Air Quality

Emissions   Exposure

URBAIR

Abatement   Damage

Cost

Urban Air Quality Management Strategy in Asia

GREATER BOMBAY City Specific Report

Prepared under contract from
The World Bank
Asia Technical Division

NILU

The Norwegian Institute for Air Research
P.O.Box 100, N-2007 Kjeller, Norway

Instituut voor Milieuvraagstukken
Vrije Universiteit, De Boelelaan 1115,
1081 HV Amsterdam, The Netherlands

NILU : OR 56/95
REFERENCE : O-92117
DATE : DECEMBER 1995
ISBN : 82-425-0717-1

URBAIR

Urban Air Quality Management Strategy in Asia

GREATER BOMBAY
City Specific Report

Prepared by

Steinar Larssen, Frederick Gram and Leif Otto Hagen
Norwegian Institute for Air Research (NILU)
Kjeller, Norway

Huib Jansen and Xander Olsthoorn
Instituut voor Milieuvraagstukken (IVM) Vrije Universiteit,
Amsterdam, the Netherlands

Rajiv V. Aundhe and Ulhas Joglekar
ADITYA Environmental Services, Bombay

K.H. Mehta
Maharashtra Pollution Control Board, Bombay

A.A. Mahashur
KEM Hospital, Bombay

The Norwegian Institute for Air Research
P.O.Box 100, N-2007 Kjeller, Norway

Instituut voor Milieuvraagstukken
Vrije Universiteit, De Boelelaan 1115,
1081 HV Amsterdam, The Netherlands

Notice

This report from the URBAIR project conducted under the Metropolitan Environment Improvement Program of the World Bank, ASTEN Division, is the version produced by the project consultants (Norwegian Institute for Air Research and Institute for Environmental Studies in Amsterdam) for the World Bank. The World Bank publishes the official version of this report. The contents is basically the same, but the layout is somewhat different.

This present version of the report is distributed upon request, from NILU, until the official World Bank version is available. The two versions can be used interchangably, as they are basically identical.

Preface

In view of the potential environmental consequences of continuing growth of Asian metropolitan areas, the World Bank and UNDP launched the Metropolitan Environmental Improvement Program (MEIP) in five Asian metropolitan areas - Beijing, Bombay, Colombo, Jakarta, and Metro Manila. In 1993, Kathmandu joined the intercountry program as the sixth MEIP city. The mission of MEIP is to assist Asian urban areas tackle their rapidly growing environmental problems. Presently, MEIP is supported by the governments of Australia, Netherlands and Belgium.

Recognizing the growing severity caused by industrial expansion and increasing vehicle population, the World Bank started the Urban Air Quality Improvement (URBAIR) initiative in 1992 as a part of the MEIP. The first phase of URBAIR covered four cities - Bombay, Jakarta, Kathmandu, and Metro Manila. URBAIR is an international collaborative effort involving governments, academia, international organizations, NGOs, and the private sector. The main objective of URBAIR is to assist local institutions in these cities to develop action plans which would be an integral part of their air quality management system (AQMS) for the metropolitan regions. The approach used to achieve this objective involves the assessment of air quality and environmental damage (e.g. on health, materials), the assessment of control options, and comparison of costs of damage and costs of control options (cost-benefit or cost-effectiveness analysis). From this, an action plan can be set up containing the selected abatement measures, for implementation in the short/medium/long term.

The preparation of this city-specific report for Bombay is based upon the collection of data and specific studies carried out by the local consultants, and upon workshops and fact-finding missions carried out in April and August 1993, and May 1994. A first draft of the report was prepared by Norwegian Institute for Air Research (NILU) and Instituut voor Milieuvraagstukken (IVM, Institute for Environmental Studies) before the first workshop, based upon general and city-specific information available from earlier studies. A second draft report was prepared before the second workshop, with substantial inputs, from the local consultants, and assessment of air quality, damage and control options, and cost analysis carried out by NILU and IES.

The participating institutions and agencies from Bombay were as follows:

Government: Nodal Organisations/Departments

- Department of Environment (DOE) Govt. of India.
- Maharashtra Pollution Control Board (MPCB).
- Municipal Corporation of Greater Bombay (MCGB).
- Bombay Metropolitan Regional Development Authority (BMRDA).
- Bhabha Atomic Research Centre (BARC).
- India Meteorological Department (IMD).
- Traffic Commissioner.
- Transport Department; Govt. of Maharashtra.

Non-Government Organisations (NGO's)

- Bombay Environmental Action Group (BEAG).
- Save Bombay Committee.
- Environmental Medical Association of India (EMAI).
- Urban Development Institute (UDI).
- Society for Clean Environment (SOCLEEN).
- Bombay Natural History Society (BNHS).

Institutions

- Indian Institutes of Technology (IIT).
- Indira Gandhi Institute of Developmental Research (IGIDR).
- National Environmental Engineering Research Institute (NEERI).

Industries

- Rashtriya Chemical & Fertilizers Ltd. (RCF).
- Gas Authority of India Ltd. (GAIL).
- Indian Chemical Manufacturers Association (ICMA).
- Bombay Chamber of Commerce & Industries.

Consultants

- Aditya Environmental Services
- Associated Industrial Consultants now AIC Watson Pvt. Ltd.
- Coopers & Lybrand, U.K.
- Econ Pollution Pvt. Ltd.
- Apte Consulting Engineers Pvt. Ltd.

Press

- The Times of India.

The report concludes with an action plan for air pollution abatement produced by the local working groups (see pp. 5-6) as a result of the deliberations and discussions before, during and after the second workshop. NILU/IES carried out cost/benefit analysis of some selected abatement measures, showing the economic viability of many of the technical control options.

It is expected that the local institutions, based upon the results from the analysis as presented in this report and the action plan formulate a prioritized strategy for improving Bombay air quality in the short, medium and long term. This prioritized action plan is expected to be the basis for the air quality work of the municipal authorities, in developing a control strategy and an investment plan.

The report is organized as follows:

- An extensive Summary.
- Background information (Ch. 1), summarizing the development in the city over the last decade regarding population, pollution sources such as industry and road traffic, and fuel consumption.
- Air quality assessment (Ch. 2), containing summary of the present air pollution situation, emissions, inventory, dispersion and population exposure calculations, and suggestions for improving the data base for the assessment.
- Projections of air pollution emissions (Ch. 3).
- Air pollution impact (damage/assessment and its valuation (Ch. 4), describing and calculating the health damage from the air pollution.
- Description of institutional framework (Ch. 5).
- Abatement measures (Ch. 6), describing the effectiveness and costs of selected technical control measures.
- Draft action plan (Ch. 7), containing the full Action Plan as developed by the local working groups, and a summary of the cost-benefit analysis of the selected technical control options.
- References (Ch. 8).

An Appendix report contains more detailed descriptions of the air quality data, the emissions inventory and emission factors, population exposure calculations, and laws and regulations.

Acknowledgements

Many contributed to the URBAIR process. URBAIR core funds were provided by UNDP, the Royal Norwegian Ministry of Foreign Affairs, the Norwegian Consultant Trust Funds, and the Netherlands Consultant Trust Funds. Substantial inputs were provided by host governments and city administrations.

City studies were conducted by the Norwegian Institute for Air Research (NILU) and the Institute of Environmental Studies (IES) at the Free University in Amsterdam, with assistance from the selected local consultants: Leader of the URBAIR activities in Bombay, K.H. Mehta, MPCB; ADITYA Environmental Services, represented by U. Joglekar and R. Aundhe; and A.A. Mahashur, KEM Hospital. The city-level technical working groups provided operational support, while the steering committee members gave policy direction to the study team. The National Program Coordinator (NPC) of MEIP - Bombay, G.N. Warade provided substantial contribution to the successful outcomes.

At the World Bank, the URBAIR was managed by Jitendra Shah and Katsunori Suzuki, and under the advice and guidance of Maritta Koch-Weser and David Williams. Colleagues from Country Departments commented on the numerous drafts. Management support was provided by Sonia Kapoor and Ronald Waas.

Many international institutions (WHO, US Environmental Protection Agency, US Asia Environment Partnership) provided valuable contribution through their participation at the workshops. Their contribution made at the workshop discussions and follow-up correspondence and discussions has been very valuable for the result of the project.

The individuals participating in the Bombay URBAIR working groups were:

Working group I
for
Air Quality Assessment

Head: Mr. V.S. Mahajan, Deputy City Engineer, Municipal Corporation of Greater Bombay

Members:

Name	Organization	Category
Dr. K.S.V. Nambi	Bhabha Atomic Research Centre	Govt.
Dr. T.N. Mahadevan	Bhabha Atomic Research Centre	Govt.
Dr. S. Kumar	India Meteorological Department	Govt.
Mr. K.S. Sonawane	Municipal Corporation of Greater Bombay	Govt. Undertaking
Mr. S.B. Patil	Maharashtra Pollution Control Board	Govt. Undertaking
Dr. V.N. Patkar	Bombay Metropolitan Region Development Authority	Govt. Undertaking
Mr. B.S. Negi	Gas Authority of India Ltd.	Govt. Undertaking
Mr. S.J. Arceivala	Associated Industrial Consultants (India) Pvt. Ltd.	Consultant
Mr. A.K. Sahu	Econ Pollution Control Pvt. Ltd.	Consultant
Mr. S.V. Athavale	Apte Consulting Engineers	Consultant
Mr. R.V. Aundhe	Aditya Environmental Services	Consultant
Mr. Mr. K. Mohan	Rashtriya Chemicals & Fertilizers Ltd.	Industry
Dr. (Ms). R.S. Patil	Indian Institute of Technology	Institution
Dr. V. Joshi	National Environmental Engineering Research Institute (NEERI)	Institution

Working group II
for
Economic Valuation

Head: Dr. A.A. Mahashur, Prof. & Head-Dept. of Chest Medicine, K.E.M. Hospital, Municipal Corpn. of Greater Bombay

Members:

Name	Organization	Category
Dr. V.N. Bapat	Bhabha Atomic Research Centre	Govt.
Ms. S.S. Bhende	Maharashtra Pollution Control Board	Govt. Undertaking
Dr. (Ms.) B.S. Sanghani	King Edward Memorial Hospital, Municipal Corporation of Greater Bombay	Govt. Undertaking
Dr. (Ms.) Nandita Sen	"	Non-Govt. Organisation
Dr. V.G. Shirke	"	Non-Govt. Organisation
Dr. S.R. Kamat	"	Non-Govt. Organisation
Ms. J.P. Rezler	Coopers & Lybrand, U.K.	Consultant
Mr. M.G. Rao	Rashtriya Chemicals & Fertilizers Ltd.	Industry
Dr. S.R. Asolekar	Indian Institute of Technology	Institution
Dr. V.K. Sharma	Indira Gandhi Institute of Development Research	Institution
Mr. S. Ramaswamy	Bombay Chamber of Commerce & Industry	Association

Working group III
for
Institutional & Policy Instruments

Head: Mr. U.K. Mukhopadhyay, Secretary, Environment Dept. & Chairman, Tech. Committee-MEIP

Members:

Name	Organization	Category
Captain P.G. Deshmukh	Transport Department	Govt.
Dr. P.S. Pasricha	Police Department (Traffic)	Govt.
Mr. G.N. Warade	Environment Department	Govt.
Mr. D.R. Rasal	Maharashtra Pollution Control Board	Govt. Undertaking
Mr. V.K. Phatak	Bombay Metropolitan Region Development Authority	Govt. Undertaking
Mr. Debi Goenka	Bombay Environmental Action Group	Non-Govt. Organisation
Mr. A.M. Ranu	Environmental Medical Association of India	Non-Govt. Organisation
Dr. Rashmi Mayur	Urban Development Institute	Non-Govt. Organisation
Dr. T.R. Saranathan	Society for Clean Environment	Non-Govt. Organisation
Mr. Bittu Saigal	Bombay Natural History Society	Non-Govt. Organisation
Mr. B.V. Rotkar	Associated Industrial Consultants (India) Pvt. Ltd.	Consultant
Dr. (Ms). P.P. Parikh	Indian Institute of Technology	Institution
Dr. Prasad Modak	Indian Institute of Technology	Institution
Dr. S.G. Advani	Indian Chemical Manufacturers Association	Association/Industry
Dr. Dharmarajan	The Times of India	Press

Contents

Page

Summary

Past and present development of Greater Bombay

Greater Bombay, like other megacities in developing nations, is increasing rapidly in size and diversity. The concentration of population and industry in these cities is high and still getting higher. This situation creates urban air pollution problems in these cities caused by increasing emissions from vehicular traffic, industry and domestic heating, cooking and refuse burning. In the future, potential risk for air pollution exposures will increase at an alarming rate, if the emissions are allowed to develop uncontrolled.

Bombay has experienced strong growth over the past decades. The population of Greater Bombay grew 38% from 1971 to 1981, and further with 20% till 1991, when the population was 9.9 million. The India GDP/capita was in 1992 US$ 330. Over the period 1965-1989 the annual growth rate in GDP/capita was +1.8%, about the same as for the USA. Over the 1980-90, the growth rate was +3.2%; this is increasing.

The number of vehicles increased by 103% over the period 1981-1991, especially motorcycles. In 1991, 628,500 vehicles were registered, corresponding to about 16 inhabitants per vehicle. The distribution was 48% cars, 39% motorcycles, 1% utility vehicles, 9% trucks and buses and 4% motor-rickshaws.

The increasing number of vehicles, among other developments have caused a substantial fuel consumption increase. From 1985 to 1990 the increase has been about 25% for both gasoline and diesel oil. Furnace oil consumption has decreased significantly (25%), replaced by low sulphur oil (LSHS). In 1991 the per capita annual consumption was 37 liters of gasoline, 67 liters of diesel oil and 106 liters of fuel oil.

These developments are reflected in the air pollution concentrations in Greater Bombay. Annual average Total Suspended Particles (TSP) concentration increased substantially from about 180 $\mu g/m^3$ to about 270 $\mu g/m^3$ during 1981-1990, an increase of about 50%. NO_x increased less than that, by about 25%, while SO_2 decreased due to replacement with lower sulphur fuel. The average lead concentration doubled from 1980 to 1987. This development is well documented through the long-term operation of the MCGB air monitoring system, producing good quality data. At present, WHO Air Quality Guidelines for TSP are substantially and frequently exceeded. The National TSP Air Quality Standard is not exceeded in Bombay, as the city is defined as an industrial area. The National standard for residential areas is exceeded.

The continued growth of population and GDP in Bombay is expected to worsen air pollution in the Bombay area substantially, unless corrective action is taken.

Air Quality Assessment

Greater Bombay's air quality has been assessed by reviewing available air quality measurements, constructing an emissions inventory, performing dispersion model calculations of long-term average concentrations, and based on this, calculating the distribution of population exposure to air pollution.

Air pollution measurements show that TSP and PM_{10} represent Greater Bombay's major air pollution problem. Concentrations exceed WHO air quality guidelines substantially and frequently in all parts of the city, with maximum concentrations of TSP at street crossings as much as 10 times the WHO guideline and about 6 times the national guideline. Hot-spot exposure occurs near main roads and in industrial areas, especially in the Chembur area. SO_2 and NO_2 pollution is not as serious as TSP and PM_{10} situation overall. CO and ozone have not been extensively measured.

The emission inventory was based upon available information, and many assumptions were made. **Main sources** of TSP and PM_{10} emissions were (relative contributions):

	TSP	PM_{10}
Diesel vehicle exhaust	8	15
Domestic wood combustion	14	14
Resuspension from roads (rough estimate)[1]	32	16
Gasoline vehicle exhaust	6	12
Domestic refuse burning (rough estimate)	11	24
Industrial fuel combustion	6	9

Population exposure distributions for TSP and PM_{10} were calculated based on

- calculated long-term average concentrations in a km^2 grid net using a gaussian, multisource dispersion model;
- population distribution in the same km^2 grid net; and
- estimated additional exposure in hot-spot areas (main road network and industrial areas).

It was calculated that 97% of the population live in areas where the WHO AQ Guideline for TSP, annual average (90 $\mu g/m^3$), is exceeded.

Estimated exposure in exceedance of two times AQG annual average TSP is 8% of the population, including an estimated 300,000 drivers, roadside residents, and residents near stone crushers.

The exposure is due to the following main sources:

For TSP: Resuspension from roads, domestic wood combustion, diesel vehicles, domestic refuse burning and gasoline vehicles.

[1] The calculation of resuspension from roads may represent an overestimate, as it is based on an overall emission figure of 2 g/km.

For PM_{10}: Diesel vehicles, domestic refuse burning, domestic wood and resuspension.

Additional exposure in industrial areas is due to process emissions.

The concept of Air Quality Management Strategy (AQMS)

The basic concept for an Air Quality Management Strategy contains the following main components:

- Air Quality Assessment;
- Environmental Damage Assessment;
- Abatement Options Assessment;
- Cost Benefit Analysis or Cost-effectiveness Analysis;
- Abatement Measures Selection (Action plan); and
- Optimum Control Strategy.

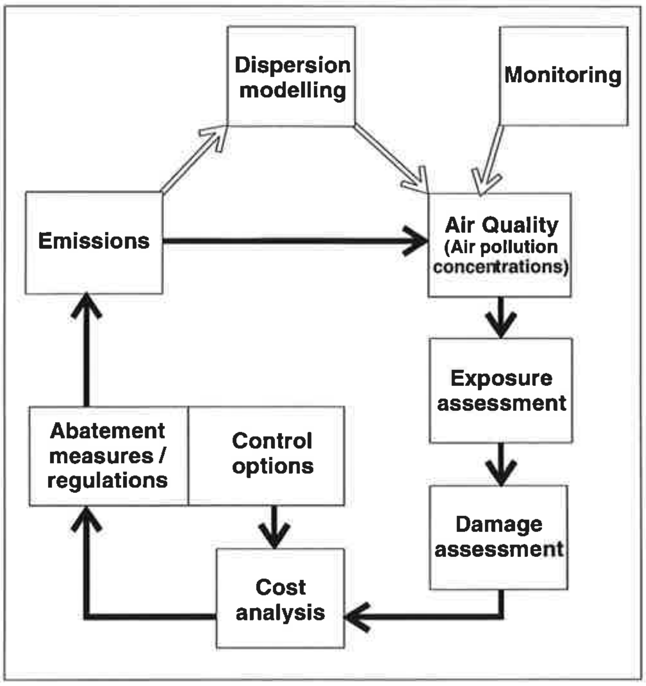
The Air Quality Assessment, Environmental Damage Assessment and Abatement Options Assessment provide input to the **Cost-benefit Analysis, or a Cost-effectiveness Analysis**, which is also based on established Air Quality Objectives (i.e. guidelines, standards) and Economic Objectives (i.e. reduction of damage costs). The analysis leads to an **Action Plan** containing abatement/control measures, for implementation in the short/medium/ long term. The final result of this analysis is an **Optimum Control Strategy**.

A successful AQMS requires the establishment/completion of an integrated system for continued air quality management. This system requires continuing activities on the urban scale in the following fields:

- inventory of air pollution activities and emissions;
- monitoring of air pollution and dispersion parameters;
- calculation of air pollution concentrations, by dispersion models;
- inventory of population, materials and urban development;
- calculation of the effect of abatement/control measures; and
- establishment/improvement of air pollution regulations.

These activities, and the institutions necessary to carry them out, constitutes the **System** for Air Quality Management that is a prerequisite for establishing the **Strategy** for Air Quality Management (AQMS).

The figure below represents a simple visualisation of the elements of the System for Air Quality Management, and the flow of information between them.



The process of developing an Air Quality Management Strategy (AQMS), for an urban area includes many steps. The most important of these are:

* identifying sources * quantifying sources — emission inventory * monitoring air pollution * assessing the exposure (impact) situation * identifying source - exposure relations ⟶ modelling * estimating the relative importance of various air pollution sources * assessing environmental damage		Assessment
* investigating short and long term control (abatement) options including urban planning needs * performing cost-benefit or cost-effectiveness analysis * developing a control strategy and an investment plan * developing institutions/regulations/enforcement * awareness raising		Control
* establishing an Air Quality Information System (AQIS)		Surveillance

As shown above, the AQMS consists of two main components, which are **assessment and control**. In parallel with the AQMS development, and to facilitate checking the effectiveness of the air pollution control actions, a third component is necessary, which is **surveillance** (monitoring).

The process of attaining acceptable urban air quality is dynamic and long term. As the urban areas develop, population, pollution sources and technology change. Throughout this process, it is very important to have an operating Air Quality Information System (AQIS), in order to:

- keep the authorities and the public well informed about the short-term and long-term AQ development
- assess the results of abatement measures, and thereby
- provide feed-back information to the abatement strategy process.

Needs for improvement of the Air Quality Assessment

There are uncertainties in this first phase URBAIR analysis of cost and benefits of air pollution reduction in Greater Bombay. The uncertainties relate for instance to the assessment of air quality and population exposure. There is a need for better assessment of e.g. the amounts and emission factors of domestic refuse burning and wood combustion, which stand out as important sources for the exposure to PM_{10}.

The present **system of air quality measurements** in Greater Bombay is based on rather infrequent 24 hour sampling (1-4 times per month at each site) at 22 stations of TSP, SO_2, NO_2 and NH_3. PM_{10}, lead and CO are not measured routinely. It is clear that it is important to improve the AP monitoring system of Greater Bombay, to include continuous monitors in routine, long-term operation. It is recommended that the system includes at least:

- a number (at least 5) of city background sites
- some (1-3) traffic exposed sites
- some (1-5) industrial area/hot spot sites
- monitors (continuous) for PM_{10}, CO, NO_x, SO_2, O_3, depending upon the site
- on-line data retrieval system directly to lab database, via telephone/modem.

The main shortcomings of the **emission inventory** concerns:

- industrial emissions (use and combustion of fuel, process emissions)
- resuspension from roads
- other coarse particle sources, such as construction
- domestic refuse burning
- consumption patterns for domestic and commercial fuel use.

Less important shortcomings regard the traffic distribution data which forms the background for the car exhaust emission distribution. It is necessary to fill the data gaps in the inventory, and up grade the inventory in general.

The determination of the **population exposure** to air pollution in Bombay, and the contributions to this exposure from various sources, is based on a combination of dispersion modelling and air pollution monitoring. A population exposure distribution of good quality is important since it is the basis for:

- estimating health damage costs
- assessing the effects on health of various measures to reduce the exposure, as part of a cost-benefit analysis.

To improve the population exposure calculations beyond what has been developed as part of the 1. phase of URBAIR, dispersion modelling expertise in Bombay should be identified, and the use of dispersion modelling should be integrated in the Air Quality Management work of the control agencies. The dispersion modelling expertise, and appropriate models for air pollution management and control strategies should rest within the Greater Bombay institutional basis.

Health impacts and their valuation

The **current health impacts and health damages** were calculated based on dose-effect relations derived from studies in cities in the USA, lacking more appropriate data. The results are presented in Table 1. The damage due to increased mortality is calculated from lost salaries. Other methods may give much higher values. Note that the impacts of lead are not included.

Table 1: Health impacts from PM_{10} and their valuation (1991).

Type of health impact	Number of cases	Total costs (million Rs.)
Mortality	2,800	11,753
Restricted activity day	19 million	523
Emergency room visit	76,000	22
Bronchitis (children)	190,000	61
Asthma attacks	741,000	741
Respiratory symptoms day	60 million	1,189
Respiratory hospital admission	4,000	38
Chronic Bronchitis	20,000	3,201
Total		17,528

A necessity for designing strategies - sets of measures - to control air pollution is insight in the sources. Table 2 presents the contributions of different source categories to the emission of PM_{10}. The table does not show that these sources are spatially distributed over the Bombay area. Spatial distribution is incorporated the dispersion model.

Table 2: PM_{10} emissions (tonnes) in Bombay (1992).

Gasoline vehicles	1,229
Diesel vehicles	2,444
Resuspension traffic particles	2,550
Domestic emissions & refuse burning	5,935
Large point sources (industrial)	~1,500
Industry - distributed sources	1,496
Total	15,154

This table shows the importance of both the traffic related emissions (the top three categories) and the domestic emissions and refuse burning. Calculations showed that the marginal benefits reduction of the industrial emissions gave the largest marginal benefits in terms of reduced health effects (table 4.6).

Institutions, laws and policies regarding air pollution

Existing laws and regulations include:

- National Ambient Air Quality Standards, which are somewhat less strict than WHO guidelines, except for TSP, which is considerably more lax than WHO guidelines, especially for areas of industrial and mixed use, such as Bombay,
- Emission standards for both stationary sources and road vehicles. For stationary sources, permits are given based on individual evaluation of the plant's impact. Present motor vehicle emission standards in India are rather strict. The regulation of April 1991 is comparable to the European regulation applicable there from 1982 (ECE R15/04). The proposed regulation of April 1995 is actually stricter than the European regulation applicable from 1988,
- Annual Environmental Audit, a new requirement for industries to submit annual audit reports.
- The Central Action Plan (1992), which prescribes 15 sensitive areas (among them Bombay) and 8 industry categories eligible for strict enforcement of compliance with emission standards.

Regulations and policies to improve Bombay's air quality which are believed to have had a significant impact are restrictions on the use of coal, the Industrial Location Policy of 1984, and the Central Action Plan of 1992, to enhance enforcement against non-compliance. Also, regulations such as restrictions on autos plying on the roads of the island city, and restrictions forbidding entry of heavy commercial vehicles to the island city during peak hours have an effect on the air quality.

The main environmental advisory, planning and law-enforcing bodies are the Pollution Control Boards (PCB), the Central Board at the Central government level, and the State Boards at the State level. The State Boards also have the responsibility to monitor pollution. In Bombay, this responsibility is shared with the Municipal Council of Greater Bombay (MCGB).

A list of suggested policies and institutional modifications have been suggested to improve environmental management (ch. 5.3).

Abatement measures

The design of **emission control strategies** requires a database of measures containing information about their costs, their effectiveness (avoided emissions) and preferably also about their benefits in terms of avoided pollution impacts and damages. This information is presented in chapter 6. The information is confined to measures appropriate for the transport sector. Lack of appropriate information did not allow identifying and evaluating measures to address domestic emissions and emissions from refuse burning. Measures which are benign from a cost-benefit point of view are:

- introduction of low-smoke lubricating oil.
- addressing gross polluters.

Other measures, from which their cost-benefit ratios are less clear - due to lack of data or methodological problems - are:

- improving the quality of automotive diesel fuel;
- clean car standards (requiring the introduction of unleaded gasoline);
- (further) development of the use of natural gas both for automotive and stationary use;
- improvement of the public transport system.

These technical measures provide only a part of a solution. Other policies, e.g. relating to public transport, land use and industrial development, have impact on the emissions.

Future air quality for a reference scenario

The **reference scenario** for the Bombay emissions of PM_{10} is shown in Figure 1.

This reference scenario is constructed by a simple extrapolation of trends in the number of vehicles and the Bombay population, assuming other factors not changing. Today, domestic sources (wood and refuse burning) represent as important an emission source as vehicle exhaust (all vehicle types together). However, under the various assumptions it appears that emissions related with traffic will grow the fastest. Important subsectors are diesel vehicles, passenger cars and motorcycles.

Clearly, environmental risks in Bombay are on the rise. If one takes into account that the Bombay population tended to grow with a rate of about 3% annually in the future more people will be exposed to higher concentrations and impacts may well double over the coming ten years.

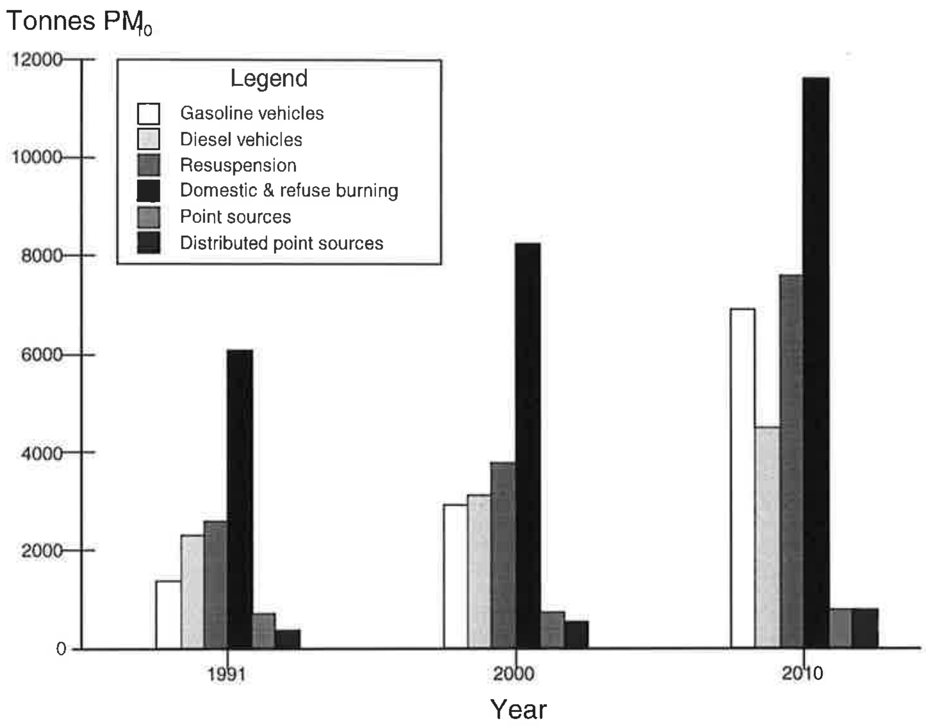


Figure 1: Reference scenario for PM_{10} emissions in Bombay.

Action plan

Through the work carried out in the local working groups, a number of proposed actions and measures have been listed, and categorized within the following categories:

- Vehicular pollution.
- Monitoring.
- Industrial pollution.
- Community sources.

A selection of "obvious" technical measures for possible short-term introduction was made, and cost-benefit analysis carried out for each measure separately.

Table 3 gives a summary of the cost-benefit analysis. For all of the selected measures except cleaner fuels in power plants, the calculated benefits are very substantial, in the tens of millions of USD annually, and the benefits are, as a rule, much higher than the estimated costs.

Table 3: Draft Action Plan of abatement measures, Greater Bombay, based on cost-benefit analysis.

Abatement measure	Avoided emissions, tonnes *PM10*/a	Mortality reduc-tion	Reduced RSD (million days)	Annual health benefits (million Rs.)	Annual costs (million Rs.)	Time frame	
						Intro-duction of measure[1]	Effect of measure
Vehicles							
Unleaded gasoline	2)	2)	2)	2)	250-360	Immediate	2-5 years
Low-smoke lub. oil, 2-stroke	450	65	1.5	150	30	Immediate	2 years
Inspection/ maintenance	800	110	2.5	250	150-300	Immediate	2-5 years
Address gross polluters	400	50	1.2	125	2)	Immediate	2 years
Clean vehicle standards - cars and vans	400	50	1.2	125	750	Immediate	5-15 years
- motorcycles and tricycles	750	100	2.4	250	600	Immediate	5-10 years
Improved diesel quality	250	35	0.75	80	300	Immediate	2-5 years
CNG replace gasoline, 50%	200	25	0.6	75	2)	Immediate	5-10 years
Fuel combustion							
Cleaner fuel oil (FO to 2% S)	150	22	0.5	50	450	Immediate	2-5 years

1 Time frame for starting the work necessary to introduce measure.
2 Not quantified.

The action plan incorporate the following measures:

Unleaded gasoline:

- We consider this an important early action, and a prerequisite for clean vehicle emission standards.
- Although the health benefits are substantial, they have not been quantified in this project.

Low-smoke lubrication oil, 2 stroke

- Setting a standard for the oil quality.
- Enforcement of standard (may be problematic).
- Taxes and subsidies to set oil price according to quality.

