.19.2-1) Use EF of uncontrolled Emission

S. No.	Source/Activity	Common Emission Factor	Reference/Remarks
		Total PM_{10}= 0.00055 Total $PM_{2.5}$= ND **Wet Drilling Unfragmanted Stone** Total PM=ND Total PM_{10}= 4.0 * 10^{-5} Total $PM_{2.5}$= ND **Truck Unloading – Fragmanted Stone** Total PM=ND Total PM_{10}= 8.0 * 10^{-6} Total $PM_{2.5}$= ND **Truck Unloading – Conveyor Crushed Stone** Total PM=ND Total PM_{10}= 5.0 * 10^{-5} Total $PM_{2.5}$= ND **(Unit: kg/Mg)**	

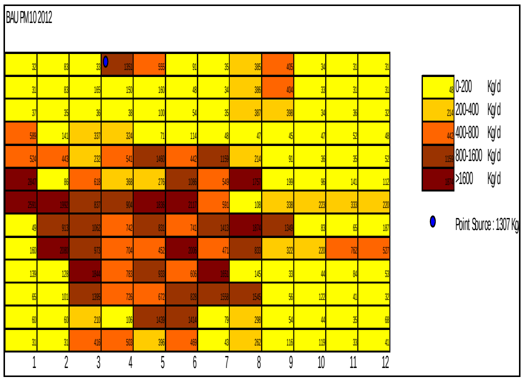
NOTE:

- The proposed EFs were involved through a consultative process wherein the proposed EFs along with the feed backs provided by each respective organization (s) were studied by an expert group and best possible option was selected based on the references available.
- The proposed EF(s) are applicable for this study only and are proposed with the sole objective of using common EFs so that inter-city comparison between the results obtained can be made.
- The participating organizations are advised that they should also study the whole documents referred here so that any city specific deviations can be suitably incorporated. However, in such a case the changes incorporated should be documented with justification.

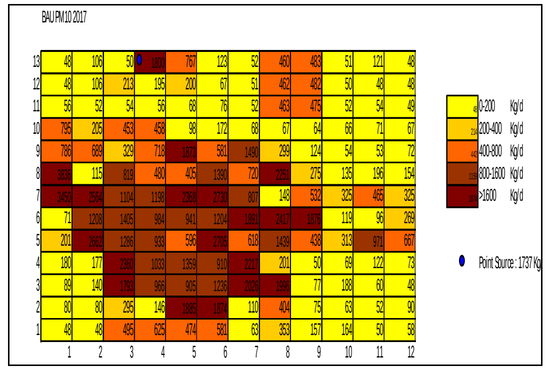
Projections of grid-wise emission load for 2012 and 2017