Inspection/Maintenance

- Annual or bi-annual inspection
- Establishment of more inspection and maintenance stations (government or private)

- Basic legislation is in place

  The potential for reduced emissions is largest for diesel vehicles. The I/M might, at the start, be concentrated on diesel vehicles.

Addressing gross polluters:

- Strict enforcement of existing smoke opacity regulation for diesel vehicles.

  Success is dependent on whether the maintenance/adjustment of engines actually takes place. Routines for ensuring that must be a part of the action.

Clean vehicle emission standard:

- Establish state-of-the-art vehicle emission standards for gasoline cars, diesel vehicles and motorcycles.
- Ensure the availability of lead-free gasoline, at a lower price than the leaded gasoline.

Improving diesel quality:

- Modifications in Indian/Bombay refineries to produce low-sulphur (0.2%) diesel
- Taxes/subsidies to differentiate fuel price according to fuel quality.

Fuel switching: Gasoline-to-LPG/CNG in vehicles:

- Changes in tax/subsidy structure to make LPG/CNG the preferred fuel
- Establishment of distribution/compression system for CNG.

Cleaner fuel oil:

- Substantial reduction of the sulphur content of furnace oil, initially to 2%.

URBAIR

Urban Air Quality Management Strategy in Asia

GREATER BOMBAY
City Specific Report

1. Background information

1.1 Scope of the study

The present city specific report on Air Quality Management for the city of Greater Bombay has been produced as part of the URBAIR program.

The major objective of the URBAIR program is to develop a generalized Air Quality Management Strategy (AQMS) to be used for Asian cities, and to apply this strategy to develop Action Plans for improvement the air quality in the following cities: DKI Jakarta, Greater Bombay, Kathmandu Valley and Metro Manila.

The developed AQMS is based on the costs and benefits analysis of proposed actions and measures for air pollution abatement. Benefits include the reduced costs of health and other damage due to air pollution, which results from the implementation of abatement measures. In this study, emphasis is put on health damage, which is estimated based on the calculation of the distribution of population exposed to air pollutants, based again on measured and calculated concentrations of air pollution, through emission inventories and dispersion modelling.

The generalized strategy is described in a separate URBAIR Guidebook on Air Quality Management Strategy. City specific reports are produced for each of the four cities, based on city specific analysis. The city specific reports conclude with prioritized Action Plans for air quality improvement, including costs and benefits figures. The Action Plans are based on a comprehensive list of proposed measures and actions developed by local working groups in each of the four cities, and evaluated by the URBAIR consultants.

1.2 General description of Greater Bombay

The City of Bombay is located on the Coast of western India, on a peninsula originally composed of seven islets. Through drainage and concentration, the islets have been joined to form the present-day Bombay Island, between the Arabian Sea to the west and Bombay Harbour and the outlet of Thana Creek to the east. Municipal boroughs and villages of Bombay Island and Salsett Island to the north were joined in 1957 to form Greater Bombay. The Bombay Metropolitan Region (BMR) continued to expand and now includes New Bombay to the east of Thana Creek and Bombay Harbour and other areas further to the north and east. In the mid 1980s BMR covered an area of more than 600 km^2. Figure 1.1 shows a map of BMR. The population density of Greater Bombay averages about 16,500 persons per km^2 (1991), and in the older central parts of Bombay it is more than 3 times that. The population was about 9.9 million in 1991.

Much of Bombay is on a flat plain, one-fourth of which is below sea level. Two ridges going north-south flank the flat area, the highest point being Malabar Hill to the south-west, 55 meters above sea level.

Bombay is India's main industrial city, with many air polluting industries located in Chembur to the east. The main roads, which follow the elongated north-east direction of Bombay, are congested most of the day, particularly the eastern and western Express Highways, and the Thana Creek Bridge Road. Much of the municipal and commercial activities take place in the southern part of the city, and commuting to and from populated areas to the north puts a large burden on the road system. Maximum traffic flow at a road section is about 120,000 vehicles per day (Annual Average Daily Traffic, AADT).

Three suburban surface electric train systems provide the main public transportation, together with the municipally owned bus fleet. Bombay harbour is India's busiest, handling more than 40% of India's maritime trade.

A few changes have occurred in BMR over the last decade or more, which has significantly altered the land use structure of the area (Coopers & Lybrand and AIC, 1994):

- Massive new housing developments in previous non-urban belts along the western corridor and the Bombay-Pune (eastern) rail corridor.
- The development of New Bombay on the mainland, east of Thane Creek.
- Development of commercial complexes in the reclamation area along Mahim Creek and Mithi River on the outskirts of the island city, and the district center Oshiwara in the northern suburbs.

Much of the area's commercial activity still takes place in the central and south Bombay area, and the capacity of the road and rail system to accommodate the increasing need for south-north commuting is much too small, creating congestion during most of the daytime.

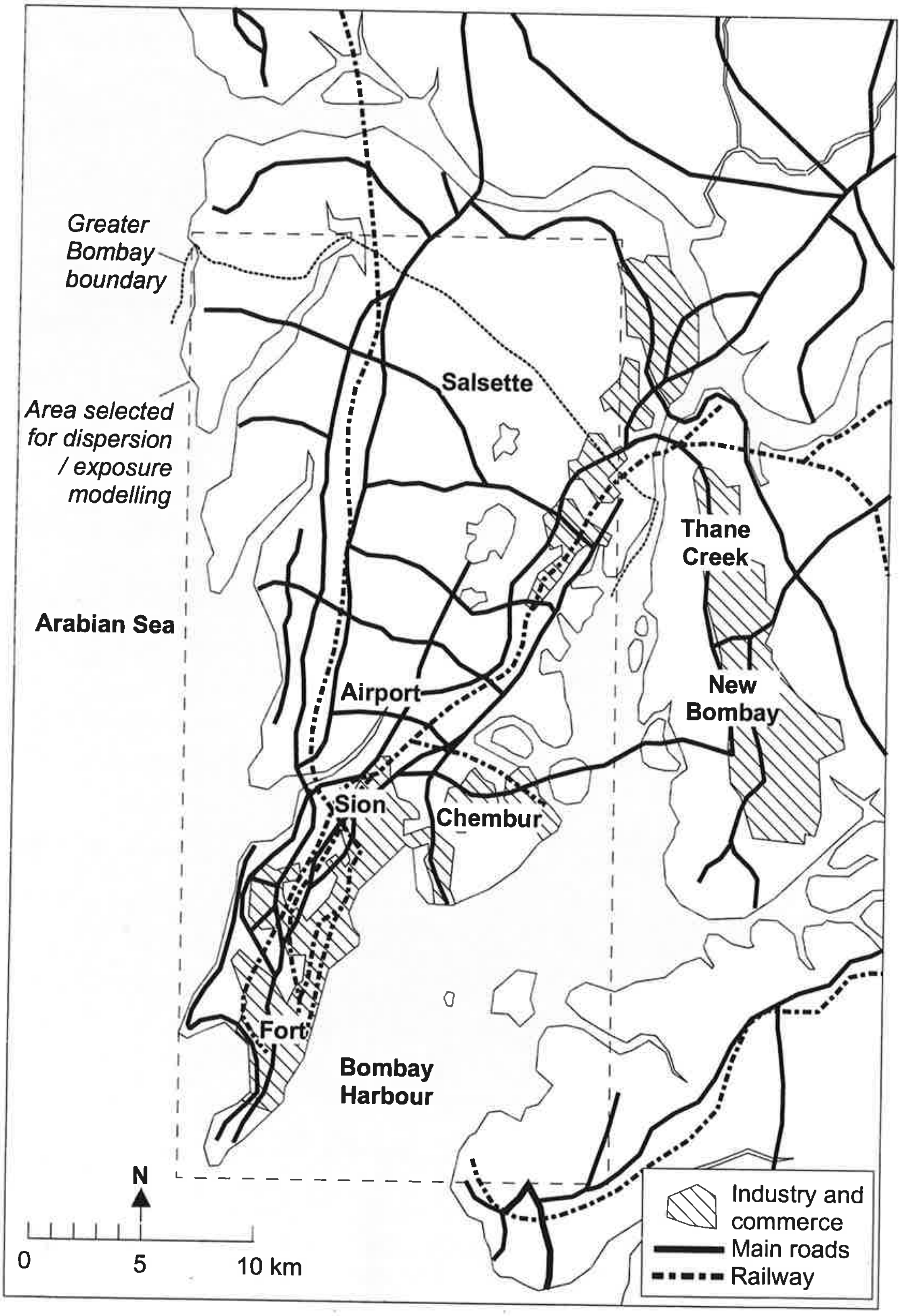


Figure 1.1: *Bombay Metropolitan Region, and Greater Bombay, with main roads, railroads, industrial and commercial areas, and modeling area used in this study.*

1.3 Data sources

Previous studies

There has been no comprehensive study of the air pollution situation in Bombay, describing air quality, sources, emissions and exposure.

The Maharashtra Pollution Control Board (MPCB), the Municipal Corporation of Greater Bombay (MCGB) and the National Engineering and Environmental Research Institute (NEERI) have presented various data on air quality and emissions, and the Bombay air pollution situation is briefly described by WHO/UNEP (1992), mainly based upon the three GEMS (Global Environmental Monitoring System) monitoring sites in Bombay, operated by NEERI.

Recently, the Study on Environmental Management Strategy and Action Plan for Bombay Metropolitan Region included the air pollution sector and proposed management options, as it does for other environmental sectors (Coopers & Lybrand and AIC, 1994).

The recently reported Comprehensive Study of Bombay Metropolitan Region has provided essential data on the traffic activity in Greater Bombay (Atkins, 1993).

URBAIR data collection

Further data on various aspects of population, pollution sources, dispersion, air quality, health aspects, and the like, has been collected during the URBAIR process, starting in Bombay in April 1993. The following local consultants have provided additional useful data according to the project description given in Appendix 8:

- Aditya Environmental Services, providing data on population, pollution sources, fuel, vehicle and traffic statistics, on air quality measurements and on meteorological/dispersion conditions.

- Dr. Mahashur who provided data on health effects of air pollution on the Bombay population, and on associated health costs.

1.4 Summary of development in Bombay, 1981-1991

Figure 1.2 gives a summary of the available data regarding population, vehicles, fuel consumption and air quality, and development over the last decade. As seen, data are not available on all these items for the whole decade.

The population has grown steadily, from about 6.0 million in 1971 to about 8.2 million in 1981 (38% increase), and to 9.9 million in 1991 (20% increase). The total number of vehicles has grown by about 103% from 1981 to 1991, especially motorcycles. Consumption of gasoline and diesel oil have also increased. Data were available only from the period 1985-1990, during which gasoline and light diesel oil consumption increased by 26% and 24% respectively,

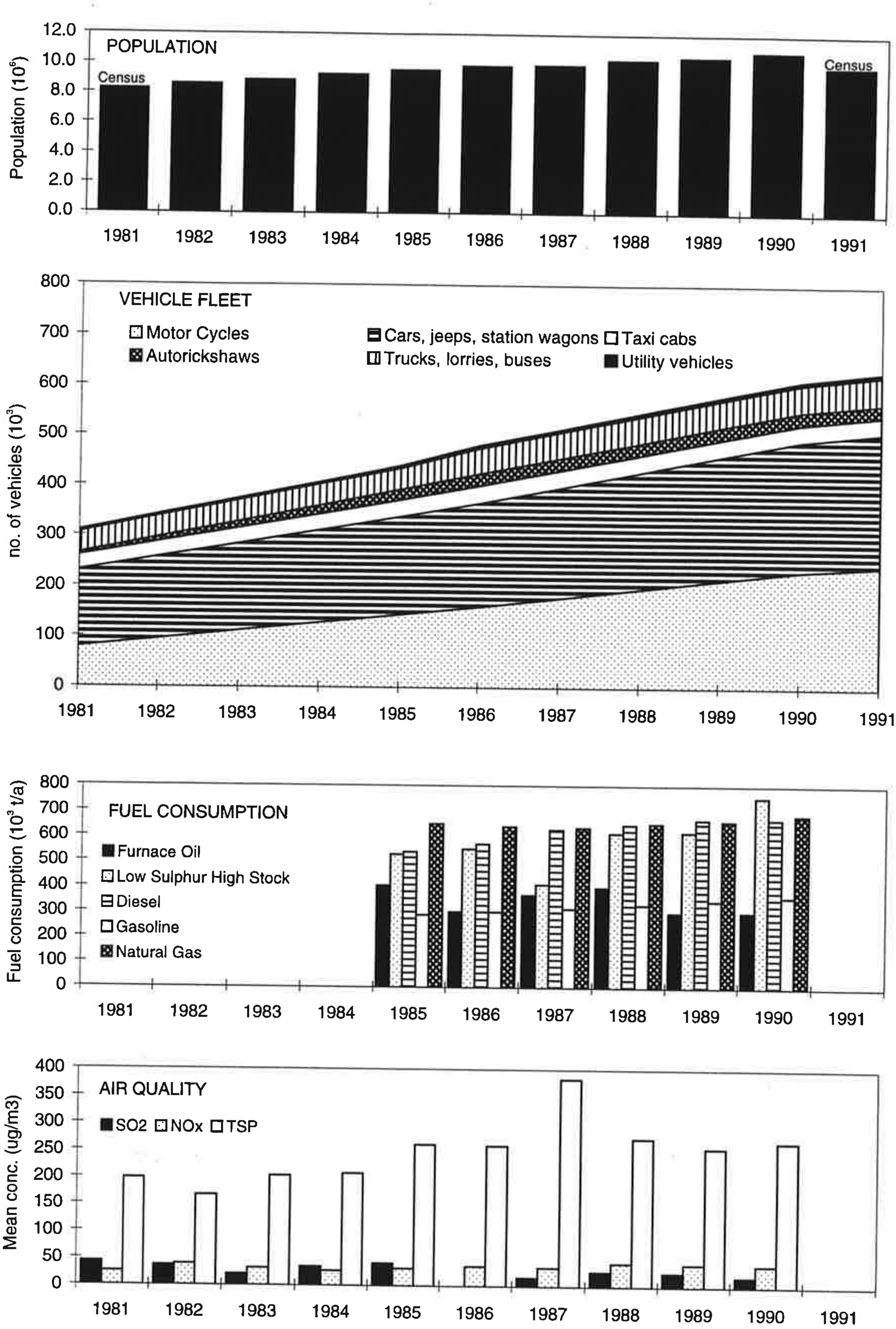


Figure 1.2: *Bombay development 1981-1992: Population, vehicle fleet, fuel consumption and air quality.*

while furnace oil decreased significantly. The 1990 GDP/capita figure for India is US$ 350. Over the period 1965-1990 the growth rate in GDP/capita was +1.9%, about the same as for the US. Over the last decade the annual increase was 3.2%.

Air quality measurements over the last decade show a definite increase in average TSP and NO_x concentrations, while SO_2 concentrations have decreased. This seems to correspond with the decrease in furnace oil consumption, while traffic emissions have increased.

TSP concentrations (annual average and maximum 24-hours) are much higher than the WHO Air Quality Guidelines (AQG, 90 $\mu g/m^3$) at many of the measuring sites. The SO_2 AQG for 24-hour averages is exceeded at times.

1.5 Population

Table 1.1 gives population data for 1981 and 1991 for Greater Bombay, total and for the Island city, and Western and Eastern Suburbs (1990). The increase from 1980 to 1990 was 20%. The average density was in 1990 about 16,500 inhabitants per km^2.

Table 1.1: Population and growth rate 1981-1991, Bombay.

	1981	1991
Island City	3,283,000	3,109,500
Western Suburbs	2,860,000	3,975,400
Eastern Suburbs	2,100,000	2,824,600
Greater Bombay	8,243,400	9,909,500
Pop. density per km^2	13,670	16,430

The age distribution is given in Table 1.2 (1991). 31.5% of the population was aged less than 15 years, and 66% was aged 15-65 years.

Table 1.2: The age distribution of the Greater Bombay population, 1991.

Years	%	Years	%
0- 9	21.2	40-44	5.7
10-14	10.4	45-49	4.8
15-19	9.8	50-54	3.6
20-24	11.7	55-59	2.4
25-29	10.7	60-64	1.9
30-34	8.1	65-69	1.1
35-39	7.1	>70	1.5

1.6 Vehicle fleet

The vehicle fleet in Bombay is here separated into these categories:

- cars (passenger cars, taxis , and light duty vehicles);
- trucks and buses;
- motorcycles (MC); and
- autorickshaws (tricycles, TC).

Table 1.3 gives the fleet data. Of the 630 million vehicles in 1991, 48% were cars (including taxis), 39% were motorcycles and 9% were trucks and buses.

Table 1.3: Vehicle fleet data, Bombay (vehicles registered in Bombay). (Source: Transport Commissioner, Bombay.)

	Vehicles (1000)					
	Cars and taxis	UV	Trucks/ Buses	MC	TC	Total
1981	180334	3677	41931	78474	4465	308881
1982	192281	4035	41932	94671	8487	341406
1983	204228	4393	41933	110868	12510	373932
1984	216175	4751	41934	127065	16532	406457
1985	228122	5109	41935	143262	20555	438983
1986	240069	5469	50500	159549	24577	480165
1987	253215	5646	51515	177577	24577	512530
1988	266361	5823	52530	195696	24577	544987
1989	279507	6000	53545	213814	24577	577443
1990	292653	6177	54562	231932	24577	609901
1991	299289	6501	56086	242008	24577	628461

UV: Utility vehicles. TC: Tricycles (Autorickshaws). MC: Motorcycles.

Table 1.4 shows that growth was substantial during 1981-1991. The average total annual increase was 7.3%, largest for TC and MC (19% and 12% per year). The number of TCs has been stable since 1985, but is again increasing since 1993.

Table 1.4: Vehicle growth rate, annual average (percent), Bombay.

	1981-1991
Passenger cars	5.2
Utility vehicles	5.9
Trucks	2.9
MC	11.8
TC	19.0
Total	7.3

The total number of vehicles per capita in Bombay in 1991 were 63 per 1 000 inhabitants, and by type:

Cars	:	30 per 1, 000 inhabitants
Trucks/buses	:	5.5 per 1, 000 inhabitants
MC/TC	:	24 per 1, 000 inhabitants

The percentage of diesel-powered cars is estimated at 20% presently.

1.7 Road and transport

Data for growth in traffic and transport activities in Greater Bombay are taken from the Traffic Survey in Greater Bombay (1988) Report (BMRDA, 1990).

The growth in traffic activity was studied across four cordons (see Figure 1.3, which also shows the main road network):

- Mid-city cordon (by Mahalakshmi);
- Island cordon (by Sion);
- Mid-suburban cordon (by Malad Creek-Pavai Lake); and
- Outer cordon (by Dahisar-Thane, i.e. Greater Bombay limits).

Traffic activity and growth during 1978-1988 is shown in Table 1.5. There has been a substantial growth across the outer cordons 5-6% p.a., while the growth has been small on Island and Mid-city (1.5-5% p.a.).

Table 1.5: Growth in traffic activities across four cordons across Greater Bombay, 1978-1988 (BMRDA, 1990).

	Total vehicle daily, 1988	Increase %	
		1978-1988	Annual
Outer cordon	80 370	58	4.7
Mid-suburban	156 400	70	5.5
Island	195 270	15	1.4
Mid-City	229 960	20	1.8

Growth across the outer cordon has mainly taken place along the western routes (Western Express Highway and Sion Panvel Roads, 192% and 124% total growth during 1978-1988 respectively). At the mid-suburban cordon the growth has been more uniform along the four main corridors, about 40-75% during 1978-1988.

Table 1.6 gives the growth rate for various vehicle categories. Motorized passenger traffic has increased the most, especially across outer and mid-suburban cordons. Goods traffic has actually decreased in Mid-City, possibly associated with shifting a few wholesale markets out of the Island City.

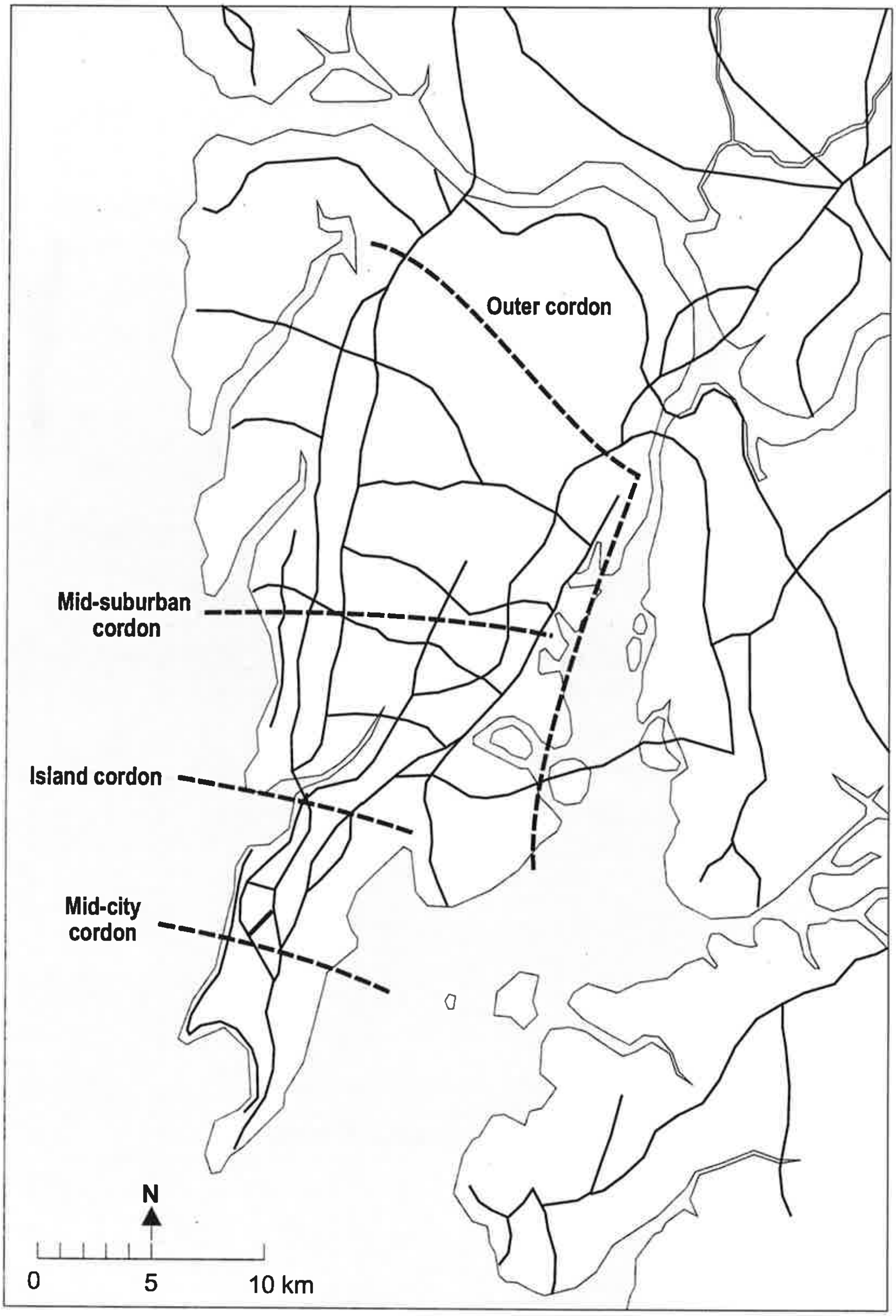


Figure 1.3: Bombay Metropolitan Region with main roads and traffic cordons.

Table 1.6: Growth rates (% p.a.) in Greater Bombay traffic, for vehicle categories (BMRDA, 1990).

	Passenger vehicles	Goods vehicles	Cycles and other vehicles
Outer cordon	6.0	4.5	-2.8
Mid-suburban	6.8	1.5	2.7
Island	2.0	0.1	-4.4
Mid-City	3.0	-2.6	-1.85

The main increase in passenger vehicle traffic growth has been due to two-wheeler traffic across all cordons (more than 200% increase in the outer cordon during 1978-1988). Private car traffic has increased moderately (by 20-30% over the decade), while autorickshaw traffic has to a large extent replaced taxis in the suburbs, indicated by the very large increase in number of autorickshaws early in the decade.

Traffic growth has resulted in a substantial decrease in traffic speed on the road network, especially on the main corridors. Deshpande et al. (1993) reports the following average speeds (km/h) along main corridors:

	1962	1979	1990
Western corridor	~50	30-40	20-30
Eastern corridor	- 30	20-25	~15

Along the Eastern corridor, the speeds are low (15-30 km/h) and have not changed substantially.

In the BMRDA study, a comparison was made between the rates of increase in population, registered vehicles, and traffic flow (Table 1.7).

Table 1.7: Broad comparison of growth rates of population, registered vehicles and traffic flow (BMRDA, 1990).

	Growth rates, 1978-1988 (% p.a.)		
	Population	Registered vehicles	Traffic flow
Island City	0.12	6.1	1.8 (Mid-City cordon) 1.4 (Island City cordon)
Suburbs	2.1	14.6	5.5 (Mid-suburb cordon)
Extended suburbs	8.2		4.9 (Outer cordon)
Greater Bombay	2.6	8.1	1.7

It is pointed out by BMRDA that this broad comparison shows that the large population growth in the extended suburbs, and partly also in the suburbs, has caused considerable traffic flow increase there, while in the Island City the population growth and traffic flow has stagnated (compared to the period 1962-78), although the number of registered vehicles has increased substantially.

1.8 Industrial sources

Bombay is the financial and commercial centre of India and also the most industrially developed Indian city. These are approximately about 40,000 small and big industries in the city (Table 1.8). Industries in the air polluting category include textile mills, chemical/pharmaceutical engineering/foundry units. Important emissions include process emissions and those from fuel consumption. For the purpose of this study fugitive emissions have been considered as unimportant and have not being taken into account. Major air pollution sources include a giant Fertilizer/Chemical complex; two oil refineries and a Thermal Power Plant (TATA) all based in Chembur, a suburb on the eastern coast of the Bombay island.

The largest concentration of industries is in the Tromby-Chembur area and in the Lalbaug area in South Bombay. In addition, industries have developed along Lal Bahadur Shastri Marg passing through the Central suburbs (to Thane); in Andheri-Kurla area in Central Bombay and along the Western Express highway leading outside Bombay. Figure 1.3 shows a map of major industrial sources in Bombay. In a bid to reduce air pollution levels, industries in Chembur have switched over to low sulphur fuels (LSHS) and natural gas.

As part of this URBAIR study, ADITYA has located and collected emissions data for about 280 large and medium industries in Greater Bombay.

There are about 40, 000 small and big industries in the city (Table 1.8). Of these, 32 have been classified as hazardous.

Table 1.8: Industrial classification in Greater Bombay.

Type of Industries	Number of Industries
Mechanical Workshop	3,348
Plastic and Rubber	32
Printing Press	1,075
Chemical	523
Textile	531
Pesticide	9
Miscellaneous	33,790
Thermal Power Plant	1
Total	40,369

Figure 1.4 shows a map with locations of major industrial sources in Bombay city

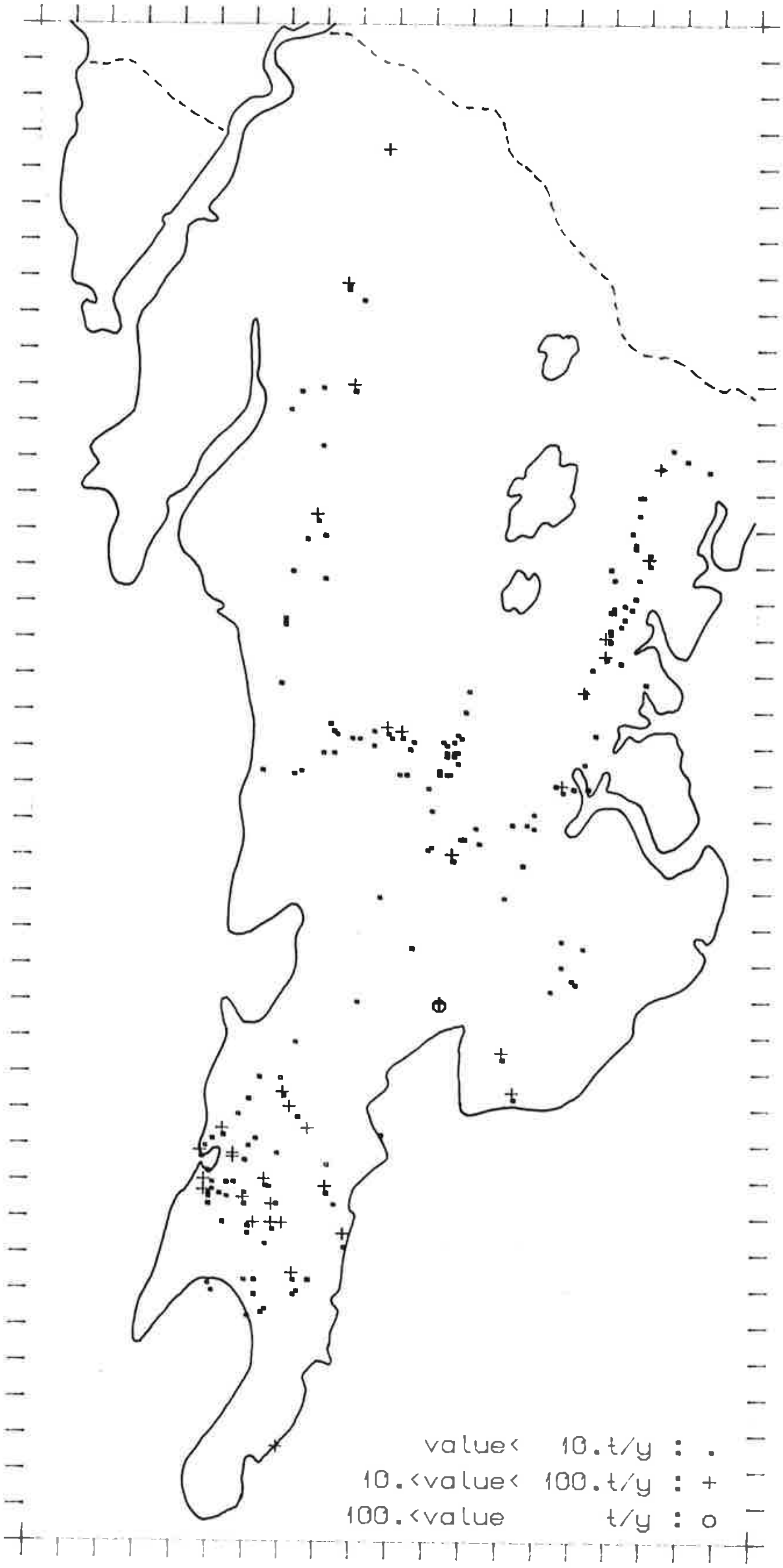


Figure 1.4: Position of the industrial sources in Bombay with TSP emissions, mapped in this study.

1.9 Fuel consumption

Fuel consumption data for Greater Bombay were available for 1985-1990. Table 1.9 gives data on various fossil fuel products.

Table 1.9: Fossil fuel consumption, Greater Bombay (million l/yr.) (Reference: URBAIR Working Group I.)
Source: (i) E.S & P Dept; MCGB (for period 1985-91).
(ii) 1992-93 Data generated under URBAIR by Aditya.

	Furnace Oil (FO)	Low Sulphur High Stock (LSHS)	High Speed Diesel (HSD)	Light diesel oil (LDO)	Gasoline	LPG	Kerosene (SKO)
1985-1986	403	527	438	99	287	201	447
1986-1987	300	549	469	99	300	202	436
1987-1988	367	408	508	118	314	204	430
1988-1989	397	612	529	118	330	213	438
1989-1990	298	616	551	115	345	213	448
1990-1991	299	755	560	108	362	214	471
1992-1993	306	1488[1]	583	46[2]	279[2]	233[3]	480[3]

Note:
1 LSHS Data for 1985-91 takes account of only part of TATA Thermal Power Plant requirement and does not account for Refineries' own consumption.
2 Incomplete data from Refineries.
3 Data from Rationing Inspectorate, Dept. of Civil Supplies.

Over the period 1985-91, gasoline, diesel (HSD) and LSHS consumption increased by 26%, 28% and 43% respectively. Furnace oil consumption decreased by 26% over the same period.

The 1992-93 data indicate a further increase. In the LSHS column, the TATA power plant consumption is not fully accounted for in the data for 1985-91, as it is for 1992-93.

Coal consumption are not available to the same extent. Consumption in 1985-86 was 2,124,000 MT/year, with a sulphur content of 0.5% and ash content of 12%.

1.10 Area sources

Much of the fuel is consumed in small installations and by small units. This also includes wood and coal combustion, which is not included in Table 1.9. Sources responsible for such distributed consumption are termed "area sources", of which one, vehicular traffic, is already treated in Ch. 1.6 and 1.7.

Full consumption for stationary area-distributed sources, as estimated by ADITYA for 1990, is shown in Table 1.10.

Table 1.10: Fuel consumption (1990, 10^3 metric tonnes/year) for area-distributed sources).
Source: ADITYA.

	FO	LSHS	HSD	LDO	LPG	SKO	Wood
Small scale industry	123	56	40	42	7		
Domestic					233[1]	387[2]	101[3]
Bakeries/crematoria							160/320
Marine (port/bay)	100	56	6	3			

1 Consumed by the non-shown population.
2 Consumed by the total population.
3 Consumed by the slum population.

Especially wood combustion is a significant source of suspended particle pollution. About 1100 of Bombay's 1400 bakeries use wood for energy, as do the crematoria. The slum population also consume a considerable volume of wood.

2. Air quality assessment

The purpose of this chapter on Air Quality Assessment for Greater Bombay is to **provide an estimate of the population exposure** to air pollutants in the area, and to quantify contributions to this exposure from the various pollution source categories.

This estimate is arrived at through the following analysis:

- Description of existing air pollution concentration measurements and their variation in time and space;
- Inventory of air pollution sources and their relative contributions;
- Description of concentration distributions in the area, by means of dispersion modelling; and
- Calculation of the population exposure, by combining spatial distributions of population and concentrations, also considering exposure on roads and in industrial areas.

2.1 Air pollution concentrations

Overview of database

Bombay's air pollution measurement programs reveals that Bombay has a substantial particle pollution problem, with frequent and spatially extended exceedances of TSP air quality guidelines, and probably also for PM_{10}. According to the SO_2 measurements, SO_2 pollution problem seems less pronounced, although guidelines are exceeded at times. NO_x concentrations seem, according to the measurements, to be of little importance presently.

In Appendix 1, the monitoring networks and results of measurements are described in more detail. The monitoring networks which have provided data in recent years, on which our assessment are based, are:

- The network of measurement sites of the Municipal Corporation of Greater Bombay (MCGB), consisting of some 22 stations. TSP, SO_2, NO_x, and NH_3 is measured as 8-hour averages (and a few 24-hour periods) per month. Most of the sites can be characterized as area-representative ("city background" sites), while some are influenced by nearby traffic. The sites are distributed over the Greater Bombay area, in commercial, industrial, and residential area.
- The GEMS network of 3 sites, operated by NEERI (National Environmental and Engineering Research Institute). At these sites, all located south of Santa Cruz airport, TSP, SO_2, and NO_2 is measured a few days per month.
- The Maharashtra Pollution Control Board (MPCB) monitors air quality from a mobile van, frequenting a number of established monitoring sites inside and outside Bombay.

- Rashtriya Chemicals and Fertilizer (RCF) Ltd, in Chembur, monitors air quality at a number of sites at its plant border, by continuous analyzers. They also monitor meteorological data at one site.

- The Indian Meteorological Department (IMD) operates meteorological stations at the Santa Cruz Airport and at the Colaba Observatory, providing data to the URBAIR project.

Suspended Particulates (TSP)

The TSP Air Quality Guidelines (AQG) applicable to Bombay are shown below together with those from WHO (see Appendix 2).

	WHO ($\mu g/m^3$)	Bombay ($\mu g/m^3$)
Long-term (annual average) :	60- 90	360*
Short-term (24 hour average) :	150-230	500**

Source: National Ambient Air Quality Standards for Industrial and Mixed Use Areas vide S.O. 384(E) under APCA, 1981.

Note: * : Annual average mean of minimum 104 (24 hourly) measurements in a year.

**: Should be met 98% of the time in a year. Should not exceed on two consecutive days.

Figure 2.1 shows measured annual average TSP concentrations at the 18 M.C.G.B. sites monitored in 1992-93. Figure 2.2 shows the monthly average at the Parel site. The annual average hence was 265 $\mu g/m^3$, while the maximum monthly average (which is made of maybe two-four 24 hourly values) was about 400 $\mu g/m^3$.

The annual average TSP values at all stations are below the Bombay AQG, however, long/short term WHO guidelines are exceeded at all stations. Although Bombay guidelines are not exceeded, it should be noted that the Bombay AQG for TSP is considerably less stringent than the WHO AQG, as is apparent from the above Table. Considering the fact that TSP readings at M.C.G.B. are all recorded at heights ranging from 4 m-10 m (on roof tops of buildings), these values are very high.

The sites with highest TSP concentrations are Maravali and Chembur Naka (both in Chembur), Sion, Parel, and Mulund. These stations are located in industrial areas and along highly trafficked roads. Maravali station has recorded very high 24 hourly average TSP values (in the range 400-500 $\mu g/m^3$) during dry seasons while Chembur, Sion, Parel, and Mulund stations have recorded values between 250-400 $\mu g/m^3$.

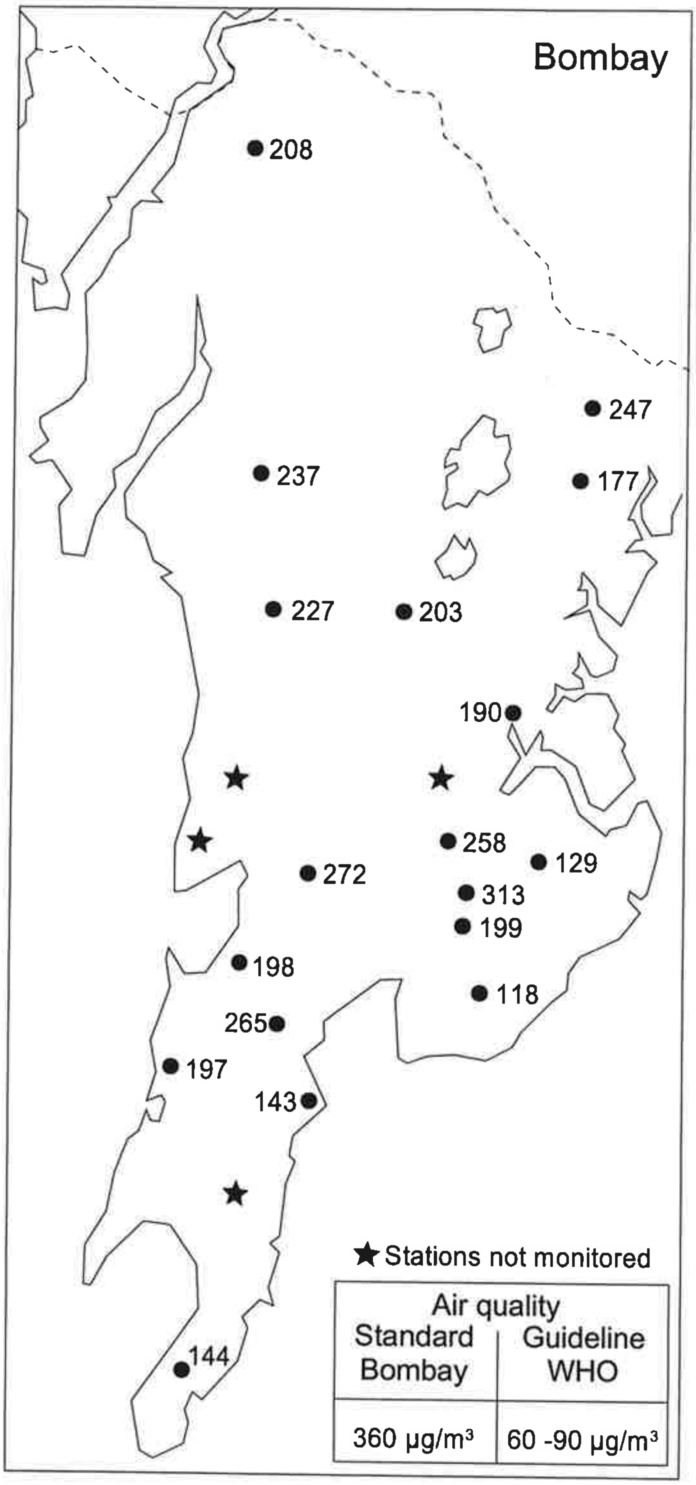


Figure 2.1: *Mean annual TSP concentrations at MCGB sites for the year 1992-1993 (µg/m³)*

Ambient air quality data Parel (µg/m3)

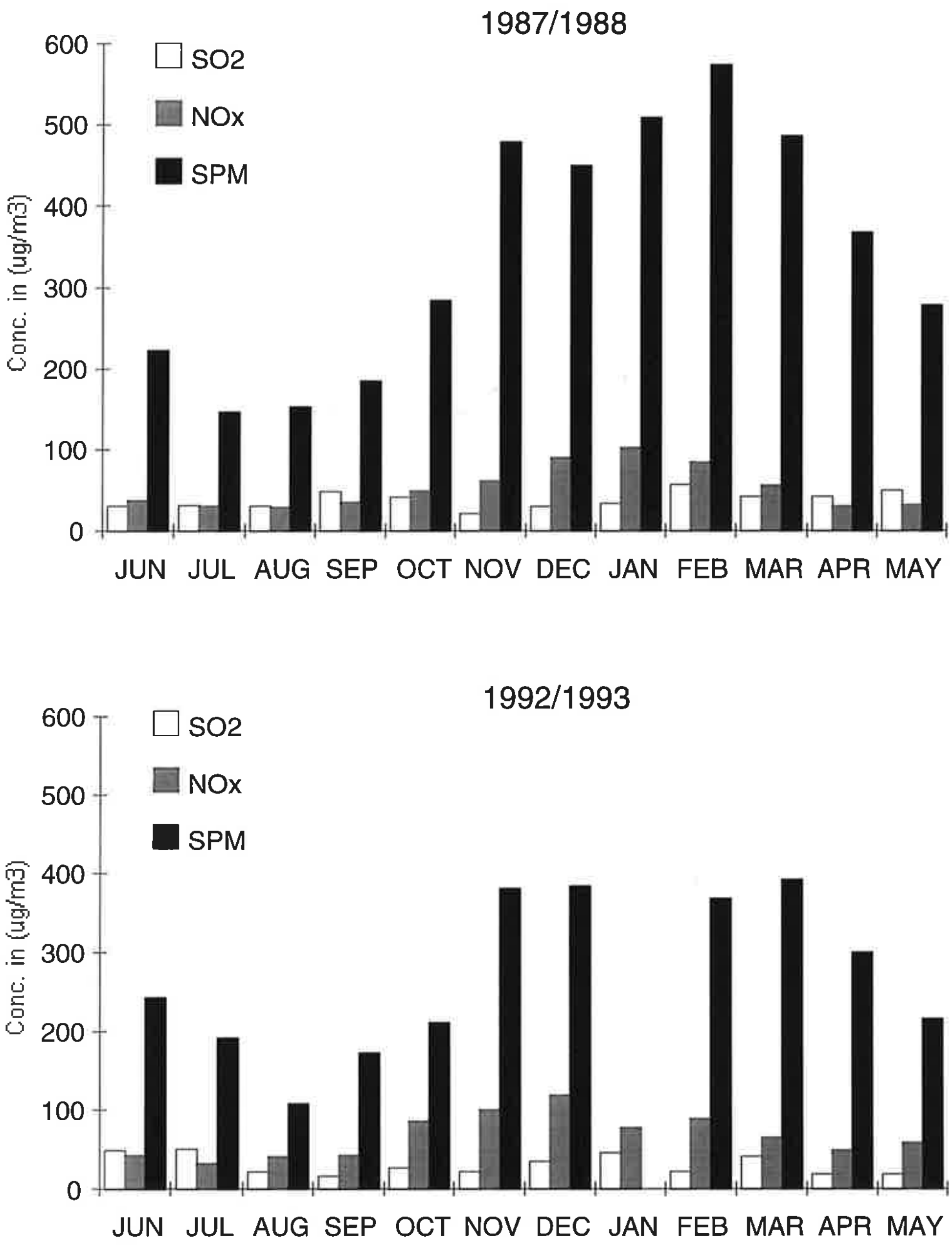


Figure 2.2: *Monthly average TSP concentrations at the MCGB Parel site ($\mu g/m^3$), for 1987-1988 and 1992-1993.*

The average TSP concentration in Bombay has increased considerably since around 1980, from about 200 $\mu g/m^3$ then to about 250 $\mu g/m^3$ in 1991. The year 1987 was exceptional with an annual average TSP concentration of close to 400 $\mu g/m^3$, according to the data we have.

Data from Parel Station (Fig. 2.2) shows the typical annual variation observed at all M.C.G.B. sites in Bombay. The concentration is much higher in the dry season (November-April) than during the monsoon (July-September). Dry season TSP could be as much as a factor of 3 higher than the wet season TSP. This reflects one or more of the following effects:

- Increased washout of particles during the monsoon;
- Decreased resuspension from the ground during the monsoon; and/or
- Increased wind speed and turbulence, thus dispersion during monsoon.

Some measurements have been performed at street junctions. Results are given in Table 2.1 (for TSP, SO_2, NO_2, and CO).

Table 2.1: Results of ambient air monitoring (μg/m³) at different traffic junctions in Bombay (MCGB correspondence).

No.	Site	Monitoring Period	SO_2			NO_2		
			N	AVG	MAX.	N	AVG	MAX.
1.	V.T.	2.12.91 - 6.12.91	12	89	127	12	175	296
2.	Nana Chowk	9.12.91 -13.12.91	12	60	104	12	124	162
3.	Maheshwari Udyan	20.01.92 -24.01.92	12	117	162	12	156	210
4.	Mahim	24.03.92 -26.03.92	8	43	120	8	90	107
5.	Worli Naka	22.04.92 -25.04.92	9	38	80	9	56	83
6.	Sion Circle	27.04.92 -30.04.92	9	90	125	9	117	167
			TSP			CO - PPM		
			N	AVG	MAX.	N	AVG	MAX.
1.	V.T.	2.12.91 - 6.12.91	12	651	1 072	15	11.1	13.3
2.	Nana Chowk	9.12.91 -13.12.91	12	480	555	23	6.5	7
3.	Maheshwari Udyan	20.01.92 -24.01.92	12	1 309	1 653	39	7.5	9.7
4.	Mahim	24.03.92 -26.03.92	8	1 144	3 170	31	6.2	15.6
5.	Worli Naka	22.04.92 -25.04.92	9	542	668	30	5.1	9.6
6.	Sion Circle	27.04.92 -30.04.92	9	708	1 094	30	5.8	9.7

N - no. of samples

Extremely high TSP concentrations were measured, up to 3,170 µg/m³ at the Mahim Junction. Recorded maximum values exceed the WHO AQG by a factor of upto 10 and the Bombay AQG by a factor of 6.

This summary of TSP results points to TSP being a general air pollution problem in Bombay, in most parts of the city, especially near streets and industrial areas, and especially during the dry season.

PM_{10}

The PM_{10} AQG's applicable to Bombay are shown below, together with WHO figure:

	WHO (µg/m³)	Bombay[+] (µg/m³)
Long-term (annual average) :	-	120*
Short-term (24 hour average) :	70	150**

+ Source: National Ambient Air Quality Standards for Industrial and Mixed Use Areas vide S.O. 384(E) under APCA, 1981.

Note: * : Annual average mean of minimum 104 (24 hourly) measurements in a year.

**: Should be met 98% of the time in a year. Should not exceed on two consecutive days.

PM_{10} has not recently been measured in Bombay. However, in 1982-1983, a respirable particles (RPM) human exposure study was carried out in Bombay (WHO, 1984). This study are summarized in Table 2.2. PM_{10} concentrations are somewhat larger than RPM, since PM_{10} (particles <10 µm in diameter) are larger than RPM (<8 µm).

Table 2.2: Respirable particle concentrations measured in Bombay, 1982 (average and maximum 24 hour concentration). Each average number represents about 100 samples.

	Winter	Summer	Monsoon
Person	127/434	67/188	58/138
Indoor	118/327	65/231	62/131
Outdoor	117/251	65/225	51/106
Monitoring site	112/204	53/100	44/122

Person	personal monitor
Indoor	in the person's home
Outdoor	outside the person's home
Monitoring site	measurements at the nearest fixed monitoring site

The RPM results indicate that concentrations of and exposure to PM_{10} in Bombay in 1982 was much higher than the WHO AQG, with maximum values as high as 6 times the guideline. Although long term concentrations were below Bombay

AQS, short term (24 hour) concentrations frequently exceeded the present standard. Now, 10 years later, the concentrations may be even higher.

Lead

Lead measurements at the 22 MCGB sites for 1980-1987 indicates that lead pollution is a significant air pollution problem in Bombay (ref. MCGB). From 1980 to 1987 the average lead concentration in air has nearly doubled. Annual average levels ranged from 0.5 μg/m^3 to 1.3 μg/m^3. The "Eastern Suburb" zone was the most exposed area, with monthly average concentrations as high as 17.9 μg/m^3, at the Mulund Site in October 1984. Also, in the Central Bombay area lead concentrations were high, with the highest monthly average of 8.4 μg/m^3 measured at Dadar in January 1985.

Considering the frequency of measurements, these very high "monthly" averages are likely to represent single, very high 24-hour values.

Nevertheless, these lead concentrations are very high, and exceed the WHO AQG average (0.5-1 μg/m^3, long-term (annual)). The Bombay AQGs for lead are 1.0 μg/m^3 (annual average) and 1.5 μg/m^3 (24 hour average), and they are exceeded at all locations.

The Indian standard for maximum lead content of gasoline is as follows:

Regular gasoline (RON 87)	:	0.56 g/l
Premium gasoline (RON 93)	:	0.80 g/l

In Bombay, the most gasoline sold in the last 8-9 years has had a considerably lower lead content, about 0.18-0.19 g/l. Some 30% of the gasoline consumed still has a high lead content, although complying with Indian standards.

SO_2 and SO_4

The Bombay AQGs for SO_2 are given below, together with WHO AQGs:

	Bombay AQG	WHO AQG
Long-term (annual) average	80 μg/m^3	50 μg/m^3
Short-term (24 hour) average	120 μg/m^3	125 μg/m^3

The summary of measurements in 1992/1993, shown in Figure 2.3, indicate that long-term average SO_2 concentrations are fairly low, and at all sites less than the WHO and Bombay AQG. The maximum 24-hour values probably exceed the AQG at some sites although only occasionally. The TCM (Pararosaniline) colorimetric method is used in these measurements.

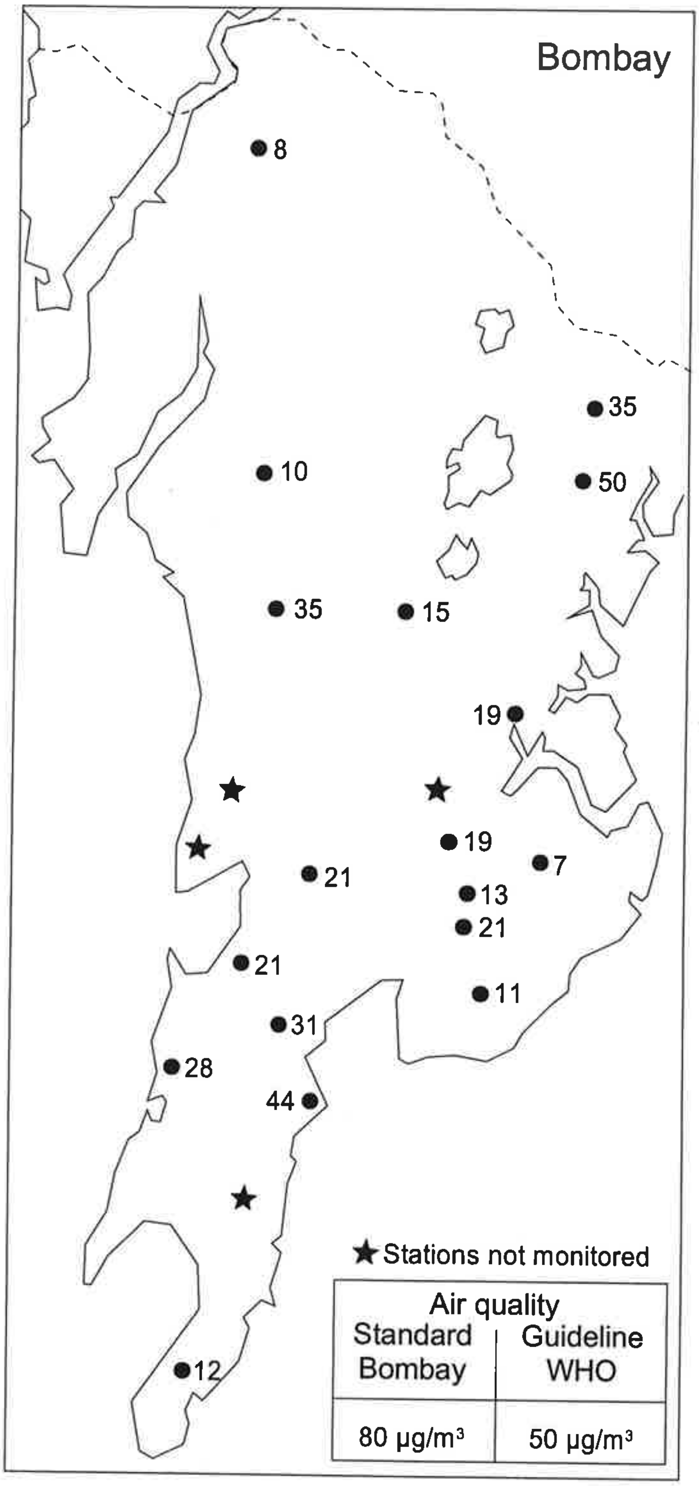


Figure 2.3: Mean annual SO_2 concentrations at MCGB sites for 1992-1993 ($\mu g/m^3$)

The annual average SO_2 concentration in Bombay (MCGB sites) has decreased since 1980, from about 45 µg/m³ then, to about 25 µg/m³ now. This decrease is also apparent at the NEERI GEMS sites.

Very high sulphate concentrations in particles were measured during the respirable particle (RPM) study in 1982 (WHO, 1984), with average concentrations in the range 20-30 µg/m³, and maximum 24-hour concentrations as high as 88 µg/m³. These are extremely high concentration. There is a contribution from sea aerosol which may at times be considerable.

NO_x

The Bombay air quality standards and WHO Guidelines are given below.

	Bombay AQS NO_x as NO_2	WHO AQG NO_2
Long term (annual) average	80 µg/m³	
Short term (24 hour) average	120 µg/m³	150 µg/m³

They are not directly comparable, since the WHO guideline specifies NO_2 specifically, while the Bombay standard specifies NO_x as NO_2, i.e. NO+NO_2, measured as NO_2. Even so, the Bombay NO_x standard is stricter than the WHO NO_2!

The summary of NO_x measurements in 1992-93, annual average, are shown in Figure 2.4. The highest concentrations, 83 µg/m³ at Sion, barely exceeds the Bombay Standards. The other stations are well below the standard. The highest 24-hour average concentrations, most probably exceeds that standard (120 µg/m³).

The annual average NO_x concentration, averaged over all stations in Bombay, has increased from about 25 µg/m³ in 1981 to about 40 µg/m³ in 1990, and 46 µg/m³ in 1993-93.

2.2 Air pollutant emissions in Greater Bombay

Total emissions

A comprehensive emission inventory was developed for Bombay as part of the URBAIR project. The local URBAIR consultant, Aditya Environmental Services, collected the necessary input data, according to the project description in Appendix 8, and as per directions given, and discussions during meetings and correspondence with the NILU URBAIR consultants. The traffic emission distribution was developed by NILU on the basis of road and traffic data provided by Atkins Inc., as part of their development of a Comprehensive Transport Plan for Bombay (Atkins, 1993). The development of the emission inventory is described in Appendix 4. The results of the emission inventory is presented in Table 2.4, based on the emission factor data given in Table 2.5 and the fuel consumption in Table 2.6. The traffic activity data are described in detail in Appendix 4. The aviation sector is considered marginal. Emission factors for particles are described in Appendix 5. The emission spread sheet calculation is shown in Appendix 7.

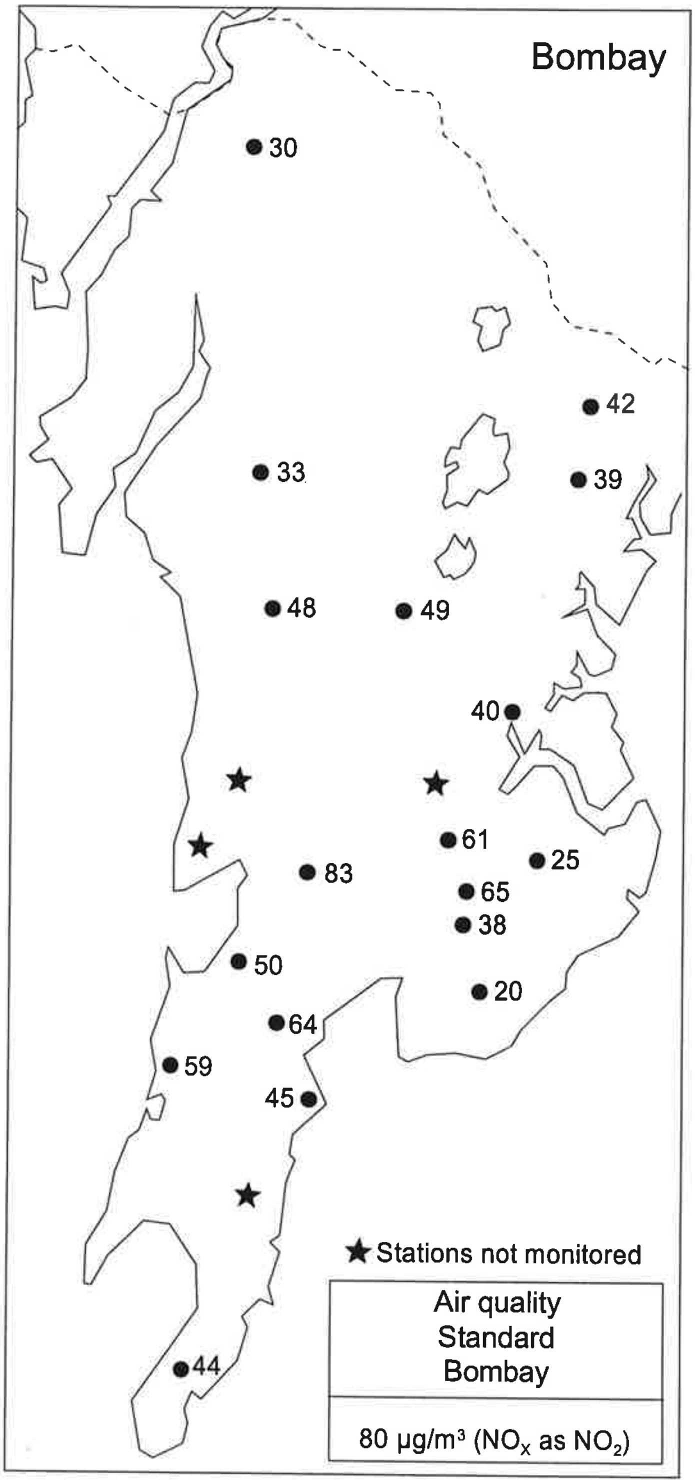


Figure 2.4: *Annual average NO_x concentrations at MCGB stations in the period June 1992-May 1993 (µg/m³).*

Table 2.4: Total annual emission in Greater Bombay, 1992-1993 (tonnes/yr.).

Emission sources		TSP	PM_{10}	SO_2	NO_x	Hours of operation
Transport sector						
Vehicle exhaust						
Gasoline	Cars	492	492	160	6 643	12
	MC/TC	737	737	250	179	12
Diesel	Cars	765	765	395	1 783	12
	Buses	445	445	566	2 891	12
	Trucks	1 234	1 234	2 120	8 024	12
Sum vehicle exhaust		3 673	3 673	3 490	19 520	12
Resuspension from roads		10 200	2 550	-	-	12
Energy/industry sector						
Power plant		~1 500	~1 500	~26 000	~11 200	24
Other fuel combustion						
Industrial	LSHS	140[1]	84	11 920[1]	1 690	24
	FO	1 652[1]	1 399	24 480[1]	2 140	24
	LDO	12[1]	6	1 510[1]	120	24
	Diesel	12[1]	6	800[1]	115	24
	LPG	0,5	0.5	-	20	24
Sum industrial		1 817	1 496	38 710	4 085	
Domestic/commercial[3]						
	Wood	4 395	2 198	59	410	12 (day)
	Kerosene (SKO)	23	23	1 628	258	10 (day)
	LPG	14	14	0,7	676	10 (day)
Sum domestic		4 432	2 235	1 688	1 344	
Industrial processes[2]						
Stone crushers		6 053				12 (day)
Other						
Refuse burning	Domestic	3 700	3 700			
	Dumps	408	408	26	153	12 (3 PM-3 AM)
Construction						
Marine (docks)	FO	540	459	8 000	750	24
	LSHS	16	8	1 120	425	24
	Diesel	2	1	120	45	24
	LDO	1	1	110	25	24
Sum marine		560	469	9 350	1 245	
Total		32,343	16,031	79,264	37,547	

1 Uncontrolled
2 Emissions from processes in Bombay is considered less important compared to the fuel combustion emissions.
3 Domestic coal/dung combustion not included, for lack of volume data.

Table 2.5: Emission factors used for URBAIR, Bombay, 1992. For references: see Appendix 5.

		TSP	PM_{10}/TSP	SO_2	NO_x	%S max.
Fuel combustion (kg/t)						
Coal, bituminous, power plant						
- uncontrolled		5A[1]		19.5S[1]	10.5	
- cyclone		1.25A	0.95	19.5S	10.5	
- ESP		0.36A		19.5S	10.5	
Residual oil (FO)	ind./comm.	1.25S+0.38	0.85	20S	7	4
Distillate oil	ind./comm.	0.28	0.5	20S	2.84	LSHS: 1
(LSHS, HSD, LDO)	residential	0.36 → 1.6[2]	0.5	20S	2.6	HSD: 1
						LDO: 1.8
LPG	ind./dom.	0.06	1.0	0.007	2.9	0.02
Kerosene	dom.	0.06	1.0	17S	2.5	0.25
Natural gas	utility	0.06	1.0	20S	11.3 · f	
	ind./dom.	0.06		20S	2.5	
Wood	dom.	15	0.5	0.2	1.4	
Refuse burning	domestic	37	1	0.5	3	
	dumps	8				
Coal	domestic	10				
Dung	domestic	10				
Road vehicles (g/km)						
Gasoline	Cars	0.2	1		2.7	87:0.25
	Trucks, light duty	0.33	1			83:0.20
	Buses and trucks, heavy duty	0.68	1			
	MC/TC	0.5	1		0.1	
Diesel	Cars	0.6	1		1.4	1
	Trucks, light duty	0.9	1			
	Buses and trucks, heavy duty	2.0			13	

1) A: Ash content, in %; S: sulphur content, in %
2) Well → poorly maintained furnaces

The inventory covers the main source categories. Figure 2.4 shows the main source contributions.