Bangalore

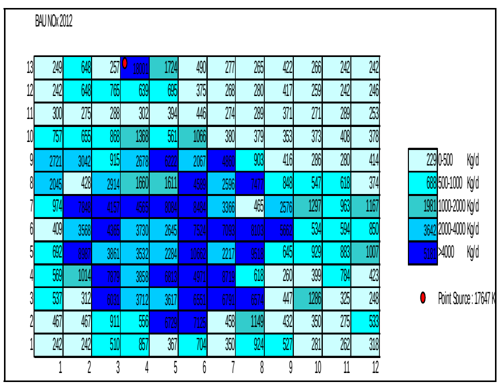
BAU-2012

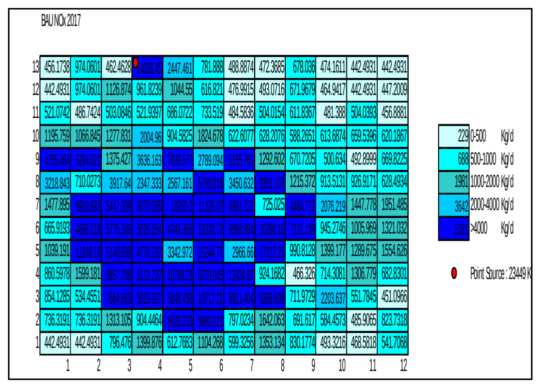


BAU-2017



PM_{10} Emission Load (kg/day)- All Sources



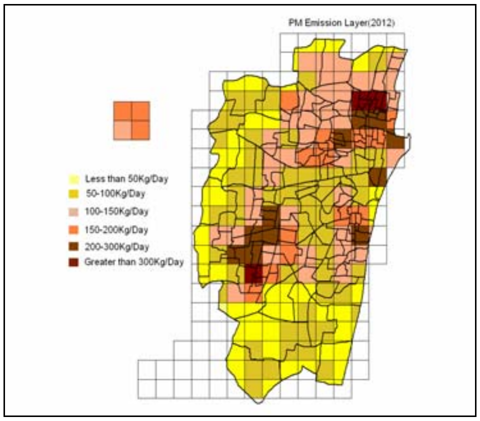


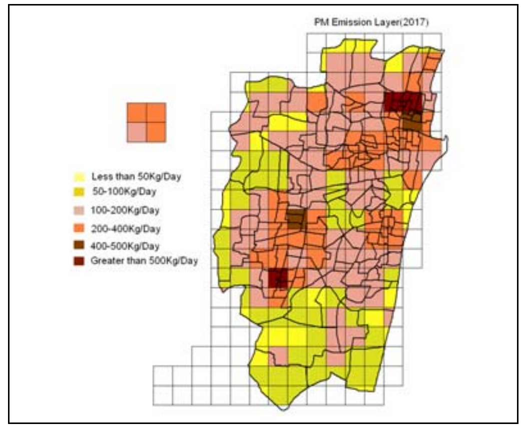
NOx Emission Load (kg/day)- All Sources

Chennai

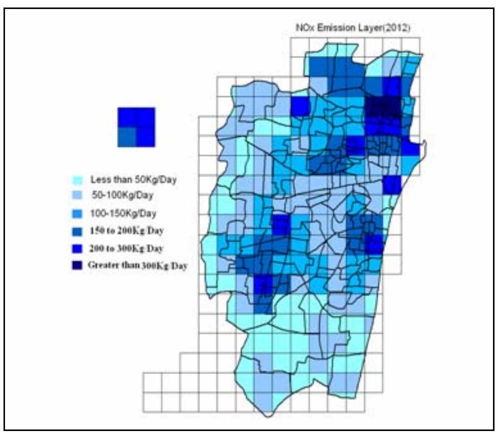