Emission factors as recommended by WHO (1993) and US EPA (1986) have generally been used, as in the other URBAIR cities (Manila, Jakarta, Kathmandu). Indian emission factors are available for some of the sources, such as vehicles, and for fuel combustion as suggested by the URBAIR Bombay working group on Air Quality (see Appendix 5), but it was decided to use the WHO/EPA factors in this first phase of URBAIR. Accepted Indian factors should be used subsequent analysis process.

Table 2.6: Fuel consumption data for Greater Bombay, for 1992-1993 (April-March), for industry, domestic purposes, and by ships in the Bombay port and bay area.
For mobile sector fuel consumption and traffic activity, see Appendix 4.

Category	Fuel type	10^3 Metric tonnes/a	
Tata Power Plant	LSHS	927	
	Coal	298	
	Gas	496	
Industrial	LSHS	499	279 in Petrochem. industry
			164 in large/medium industry
			56 in small scale industry
	FO	306	183 in large/medium industry
			123 in small scale industry
	LDO	42	
	Diesel (HSD)	40	
	LPG	7	
Domestic	Wood	289	
	SKO	480	
	LPG	233	
Marine (port/bay)	FO	100	
	LSHS	56	
	Diesel	6	
	LDO	3	

Emissions from the Tata power plant have been calculated based on the fuel consumption figures of Table 2.6 and assuming ESP emission control. The emissions do not contribute much to ground level exposure, due to their tall stacks (278 m).

Emissions from the dockside are primarily from petroleum products sold to ships. It is not known how much of this is actually burnt in the docks. Emissions also comes from ships waiting in the bay for dock space. These emissions are substantial and contribute to the extra urban background concentrations, particularly SO_2 and SPM. These emissions must be calculated from ship counts and waiting time.

No specific data on industrial process emissions are available. Emissions from large/medium industries have been collected on a separate file, which gives emissions from about 280 large/medium plants in Bombay. Emissions from processes and fuel combustion have not been separated. Also the emission data are for some of the plants based on actual emission measurements, for which the representativity is not known.

TSP

Total annual TSP emissions are estimated at about 32, 400 tonnes/a, for the sources given, for 1992-1993. Road traffic, particularly resuspension and diesel trucks, wood burning, domestic refuse burning and furnace oil (FO) use in industry give large contributions. These sources are distributed area sources, emissions are exhausted at low height, and thus they give significant contributions to the exposure of the population.

Stone crushers are located in some areas and expose nearby populations. Emissions from stone crushers have been worked out separately (by Aditya), assuming uncontrolled emissions.

The emission figure for **domestic refuse burning** refers to burning street litter and leaves which is common, although little is known about the magnitude of the practice. A first gross estimate of 1 kg per household per week was used. The emission factor is highly uncertain. 37 g/kg has been used, based on WHO (1993), supported by NILU experiments (Semb, 1986). For burning at municipal refuse dumps, 8 g/kg has been used, with reference to WHO (1993).

For **construction**, an emission figure has not been developed, for lack of data.

Estimates of TSP emissions from construction tend to be substantial, such as for Manila (Larssen et al., 1995).

The following rough estimate for **road dust resuspension** is used:

US EPA suggests the following emission factors (EPA AP 42):

- local streets (AADT < 500): 15 g/km
- collector streets (AADT 500-10 000): 10 g/km
- Major streets (AADT 10 000-50 000): 4.4 g/km
- Freeways/expressways (AADT >50 000): 0.35 g/km

These factors are considered valid for dry road conditions. Much of the traffic activity takes place on roads with AADT >50 000. Assuming the traffic activity share on these road classes are 5%/25%/30%/40% respectively, and that the roads are wet 50% of the time, EPA emission factors give a grand average factor of somewhat more than 2 g/km. A recent evaluation of emission rates from roads, based on measurements, supports in general the EPA emission factors for pared roads, although the study concludes that more investigations is needed (Claiborn et al., 1995). We select 2 g/km as an average resuspension emission factor.

PM_{10}

Total PM_{10} emissions are calculated at about 16, 000 tonnes/a for 1992-1993.

Refuse burning, resuspension, vehicle exhaust from diesel trucks and fuel oil combustion in industry were the dominant PM_{10} sources. Source distributions are shown in Figure 2.5.

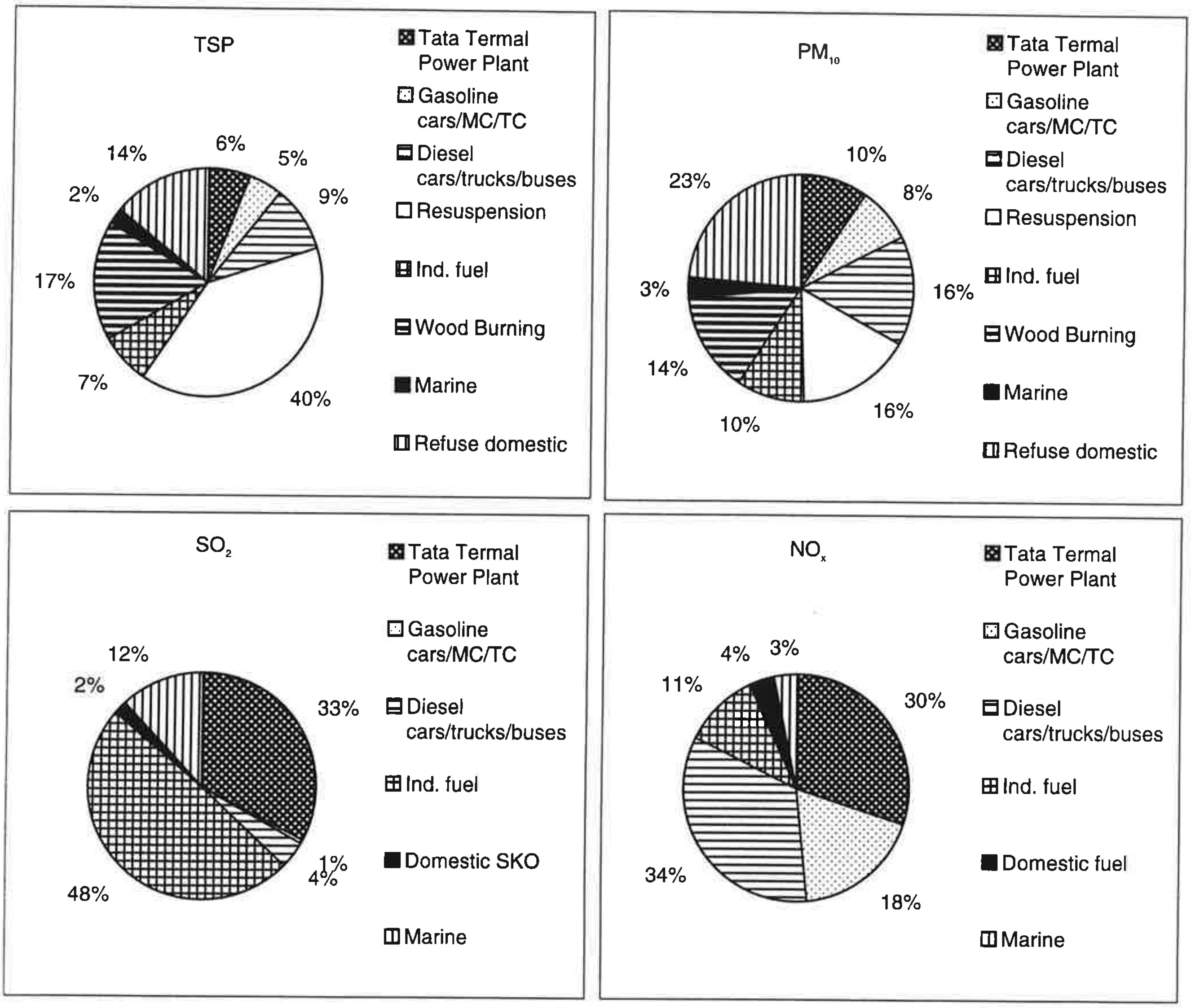


Figure 2.5: Source contributions to emissions of TSP and PM_{10}, Greater Bombay, 1992.

SO_2

SO_2 emissions are calculated on the following maximum sulphur contents of fuel:

Fuel Oil (FO)	:	4%
Light diesel oil (LDO)	:	1.8%
Distillate (LSHS, HSD)	:	1%
Motor diesel	:	1%
Kerosene	:	0.25%
Gasoline 87 RON	:	0.25%
93 RON	:	0.2%

Total emissions are calculated to about 79 000 tonnes/a, with FO and LSHS used in industry being the main contributors, in addition to the Tata power plant. The actual sulphur contents, and thus actual emissions, may be lower.

NO_x

Total annual NO_x emissions are calculated at 26, 000 tonnes/a, with vehicle exhaust being the main contributor, especially diesel trucks and gasoline cars, in addition to the power plant.

Spatial emission distribution

As a basis for a cost-benefit or cost-effectiveness analysis of abatement measures for Greater Bombay, it was necessary in the URBAIR study to establish a base-line situation for air pollution exposure. It was then necessary to establish spatial concentration fields over the urban area. The main air pollution problem in Bombay is high particle concentrations, and to model the spatial distributions, a gridded particle emission survey was needed.

The calculated total emissions were distributed over a km^2 grid net of $42x20\ km^2$, covering the area shown in Figure 2.6.

Point source emissions were distributed according to their actual location. Fuel consumption in small industries and domestically was distributed according to the population distribution, as described in Appendix 4. Traffic emissions on the main road network were distributed according to the locations of the various. The rest of the total diesel and gasoline used was distributed according to the non-slum population distribution.

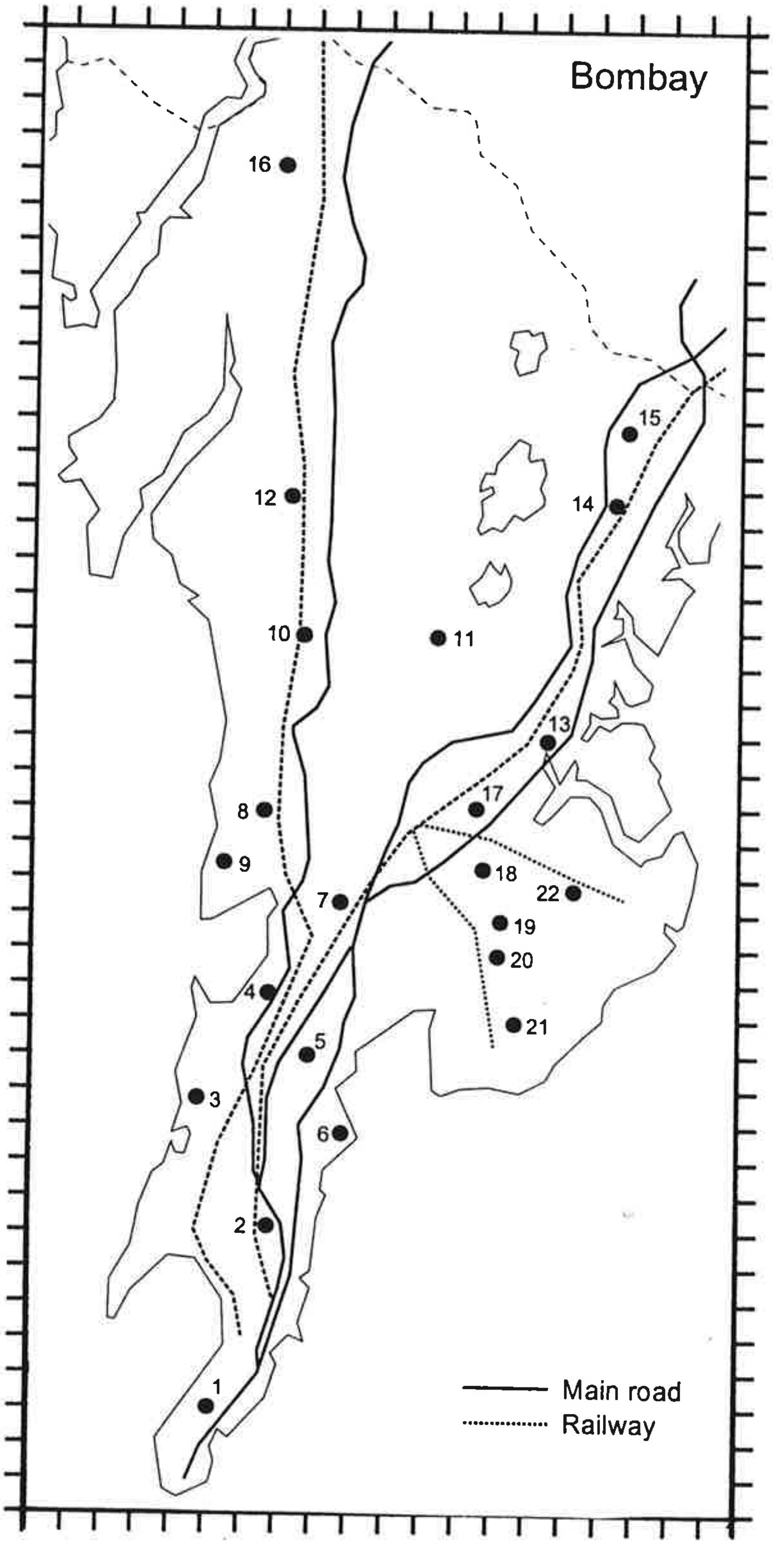


Figure 2.6: Exposure modeling area, Greater Bombay.

2.3 Dispersion model calculations, Greater Bombay

2.3.1 Dispersion conditions

General description of topography, climate and dispersion

Bombay consists of several islands on the Konkan coast. The mean elevation of Bombay is 11 m above mean sea level.

Bombay has a tropical savannah climate with monthly mean humidity ranging between 57-1987 percent. The annual mean temperature is 25.3 °C, rising to a monthly maximum of 34.5 °C in June and with a monthly minimum of 14.3 °C in January. The total annual mean precipitation is 2 078 mm with 34 percent (709 mm) falling in the month of July. Due to the summer monsoon the maximum time of insulation occurs in the winter.

In the winter the predominant local wind direction is northerly. In the summer monsoon season north-westerly winds predominate. There is virtually always a sea breeze during the day with mean wind speeds between 1.5-2 m/s. Calm winds occur at night between 22:00 and 06:00. The mixing depth varies between 30 m and 3, 000 m (NEERI, 1991).

Studies have shown that active monsoon conditions were associated with a lowering of the mixing layer height, an absence of inversion/stable layers, and decreased convective instability in the lower layers of the monsoon atmospheric boundary layer. The reverse was observed on monsoon break days. In weak and break monsoon conditions there is a subsidence and feeding of dry air from aloft. During moderate to active monsoon conditions the moisture reaches higher levels due to synoptic scale convergence (Parasnis and Goyal, 1988).

The adverse meteorological situations that could lead to high pollution concentrations in Bombay are in the winter time when weak and break monsoon conditions dominate. In the early mornings when the inversion layer is deepest, this lead to poor vertical mixing of pollutants.

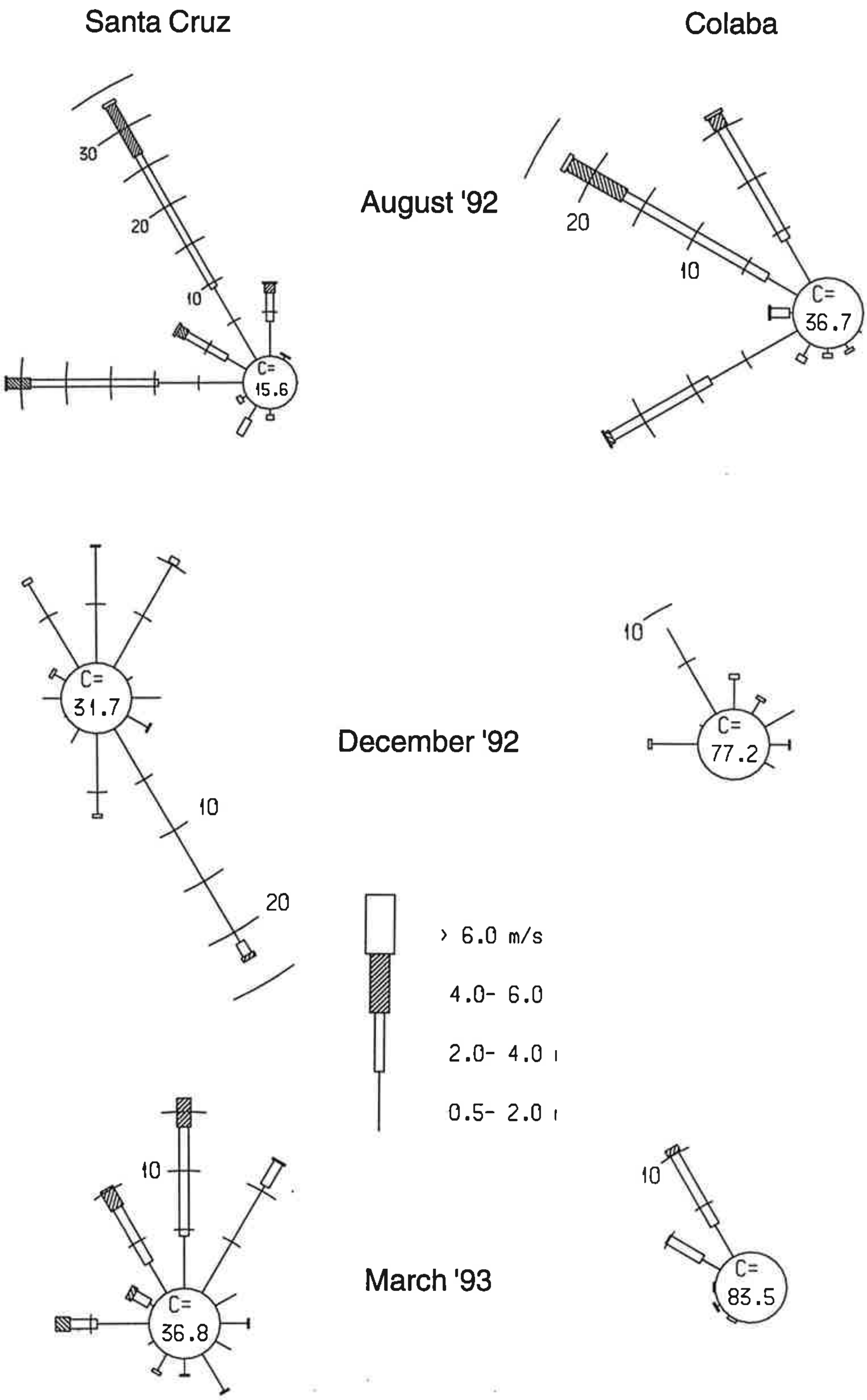
In the daytime, when there is high insulation the sea breezes blow from the sea towards the land. This wind direction may cause stagnation of the airmass when the monsoon winds run in the opposite direction. This may happen during daytime in the winter season and during the early morning in the summer season.

Dispersion conditions

Dispersion of air pollution emissions is dominated by wind conditions and the vertical stability of the atmosphere.

Wind statistics from the meteorological stations at the airport (Santa Cruz) and at Colaba Observatory (at the southern tip of Bombay) has been obtained from the Indian Meteorological Department (IMD).

Figure 2.7 shows wind roses from Santa Cruz for December (winter), May (summer) and monsoon (August) conditions, 1992/1993.



	August 1992	December 1992	March 1993
Average wind speed, m/s	2.3	0.8	1.3

Figure 2.7: Wind roses for 1992-1993, Santa Cruz Airport and Colaba.

The large “calm” percentage at Colaba, and much lower wind speed there than at Santa Cruz indicates that the wind counter has a high starting velocity, or that it is shielded by nearby vegetation or buildings.

During the monsoon (August), winds are fairly strong, and the dominating directions at Santa Cruz are from west and northwest. At Colaba in South Bombay, the wind direction seems to be shifted some 30° anti-clockwise.

During winter (December), winds are very weak, and southeast is a main wind sector, as well as the northerly sector. During summer (March) the wind speed is pricking up again, and the northerly sector dominates.

From these data, and from calculations of the stability class based on hourly observations of wind and cloud cover, a combined wind/stability matrix has been constructed. Such a matrix representing the statistics of dispersion climatology can be used as input to dispersion models for calculation of long-term average concentrations of pollutants, based also on emission data. The combined matrix is given in Table 2.7, which is based on the Santa Cruz data. This matrix is used for the dispersion conditions, uniformly over the entire modeling area.

Table 2.7: Wind/stability frequency matrix (%, annual), Santa Cruz Airport, June 1992-May 1993.

YEAR AVERAGE SANTACRUZ

	I	N	SS	S	I	N	SS	S	I	N	SS	S	I	N	SS	S
	0.3-2.0 m/s 1.1 m/s				2.0-4.0 m/s 2.9 m/s				4.0-6,0 m/s 4.8 m/s				> 6.0 m/s 6.8 m/s			
30	1.6	.9	.5	.8	.3	1.4	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0
60	.7	.4	.5	.8	.2	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
90	1.4	.1	.1	.5	.4	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
120	1.9	.2	.3	.4	.5	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
150	1.9	.1	.2	.5	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
180	1.3	.1	.2	.1	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
210	.6	.3	.1	.0	.1	.6	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0
240	.4	.5	.1	.0	.2	1.0	.0	.0	.1	.3	.0	.0	.1	.0	.0	.0
270	1.2	1.9	.6	.2	1.5	3.8	.0	.0	.4	1.6	.0	.0	.0	.4	.0	.0
300	1.8	1.4	.3	.2	1.3	3.6	.0	.0	.3	1.5	.0	.0	.0	.3	.0	.0
330	2.4	1.2	.5	.2	1.5	2.7	.0	.0	.3	.9	.0	.0	.0	.2	.0	.0
360	4.3	1.1	.5	.8	2.4	2.4	.0	.0	.2	.2	.0	.0	.0	.0	.0	.0
	10.5	.0	4.2	16.7	Calm											

Stability classes:	Velocity classes (m/s)	Frequency of calm:
I - unstable	0.3-2.0 (1.1 m/s average)	In unstable class: 10.5%
N - neutral	2.0-4.0 (2.9 m/s average)	In neutral class: 0%
SS - slightly stable	4.0-6.0 (4.8 m/s average)	In SS class: 4.2%
S- stable	>6.0 (6.8 m/s average)	In stable class: 16.7%

The calm frequencies are distributed in the direction sectors within each of the stability classes of the 0.3-2 m/s velocity class, proportional to the occurrence of wind.

2.3.2 Dispersion model calculations, city background

Model Description

The dispersion modeling work in the first phase of URBAIR concentrates mainly on the calculation of long-term (annual) average concentrations representing averages within km^2 grids ("city background" concentrations). Contributions from nearby local sources in specific receptor points (streets, industrial hot spots) must be evaluated additionally.

The dispersion model used for URBAIR in Greater Bombay is a multisource Gaussian model treating area, point, and volume sources separately.

Meteorological input to the model is represented by a joint wind speed/direction/stability matrix representing the annual frequency distributions of these parameters. The dispersion conditions are assumed spatially uniform over the model area.

For point sources, account is taken of plume rise (Briggs equations), the effects of building turbulence, and plume downwash.

For area sources, the total emissions in a km^2 grid is simulated by 100 ground level point sources equi-spaced over the km^2.

The following dispersion parameter definitions were used:

Low level area sources:	McElroy-Pooler classification
Point sources (stacks) :	Brookhaven classification

The actual software package used in the KILDER model system was developed at NILU (Gram and Bøhler, 1992).

Total suspended particles (TSP)

Calculated annual average TSP concentration distributions are shown in Figure 2.8 for the following source categories:

- road traffic (vehicle exhaust);
- area sources - domestic fuel combustion (wood, SKO, LPG), fuel combustion in small industries (LSHS, LDO), and also stone crushers and burning in refuse dumps; and
- point sources (emission from about 280 large and medium industrial plants).

The distribution from all sources are combined, when a background concentration of 60 $\mu g/m^3$ is added. This background concentration has been estimated based on measurements carried out near Vikram and Thal South of Bombay (data provided by M.G. Rao, RCF and by ADITYA).

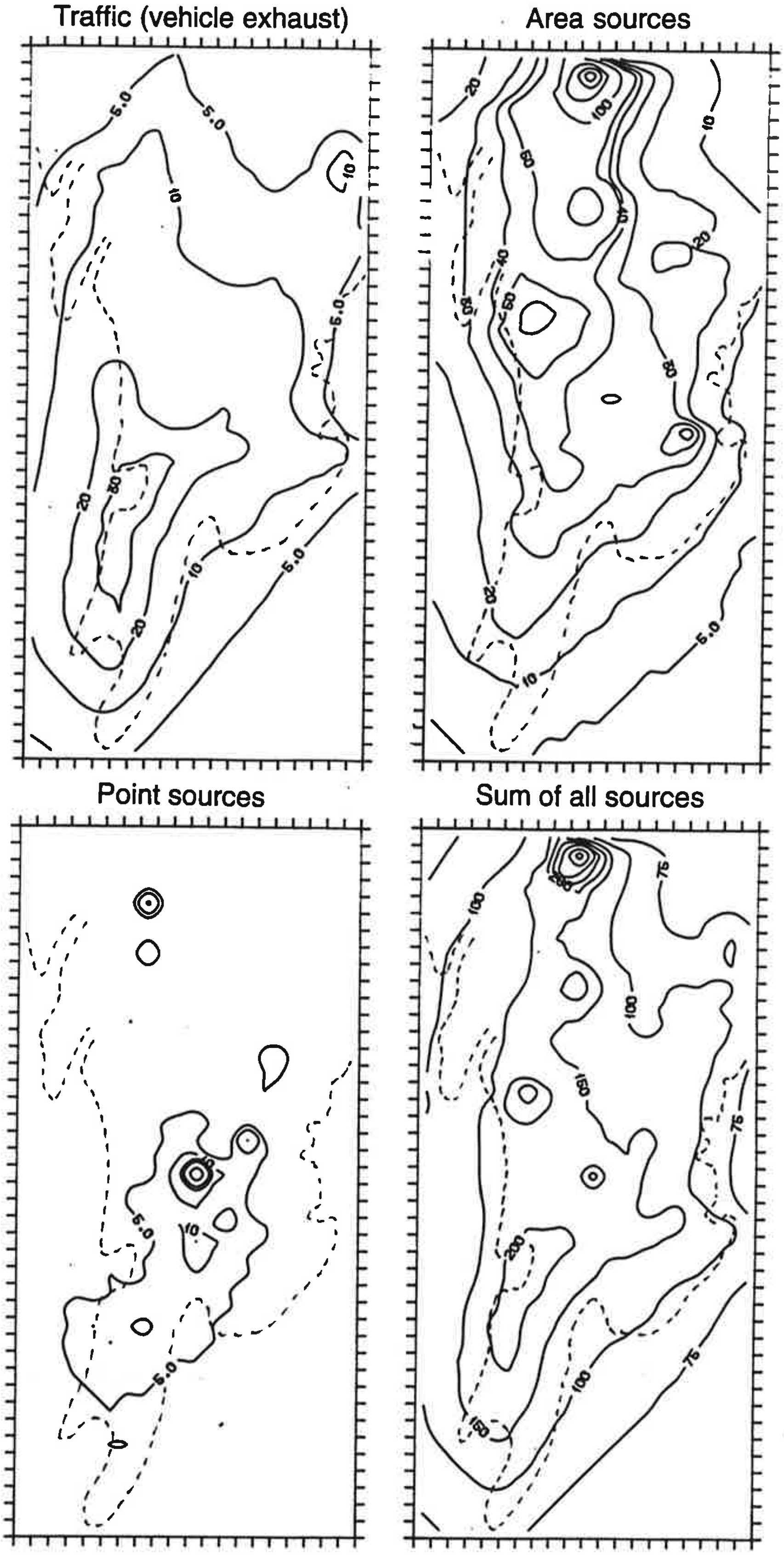


Figure 2.8: *Calculated annual average TSP concentration distributions, Greater Bombay, June 1992-May 1993.*

It should be noted that resuspension from roads has also been added to the total distribution. The concentration distribution from resuspension is proportional to that from traffic, with the emission factor as proportionality factor. The concentrations from resuspension are calculated to be about 2.5 times those from exhaust particles, based on emission factors.

Resuspension from roads is the most important TSP source, according to our estimates.

Domestic burning of refuse has **not** been added to area sources when calculating the concentrations. The rough estimate of emissions from refuse burning is about the same as from vehicle exhaust. This emission should be distributed according to the population burning refuse. It might be estimated that concentration contribution from refuse burning would be about the same as from traffic, about 20-30 μg/m³ in the maximum zone.

The concentration peaks corresponds to:

- stone crushers (in the area source distribution); and
- specific industrial sources (in the point source distribution).

In Figure 2.9, measured annual TSP concentrations are plotted (from Figure 2.1). The calculated and measured values are of the same magnitude, and compare generally. Quite a few of the sites with high measured values compared to measurements were classified as situated in industrial areas, indicating possibilities for contributions from local sources in the sub-grid scale.

In this comparison it should be noted that TSP from refuse burning is in addition to the calculated concentrations.

PM_{10}

PM_{10} concentration distributions have not been calculated, but can be estimated based on calculated TSP concentrations and PM_{10}/TSP ratios (Table 2.8). Estimated PM_{10} concentration contributions in the maximum zone (Dadar-Sion):

Table 2.8: Calculated TSP concentrations and PM_{10}/TSP ratios.

	Concentration level (μg/m³) TSP	PM_{10}
Vehicle exhaust	~ 30	~ 30
Resuspension	~ 80	~ 20
Area sources	~ 30	~ 15
Point sources	~ 5	~ 3
Extra-urban background	60	~ 30
Sum	~205	~100

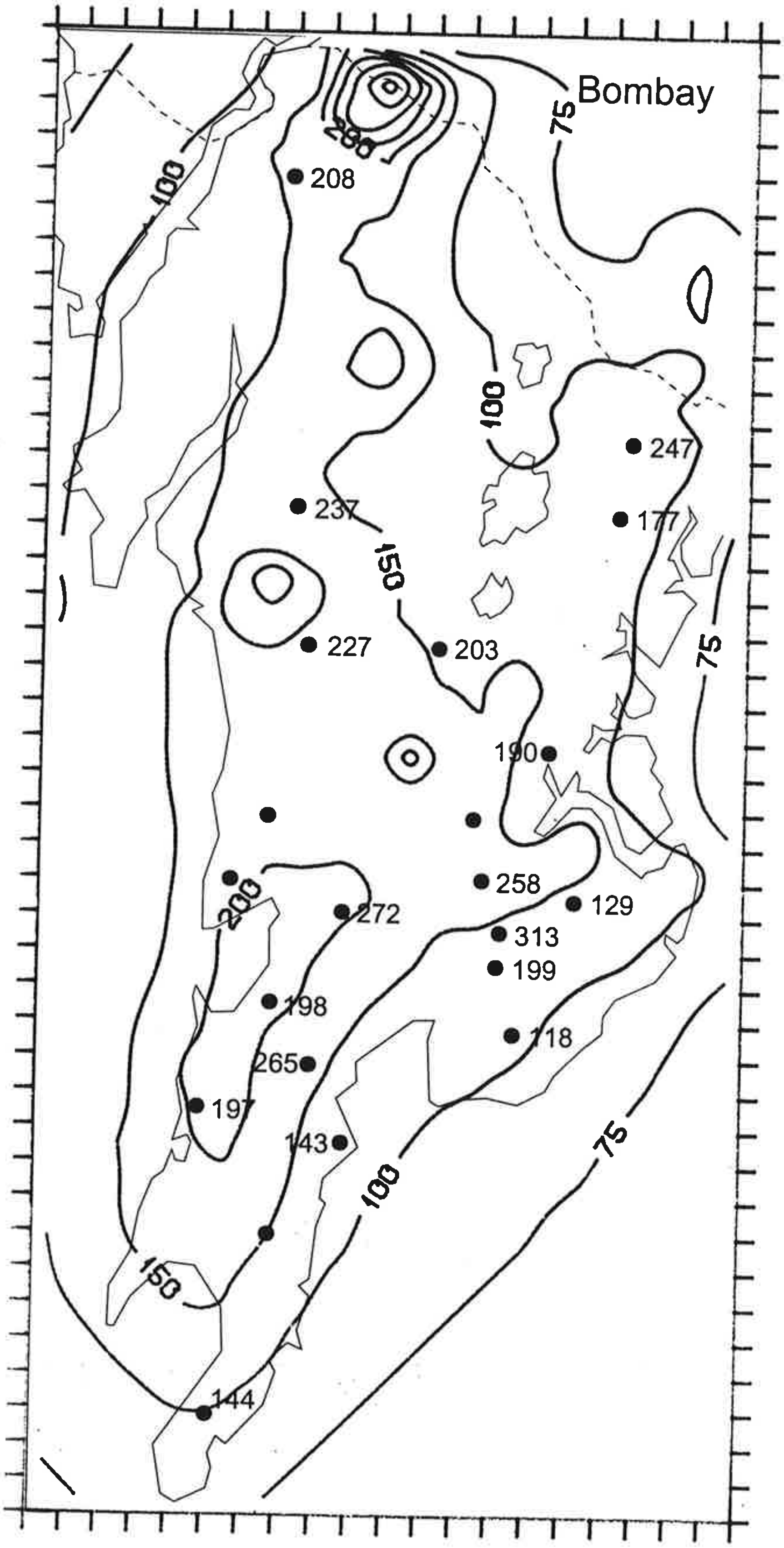


Figure 2.9: *TSP, annual average, Greater Bombay, June 92-May 93. Calculated and measured values.*

Annual average PM_{10} concentrations of about 100 µg/m³ can be expected in the Dadar-Sion area, about 50% of the TSP concentrations. This is a bit higher than the PM_{10} concentrations reported in Table 2.3, as measured in 1982. It can be expected that the PM_{10} concentrations have increased since then.

SO_2

Figure 2.10 shows calculated SO_2 concentration distributions (annual average, June 1992-May 1993), in the same fashion as for TSP. In this case, the distribution represents the sum from traffic (vehicle exhaust), area sources (fuel combustion) and point sources, with no extra-urban background added.

The traffic (vehicle exhaust) source is actually the most important source for ground level SO_2 concentrations in Bombay.

Calculated annual average SO_2 in the maximum zone of Dadar-Parel (excluding peaks near specific industries) is around 70 µg/m³. This is quite a bit higher than those measured, which are in the range of 30-40 µg/m³. The discrepancy might be partly accounted for by assuming that the average SO_2 contents in fuel is less than the maximum content assumed.

NO_x

Figure 2.11 shows the calculated NO_x concentration distributions, from vehicle exhaust, fuel combustion in area sources, and point sources. Calculated concentrations are highest in the Dadar-Sion area, around 200 µg/m³. Measured NO_x concentrations are about half that, about 100 µg/m³ (see Appendix 1). Vehicle exhaust is the most important source for ground-level NO_x concentrations.

2.3.3 Pollution hot spots

Pollution hot spots, give large concentration contributions in their neighbourhoods, adding to the general city background.

Pollution hot spots are:

- along the main roads; and
- near industrial areas with significant emissions from low stacks.

The calculated concentration distributions of Figure 2.8, 2.9 and 2.10 indicate industrial pollution hot spots, such as stone crushers, and specific industries. Also, the measurements described in Figure 2.1, and in Table 2.1, show that the highest concentrations measured are indeed in industrial zones (e.g. Maravali) and near road crossings.

Such hot spot pollution areas may contribute significantly to air pollution exposure.

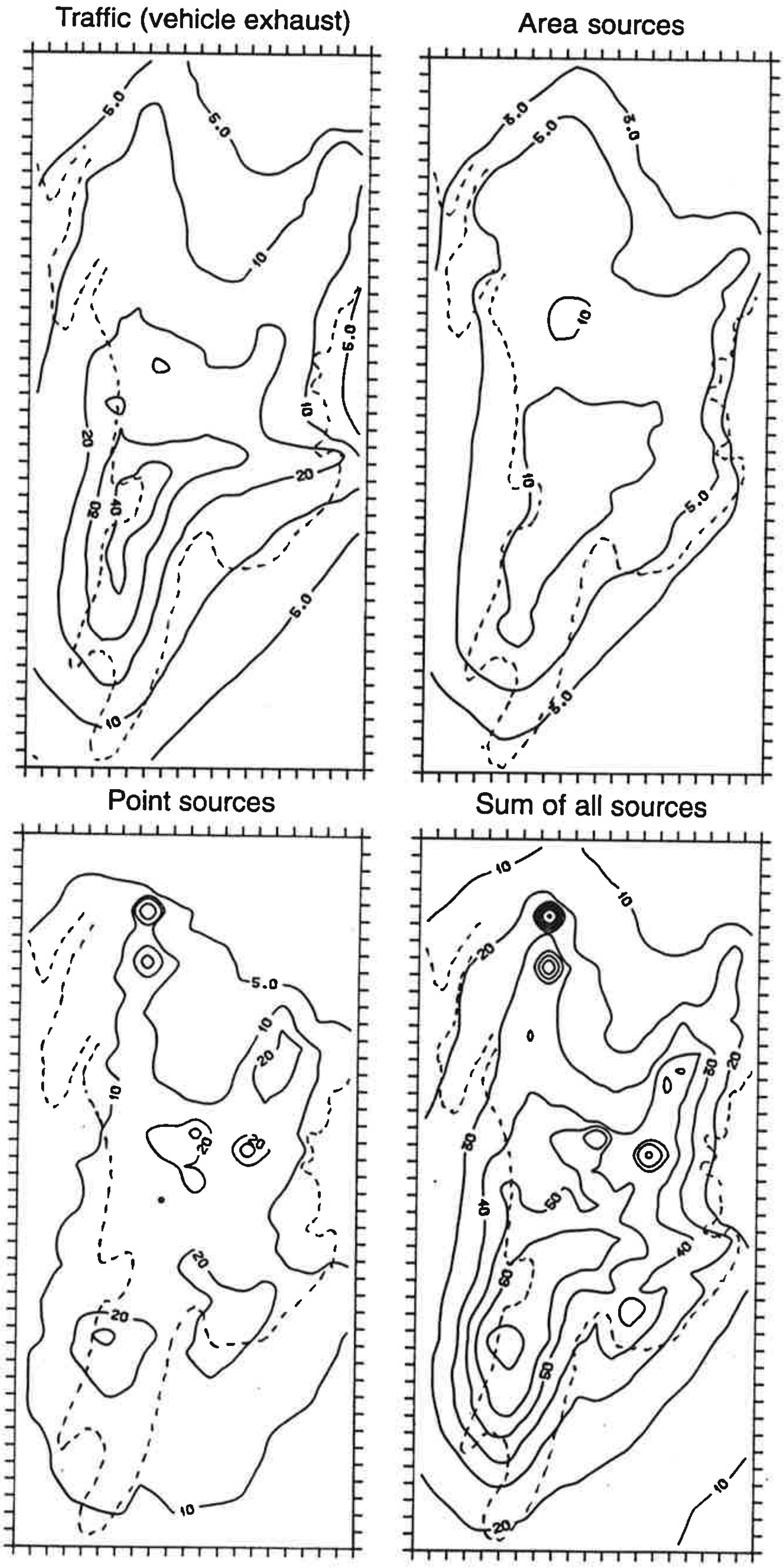


Figure 2.10: Calculated annual average SO_2 concentration distributions, Greater Bombay, June 1992-May 1993.

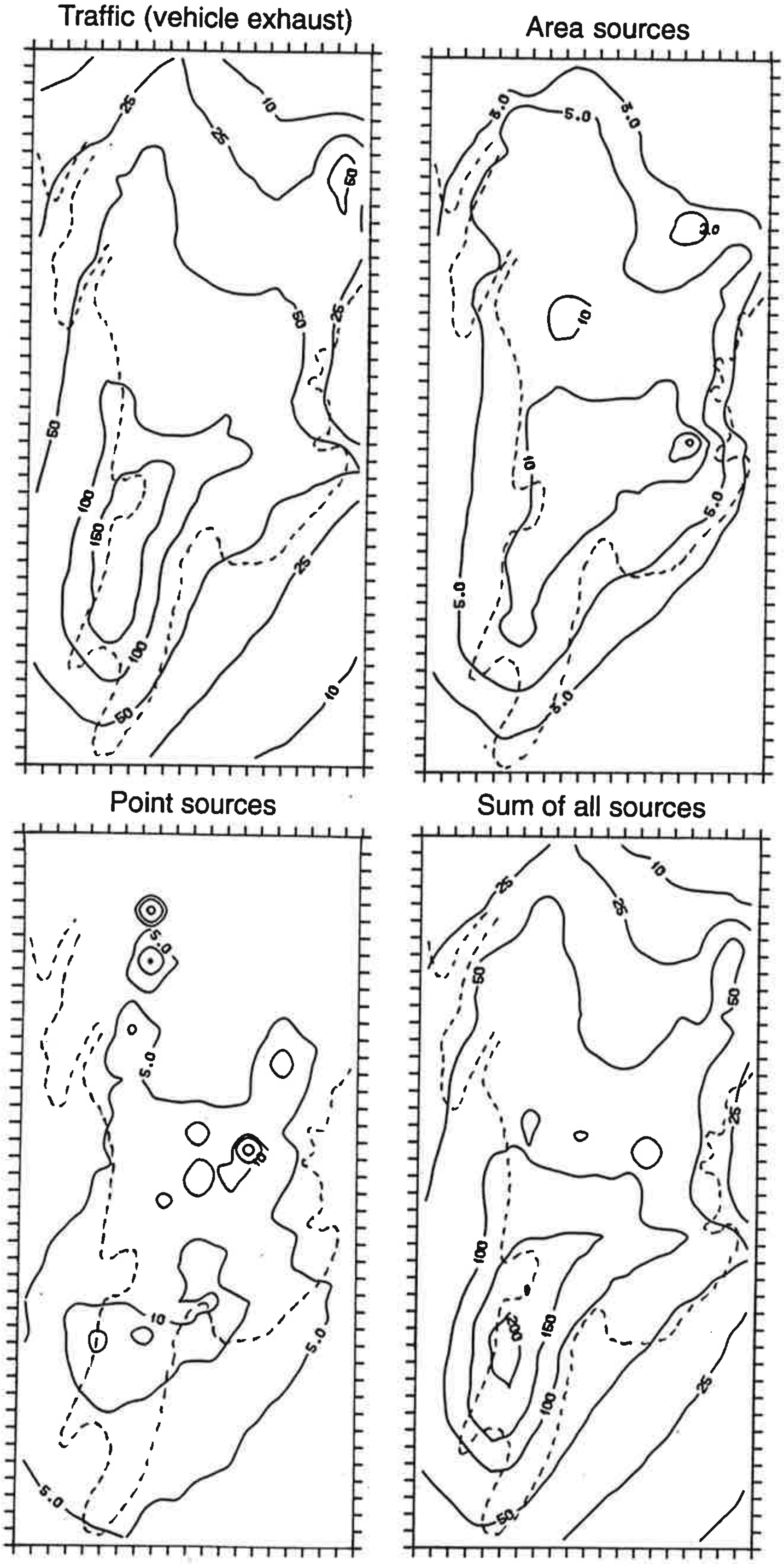


Figure 2.11: Calculated annual average NO_x concentration distributions, Greater Bombay, June 1992-May 1993.

2.4 Population exposure to air pollution, Greater Bombay

The term "population exposure" is defined as follows:

- the number of inhabitants experiencing concentrations of pollution compounds above given concentrations.

The cumulative population exposure distribution gives the percentage of the total population exposed to concentrations above given values. People are exposed to air pollutants at home, during commuting on roads, at work, and other places. The correct mapping of pollution exposure requires data on:

- Concentration distributions, and their variation with time;
  - at peoples residences (general city air pollution, "city background");
  - along main roads; and
  - near other hot spots, such as near industrial areas.

- Population distribution (residences and workplaces), the number of commuters, and time-dependent travel habits.

The database for population exposure calculations are often incomplete. The methodology must be developed for each city, based on the actual database.

The methodology used for Greater Bombay is described in Appendix 6. It is, described briefly, as follows:

- The concentration distribution with all sources accounted for, is calculated (except contributions from domestic refuse burning, as mentioned).

- Residents close to the main roads are given an added exposure.

- The residence exposure is calculated from this concentration distribution and the km^2 population distribution.

- An added exposure for travelling on roads is calculated for commuters and drivers.

This method gives a rough estimate of actual population exposure in Bombay. With the method used, industrial hot spot exposure is not accounted for, except near stone crushers.

TSP

Population exposure has been calculated for **TSP**, the major air pollution problem in Greater Bombay. The calculation has been done for **annual average** TSP, to serve as input to health damage analysis.

This is not to diminish the importance of exposure to high short-term concentrations of suspended particles, and other pollution compounds, in hot spots such as on or near the main roads and near polluting industries. Calculating such exposure requires, however, a more extensive database than was available to URBAIR for Greater Bombay. Also, comprehensive dose-effect relationships regarding health have not yet been developed for short-term exposures, although air quality guidelines have been set for short-term exposures.

The results of the population exposure calculations for annual average TSP in Greater Bombay, (present conditions 1992-1993), are shown in Figure 2.12.

The present TSP exposure situation in Greater Bombay can be summarized as follows:

- About 97% of the population is exposed to TSP concentration above the WHO air quality guideline (AQG, 90 $\mu g/m^3$).

- About 8% of the population is exposed to TSP above 2xWHO AQG (180 $\mu g/m^3$), including some estimated 300, 000 drivers.

- The most seriously exposed are roadside residents and public transport drivers, policemen and other roadside workers (estimated to 300, 000, or 3% of the population), and residents near stone crushers.

General exposure at residences are due to the following main sources:

For TSP: Resuspension from roads, domestic wood combustion, diesel vehicles, and domestic refuse burning.

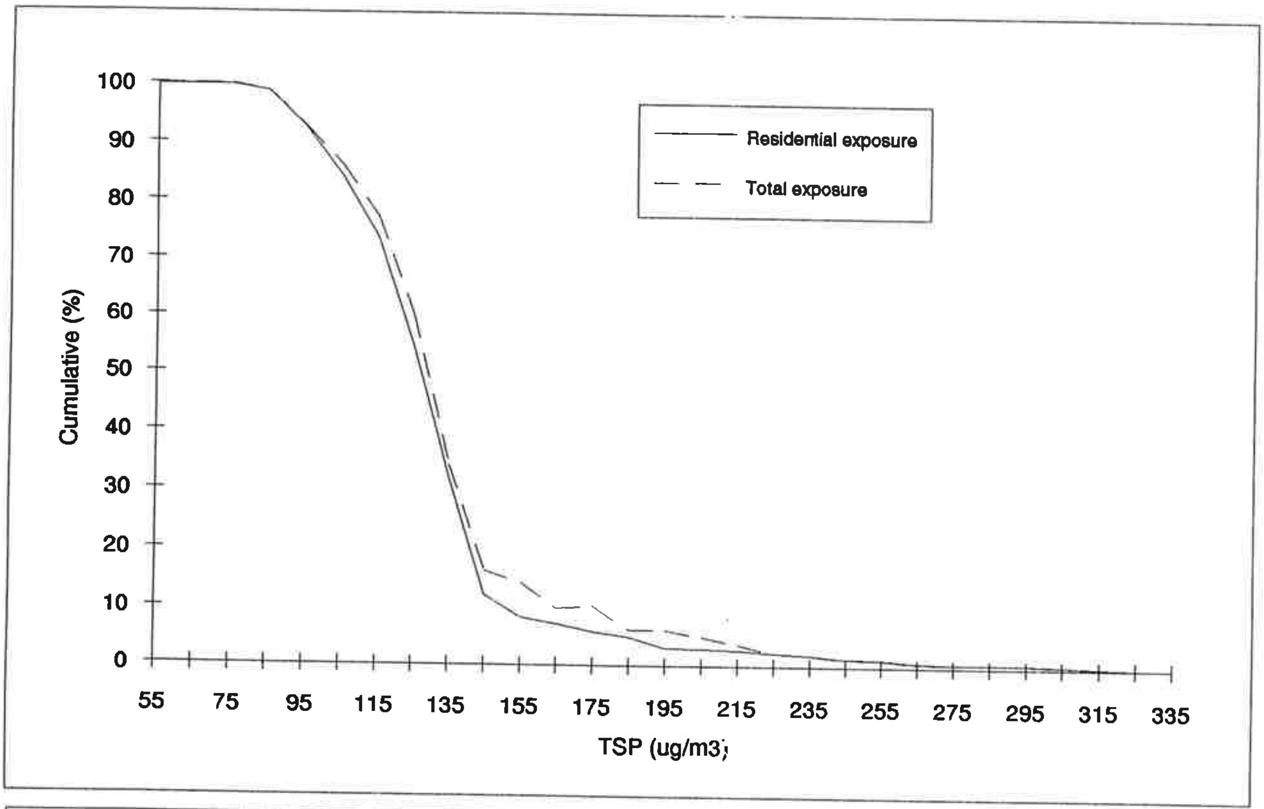
For PM_{10}: Diesel vehicles, domestic refuse burning, domestic wood, and resuspension.

Additional exposure in hot spot areas near industries may be significant.

PM_{10}

Corresponding population exposure to PM_{10} can be estimated by multiplying the TSP axis in Figure 2.12 by about 0.5.

From the Table it is clear that in Bombay the long-term WHO AQG for TSP, 90 $\mu g/m^3$, is exceeded to a larger extent than the corresponding PM_{10} guideline of 60 $\mu g/m^3$. Thus, for long-term exposure to particles, TSP is the limiting parameter.



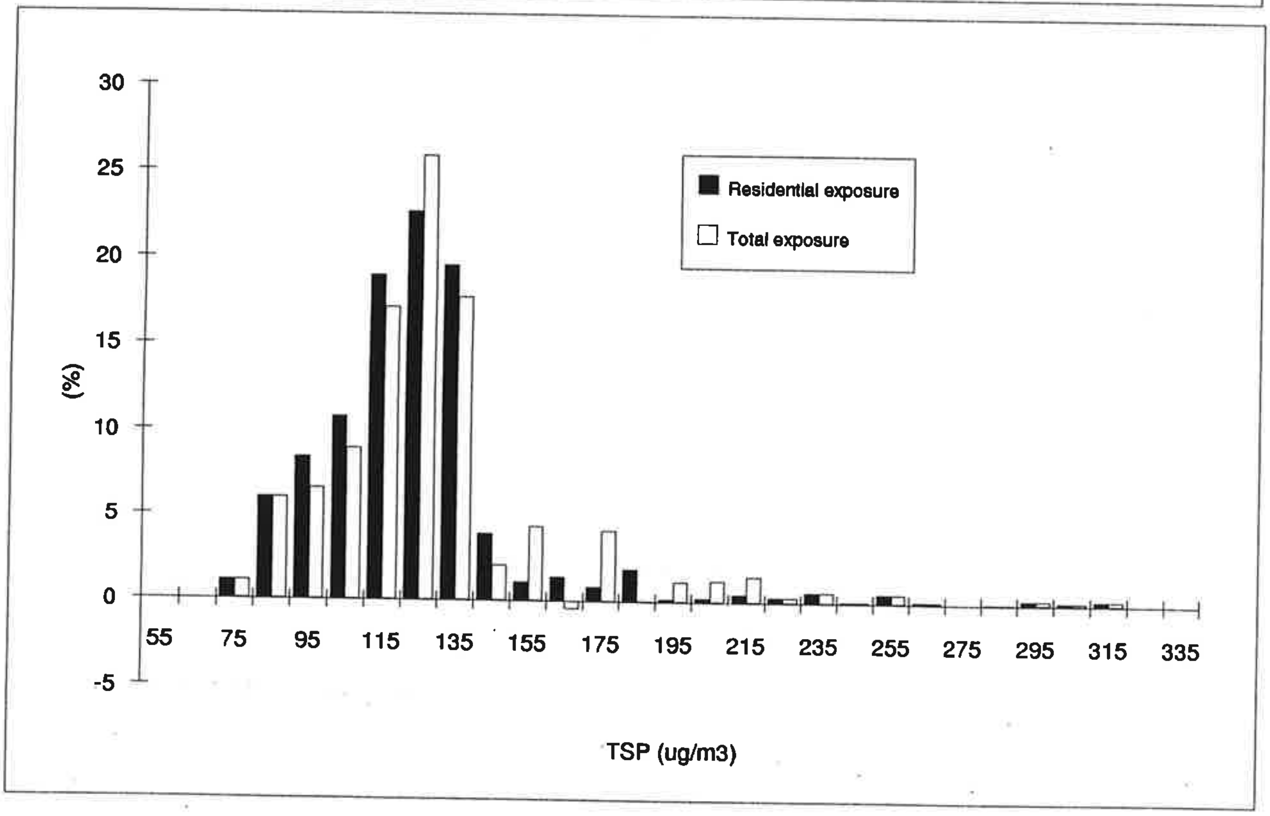


Figure 2.12: Calculated population exposure distribution, Greater Bombay modeling area, TSP, annual average, present conditions (1992-1993).

2.5 Summary of the Air Quality Assessment

Greater Bombay Air Quality:

- Concentrations of TSP, SO_2 and NO_x have for many years been measured regularly at more than 22 fixed locations, for a few days each month. The locations are partly area-representative stations, partly street-side, and some are in industrial areas.

- This database, which has its limitations, shows:

  - TSP frequently exceeds WHO AQG at all stations. Concentrations at street crossings are sometimes extremely high, exceeding the AQG by a factor of 10 or more.

  - Relative to their respective AQGs, TSP and PM_{10} are the most important pollution parameters in Bombay.

It is desirable to substantially improve the air quality monitoring system of Greater Bombay (see Ch. 2.7).

Emission sources:

Large amounts of suspended particles come from road traffic, exhaust (particularly from diesel vehicles) and resuspension of road dust. Other particle sources are domestic refuse burning (roughly estimated), wood combustion and industrial and marine fuel oil combustion. Road traffic dominates NO_x emissions, while power plant and industrial fuel oil combustion dominates SO_2 emissions.

Estimated contributions from sources are as follows:

TSP:	Resuspended road dust	32% (rough estimate)
	Wood combustion	14%
	Diesel vehicle exhaust	8%
	Domestic refuse burning	11% (rough estimate)
	Industrial fuel combustion	6%
PM_{10}:	Diesel vehicle exhaust	15%
	Domestic wood	14%
	Domestic refuse burning	24%
	Resuspension from roads	16%
	Gasoline vehicle exhaust	12%
SO_2:	Industrial fuel combustion	82% (incl. power plant 33%)
	Diesel vehicle exhaust	4%
	Marine fuel combustion	12%

Improvements of the emission inventory is needed, especially regarding industrial emissions, domestic refuse burning, resuspension and construction (see Ch. 2.7).

Population exposure:

Calculations shows that about 97% of the population is exposed to annual average TSP concentrations exceeding the WHO AQG.

Estimated exposure of annual average TSP in exceedance of 2xAQG is 8% of the population, including an estimated 300, 000 drivers, other roadside workers, roadside residents, and residents near stone crushers.

The exposure is due to the following main sources:

For TSP: Resuspension from roads, domestic wood combustion, diesel vehicles, and domestic refuse burning; and
For PM_{10}: Diesel vehicles, domestic refuse burning, domestic wood, and resuspension.

Additional exposure in industrial hot spots may be significant.

Method for calculating effects of abatement measures on population exposure:

A simplified procedure for calculating of emissions and population exposure has been programmed into spreadsheets, to estimate of the effects of various abatement measures on exposure distribution.

2.6 Improving Air Quality Assessment (AQA) for Greater Bombay

2.6.1 Shortcomings and data gaps

Air Quality

The present measurement system operated by MCGB can be briefly characterized as follows:

- 24 hour (3x8 hours) samples of TSP, SO_2, NO_2 and NH_3 are collected infrequently (1-4 days per month).

- PM_{10}, lead, CO and O_3 and other compounds are not routinely measured.

- Monitoring on roof-tops (4-12 m above ground).

- None of the stations are monitored as frequent as required under the National AQS (at least 104 days per year).

- Many of the measurement sites are not clearly defined in terms of their representativity, as:
  - city background stations (commercial, industrial, and residential);
  - traffic exposed (street side) stations; and
  - industrial hot spot stations.

It is clear that the MCGB air monitoring laboratory operates under considerable financial constraints. Although the quality of the analyses are very good, financial constraints affect their methodological and manpower capacities. It is important to improve air quality monitoring in Greater Bombay.

It is anticipated that an improved monitoring system should include:

- at least 5 city background sites, covering areas of typical and maximum concentrations;
- 1-3 traffic exposed sites (to monitor street level pollution);
- 1-5 industrial area and hot spot sites;
- continuous monitors for PM_{10}, CO, NO_x, SO_2, O_3, depending upon the site;
- an on-line data retrieval system direct to a lab database, via telephone or modem.

Emissions

The main shortcomings of the emission inventory concerns:

- industrial emissions (use and combustion of fuel, process emissions);
- resuspension from roads;
- other coarse particle sources, such as construction;
- domestic refuse burning;
- consumption patterns for domestic and commercial fuel use; and
- absence of local emission factors.

Less important shortcomings regard traffic distribution data which forms the background for the car exhaust emission distribution.

It is necessary to fill the data gaps and upgrade the inventory.

Population exposure

The determination of population exposure to air pollution in Bombay, and the contributions to this exposure from various sources, is based on a combination of dispersion modeling and air pollution monitoring.

A good quality population exposure distribution is important since it is the basis for:

- estimating health damage costs; and
- assessing the effects on health of various measures to reduce exposure, as part of a cost-benefit analysis.

To improve the population exposure calculations beyond what has been developed as part of the first phase of URBAIR, dispersion modeling expertise in Bombay should be identified and the use of dispersion modeling should be integrated into the control agencies' Air Quality Management work. Dispersion modeling expertise and appropriate models for air pollution management and control strategies should rest in Bombay.

2.6.2 Proposed Actions to improve Air Quality Assessment

Actions	**Time schedule**
Air Quality Monitoring • Design and establish a modified/improved/extended ambient air and meteorological/dispersion monitoring system - evaluate sites; number (at least 10) and locations; - select parameters (CO, NO_x, O_3, HC, TSP and PM_{10} recommended)/methods/monitors/operation schedule; and - upgrade laboratory facilities, and manpower capacities. • Design and establish a Quality Control/Quality Assurance System • Design and establish an Air Quality Information System, including - database; and - information to . control agencies; . lawmakers; and . public.	This activity should start immediately, and a proposed schedule is as follows: • By 31 December 1995: Finalize plan for an upgraded air quality monitoring system, including plans for laboratory upgrading. • During 1996: - Establish of 1-2 new modern monitoring stations; and - Carry out first phase of laboratory upgrading. This activity should also start immediately, phased in with the improved monitoring system, and the laboratory upgrading.
Emissions • Improve emission inventory for Greater Bombay a) Improve industrial emissions inventory(location, process, emissions, stack data) b) Improve road and traffic data inventory c) Improve domestic emissions inventory d) Study resuspension - from roads - from other surfaces	• 1. priority: - industrial emissions inventory - study of resuspension from roads - start developing an emission inventory procedure.

e) Estimate contribution from construction and refuse burning. f) Establish emission factors for Indian conditions. • Develop an integrated and comprehensive emission inventory procedure, include emission factor review, update and quality assessment procedures. • Improve methods and capacity for emission measurements.	
Population exposure Assess current modeling tools/methods, and establish appropriate models for control strategy in Greater Bombay.	

3. Projections of PM_{10} emissions in Bombay

3.1 Introduction

This chapter presents expected developments of PM_{10} emissions in Bombay if only measures currently decided upon are taken. This forecast, of future air quality and exposure, is derived from:

- emissions by the various source categories in 1992 (see chapter 2);
- forecasts of variables explaining emissions, such as fuel consumption, vehicle mileages, or production values;
- technological developments relevant to emissions but independent of environmental policies;
- environmental measures already taken (see chapter 5); and
- the number of people exposed to specific air pollutants concentrations.

The time horizon is the year 2010. This choice is based on the expectation that it may take at least fifteen years to fully deploy an environmental policy; For example, the typical lifetimes of vehicles are 10-15 years, which implies that it will take 15 to 20 years to renew the vehicle fleet (unless this chosen for a forced development).

Few expectations of specific developments in the Bombay area were found. This should be remembered when evaluating the forecast results.

3.2 Traffic

The evolution over time of emissions from road traffic is the result of several developments:

- the size of the vehicle fleet;
- the vehicle technology (gasoline, four-stroke, two-stroke/mixed lubrication, diesel);
- emission control techniques required by legislation; and
- the use pattern (annual mileage, driving pattern).

The number of vehicles and their use are in turn dependent on socio-economic developments such as income, demographic situation, availability of alternative modes of transport (mass transit systems), and the like. However, such studies for the Bombay area were not found.

A key factor is the development of the vehicle fleet. Table 3.1 presents assumed projections for its development. The chosen growth rates are the growth rates during 1980-1990 as derived from the statistical data in Table 3.1 (see also Chapter 1).

Table 3.1: The Bombay vehicle fleet ('000), assumed growth rates (%) and future size of vehicle fleet

Vehicle category	1981	1991	Growth rate (%) historical	Growth rates 1991-2010	2010
Passenger cars/Jeeps	150,711	264,951	6	6	800,000
Trucks	41,931	56,086	3	3	100,000
Utility vehicles	3,677	6,501	6	6	20,000
Taxi cab	29,623	34,338	1.5	1.5	45,000
Autorickshaws	4,465	24,577	18	10	
Motorcycles	78,473	242,008	12	10	480,000

In order to account for differences in vehicles emission characteristics, a further division is made. The vehicles are grouped by engine type (gasoline engines, either four stroke or two stroke (mixed lubrication), and diesel engines). These growth rates are used for making forecasts. A more elaborated projection, taking into account developments in income, income elasticity of vehicle ownership and other factors was outside the scope of this study.

It is assumed that annual mileages associated with each vehicle category increases at the same rate. In fact the calculation of future emission is based on a projection of future mileage of the Bombay vehicle fleet (mileages multiplied by appropriate emission factors).

3.3 Large point sources

Large point sources include the power plants, oil refinery, the fertilizer complex and other large industries (see Chapter 1). It is assumed that these emissions grow 4% annually.

This might seem too large a figure considering that in the state of Maharashtra 61 industrial facilities (of which 60 were built before 1981) did not comply with standards (Note of the Central Pollution Control Board, Delhi, 1993). It might be expected that eventually those older facilities will either comply with standards or close at the end of their lifetime. However, these firms constitute only a minority (20%) of 353 facilities.

3.4 Fuel combustion (other than in large point sources)

Industrial, distributed sources. The main source of PM_{10} and SO_2 is furnace oil (4% sulphur). Although this type of fuel constitutes about a third of total fuel consumption in this category, its contribution to PM_{10} emissions is more than 90%.