BAU -2012

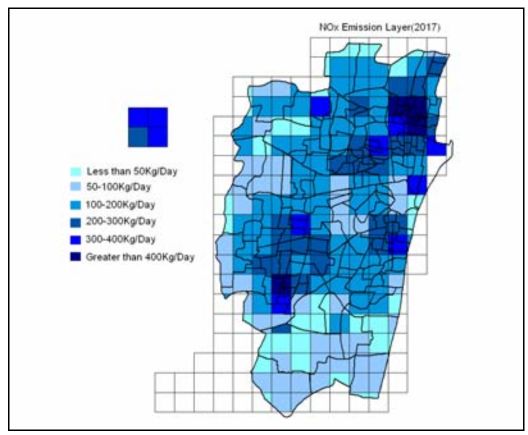
BAU- 2017





PM_{10} Emission Load (kg/day)- All Sources



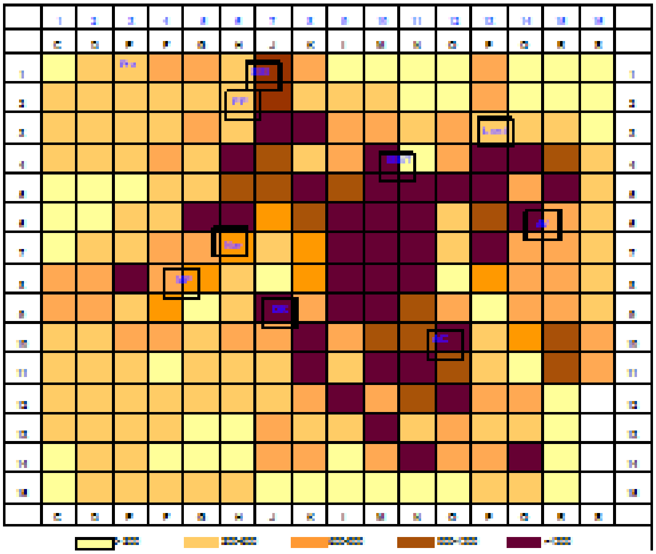


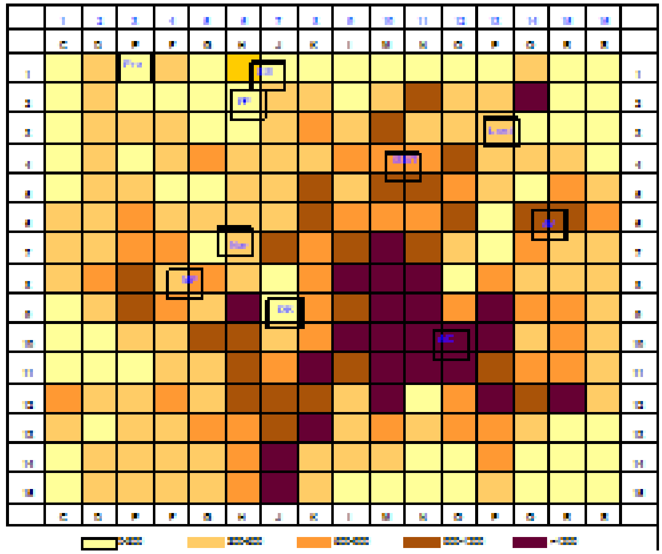
NOx Emission Load (kg/day)- All Sources

Delhi

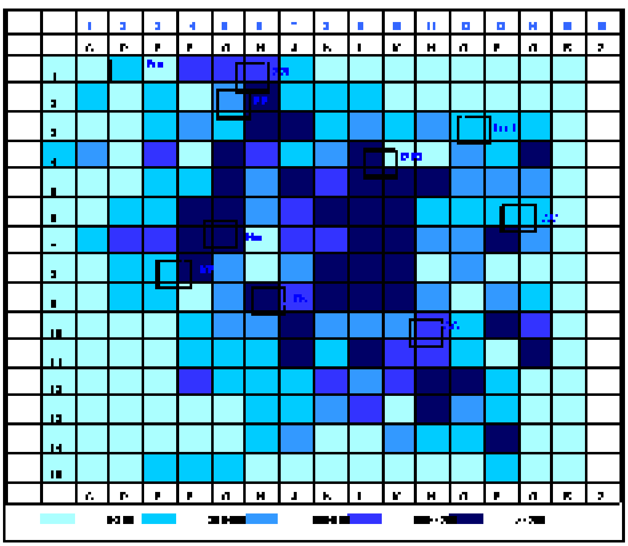
BAU - 2012