It is assumed, arbitrarily, that the emissions grow at 4% per year.

Area sources. Two sources dominate this category: wood burning and refuse burning. Emissions are assumed to develop with the expected population growth in Bombay (3.5% per year).

3.5 Population risk

The population in the Bombay modeling area was, in 1981, 8.2 million. Since then the population has grown to 9.8 million in 1991. It is assumed that this trend continues with a growth rate of 3.5% (1990-2010).

3.6 Conclusions

The results of the calculations are presented in Table 3.2 and in Figure 3.1.

Table 3.2: Preliminary scenario for developments of PM_{10} emissions (tonnes) in Bombay.

	1991	2000	2010
Gasoline	1,382	2,930	6,932
Diesel	2,310	3,141	4,527
Resuspension traffic particles	2,595	3,780	7,593
Domestic emissions & refuse burning	6,066	8,255	11,645
Large point sources (industrial)	706	746	803
Industry - distributed sources	378	537	798
	13,437	19,389	32,295

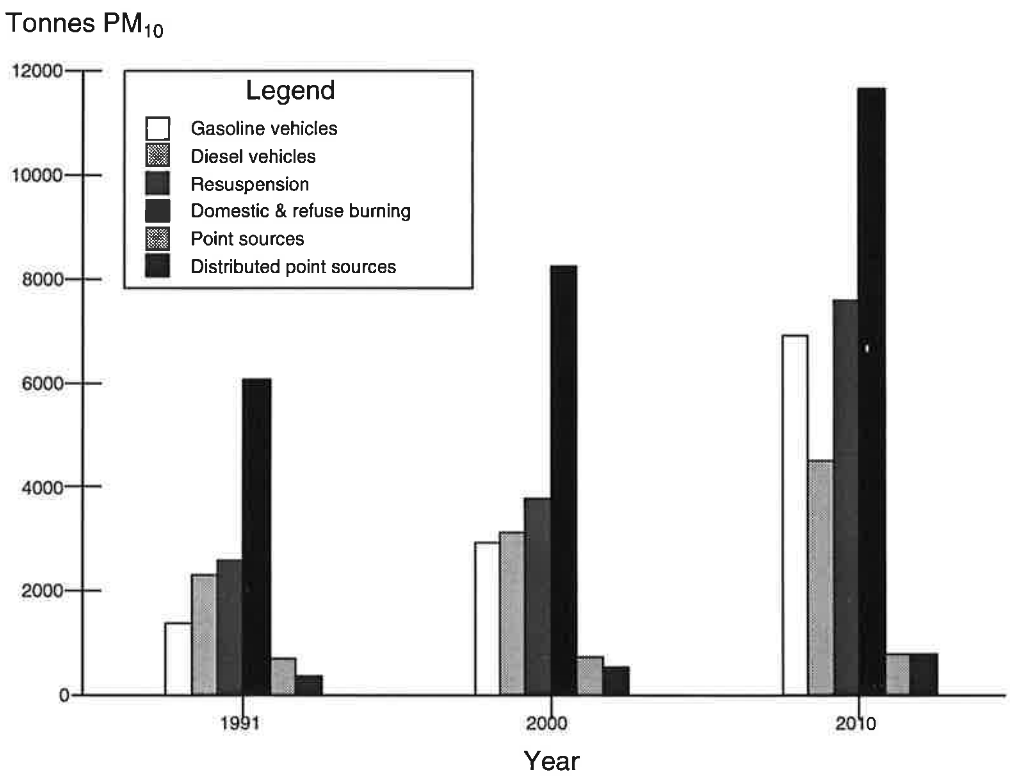


Figure 3.1: Reference scenario for PM_{10} in Bombay.

Today, wood and refuse burning represent as important an emission source as total vehicle exhaust. However, under the various assumptions it appears that traffic emissions will grow the fastest. Important subsectors are diesel trucks and buses, passenger cars, and motorcycles. The latter vehicles, when equipped with two-stroke mixed lubrication engines, emit extraordinary large amounts of pollutants compared to other vehicles. Clearly, environmental risks in Bombay are on the rise.

4. The impacts of air pollution and their valuation

4.1 Introduction

Air pollution in most urban areas is a major public concern. As the level of air pollution is highly related to energy use, and energy use is highly related to economic development, air pollution has hit large cities in the industrialized countries in Europe and North America first. The major reason for concern is the effect of air pollution on public health. Exemplary of this are the "killer fogs", which hit London in 1952 and 1956, causing 4,000 and 1,000 deaths, respectively (Lave and Seskin, 1977).

With the economic development and growth of large cities in Asia, air pollution problems have become endemic. This chapter presents an overview of major impacts of air pollution in Bombay, including an estimation of the monetary value of these damages.

Chapter 2 concludes that the concern about air pollution is mainly due to high concentrations of suspended particles and lead. Therefore, this chapter concentrates on PM_{10}. Unfortunately, current data regarding lead exposure were not available.

The estimate of the impacts on health is mainly based on Ostro's work described in the general URBAIR report (Ostro, 1994).

It is emphasized that health is not the only adverse impact of air pollution However, because of a lack of appropriate data it was not possible to quantitatively assess different impacts such as reduction of economic life of capital goods, tourism, crop growing and other intangible impacts.

Sections 4.3 and 4.4 deal with the calculated impacts on death rates and health in Bombay. Section 4.2 gives a summary of health studies carried out in the study area. Section 4.5 presents a calculation of costs which can be attributed to these impacts.

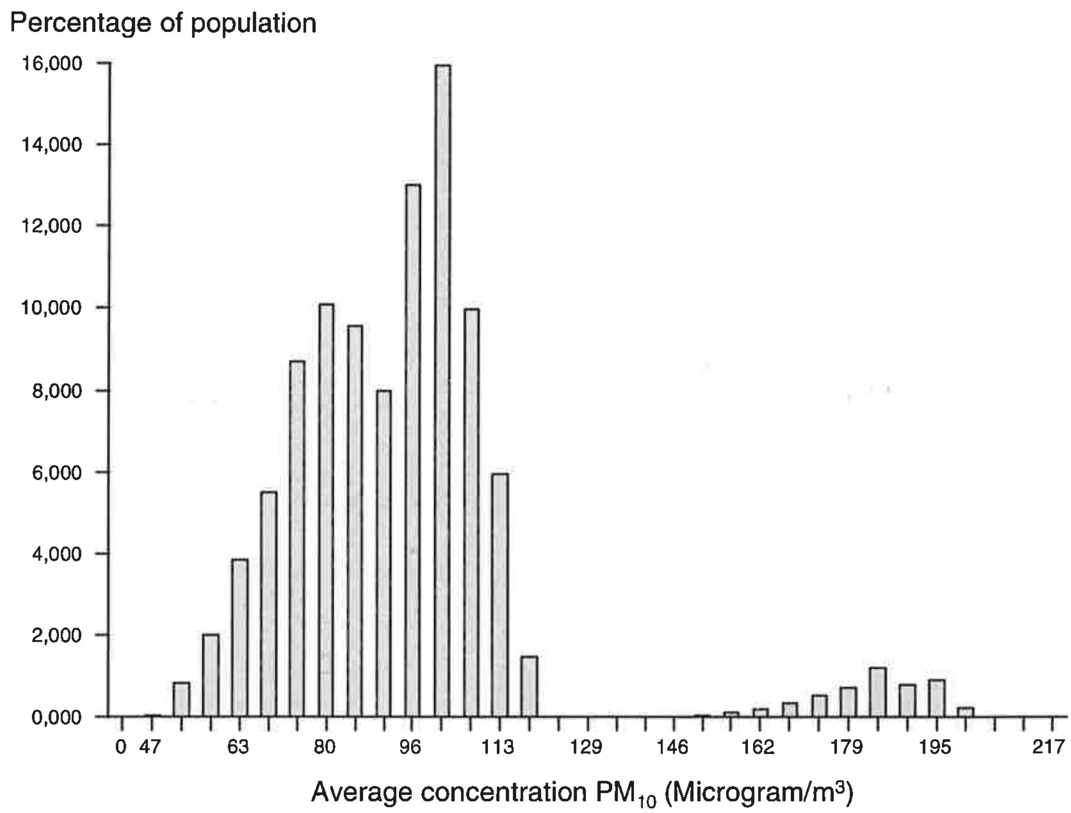


Figure 4.1: Frequency distribution of the PM_{10} exposure of the Bombay population (1991).

4.2 Summary of studies done by Environmental Pollution Research Center (by A.A. Mahashur)

In addition to inadequate housing, sanitation, poor water supply and malnutrition, Bombay's urban populations (of which 60% is slum's) are exposed to rising levels of air pollution. It is experimentally established that air pollutants like SO_2, ozone, oxides of nitrogen, benzopyrene, and suspended particulate matter (SPM) leads to increases in respiratory system morbidity. High SO_2 levels have been shown to cause increased incidence of chronic bronchitis, frequent colds and decline in lung functions. Also, tropical weather with higher humidity of concentrates ozone and SO_2 in the upper airways.

In Bombay, a tropical island showing high SPM and raised SO_2 levels, various symptoms were suspected to be related to increased pollutants levels. Hence the Environmental Pollution Research Center (EPRC), KEM Hospital has conducted studies since 1976 in different parts of Bombay correlating air pollution to health morbidity.

In 1978 (when automobile fuel had higher concentration of lead and sulphur) EPRC conducted a study on 1008 subjects (522 male and 486 female) of a community in Parel, a residential area centrally situated in Bombay. In 1978, because of coal gas factory and many textile mills, along with main arterial roads, there were high pollution levels in the area. The incidence of respiratory symptoms (coughing and dyspnoea) was observed to be higher in this suburb than the population studied in Chembur in the same year (a locality surrounded by chemical and fertilizer factories and thermal power station, but having comparatively low vehicular traffic).

In 1990, following the use of low sulphur fuel and closing the coal gas factory and many of the textile mills, SO_2 levels in Parel had come down from 103 µg/m³ to 29 µg/m³. At the same time due to increases in vehicular traffic, NO_2 levels had increased from 16 µg/m³ to 54 µg/m³, and SPM levels had increased from 242 µg/m³ to 304 µg/m³. Different studies conducted in this area suggested that though frequent colds, headache and eye irritation had lowered, cough, dyspnoea and hypertension had increased. Though the prevalence of bronchitis has decreased, the cardiac diseases had increased (Table 4.1). Table 4.1 shows mean SO_2, NO_2 and SPM levels in different years in Parel, along with the mortality rate (per 100,000) due to respiratory diseases, heart diseases and cancer.

Table 4.1: Pollution trend and mortality rates in Parel. Numbers in 100,000.

	Year			
Pollutants	1978	1982	1986	1990
SO_2	102	62	37	29
NO_2	16	41	52	54
SPM	242	219	326	304
Mortality rate				
Respiratory diseases	117.0	109.6	129.1	113.7
Heart diseases	156.7	263.2	164.5	170.7
Cancer	51.8	48.2	35.5	40.8

In 1988, a cross sectional study examined symptom and disease patterns in four localities:

- 421 subjects (194 male and 227 females) of a community which is about 2 km away from a big fertilizer factory (Tolaram Nagar);
- 397 subjects (185 males and 212 females) of a locality with comparatively low pollution (Telecom township);
- 297 subjects (131 males and 166 females) of Parel (central suburb); and
- 430 subjects (209 males and 221 females) of Dadar (central suburb).

It was observed that coughs and dyspnoea were higher in Tolaram and Parel, compared to Dadar and Telecom. Also, bronchitis, TB, cardiac diseases, and restrictive lung diseases were more prevalent among subjects of Parel and Tolaram Nagar as compared to the other two localities.

In 1978, along Parel, a similar study was conducted in a community of Chembur, consisting of a population of 1122 (586 males and 536 females), surrounded by fertilizer and chemical factories and thermal power stations. Automobile traffic has added to the pollution in this area. To check for the effect of increased pollution, a cross sectional study was conducted in 1990 on:

- 409 subjects (161 males and 248 females) of a community near the fertilizer factory;
- 342 subjects (144 males and 198 females) of a community about 2 km away from the factory; and
- 341 subjects (167 males and 174 females) in another community devoid of industrial pollution.

The results showed that the incidence of respiratory symptoms like coughs and dyspnoea had increased by 8-13%, and the prevalence of bronchitis, cardiac, and other chest disorders had increased from 4.5%, 4.3%, and 0.1% to 7.6%, 6.7%, and 4.4% respectively during 1978-1990 (Table 4.2). Also, it was observed that the incidence of different respiratory symptoms and cardiac diseases, respiratory tract infection, and skin allergy were about 5 to 10% higher among people of the communities near the factory. Furthermore, the lung functions of subjects of both these communities were about 5 to 8% lower than the subjects in the control community. In 1990, an awareness survey was conducted in different communities near the chemical and fertilizer factories of Chembur. More than 95% of the population of these communities complained of strong smells, causing discomfort. The incidence of symptoms decreased as distance from the chemical factories increased. For example incidence of headache and eye irritation was 80% in MSEB colony, just about 100 metres away from the Oswal Agro chemical factory, 73% in Railway Colony, about 500 meters away from the RCF factory, and 50% in Tolaram Nagar, about 2 km away from the RCF factory.

In 1980-1981, a similar study of food and water, was carried out in two middle-class communities in central Bombay. 552 subjects of a community near a wholesale vegetable market, with fairly dirty ground conditions and bad ventilation were compared to 671 subjects in a comparatively clean location. The results suggested that contamination of the food supply was due to unhygienic handling, and water supply contamination was due to sanitary effluent. The prevalence of respiratory diseases were about 3-4% higher in communities near the market, compared to the control.

In 1986-1988, a three year prospective study of two high-density traffic areas of Bombay (King Circle and Peddar Road) was carried out. 383 subjects (164 males and 219 females) from King's circle and 473 subjects (241 males and 232 females) from Peddar Road were selected for the study. It was observed that the mean CO levels were 9 to 18 PPM, reaching a maximum of 63 PPM in these two areas, contributing to a high prevalence of coughs, bronchitis, and cardiorespiratory disorders. Also, a significant correlation was observed between SPM levels and frequency of colds and attacks of breathlessness with NO_2 and SPM levels. The prevalence of cardiac diseases has increased in these localities (Table 4.2).

In 1988, 507 subjects (144 males and 203 females) of a locality around Amboli quarry and in 1991, 587 subjects (246 males and 341 females) of a locality around Kandivli quarry were studied. Mean SPM levels observed at both these quarries were 2016 $\mu g/m^3$ and 618 $\mu g/m^3$. It was observed that people living near quarries were more affected than the quarry workers. Though the incidence of respiratory symptoms like cough and dyspnoea were higher among workers, the lung functions of residents were about 5 to 15% lower than workers. About 10% of radiographs of workers showed either vascular markings or nodular shadows.

To look for the effect of CO gas on carboxyhemoglobin, a study on employees of Dahisar and BPH check posts was conducted in 1992. 211 male employees from the Dahisar check post and 198 male employees from the BPH check post were included in the study. In addition, another study examined 45 traffic police and 75 vendors working at six traffic junctions in Bombay. The mean COHb levels of non-smokers of check posts was 1.7% and that of traffic police was 2.3%. Among check post employees, occupational history showed significant correlation with COHb levels. The traffic junction study showed a significant correlation between ambient CO levels and COHb levels.

Table 4.2 summarizes different studies done by EPRC, in different communities in different years, along with pollutant levels, incidence of different respiratory symptoms, and prevalence of respiratory diseases. A similar type of study was conducted in Navy Nagar, a comparatively clean area, devoid of vehicular or industrial pollution. The table shows that the incidence of various respiratory symptoms in communities near quarries, traffic police, employees of check posts, and the residential population of Chembur, staying near chemical factories are higher, compared to those of Navy Nagar. Furthermore, the prevalence of bronchitis and cardiac diseases were significantly higher among traffic police, compared to other localities. Similarly, people living near fertilizer factories or heavy traffic demonstrated prevalence of bronchitis and cardiac diseases higher compared to the control area Navy Nagar.

Table 4.3 shows the sex and age distribution and lung function levels observed in different studies. The table shows that lung function levels of Telecom (the control area of Chembur) subjects were higher than the Chembur subjects, near the fertilizer and other chemical factories. There was no difference observed in lung functions of Parel subjects of different years, but they were significantly less than those of Navy Nagar subjects (the Bombay control area). Peddar Road and King's Circle subjects showed significant deterioration in lung function levels (by 200 to 500 ml) in a 1988 study, compared to a 1986 study. Also, BPH and Dahisar check post employees showed low lung function levels compared to Navy Nagar.

Table 4.2: Summary of EPRC studies along with air pollutant levels.

Locality	Year	Pollutant levels SO_2	NO_2	SPM	Symptoms Cough	Colds	Dyspnoea	Disorder prevalence Bronchitis	TB	Cardiac	Other chest
Chembur n= 1122	1978	51	12	196	3.0	21.9	5.9	4.5	0.2	4.3	0.1
Chembur n= 751	1990	12	53	372	16.2	10.9	13.1	7.6	0.5	6.7	4.4
n=341 Telecom (control)	1990	18	40	231	7.4	5.6	7.6	1.2	0.3	2.1	6.5
Parel n=1008	1978	103	16	242	5.4	17.3	7.9	4.5	0.9	6.8	1.0
Parel n=757	1979	90	25	264	6.1	7.6	6.4	5.0	0.3	7.6	*
Parel n=676	1980	*	*	*	11.6	7.5	6.5	*	*	*	*
Parel n=349	1986	37	52	326	6.9	29.0	17.0	2.1	0.9	4.0	4.6
Parel n=297	1987	29	53	339	12.1	13.5	12.5	3.3	1.3	10.1	6.7
Parel n=297	1988	38	59	323	5.7	22.0	14.7	4.1	0.0	11.0	5.3
Parel n=492	1991	29	54	304	7.9	11.6	10.8	2.4	0.6	4.1	*
Peddar road n=473	1986		*		11.0	14.0	13.0	5.7	2.3	5.6	9.1
Peddar road n=291	1987		11		8.0	12.0	9.0	3.0	1.0	7.0	5.0
Peddar road n=236	1988		*		5.1	9.7	9.8	3.0	1.7	7.2	3.0
			CO (PPM)								
King circle n=383	1986		*		9.9	16.0	17.0	4.1	0.8	7.0	5.5
King circle n=283	1987		13.3		7.0	12.0	9.0	2.0	1.0	11.0	1.0
King circle n=210	1988		*		8.1	17.6	10.4	3.3	0.9	8.6	1.9
Quarries			SPM (µg/m3)								
Amboli n=506	1988		2016		24.0	*	22.6	1.5	0.9	1.1	
Kandivli n=587	1991		618		8.5	9.7	7.2	2.6	0.3	1.5	
Check posts											
Dahisar n=211	1991				14.2	6.6	7.6	6.2	*	1.9	
BPH n=198	1991				8.6	7.1	8.6	2.5	*	9.1	
		SO_2	NO_2	SPM							
Navy Nagar n=413	1990	6	11	107	8.7	6.3	8.5	2.2	0.4	2.4	

Table 4.3: Sex-wise distribution of age and summary of lung function levels.

Locality	Year	Sex	Age groups (%)				FVC		FEV1	
			1-10	11-20	20-44	45+	7-19	>19	7-19	>19
Chembur	1978	Male	20.5	24.5	34.9	20.1	2.19±0.73	3.20±0.76	1.98±0.64	2.66±0.61
		Female	17.5	24.7	44.2	13.6	1.71±0.51	2.04±0.46	1.61±0.45	1.84±0.62
	1990	Male	22.0	27.2	28.5	40.6	2.64±1.09	3.24±0.88	2.40±1.02	2.82±0.63
		Female	15.0	18.4	44.8	21.7	2.11±0.59	2.08±0.64	1.97±0.58	1.86±0.63
Telecom (control)	1990	Male	17.4	38.3	26.3	18.0	2.71±1.04	3.31±0.73	2.56±0.97	3.05±0.69
		Female	13.8	27.6	42.0	16.7	2.04±0.59	2.12±0.52	1.94±0.57	1.95±0.54
Parel	1978	Male	20.5	24.5	34.9	20.1	2.11±0.75	3.13±0.60	1.94±0.66	2.62±0.57
		Female	17.5	24.7	44.2	13.6	1.73±0.84	2.02±0.52	1.73±0.81	1.77±0.45
	1986	Male	14.2	25.9	37.7	22.2	*	3.39±1.10	*	2.87±0.95
		Female	08.1	15.1	47.8	29.0	*	2.59±0.40	*	1.90±0.40
	1991	Male	17.6	29.2	33.8	19.4	2.45±0.89	3.05±0.72	2.27±0.86	2.63±0.63
		Female	14.5	18.1	39.9	27.5	1.94±0.46	2.00±0.43	1.80±0.44	1.77±0.44
Peddar road	1986	Male	16.6	18.3	45.6	19.5	*	3.36±0.57	*	2.84±0.53
		Female	15.5	15.1	42.2	27.2	*	2.27±0.40	*	1.96±0.36
	1988	Male	17.2	28.0	30.1	24.7	2.56±1.02	2.84±0.57	*	2.61±0.57
		Female	11.9	22.4	37.1	28.7	1.82±0.49	1.83±0.37	*	1.74±0.34
King's circle	1986	Male	14.6	20.7	34.8	29.9	*	3.34±0.65	*	2.88±0.55
		Female	15.5	11.9	40.8	32.4	*	2.25±0.72	*	1.62±0.45
	1988	Male	17.1	29.3	26.8	26.8	2.75±0.81	2.45±0.45	*	2.23±0.46
		Female	11.7	18.8	38.3	31.3	2.13±0.64	1.96±0.36	*	1.78±0.35
Kandivli	1988	Male	7.7	41.5	42.3	8.5	2.67±0.57	3.41±0.79	2.45±0.53	2.97±0.77
		Female	2.9	29.3	55.7	12.0	1.78±0.42	2.20±0.52	1.64±0.40	1.95±0.49
Navy Nagar	1990	Male	11.3	40.5	36.9	11.3	2.87±0.91	3.78±0.58	2.69±0.89	3.39±0.56
		Female	4.7	21.5	64.9	8.9	2.22±0.65	2.49±0.86	2.12±0.59	2.23±0.84
Locality	Year	Sex	Age groups(%)				FVC		FEV1	
Check posts			15-25	26-35	36-45	45+	Non-smoker	Smoker	Non-smoker	Smoker
Dahisar	1991	Male	13.3	37.4	37.4	11.8	3.20±0.64	3.22±0.78	2.82±0.60	2.76±0.65

4.3 Death

Health impacts are divided in mortality (excess deaths) and morbidity (excess illness). Mortality and morbidity are derived from air quality data using dose-effect relationships. In principle, such relations are found by statistical comparison of death rates and morbidity in urban areas with different air quality. Appropriate dose-effect relations have been estimated by Ostro (1994). Admittedly, these dose-effect relations are derived from studies of US cities and it is somewhat speculative to apply them to Bombay. However, until specific dose-effect relations for tropical conditions are derived, Ostro's relations are the best available.

Although it is clear that indoor pollution, such as that caused by cooking, can also damage health, the analysis was restricted to outdoor concentrations.

Mortality due to PM_{10}.

The relation used between air quality and mortality is:

Excess death = 0.00112 x ($[PM_{10}]$ - 41) x P x c

where	P:	number of people exposed to a specific concentration
	c:	crude rate mortality = 0.0076 in Bombay
	PM_{10}:	Annual average concentration (μg/m³) of PM_{10}

41 is the PM_{10} benchmark (corresponding to the WHO guideline of 75 μg/m³ TSP on a yearly basis, section 2.1, and thus a PM_{10} /TSP ratio of 0.55), above which mortality will increase.

From this relation and the data presented in chapter 2 (summarized in figure 4.1) it was concluded that excess mortality due to PM_{10} was about 2800 cases out of an exposed population of 9.8 million. Note that mortality is proportional to the population: if the air quality does not detoriate mortality would increase with population growth.

4.4 Illness (morbidity)

Particles. The following effects can be attributed to particles: chronic bronchitis (CrBr), restricted activity days (RAD), respiratory hospital diseases (RHD), emergency room visits (ERV), bronchitis (B), asthma attacks (A) and respiratory symptoms days (RSD).

The following dose-effect relationships were described in the general URBAIR Guidebook (Larssen et al., 1995).

ChBr : the change in yearly cases of chronic bronchitis per 100,000 persons is estimated at 6.12 per μg/m³ PM_{10}. The total number of yearly cases of chronic bronchitis per 100,000 persons is than 6.12 x ($[PM_{10}]$ - 41).

RHD	:	the change in respiratory hospital diseases per 100,000 persons is estimated at 1.2 per μg/m³ PM_{10}. Using the WHO standards, respiratory hospital diseases per 100,000 persons are estimated at 1.2 x {[PM_{10}] - 41).
ERV	:	the number of emergency room visits per 100,000 persons is estimated at 23.54 per μg/m³ PM_{10}, and the total number per 100,000 persons at 23.54 x ([PM_{10}] - 41).
B	:	the change in the annual risk of bronchitis in children below 18 years is estimated as 0.00169 x ([PM_{10}] - 41). The number of children below 18 is estimated at 35% of the total population.
A	:	Likewise, the change in daily asthma attacks per asthmatic person is estimated at 0.0326 x ([PM_{10}] - 41). The number of asthmatic persons is estimated at 7% of the population.
RSD	:	the number of respiratory symptoms days per person per year is estimated at 0.183 x ([PM_{10}] - 41).

Table 4.4: Impact of PM_{10} air pollution on health in Bombay, 1991.

Type of health impact	Number of cases (thousands)
Chronic bronchitis (Ch Br)	20
Restricted activity days (RAD)	18,680
Emergency room visits (ERV)	76
Bronchitis in children (B)	190
Asthma (A)	741
Respiratory symptom days (RSD)	60 (millions)
Respiratory hospital admissions (RHD)	4

* Figures are presented in detail for reasons of consistency, not to suggest large reliability.

4.5 Valuation of health impacts

Mortality

Admittedly, a monetary value for mortality is a debatable figure. Many argue that on ethical grounds such a valuation cannot be made. However, deleting mortality damage would seriously underestimate total damage.

Two different approaches can be used to value a case of mortality; one is based on willingness to pay (WTP), the other on salaries. The WTP approach is described in the general URBAIR report. In the USA a value of about US $ 3 million per statistical life is often used. Although such a valuation is not readily transferable from one country to the other, an approximation can be derived by correcting the USA figure by a factor of purchasing power in India, divided by the purchasing power in the USA. This factor is 970/21,900 =0.044 (Dichanov, 1994). At and exchange rate of 1 Rs. =US$ .3, this results in a value of Rs. 4.25 million per statistical life in India.

The other approach is based on lost income due to mortality. The value of a statistical life is then estimated as the discounted value of expected future income at the average age. If the average age of population is 24 years, and the life expectancy at birth is 62 years, the value is:

$$V = \sum_{t=0}^{38} w / (1+d)^t$$

with w = average annual income and d = the discount rate (Shin et al., 1992). In this method, the value of persons without a salary (e.g. housewives) is taken to be the same as the value of those with a salary. If we estimate the daily wage in Bombay at Rs. 75, per day (average, chief wage earner) assume 200 working days in a year, and use d = 5% as the discount rate, the value of a statistical life is V = Rs. 250,000 per statistical life. For comparison, the highest compensation in the Bhopal case amounted to Rs. 200,000.

Considering both approaches to the valuation of premature death, the cost figure associated with increased mortality due to PM_{10} air pollution in 1990 ranges from Rs. 0.7 billion to Rs. 12 billion.

Morbidity

The valuation of illness was accomplished in consultation with Dr. A.A. Mahashur and Dr. B. Sanghani of KEM Hospital in Bombay, following the example of Ostro (1992).

RAD: Restricted activity day. Ostro's calculation (1992) of 20% work loss (valued at average wage) and 80% lower productivity (valued at one-third of average wage) was found reasonable. The average wage is about Rs. 60 per day. The estimate is thus: 0.2 x 60 + 0.8 x 20 = **Rs. 28**.

ERV: Emergency room visit. The private hospitals charge for an ERV is about Rs. 100-150, including the doctor's bill and medication. To this should be added the cost of loss of one work day (Rs. 60) and the cost of transport (2 x about Rs. 50), resulting in a total of **Rs. 260-310**.

RSD: Respiratory symptoms day. No surveys on willingness to pay to prevent a RSD have been carried out in India. Therefore, a reliable valuation is difficult to calculate. Considering the valuation in Jakarta (US $2), India's lower per capita income, and the RAD valuation above, an estimate of **Rs. 20** seems appropriate.

Bronchitis in children: Cases of bronchitis in children may be high, because doctors often don't want to use the more ominous word "asthma". The duration of bronchitis averages 13.2 days, valued at RSD (Rs. 20). Ostro's figure of 2 days of a parent restricted activity (RAD, valued at Rs. 28 per day) seems reasonable. This brings the total to 13.2 x 20 + 2 x 28 = **Rs. 320**.

Asthma: A severe asthma attack lasts on average 9.1 days. The daily hospital fee in private hospitals is about Rs. 1000; to this, 9.1 work loss days should be added. The total for a severe attack is then 9.1 x (1060) = Rs. 9,646. For a milder attack, the same figure as for ERV (Rs. 260-310) could be used, to which costs of

Asthma: A severe asthma attack lasts on average 9.1 days. The daily hospital fee in private hospitals is about Rs. 1000; to this, 9.1 work loss days should be added. The total for a severe attack is then 9.1 x (1060) = Rs. 9,646. For a milder attack, the same figure as for ERV (Rs. 260-310) could be used, to which costs of medication (Aerosols and tablets) about Rs. 200 should be added. For still milder attacks only the medication costs apply. The range is then Rs. 200-9,646. Considering that milder attacks are more frequent, the average valuation is estimated at **Rs. 1000** per attack.

RHA: Respiratory hospital admission. The valuation is the same as for a severe asthma attack, **Rs. 9,646**.

Chronic Bronchitis: Chronic bronchitis becomes more serious over the years. Elderly people, and younger smokers are especially vulnerable. The average age of getting a chronic bronchitis is about 35 years. Average life expectancy at birth is 62 years. It is estimated that the number of work loss days per year is about 50, valued at Rs. 60 per day, resulting in Rs. 46,000 if discounted by 5%. To this should be added the costs of hospital visits, which are estimated at 0.5 times per year. Such a visit would average 13.1 days at a fee of Rs. 1000 per day. Hospital costs would amount to Rs. 100,000 if discounted by 5%. Finally, the costs of drugs per year would be about Rs. 1000, totalling to a discounted amount of Rs. 15,200 over 27 years. The valuation of a case of chronic bronchitis is thus Rs. 46,000 + Rs. 100,000 + Rs. 15,000 = **Rs. 161,000**.

The result is presented in table 4.5. It summarizes these health cost figures and the evolving total costs, by combining the figures for mortality and illness.

Table 4.5: Valuation of health impacts.

Type of health impact	Specific costs Rs.	Total costs million Rs.
Effects of PM_{10}		
Mortality	4.25 million (US WTP)	11,753
	250,000 (lost salary)	691
Restricted activity day	28	523
Emergency room visit	260-310	22
Bronchitis (children)	320	61
Asthma attacks	1000	741
Respiratory symptoms day	20	1,189
Hospital admission	9646	38
Chronic Bronchitis	161,000	3,201

4.6 Conclusions

Air pollution damage consists of various components: damage to human health, materials, vegetation and crops, buildings and monuments, ecosystems and tourism. Assessing these impacts is hampered by incomplete and missing data. Nevertheless, damage to human health, mortality and morbidity from PM_{10} is estimated by using dose-effect relationships which have been derived for health

The valuation of loss of life is difficult and can only be estimated. The selected value of a statistical life is Rs. 260,000, a figure estimated by the human capital approach (earnings lost due to premature death).

Costs of morbidity (illness) are relatively more reliable. They consist of foregone wages and medical treatment costs. This valuation of damage to human health contains a tendency to underestimation as suffering due to illness or premature death is not included.

Table 4.6 provides preliminary information which can be used to calculate measures' benefits, if reduced emissions are known. The top row summarizes the health impacts. Next the results of calculations with the dispersion model are presented (see chapter 2). The first column indicates assumptions about the amount of emission reduction in the three source categories. From these assumptions, and the resulting distribution of PM_{10} exposure, the associated mortality and morbidity was calculated, and subsequently the associated health damage. The final column presents “marginal” benefits of the emission reduction: health costs avoided by the absolute emission reduction.

The table shows also “marginal” benefits from addressing each category of emissions, simply calculated from the health benefits at 25% emission reduction and the corresponding reduced emission. It appears that addressing emissions from industry is the most effective in terms of benefits per tonne of emission reduced. This relates to the high estimated PM_{10} concentrations near stone crushers. However, considering industry's limited share of total emissions, the scope for improving Bombay's air quality by addressing industrial emissions is small. Not taking into account costs of measures, and only considering the health benefits, emission reduction should be first targeted at domestic emissions, then traffic.

Table 4.6: Reduction of emissions and related benefits. Situation 1991, 9.8 million inhabitants in Bombay modeling area. Mortality costs estimated with the lost salary method.

Source category	Emission (tonnes)	Mortality (cases)	Respiratory symptom days (million)	Health costs Rs. (million)	"Marginal" benefits (Rp. million per tonne)
All source reference		2765	60	6,467*	
Industry	706				
Domestic	6443				
Traffic	6286				
Reduction of industry sources		Avoided	Avoided	Avoided	Avoided
25%		64	1.4	151	0.85
50%		121	2.6	284	
Reduction of domestic sources					
25%		466	10	1091	0.34
50%		971	21	2271	
Reduction of traffic sources					
25%		216	4.6	505	0.67
50%		421	9	985	

* Mortality valued according to the lost salary method (see table 4.5).

5. Institutional Framework

5.1 Environmental institutions in Bombay

A flowchart of environmental institutions in Bombay is shown in Figure 5.1. At the central government level, the main law-enforcing body is the **Central Pollution Control Board** (CPCB), within the Ministry of Environment and Forests. At the State level, the **Maharashtra Pollution Control Board** (MPCB) is responsible for monitoring and enforcing all pollution control regulations, and issuing permits for new projects and activities. An exception is motor vehicle regulations, which are enforced by the **Transport Commissioner**. At the local level in BMR, air quality monitoring is split between MPCB and the **Municipal Corporation of Greater Bombay** (MCGB), with the latter monitoring within the city limits. Functions of the boards are described in Chapter 5.2.1.

5.2 Air pollution legislation

5.2.1 A note on legislation on air pollution control in India (by K.H. Mehta)

The "Protection & Improvement of Environment" is a subject of concern to the Government. Therefore, Government of India has made provision for this in its constitution.

There were provisions already existing in various enactments to tackle environmental pollution, these being the Indian Penal Code, The Criminal Procedure Code, The Factories Act, The Wild Life Protection Act, The Forests Conservation Act, The Merton Shipping Act, The Mines and Minerals (Regulation & Development) Act, The Atomic Energy Act as well as local laws relating to local bodies and corporations etc. All these legislations have some provisions for regulation and legal action in respect of specific environmental issues. However, the environmental scenario in India undergoing change with industrialisation, modernisation, urbanisation etc., the existing legislations were found either inadequate or not effective to check the degradation of environment. After the Stockholm Conference on Human Environment in June, 1972, it was considered appropriate to have uniform laws all over the country for broad environmental problems endangering the health and safety of people as well as of flora and fauna. The Parliament of Government of India therefore brought in operation the specific and comprehensive legislation institutionalizing simultaneously the regulatory agency for controlling pollution of various categories.

The specific environmental legislation in India are under:

1. The Water (Prevention & Control of Pollution) Act, 1974.
2. The Water (Prevention & Control of Pollution) Cess Act, 1977.
3. The Air (Prevention & Control of Pollution) Act, 1981.
4. The Environment (Protection) Act, 1986.
5. Public Liability Insurance Act, 1991.

There have been number of amendments to these Acts and a set of Rules also have been laid down for the efficient enforcement of these legislations.

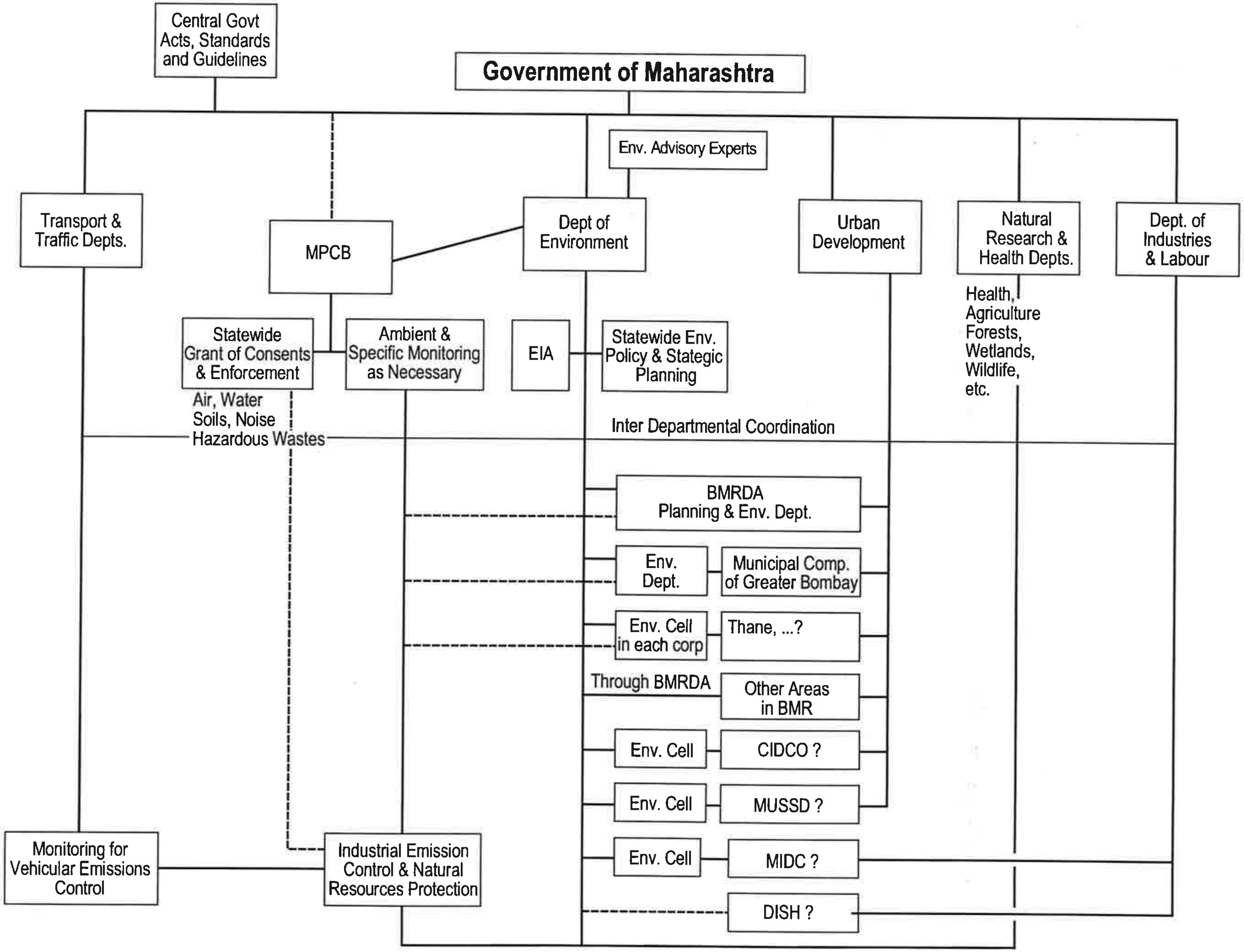


Figure 5.1: Organizational Schedule.
(Source: Coopers & Lybrand and AIC, 1994.)

The Acts prescribe the regulatory agency of Environment & Forests, Government of India as the nodal agency at the Central level and is in charge of policy formulation, planning and co-ordination of all the issues and programmes related to environment protection. Central Pollution Board is law-enforcing body at the Central level. It is entrusted with the work of enforcement of environmental legislations in Union Territories. It has also the role of co-ordinating the activities and State Boards, laying down the environmental standards, planning and getting executed a Nation-wide programme for Prevention Control or Abatement of Pollution etc. The State Pollution Control Board is the agency for enforcement of environmental legislation in the respective State. The State Pollution Control Boards are under the administrative control of Department and Environment in the respective State.

The specific legislation for control of Air Pollution is the Air (Prevention & Control of Pollution) Act, 1981 (No. 14 of 1981). The same has been amended by The Air (Prevention & Control of Pollution) Amendment Act, 1987 (No. 47 of 1987).

The Laws and Regulations for Air Environment

1. The Air (Prevention & Control of Pollution) Act, 1981.

   This Act provides for prevention, control and abatement of air pollution. This act is made applicable to any specific area by issuing a gazette notification. Once an area is notified under this Act, no industrial or any other activity that may cause air pollution can be commenced or carried out without permission from concerned State Pollution Control Board.

Functions of Central Board

a) Advise the Central Government on any matter concerning the improvement of the quality of aim and the prevention, control or abatement of air pollution.

b) Plan and arrange to execute a nationwide programme for the prevention, control or abatement of air pollution.

c) Co-ordinate the activities of the State Boards.

d) Provide technical assistance and guidance to the State Boards, carry out and sponsor investigations and research relating to problems of air pollution and prevention, control or abatement of air pollution.

e) Lay down standards for the quality of air.

Functions of State Boards

a) to plan a comprehensive programme for the prevention, control or abatement of air pollution and to secure the execution thereof;

b) to advise the State Government on any matter concerning the prevention, control or abatement of air pollution;

c) to collect and disseminate information relating to air pollution.

d) to collaborate with the Central Board in organizing the training of persons engaged or to be engaged in programmes, relating to prevention, control or abatement of air pollution and to organize mass-education programme relating thereto;

e) to inspect, at all reasonable times, any control equipment, industrial plant or manufacturing process and to give, by order such directions to such persons as it may consider necessary to take steps for the prevention, control or abatement or air pollution;

f) to inspect air pollution control areas at such intervals as it may think necessary, assess the quality of air there in and take steps for the prevention, control or abatement of air pollution in such areas;

g) to lay down, in consultation with the Central Board and having regard to the standards for the quality of air laid down by the Central Board, standards for emission of air pollutants into the atmosphere from industrial plants and automobiles or for the discharge of any air pollutant into the atmosphere from any other source whatsoever not being a ship or an aircraft.

Provided that different standards for emission may be laid down under this clause for different industrial plants having regard to the quantity and composition of emission of air pollutants into the atmosphere from such industrial plants;

h) to advise the State Government with respect to the suitability of any premises or location for carrying on any industry which is likely to cause air pollution;

i) to perform such other functions as may be prescribed or as may, from time to time, be entrusted to it by the Central Board or the State Government.

2. The Environment (Protection) Act, 1986,
and Environment Protection rules formed under the Act.

The Environment (Protection Act is an umbrella Act. This Act empowers the Central Government to take necessary measures for the purpose of:

a) Protecting and improving the environment.
b) Prevention, control and abatement of pollution.

Under the provisions of this Act, the Government is empowered to lay down standards for environmental quality and limits for emissions/discharges for pollutants from various sources are specified. This Act also empowers the Government to prohibit and/or restrict certain activities industrial or otherwise, in specified areas to ensure protection of environment.

This Act also confers on the enforcement agencies necessary punitive powers to restrict any activity detrimental to environment.

3. The Motor Vehicles Act 1988
   and The Central Motor Vehicles Rules 1989.

   Implementation and enforcement of standards laid down for pollutants from automobiles is looked after by The Transport commissioner.

   Although The Air Act, The Environment (Protection) Act provide for prescribing of standards for automobile emissions by Central Pollution Control Board or Ministry of Environment and Forests, implementation and enforcement of standards laid down for pollutants from automobiles is looked after by The Transport Commissioner. (His office is responsible for registration of motor vehicles, and hence better equipped for enforcement.)

4. The Bombay Smoke-Nuisances Act 1912.
   and Rules under the act.

   No stack can be rected or modified unless the conforms to the regulations as laid down under this Act.

   No furnace, flue or chimney shall be erected, altered, added to or re-erected except in accordance with plans and for the purpose approved by the commission.

   No furnace, flue or chimney erected, altered to or re-erected otherwise than in accordance with the plans approved by the Commission shall be used for any purpose except with the permission of the Commission and in accordance with the terms and conditions subject to which such permission may be granted.

   Section 2b: Altitude of chimneys from which smoke may be emitted - Smoke shall not be emitted from a furnace at a lower altitude than 100 feet (30 mts.) from the firing floor level (unless specifically exempted).

5. The Bombay Municipal Corporation Act, 1818.
   (section 63 (amended) and section 390)

   As a part of its civic duties, The Municipal Corporation of Greater Bombay conducts air quality monitoring.

5.2.2 Air pollution standards and regulations (Ref.: Metha, 1993)

National Ambient Air Quality Standards have been established by the Ministry of Environment and Forests, Government of India. Standards are established for different types of areas (industrial, residential, and sensitive) (Appendix 2).

Emission standards include:

- Industry-specific emission standards, and stack height. These standards are mandatory through permits to individual industries.

- The Maharashtra Pollution Control Board has as of June 1992 granted about 7, 500 permits to industries in Bombay.

- Vehicles emission standards. Implementating of these standards rests with the Office of the Transport Commissioner. Regular emission tests, performed by authorized agents, are mandatory (Appendix 3).

Environmental Audit. A new requirement for industries is to submit an annual "Environmental Audit" report. The purpose is to improve compliance survey techniques.

Central Action Plan (1992). Promulgated by the Government of India to speed up enforcement against non-compliance with emission standards. Under the "Sensitive Area Approach" of this plan, the Chembur Area of Bombay is one of 15 sensitive areas designed by the Government. 8 industry categories have been identified as highly polluting: Cement, Thermal power plants, Iron & steel, Fertilizer, Zinc/Copper/Aluminium smelters, Oil Refinery.

Under the Central Action Plan, strict compliance with *Environmental Standards* and *Minimal National Standards* must be achieved within set time limits. Monthly progress reports are required. In Bombay, there is no industry that would call for legal action for non-compliance under the Central Action Plan.

Licensing of industries

According to the Pollution Acts, industry-specific discharge and emission standards called MINAS (Minimum National Standards) have been prescribed. All industries, including SSI units, must comply with these standards and meet other stipulations laid down in these Acts. The responsibility rests with the State Pollution Control Boards to enforce the provisions of the Acts. The units under their jurisdiction obtain permission to discharge pollutants, or their 'CONSENT'.

All existing units must obtain the CONSENT of their respective Boards. New units must obtain a NOC (No Objection Certificate) from the relevant Board before they can start operations. Financial institutions and banks demand proof of a NOC before disbursing loans, even though the loans may have been sanctioned on the basis of the projects techno-economic feasibility.

In order to obtain a NOC from a Pollution Control Board (PCB), an application must made with a complete project-report, including the proposed pollution control measures. Since, pollution control is site specific, the PCBs also must be appraised of the proposed project site and, if appropriate, the PCB may even ask for an EIA (Environment Impact Assessment) reports for site clearance.

The Boards have declared some regions as sensitive because of their fragile environmental condition. New industries, especially pollution-intensive ones, may not be allowed in sensitive areas or may be prescribed much stricter standards. Proximity to protected monuments, or national wildlife parks or sanctuaries are also reasons for industries to seek out a prior site-clearance.

Non-compliance with the laws invites prosecution, fines, penalties, and even imprisonment. Under EPA 86 the PCBs are even empowered to close an unit if they believe it to be in the public interest. Without going to a court of law, they can implement closure decisions by directly ordering concerned authorities to cut power and water supply to violating units.

State and local regulations and policies regarding environmental protection in Maharashtra and Bombay include:

- *The Environmental Safety Committee,* established after the Bhopal accident, providing experts for safety inspection of major plants;
- *Industrial Location Policy,* 1984, for Bombay Metropolitan Region. Within this policy, expansion of large and medium scale units is not permitted in Bombay. Many restrictions also exist for small-scale unit development; and
- *Restriction on the Use of Coal,* a ban on issuing new permits for using coal in Bombay.

5.3 Suggestions for improvement

The following suggestions for improvement are extracted from the Bombay EMS Study (Coopers & Lybrand and AIC (1994), Preferred Options for EMS) and an URBAIR report by Mr Mehta, MPCB.

1. State Environment Dept. could be strengthened for a stronger role in environmental policy making.
2. Within BMRDA an environmental wing with responsibility for environmental planning has been established, and needs strengthening..
3. At the metropolitan level, an organisation responsible for strategic environmental planning for BMR could be established.
4. In all sectoral organisations "Environmental cells" could be created to include environmental consideration in their decision making.
5. A dedicated BMR transportation authority should be established, with representation from all relevant agencies and organisations.
6. A charge on fuels could be used to raise environmental management funds.
7. Environmental regulation could be made more effective by tightening emission standards and by introducing fees and fines for pollution offences.
8. The Department of Environment should be given representation on the BMRDA Policy/Executive Committee so that environmental issues will

receive proper consideration at the planning stage. (This has already been implemented.)

9. The State Environment Dept. should receive proper orientation for strategic air quality management. It should outline priorities for air quality imperatives and goals. Targets should be identified and a timetable for implementation should be prescribed. Thus Department of Environment is expected to provide leadership and professional management (DOE).

10. Today the activities of MPCB, MCGB, and other organisations concerned with air quality monitoring and air pollution control are uncoordinated. These are largely sector-driven, not systematically integrated, and duplicate activities. Cross-sectoral issues between environment, development, and investment are not properly addressed. As a nodal agency, this should be done by the State Environment Dept.

11. MPCB needs finance, adequately trained and technically qualified personnel, and equipments.

12. The Department of Environment needs a special Advisory Committee to help with policy-making and program development. The same Committee can also help co-ordination between different agencies involved with air quality management.

13. The Air Act (1981) permits action against defaulting industries. However, this action is time taking, since the complaints must be filed in a court of law, where judgements are not normally delivered expeditiously. Closing polluting industries is felt to be too harsh and often met with opposition from other Departments, especially Labour. It is therefore necessary that MPCB should be able to penalize the defaulter on the spot in keeping with "Polluter Pays"-principle. This provision should be included in future legislation. Special courts for trying cases under The Air Act (1981) and the Environment Protection Act (1986) are necessary (Central Environment Ministry).

14. There is a dire need to establish an "Environmental Training and Information Center" to the decision makers and managers in governmental departments, industry and NGOs. It is necessary to identify the needs of different groups and design courses to meet them. Such an Information Center should be equipped with a database, environmental status and survey reports, and other useful information which will be helpful in decision-making (DOE).

15. There is need to strengthen MCGB's Air Quality Monitoring and research laboratory so that monitoring of air pollutants related to global warming and ozone layer depletion can also be undertaken. This would require staff training and also upgrading laboratory facilities with sophisticated instruments and equipments (MCGB).

16. There is great scope for improving MPCB's and MCGB's working. Therefore, effective monitoring and work reviews is necessary (DOE & MCGB).

17. Present procedure requires checking vehicles and issuing "Pollution Under Control" certificates only through approved centers. This work should be carried out by the staff of the Regional Transport Office, at least occasionally as a surprise check. This would increase identification of defaulters and help create awareness. This may need more manpower and equipment (Transport Department).

6. Abatement measures: Effectiveness and costs

6.1 Introduction

This chapter presents information about measures appropriate for reducing air pollution in Bombay. This information can be used to draft an action plan.

The chapter is organized by source category: traffic, power plants, fuel combustion other than in power plants, non-combustion sources, construction, and refuse burning.

For the main source categories brief characteristics are presented of appropriate measures:

- their effectiveness in terms of both emission reduction and reduced impacts in the year 1990 (using table 4.6) The reference data are: mortality 2765 (due to PM_{10}), and number of respiratory symptom days 60 million in 1990, and total health costs Rs. 6.5 billion (see table 4.6);

- their costs (mostly annual costs at the societal level);

- their benefits estimated by simply interpolating from the Table 4.6 figures; such as inferring that the specific health benefits of reducing emissions from traffic sources is Rs. 0.67 million per tonne reduced emissions;

- the policy instruments which might be used in order to implement measures; and the institutions which might be involved. This issue is only briefly addressed, or even skipped, due to lack of information; and

- the term in which the measure can result in emissions reduction (short-term 2 year, mid-term 2-5 year, long term > 5 year).

The list of measures is derived from the information presented by the local URBAIR working group, the general URBAIR guidebook, and from earlier plans (see chapters four and five) addressing parts of the problems in Bombay.

6.2 Traffic

Chapter 3 shows what to expect of future traffic emissions if no environmental measures are taken. This section describes the effectiveness (abated emissions) and, to the extent possible, the benefits of various measures such as:

- introducing unleaded gasoline;
- implementing a scheme for inspection and maintenance;
- addressing excessively polluting vehicles;
- improving diesel fuel quality;
- improving quality of lubricating oil in two-stroke engines;
- switching fuel (gasoline to or LPG/CNG) in the transportation sector, induced by price-shifts;
- adopting clean vehicle emission standards; and
- other measures.

6.2.1 Introducing of unleaded gasoline

Unleaded gasoline addresses the lead problem and is a prerequisite for introducing strict emission standards, as is common in many other countries in the world. An "intermediate" approach is to reduce the permitted lead content of gasoline. Current plans call for reducing the maximum lead content to 0.15 grams per litre. The present level is 0.18 to 0.19 g/litre for gasoline supplied from Bombay refineries, about 70% of the total supply. The remainder has a lead content of 0.56 to 0.80 g/litre.

Introducing unleaded gasoline requires, assuming simultaneous introduction of vehicles with catalytic converters, separate fuel distribution system that does not mix leaded with unleaded fuel. Retailers usually sell both fuels. Older engines may require leaded fuel because of the material used for it's valve seats or the high RON-number gasoline required.

Unleaded gasoline is widely available in many countries, so technical obstacles cannot be a major constraint.

Removing the lead compound in gasoline requires reformulation in order to maintain it's ignition properties (octane number). This can be done by increasing the aromatics content or adding oxygenated compounds such as MTBE (methyl-tertiary-butyl-ether). Aromatics include benzene, a carcinogenic compound. This is an environmental concern, both from the evaporation of gasoline (at production, storage and handling) and from the possible increase in benzene in exhaust gases (Tims et al, 1981, Tims, 1983). A limit on benzene in gasoline may be necessary. A decision on the scale of the limit requires data of current air quality regarding benzene (AIAM, 1994). Experience in other countries indicates that this issue can be resolved. It should be noted that catalytic devices effectively destroy benzene in exhaust, so any net outcome in airborne benzene will probably be small.

Unleaded gasoline with a high RON-number is usually produced by adding MTBE, the preferred lead substitute. It must be imported now, but plants may be built in India.

Effectiveness. Reduced emissions are proportionate to the eventual market shares of unleaded and low-lead gasoline and, in case of low-lead gasoline, the lead content.

Costs of the measure. Reducing lead in gasoline requires reformulating the gasoline in order to retain the required RON number. In order to obtain gasoline with sufficiently high RON numbers the lead replaced oxygenated compounds; MTBE is a preferred substitute. These changes lead to an increase in production costs in the range of Rs. 0.7 to 1 per litre gasoline, depending on the local market for refinery products, the required gasoline specifications, and the costs of MTBE (Turner et al, 1993).

Policy instruments and target groups. Lowering lead in gasoline sold is usually effected by lowering the maximum allowed lead content. In countries where gasoline is taxed, unleaded gasoline is taxed less and leaded fuel taxed more so that the net yield for the fiscal authority does not change.

The oil industry and the gasoline distribution firms will have to produce unleaded gasoline. The oil industry is the main actor in the process (AIAM, 1994).

Term. Large-scale availability of unleaded fuel can be implemented within 5 years. Low-lead gasoline may be produced at short notice, technically.

Summary. Introducing lowlead and unleaded fuel	
Effectiveness:	*Depending on rate of introduction*
Costs	*Costs at refinery Rs. 0.7-1 per litre unleaded fuel (corresponding with Rs. 250-360 million - 1990[1])*
Benefits	*Unknown in Bombay* *Unleaded fuel required when catalytic-exhaust gas control is introduced* *Need to control of benzene and aroma tics, to not offset benefits*
Instruments/institutions	
Term	*two-five years*
Target groups	*The oil industry. Firms which sell gasoline*

6.2.2 Improving diesel quality

Diesel's ignition and combustion properties are important parameters in explaining PM_{10} emissions from diesel engines (Hutcheson and van Paassen, 1990, Tharby et al, 1992). Its volatility (boiling range) and viscosity (and its cetane number, an indicator of its ignition properties) are major characteristics which determine these properties, and, consequently, PM_{10} emissions. The specification for diesel fuel cetane number for automotive purposes is a minimum 42. In the US, Western Europe and Japan the corresponding quality varies from 48 to 50.

Another factor is the presence in diesel fuels of detergents and dispersants: these additives keep injection systems clean and have discernable efficiency effects (Parkes, 1988).

The Indian automobile manufacturing industry advocates an improvement in fuel quality (AIAM, 1994).

1 Sales of gasoline in 1990 362 million liters (Table 1.8), corresponding with Rs. 250-360 million.

Effectiveness. It is assumed that an improvement of fuel properties, as expressed in an increase of its cetane number[2] and a quality improvement by detergent additives, results in a decrease of 10% - as an order of magnitude (AIAM, 1994, Mehta et al, 1993) - of PM_{10} emissions: or about 230 tonnes (1990).

A reduction of the **sulphur** content leads to a proportional decrease of emissions of SO_2. In addition, PM_{10} emissions decrease as a part of the PM_{10} particles emitted consists of sulphates originating from the sulphur in the fuel.

Costs. The costs of improving diesel fuel, in particular increasing the cetane number, is determined by the oil-product market, the refinery structure (capacity for producing light fuels/visbreaking/hydrotreating and the like), and Government involvement in the national market. The latter eventually determines the at-the-pump-price for fuels.

The costs of reducing the sulphur content of diesel fuel are due to more extensive desulphurization at the refinery. The costs per litre for a reduction from 0.7% to 0.2% are in the order of magnitude of Rs. 0.3 per litre. Sulphur in diesel fuel leads at combustion to the formation of corrosive sulphuric acid. Therefore, reducing the sulphur content has a financial benefit due to lowering the costs of vehicle maintenance and repair.

Policy instruments and target groups.

Improving the quality of diesel fuel affects India's energy policy. The oil industry must take the necessary steps and expand capacity for producing better quality diesel fuel.

Term. The typical period for adjusting refineries (such as extension of visbreaking capacity) is about 3-5 years.

Summary. Improving diesel fuel quality	
Effectiveness:	*250 tonne PM_{10} (1990)*
Costs	*Rs. 0.3 per litre*
	(about Rs 300 million annually)
Benefits	*Mortality : 35, RSD : 0.75 million, Rs. 80 million*
	Reduction of SO_2 emissions
Instruments/institution	*Energy authorities*
Term	*two-five years*
Target groups	*Petroleum industry*

2 The physico-chemical properties - as expressed in the **cetane number** - of diesel fuel influence the magnitude of the **TSP** emissions of diesel-powered vehicles. The relation between these properties (such as volatility and viscosity) and the production of TSP in a diesel motor is not straightforward; the characteristics of the diesel motor, its load and its injection timing plan are other important parameters.

6.2.3 Introduction of low-smoke lubricating oil for two-stroke, mixed-lubrication engines

A characteristic of the Bombay traffic is the large share of motorcycles and autorickshaws, both equipped with two-stroke mixed lubrication engines. These vehicles cause about a third (2,700 tonnes) of PM_{10} emissions (from traffic exhaust). A substantial fraction of the particles emitted by these vehicles are in fact micro-droplets of unburned lubrication oil. According to Shell (private communication, 1993) the lubricating oil used in most south-east Asian countries is cheap, and of poor quality with respect to combustion properties.

Effectiveness. It is assumed that a better-quality lubrication oil will halve emissions (1,350 tonnes reduction).

Costs. Introducing these oils is estimated to double the costs of lubricating oil. We estimate the annual consumption of these oils at 1000 tonnes[3]. A first guess of the total costs of low-smoke oil is then Rs. 30 million.

Policy instruments and target groups. A standard might be set for quality. Enforcing such a regulation might be a problem. The oil industry and lubricating oil importers are the main target groups.

Summary. Low-smoke lubricating oil for two-stroke, mixed-lubrication engines

Effectiveness:	*450 tonne PM_{10} (1990)*
Costs	*Rs. 30 million*
Benefits	*Mortality : 65, RSD : 1.5 million; Rs. 150 million*
Instruments/institution	
Term	*two years*
Target groups	*Petroleum industry*

6.2.4 Implementation of an inspection and maintenance scheme

Effectiveness. Next to the threat of traffic safety and unnecessary costs of increased fuel consumption a major problem are large emissions associated with maladjusted fuel injection systems or carburettors and worn-out motor parts. Introducing a scheme requiring semi-annual inspection and maintenance, will probably result in a substantial reduction of $\mathbf{PM_{10}}$, **VOC,** and **CO** emissions. An accurate assessment of emission reduction associated with an inspection and maintenance scheme requires statistical data about emission characteristics of the Bombay vehicle fleet relative to its state of maintenance. This information is not available.

It is assumed that through the proposed inspection and maintenance scheme emissions of $\mathbf{PM_{10}}$, **VOC and CO** would decrease by a third (35% reduction of tail-pipe emissions) in line with a World Bank estimate for Manila (Mehta, 1993), and also with an estimate by the Indian Automobile Manufacturers (AIAM, 1994).

3 Motorcycle and autorickshaw mileage is estimated at 1.78 billion km. At an average fuel efficiency of 0.02 liter/km and average content of lubrication oil of 2 to 5%, the annual consumption of lubrication oil is about 1,000 tonnes.

Costs of an inspection and maintenance scheme. Presently, capacity for vehicle-emission testing is insufficient. In order to circumvent problems due to a lack of capacity by government agencies, testing can be done by private firms[4]. Proposals have been made for Indonesia (Budirahardjo, 1994) and Manila (Baker et al, 1992). Such a scheme might involve total costs of about US$ 5-10 million or Rs. 150-300 million for vehicle owners (US$ 2-5 or Rs. 60-150 per test[5], 1.5 million vehicles, environmental inspection part of roadworthiness test). Note that this scheme involves all vehicles.

It is assumed that the maintenance costs will be offset by reduced fuel costs associated with better engine performance.

Policy instruments and target groups.

Term. An inspection and maintenance scheme can be implemented within 5 years.

Summary. Implementation of an inspection and maintenance scheme

Effectiveness:	*35% reduction, 800 tonnes PM_{10}*
Costs	*Rs. 150-300 million. Maintenance costs are expected to be offset by improved fuel efficiency*
Benefits	*Mortality : 110, RSD : 2.5 million, avoided health costs Rs. 250 million* *Reduction of CO, VOC emissions, improvement of road safety (if roadworthiness is included in the scheme)*
Instruments/institution	*Implementation of existing rules.* *Arrangement for involvement of private firms.*
Term	*Two-five years*
Target groups	*The scheme could be carried out by the private sector.*

4 Such a scheme might be:
- firms are licensed to carry out inspection.
- authorities spot-check the firms whether inspections are made properly
- vehicles which pass the test get a sticker valid for a specific period, and drivers must show a test report on request.
- vehicles are spot-checked also.