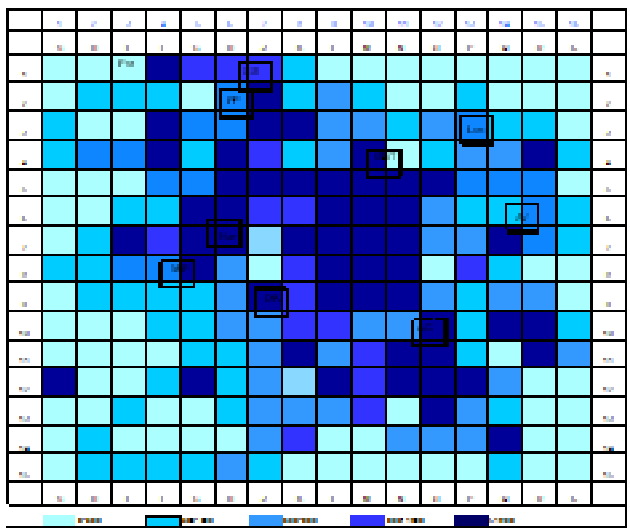
BAU – 2017





PM_{10} Emission Load (kg/day)- All Sources

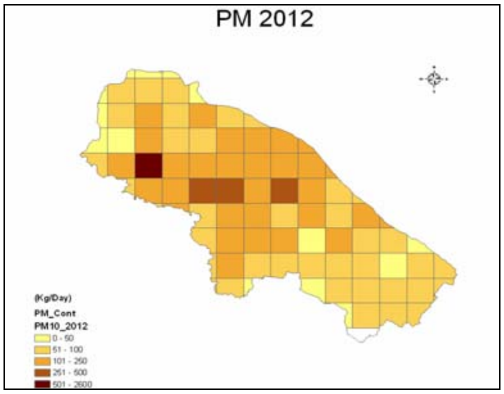


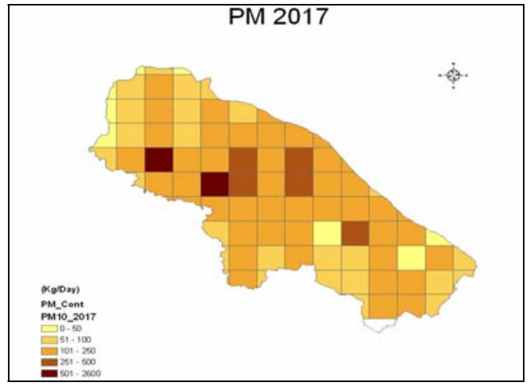


NOx Emission Load (kg/day)- All Sources

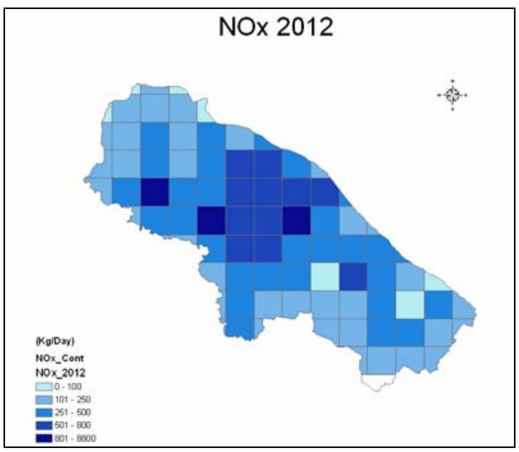
Kanpur

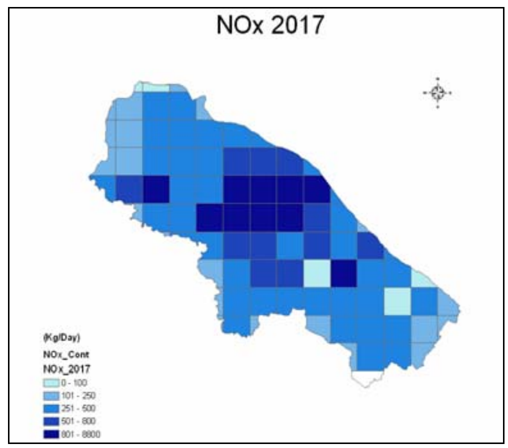
BAU - 2012 | **BAU – 2017**





PM_{10} Emission Load (kg/day)- All Sources

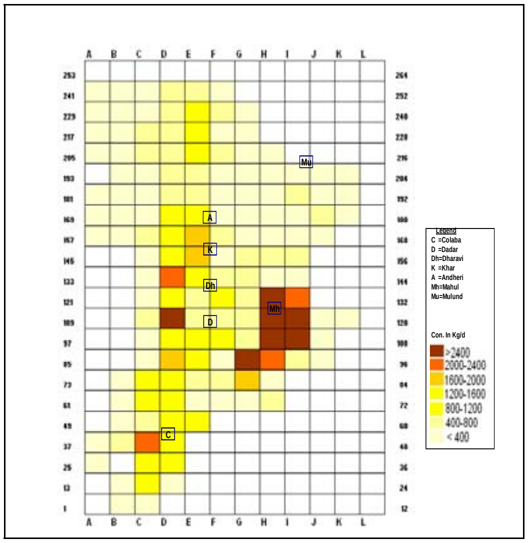


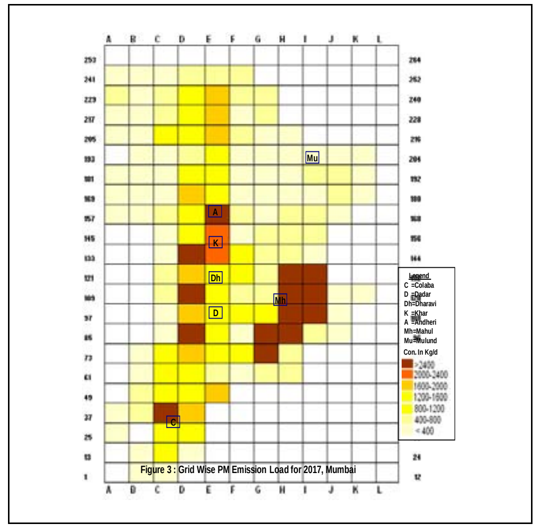


NOx Emission Load (kg/day)- All Sources

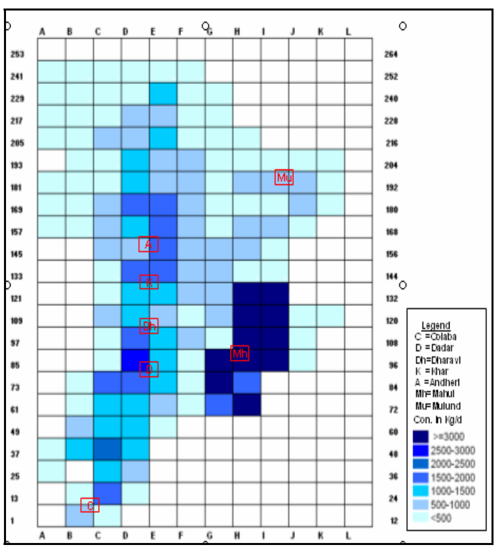
Mumbai

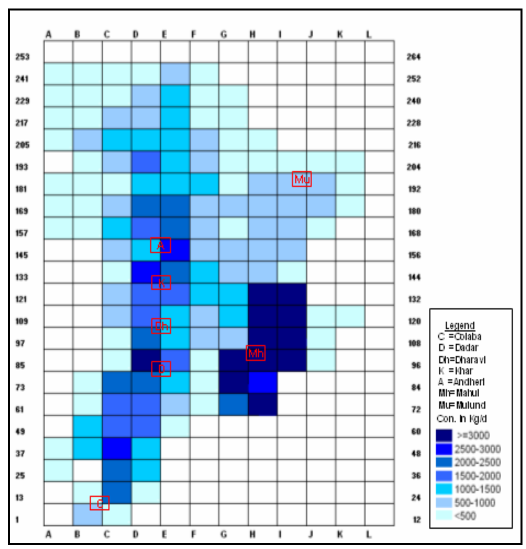
BAU - 2012 **BAU – 2017**





PM_{10} Emission Load (kg/day)- All Sources

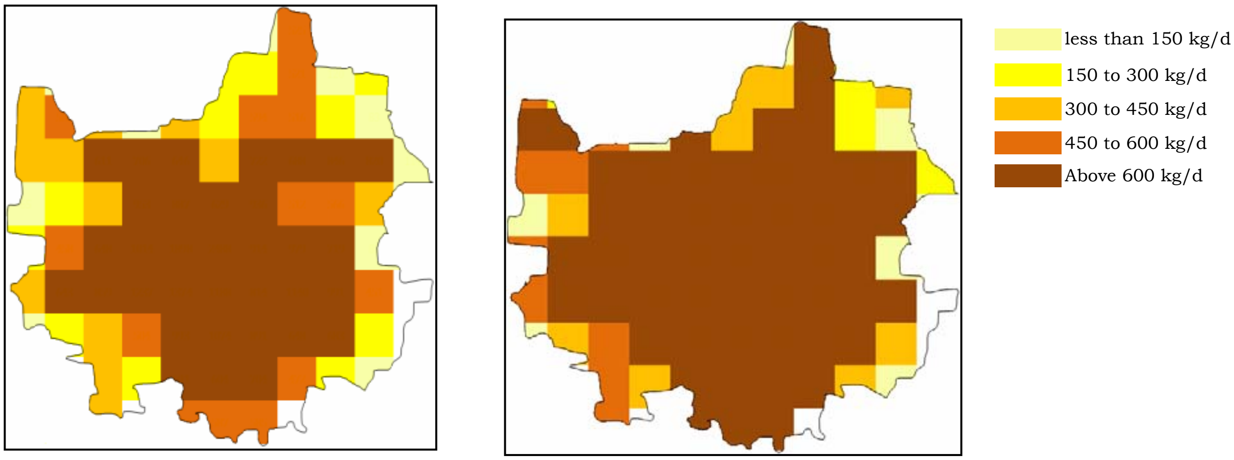




NOx Emission Load (kg/day)- All Sources

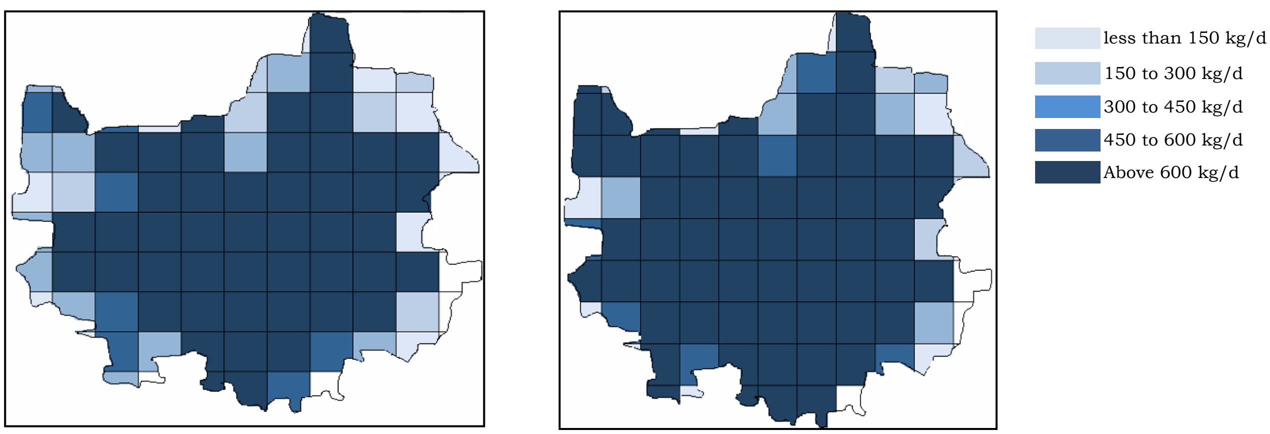
Pune

BAU - 2012 **BAU – 2017**



BAU 2012- PM **BAU 2017-PM**

PM_{10} Emission Load (kg/day)- All Sources



BAU 2012-NOx **BAU 2017-NOx**

NOx Emission Load (kg/day)- All Sources