5 Order of magnitude. Costs in Manila estimated at US$ 3. Costs in the Netherlands (including roadworthiness) US$ 30.

6.2.5 Address excessively polluting vehicles

About 25% of the various vehicles are estimated to emit excessively (more than twice the average). These vehicles are badly maintained, use worn-out engines, or whose engine controls are maladjusted.

Emission reduction which might be obtained through a program focusing on these vehicles is 400 tonnes PM_{10} (15% reduction of total tailpipe emissions)

This measure may include a system of spot-checks of vehicles on the road, in combination with a penalty system. Awareness campaigns might contribute to the feasibility of such a measure.

Summary. Address excessively polluting vehicles	
Effectiveness:	*400 tonnes PM_{10}*
Costs	
Benefits	*Mortality 50, RSD 1.2 million, Rs. 125 million. Instrument/institution Motor Vehicles Act (1988) and Environment Protection Act (1986), second amendment Rule (1990), Ministry of Surface Transport and Transport Department of the State*
Term	
Target groups	*Traffic authorities/Vehicle owners/*

6.2.6 Fuel switching in the transportation sector

A major option for addressing air pollution due to PM_{10} emissions from vehicles is using gaseous fuels, such as LPG and CNG. LPG is widely used in areas where supply is abundant and fuel taxes favour the use of LPG. The use of LPG or CNG requires adapting the engine and its controls, which will only pay off when LPG or CNG prices are lower than gasoline or diesel.

CNG has already been introduced as an automotive fuel is in Bombay. However, its introduction is hampered by a lack of filling stations.

LPG (Liquid Petroleum Gas) can be used as a clean alternative to both gasoline and diesel. PM_{10} emissions are very low. Its advantage over CNG is that distributing LPG is easier (the liquefied gas can be transported in tanks) and its energy density (energy per volume of fuel) is higher than CNG, implying longer mileages. Its market price is a disadvantage.

Effectiveness. CNG is used as a fuel substitute in four-stroke gasoline cars. It is very effective in reducing of PM_{10} emissions (90%). If all gasoline cars had been modified to use CNG in 1990 emission would have been 400 tonnes less.

Costs. A greater introduction of CNG requires investments in:

- natural gas distribution (connection filling stations with the piping grid);
- compressors at the filling station; and
- conversion kits for the vehicles.

Whether these investments are made depends ultimately on the price difference between CNG and gasoline.

Policy instruments and target groups

The main bottleneck for introduction CNG and LPG seems to be the lack of filling stations, which is in turn related to a limited gas distribution system. Connecting a filling station to the gas distribution grid may require large investments. A scheme for subsidies or cheap loans might facilitate this.

The viability of the scheme will increase with the greater use of natural gas in other sectors, which will justify extending the distribution grid; this touches on energy policy.

Summary. Introduction of CNG to replace 50% of gasoline consumption (1990 situation), passenger cars

Effectiveness:	*200 tonnes*
Costs	*Costs for vehicle owner depends on the price differential between gasoline and CNG (natural gas is cheaper)*
Benefits	*Mortality : 25, RSD 0.6, Rs. 75 million*
Trade-off	*Increased emissions of methane (greenhouse gas), the main constituent of natural gas.*
Instruments/institution	*Department of Energy*
Term	
Target groups	*Energy authorities*

If in 1990 all gasoline vehicles (including motorcycles) had been equipped with catalytic converters (emission reduction 1000 tonnes), mortality have been reduced by 150, the number of RSD would have been reduced by 3 million, and health costs avoided would have been Rs. 320 million (estimated from table 4.6).

6.2.7 Adoption of clean vehicle emission standards

Many countries with severe air pollution problems due to vehicles have adopted standards for permissible emissions from vehicles. Current standards require vehicles with four-stroke gasoline engines to be equipped with exhaust gas control devices based on the use of three-way catalysts (closed loop systems). A few countries, including Austria and Taiwan, have also set standards for motorcycles emissions, requiring that two-stroke engine powered vehicles must be equipped with open-loop catalysts. The latter devices control VOCs (PM_{10}) emissions and CO, but not NO_x. Weaver and Chan (1993) recently published a report on how to introduce standards for these vehicles.

The catalyst technology prohibits the use of leaded gasoline, and the sulphur content should be <500 PPM. Therefore, introducing such standards requires a structure for producing and distributing unleaded gasoline[6].

Diesel-powered vehicles are also subject to regulations. The emission requirements are met by adjusting the motor management plan and the motors design.

Tailpipe emission treatment is also envisaged, as well as retrofitting abatement equipment in existing buses. In that case requirements for diesel fuel quality are stronger (such as sulphur content below 0.02%, which is significant in Bombay). This type of standard is now being introduced in some parts of the world.

Effectiveness

Closed-loop catalytic treatment of exhaust gases (three-way catalysts) of gasoline-engine vehicles. All exhaust emissions, NO_x, CO and VOC, are reduced by about 85%. In addition lead emissions are reduced by 100% as unleaded fuel is a prerequisite for these type of standards.

Open-loop catalytic treatment of exhaust gases of two-stroke motorcycles reduces CO, VOC, and PM_{10} (oil mist) emissions, two-stroke engines being a major source, typically by 90%. Successful use of these catalysts also requires unleaded gasoline. An alternative is using well-designed and maintained four-stroke engines. A similar emission reduction is estimated to be obtained.

If in 1990 all gasoline vehicles (including motorcycles) had been equipped with catalytic converters (emission reduction 1,000 tonnes), mortality would have been reduced by 150 while RSD would have been reduced by 3 million, and avoided health costs would have been Rs. 320 million (estimated from Table 4.6).

The use of catalytic devices for treating exhaust gases requires unleaded gasoline (see section 6.2.1). Improved health due to reduced lead pollution should be added to these benefits.

Costs

Due to methodological difficulties (definition of the reference situation, costs for whom) it is not possible to calculate costs of a possible introduction of these standards in Bombay. However, costs can be estimated on a vehicle-by-vehicle basis.

The costs of **closed-loop catalytic treatments of exhaust gases** is mainly related to the extra purchasing costs of vehicles: ranging from US$ 300 to 500, on average about US$ 400 (Wang et al, 1993) in the USA. These devices have a minor adverse effect on fuel economy. However, associated costs are compensated by decreased maintenance costs, due to the increased life-time of replacement

6 A single gram of lead will contaminate the catalyst and render it useless. In addition, lead destroys the oxygen sensor of the fuel injection system.

parts, such as the exhaust system. The total annual costs per automobile are estimated at US$ 100 (US$ 50 depreciation per car and US$ 50 extra fuel costs) or Rs. 3,000.

The costs of **open-loop catalytic treatment of exhaust gases** of two-stroke motor cycles are related to increased equipment costs and decreased fuel costs due to improved engine operation. Taiwan adopted standards which require the use of open loop catalytic devices which result in an US$ 60-1980 cost increase, which is offset by fuel savings (Binnie & Partners, 1992). Total annual costs are estimated at US$ 75 or Rs. 230 per vehicle (depreciation + increased fuel costs). It is assumed that the cost of motorcycles is similar to the cost of four-stroke engines.

Other expenses are related to the higher cost of unleaded gasoline due to increased production costs and adjusting the logistic system (modification of pump nozzles). A very rough estimate of the costs is Rs. 3,000 annually per car (Rs. 1,500 depreciation of control system plus increased fuel costs Rs. 1,500, depending on the possible subsidies and levies on gasoline). An obvious issue is to what extent the costs of unleaded fuel should be attributed to the PM_{10} problem (and to the problem of lead pollution).

Policy instruments and target groups

The groups involved in introducing "clean" vehicles are:

- the petroleum industry and gasoline retailers (introducing clean cars requires unleaded gasoline);
- the Indian car and motorcycle industry;
- workshops (must acquire the skill to maintain clean vehicles); and
- vehicle owners (must pay the price).

Term. In practice, standards are set only for new cars and motorcycles; it is too expensive to equip existing vehicles with the necessary devices. Practically all vehicles currently sold on the world market are now designed to be equipped with catalytic converters.

The effect of these standards will reflect the rate of replacement of existing vehicles.

Summary. Adoption clean vehicle standards. Gasoline passenger cars and vans	
Effectiveness:	*80% effectiveness per (gasoline) vehicle (for 1990 in total 400 tonnes)*
Costs	*Rs. 3,000 per vehicle (including costs of unleaded fuel)- order of magnitude! In total Rs. 750 millions annually.*
Benefits	*Mortality 50: , RSD : 1.2 million, Rs. 125 million (hypothetical situation in 1990)* *Reduction of emissions of lead, CO, NO_x and VOC, in fact the main justification of introduction of these systems in other countries.*
Instruments/institution	
Term	*two-five years. Tied to the renewal of the car fleet.*
Target groups	*Oil industry - the first move is to make unleaded fuel available, vehicle importers, vehicle manufacturers*

Summary. Adoption clean vehicle standards for motorcycles and tricycles (Two-stroke engines, either requiring catalytic converters or four-stroke engines)	
Effectiveness:	*80% effectiveness per vehicle (for 1990 in total 750 tonnes)*
Costs	*Rs. 230 per vehicle (including costs of unleaded fuel)- order of magnitude! In total Rs. 600 million.*
Benefits	*Mortality 100, RSD 2.4 million, Rs. 250 million (hypothetical situation in 1990)* *Reduction of emissions of Lead, CO, NO_x and VOC, in fact the main justification of introduction of these systems in other countries.*
Instruments/institution	
Term	*two-five years. The result of such measures turns up with the renewal of the fleet.*
Target groups	*Petroleum industry - the first move is to have unleaded fuel available, vehicle importers, vehicle manufacturers*

6.2.8 Improvement abatement or other propulsion techniques

In USA and the European Union tightening these standards is being discussed. Possibilities are:

- improving current abatement techniques;

- improving inspection and maintenance, as it now appears that a small number of maladjusted and worn-out cars cause disproportionally large emissions; and

- enforcing the use of "zero-pollution" vehicles, especially electric vehicles in downtown areas.

A bottleneck in decreasing automotive air pollution are diesel engines, as exhaust gas treatment similar to gasoline cars is not possible. However, diesel engines emit less CO_2.

6.2.9 Resuspension emission

Resuspension is clearly a high-priority issue. Unfortunately, quantitative information about measures appropriate to Bombay have not been found. Resuspension is still a highly important matter for further analysis in order to propose viable measures.

6.2.10 Improving traffic management

For reasons of consistency some remarks regarding traffic management measures are made. Traffic management includes a variety of measures, ranging from traffic control by policemen or traffic lights to one-way streets, new roads and road-pricing systems. Traffic management is usually carried out for a variety of reasons; solving congestion problems is a major one. Curb-side traffic management may improve air quality[7], but it may also increase emissions, as traffic management usually results in increased use of the transport system. In terms of exposure traffic management can be beneficial as air quality in downtown areas improves and road exposure declines, but, in terms of total exposure, the net result may be small.

It is noted that improved traffic management may have other environmental benefits such as reduction of noise and congestion. More detailed analysis is needed, but traffic management seems to be a cost-effective policy.

6.2.11 Construction and improvement of mass-transit systems

In Bombay (BMR) almost 80% of passenger trips are made by public transport (44% by bus and 36% by suburban trains) (Cooper & Lybrand and AIC, 1994). This compares favourably with many other Asian cities. However, the present public system is inadequate to meet demand, resulting in a shift towards the use of private vehicles.

---

7 Accelerating vehicles, a dominat feature of congested traffic, emit disproportionaly large amounts of pollutants.

A methodology to assess costs and effectiveness of a measure to improve the Bombay public transport system involves elaborating issues such as:

- describing a future system appropriate to Bombay;
- assessing the performance of a such system (passenger*km)
- assessing the construction costs;
- describing the baseline (future situation without such system)
- avoiding emissions;
- assessing non-environmental benefits; and
- designing a scheme to identify costs and benefits to impute to the environmental aspects.

The costs of constructing mass-transit systems are high and projects cannot be justified only from an air pollution point of view. However, mass-transit systems have a wide variety of other benefits, including reduction of congestion.

6.3 Large point sources

Cleaner fuels in existing power plants

Power plants may have a significant impact on concentrations under special weather conditions. However, normally, power plants hardly contribute to air quality problems in Bombay. The use of cleaner fuel (low sulphur oil or coal) or natural gas might be contemplated but the benefits relate to SO_2 or CO_2 emissions, of which the associated problems are of an extra-urban scale.

Other point sources.

The use of furnace oil (residual fuel oil or buker fuel) with a sulphur content of about 4 % (by weight) contributes about 75% of emissions from large point sources. The obvious measure is to reduce the sulphur content. The order of magnitude of the costs to use 2% sulphur fuel instead of 4% sulphur fuel is about Rs. 750 million (fuel consumption 200,000 tonnes annually). However, as these point sources contribute little to ambient PM_{10}, the benefits are small (see table 4.6).

6.4 Distributed industrial/commercial sources

The main source of PM_{10} emissions due to fuel combustion is the use of furnace oil by small industries (source category domestic). This emission is estimated at about 300 tonnes (chapter 2). Halving these emission by using 2% sulphur oil, would cost about Rs. 450 million, resulting in avoided mortality of 22, 0.5 million fewer RSD, and Rs. 50 million less health damage (derived from table 4.6, reduction of domestic (and distributed) sources).

6.5 Refuse burning and domestic emissions

These sources, together with resuspension, are by far the main sources of air pollution in Bombay. Refuse burning can be avoided by extending the public refuse collection system, requiring an increase in municipal taxes.

Domestic emissions are caused by cooking on local type stoves. Traditional cooking on chullas is undesirable from various points of view. First, it constitutes a public health threat (indoor pollution), especially for women. Secondly, they are energy inefficient. And finally, they contribute adversely to air quality.

6.6 Conclusions

This chapter describes a number of measures which are appropriate for improving the Bombay's air quality. It deals with several measures, their effectiveness, costs, benefits, implementation, and the institutions and authorities involved. An important issue was to indicate the benefits, reduced health impacts, and reduced damage costs. Together with the costs of the measures, this information gives clues for prioritizing measures. It should be noted that the quantitative information presented often must be characterized as orders of magnitude.

Identifying measures to address traffic emissions was rather straightforward as some of the major causes of air pollution are obvious. Measures which stand out from a cost-benefit point of view are:

- an inspection and maintenance scheme;
- introducing unleaded gasoline; and
- introducing low-smoke lubricating oil;

Other measures, with less clear cost-benefit ratios due to lack of data or methodological problems are:

- improving automotive diesel fuel quality;
- clean car standards;
- further development of the use of natural gas for automotive and stationary use; and
- improving the public transportation system.

A similar listing of measures addressing other sources was not possible due to lack of information. This is an unfortunate circumstance as, presently, these other sources, in particular refuse burning and cooking with wood, appear (see table 3.2, and table 4.4) to be more important to PM_{10} exposure in Bombay than traffic sources.

7. Draft Action Plan

The assessment given here of air pollution and exposure in Greater Bombay, the associated health damage, and the analysis of the costs and benefits of various measures to reduce exposure and damage, described in Chapters 2-6, is based on the present state of knowledge. Shortcomings in the database have been indicated throughout the text. Nevertheless, the analysis forms the basis for proposing a plan of actions to reduce air pollution in a cost-effective manner. Improving the database is necessary to extend the action plan to include additional measures.

It should be noted that the additional road side exposure for commuters and drivers has not been considered in the present analysis. This means that the benefits, are underestimated.

The "actions" are of two categories:

1. Technical and other measures which will reduce exposure and damage.

2. Improving of the database, and the regulatory and institutional basis for establishing an operative System for Air Quality Management in Greater Bombay.

The time frame in which the actions/measures could be implemented and will be effective, is indicated as short (<5 years), medium (5-10 years) or long-term (>10 years).

7.1 Actions to improve Greater Bombay air quality and its management

7.1.1 Actions to improve air quality

Actions and measures have been proposed by the local Bombay URBAIR working groups, through other projects, notably the Coopers & Lybrand/AIC report (1994), and by the URBAIR consultants.

Proposed actions or measures to reduce air pollution impact can be put in the following categories:

1. Improved fuel quality;
2. Technology improvements;
3. Fuel switching;
4. Traffic management; and
5. Transport demand management.

Each action/measure can be briefly described, for instance according to the following items:

- What — Description.
- How — Policy instrument to instigate and implement the measure.
- When — When should actions be implemented.
- When can results be expected.
- Who — Institutions/organizations responsible or affected.
- Effects — Reduced emission/exposure/damage costs.
- Cost — Cost of measure.
- Feasibility
- Remarks

The list of measures proposed by the Bombay URBAIR working group is presented in Table 7.4 (pp 116-121).

In this list the measures are categorized as follows:

- Vehicular pollution
  - Exhaust monitoring
  - Expiry of PUC Certificate
  - Adulterated fuels
  - High pollution vehicles
  - Fuel quality policy (gasoline/diesel)
  - Use of CNG
  - Traffic flow
  - Pedestrian flow
  - Inspection/maintenance
  - Mass transit
- Monitoring
  - Air quality monitoring
  - Meteorological monitoring
  - Health monitoring
- Industrial pollution
  - Reporting format
  - Emission factors
  - Stone crushers
  - Waste burning
- Community sources
  - Refuse burning
  - Wood burning
  - Dust resuspension
  - Decongestion
  - Emission inventory
  - Energy demand
  - Organization

In this list, the measures are described as follows:

- Description of measure;
- Lead agency;
- Cost estimate;
- Time frame; and
- Status.

In addition to this URBAIR action list, the MCGB, MPCB and the Transport Commissioner have presented lists of additional action items. There are presented here as Annexes to Table 7.4 (pp 122-132).

Table 7.5 (p 133) lists additional proposed measures, suggested by URBAIR consultants, which are not included in the Bombay Working Groups' action plan (Table 7.4). This list includes low smoke lubrication oil for 2-stroke vehicles (already on the market in Bombay), ban of further sales of new 2-stroke motorcycles, and parking restrictions.

Various technical abatement measures for costs and benefits were analyzed in Chapter 6.

The draft **Action Plan** of proposed prioritized technical measures to be introduced in the short term is given in Table 7.1.

For most of the measures the estimated benefits are substantial. The estimated costs are also substantial, except clean vehicle standards for cars and vans, where costs exceed benefits.

Lowering of lead in gasoline, is an important measure in itself to reduce lead concentrations, especially since it is a prerequisite for clean vehicle standards.

The success of the measures rests with enforcement. It is important to ensure that conditions are met for carrying out the technical improvements and adjustments which are necessary, such as workshop capacity and capability for adjusting engines, and the availability of spare parts at a reasonable price.

Table 7.1: Draft Action Plan of abatement measures, Greater Bombay, based on cost-benefit analysis.

Abatement measure	Avoided emissions, tonnes PM10/a	Mortality reduction	Reduced RSD (million days)	Annual health benefits (million Rs.)	Annual costs (million Rs.)	Time frame	
						Introduction of measure[1]	Effect of measure
Vehicles							
Unleaded gasoline	2)	2)	2)	2)	250-360	Immediate	2-5 years
Low-smoke lub. oil, 2-stroke	450	65	1.5	150	30	Immediate	2 years
Inspection/ maintenance	800	110	2.5	250	150-300	Immediate	2-5 years
Address gross polluters	400	50	1.2	125	2)	Immediate	2 years
Clean vehicle standards - cars and vans	400	50	1.2	125	750	Immediate	5-15 years
- motorcycles and tricycles	750	100	2.4	240	600	Immediate	5-10 years
Improved diesel quality	250	35	0.75	80	300	Immediate	2-5 years
CNG replace gasoline, 50%	200	25	0.6	75	2)	Immediate	5-10 years
Fuel combustion							
Cleaner fuel oil (FO to 2% S)	150	22	0.5	50	450	Immediate	2-5 years

1 Time frame for starting the work necessary to introduce measure.
2 Not quantified.

To reiterate Chapter 6, the actions plan incorporate the following measures:

Unleaded gasoline:

- An important early action and a prerequisite for clean vehicle emission standards.
- Although health benefits will be substantial, they have not been quantified in this project.

Low-smoke lubrication oil, 2 stroke

- Setting a standard for the oil quality.
- Enforcement may be problematic.
- Taxes and subsidies to set oil price according to quality.

Inspection/Maintenance

- Annual or bi-annual inspection;
- Establishment of more inspection and maintenance stations (government or private); and
- Basic legislation is in place.

- The potential for reducing emissions is greatest for diesel vehicles. The inspection and maintenance might at the start concentrate on diesel vehicles.

Addressing gross polluters:

- Strict enforcement of existing smoke opacity regulation for diesel vehicles.

  Success is dependent on whether the maintenance and adjustment of engines actually happens. Ensuring this must be a part of the action.

Clean vehicle emission standard:

- Establish state-of-the-art vehicle emission standards for gasoline cars, diesel vehicles, and motorcycles.
- Ensure the availability of lead-free gasoline at a lower price than leaded gasoline.

Improving diesel quality:

- Modifications in Indian and Bombay refineries to produce low-sulphur (0.2%) diesel
- Taxes or subsidies to differentiate fuel price by fuel quality.

Fuel switching: Gasoline-to-LPG or CNG in vehicles:

- Changes in tax or subsidy structure to make LPG or CNG the preferred fuel
- Establishment of a distribution and compression system for CNG.

Cleaner fuel oil:

- Substantial reduction of the sulphur content of furnace oil, initially to 2%.

Table 7.2 lists other selected abatement measures, also of other categories, for which cost-benefit analysis has not been performed, which could be introduced in the short term, and have a beneficial effect on air quality.

Table 7.2: Additional measures for short to medium-term introduction.

Abatement measure/action		Time frame: Introduction of measure	Time frame: Effect of measure
Vehicles			
Address dilution and adulteration of fuel		Short term	Short term
Restrict life time of public UVs and buses		Short term	Medium term
Traffic management			
Improve capacity of existing road network	- improve surface - remove obstacles - improve traffic signals	Short term	Medium term
Extend/develop road network: Improve/eliminate bottlenecks		Short/medium term	Medium term
Transport demand management			
Improve existing bus and rail system	- improve time schedules - improve junctions/stations - make integrated plan	Short term	Medium term
Develop parking policy	- restrictions in central area - parking near mass transit terminals - car-pooling	Short term	Short term Short term Short term

7.1.2 Actions to improve the Air Quality Management System

Such actions concern:

- improving the Air Quality Assessment;
- improving the Assessment of Damage and Costs;
- improving the institutional and regulatory framework; and
- building of awareness among the public and policy-makers.

Chapter 2.6.2 presents the necessary actions to improve the Air Quality Assessment. They are summarized in Table 7.3.

Table 7.3: Actions to improve the Air Quality Assessment of Greater Bombay

Air Quality Monitoring
• Improve the ambient air quality monitoring system. • Upgrade laboratory facilities and manpower capacities. • Establish and improve a quality control system. • Establish a database suitable for providing Air Quality information to the public/control agencies/law makers.
Emissions
• Improve inventory of industrial emissions. • Develop integrated, comprehensive emission inventory procedure. • Study resuspension on roads.
Population exposure
• Establish appropriate dispersion modeling tools for control strategy in Greater Bombay.

Table 7.4: *Categorized Draft Action Plan, Greater Bombay.*

ISSUE	ACTION REQUIRED IN BRIEF	LEAD AGENCY	COST ESTIMATE (Rs. Lakhs)	TIMEFRAME	PRIORITY ESTIMATE	ANNEXURE NO.
VEHICULAR POLLUTION						
1) Exhaust Monitoring	Stricter enforcement of existing legal provisions. Compliance to be checked : a) Four wheelers - At annual tax payment. b) Three wheelers - Vigilance monitoring. c) Two wheelers - Awareness campaigns. At all transactions eg: Transfer/Hypothetication tax payment etc.	Transport Dept.	342.81	1 year		I
2) Expiry of PUC Certificate	Month of expiry of validity should be prominently displayed on each PUC certificate. This will enable the enforcement agency to detect defaulters.	Transport Dept.				
3) Adulterated Fuels	Increased vigilence is needed to prevent sale of adulterated fuels. Set up a cell to receive complaints and take prompt action. Make public names/addresses of retail outlets found guilty. This will act as determent and reduce incidence of sale of adulterated fuels.	Oil Companies BIS				
4) High Polluting Vehicles	Identify high polluting vehicles (especially commercial vehicles such as trucks/tempos etc.) and levy stiff penalities. Also prevent entry of such vehicles into the city by asking for a PUC certificate and by posting staff at entry points.	Transport Dept./ Traffic Dept.				
5) Policy on fuel quality	<u>Petrol</u>					
	a) Reduce content of lead in petrol to 0.15 g/lt.	Oil Cos.				

Table 7.4: Cont.

ISSUE	ACTION REQUIRED IN BRIEF	LEAD AGENCY	COST ESTIMATE (Rs. Lakhs)	TIMEFRAME ESTIMATE	PRIORITY	ANNEXURE NO.
	b) Provide lead free petrol (0.015 g/lt.)	BIS				
	c) Use of catalytic converters to be made compulsory for all vehicles.					
	d) Reduce sulphur content to 0.15% as per US/European standards.					
6) Use of CNG	Increase use of CNG in taxis/cars. Provide more filling stations. Increase awareness about use of CNG.	GAIL				
7) Traffic Flow	a) Improve traffic speed by ensuring proper repairs/maintenace of roads. Ensure better utilisation of existing road network by removing obstruction from roads and footpaths. Ensure that utility companies carryout proper resurfacing of roads whenever any digging is carried out.	MCGB				
	b) Provide additional sets of signals at elevated locations to ensure free flow of traffic.	Traffic Police				
8) Pedestrian Flow	Provide and maintain footpaths, remove hawkers and other encroachments.					
9) Inspection & Maintenance	Lower time span for fitness certification of vehicles to 10 years from the present limit of 15 years.	Transport	91	1 year		
	In addition to existing requirement, specify engine performance criteria and establish standard practices for fitness testing. Appoint/nominate private garages for fitness determination as authorised agencies or initiate procedure for approval of garages to ensure					

Table 7.4: Cont.

ISSUE	ACTION REQUIRED IN BRIEF	LEAD AGENCY	COST ESTIMATE	TIMEFRAME ESTIMATE	PRIORITY	ANNEXURE NO.
	quality and explore possibility of checking PUC Certificate by private agencies.					
10) Mass Transit	Improve present Mass Transit facilities. Provide additional mode of Mass Transit which will effectively reduce vehicular emissions.	BMRDA/MCGB/ Railways				
MONITORING						
11) Air Quality Monitoring	a) Make daily monitoring raw data publicly available.					
	b) Rationalise ambient air quality monitoring locations by reducing and/or relocating some stations to provide increased frequency of monitoring network to provide better coverage of impacted areas. The frequency of monitoring should conform to the C.P.C.B. standards.	MCGB				
	c) Optimise sampling station height and identify locations for extended monitoring through rapid surveys. Ensure better co-ordination among monitoring agencies and optimise resource use through sharing monitoring locations. Monitor additional parameters : HC & Pb at 2 locations. Locations to be determined through rapid surveys. Monitoring of PM10 and CO to be carried out regularly.	MCGB				
	d) Standardise data collection/analysis methods and reporting formats. Provide for better training	MCGB				

Table 7.4: Cont.

ISSUE	ACTION REQUIRED IN BRIEF	LEAD AGENCY	COST ESTIMATE	TIMEFRAME ESTIMATE	PRIORITY	ANNEXURE NO.
	facilities. Establish procedures for quality assurance. Arrange for data sharing and common processing facilities. Introduce quality audit for monitoring/analysis activities.					
12) Meteorological Monitoring	Establish meteorological monitoring stations with automatic recording facility in the city to provide data for air quality modelling at four locations (Chembur, Central Bombay, Western suburb and Central suburb) as recommended by the expert sub-committee. Procure one SODAR for conducting low level inversion studies.	MPCB Environment Dept.				
13) Health Monitoring	Strengthen present health monitoring carried out by KEM hospital. Provide necessary equipment to other hospitals in Bombay for monitoring health effects of air pollution throughout the city of Greater Bombay. Improve and standardise maintenance of records in hospitals. Make arrangements to pool the data collected and analysis of the same.	KEM Hospital				
	Evaluate indoor air quality by rapid surveys to estimate health damage.	MCGB MPCB	5 Lakh	14 months	Medium Priority	
<u>**INDUSTRIAL POLLUTION**</u>						
14) Reporting Format	Standardise formats for industrial emission data. Standardise industry specific monitoring/analysis methods as per international procedures. Introduce compulsory quality audit.	MPCB				

Table 7.4: Cont.

ISSUE	ACTION REQUIRED IN BRIEF	LEAD AGENCY	COST ESTIMATE	TIMEFRAME ESTIMATE	PRIORITY	ANNEXURE NO.
15) Emission Factors	Identify target industries to generate database of fugitive/process emissions through rapid surveys to establish industry specific emission factors.	MPCB MCGB CPCB				
	Change over to cleaner fuels.					
16) Stone Crushers	Take punitive action against units which violate environmental laws through better coordination among agencies.	MPCB				
17) Waste Burning	Industrial solid and hazardous waste burning by road sides/close to factory premises.					
COMMUNITY SOURCES						
17) Refuse Burning	Discourage practice of refuse burning on dumps through stricter vigilance. Conduct special surveys to determine magnitude of the problem and to establish emission factors for Indian conditions.	MCGB MPCB				
18) Wood Burning	Increase use of electricity in crematoria. Invite participation of social organisations for increased awareness about need of forest conservation and to influence public opinion for change in religious practices. All crematoria should be provided with efficient pyres.	MCGB/ BMRDA				
	Encourage change over to cleaner fuels by bakeries and other commercial establishments. Provide incentives.	MCGB/ BMRDA				

Table 7.4: Cont.

ISSUE	ACTION REQUIRED IN BRIEF	LEAD AGENCY	COST ESTIMATE	TIMEFRAME ESTIMATE	PRIORITY	ANNEXURE NO.
19) Dust Resuspension	Establish contribution of roaddust resuspension, road repair activity and construction debris in air pollution problem. Remove accumulated dirt from road side.	MPCB/MCGB				
20) Decongestion	Decongest business areas through entry toll tax/high parking fees and area licencing. Such entry tax should should be high enough to discourage use of private vehicles in busy districts.	MCGB/BMRDA				
21) Emission Inventory	Complete and upgrade emission inventory for Bombay for SO_2, NO_x, TSP, HC, PM10 etc.	MPCB/MCGB				
22) Energy Demand	Identify energy demand and consumption patterns for domestic (slum and non-slum) and commercial sectors.	MPCB/MCGB				
23) Organisation	Designate co-ordinating agency for A.Q.M.S. Such agency should co-ordinate beorking of various concerned Govt./Semi- government agencies. This agency should oversee progress of this action plan and implementation.	MPCB/MCGB/ BMRDA/ Transport Dept.				

Signatures of major concerned agencies :

1) Maharashtra Pollution Control Board
2) Municipal Corporation of Greater Bombay
3) Environment Department
4) Bombay Metropolitan Region Development Authority
5) Transport Department
6) Traffic Police
7) Bhaba Atomic Research Centre

ANNEX I to Table 7.4

ACTION PLAN BY M.C.G.B.

SR. NO.	ACTION	TIMEFRAME ESTIMATE	CONCERNED DEPARTMENTS
1.	Improve traffic speed by ensuring proper repairs/maintenance of roads and ensure better utilisation of available roads through removal of breakdown vehicles from roads.	6-12 months	Traffic & Roads
2.	Decongest business areas through entry tax/cordon pricing and area licencing. Such entry tax should be high enough to discourage use of private vehicles in busy districts.	6-12 months	Traffic & Roads
3.	Rationalise ambient air quality monitoring locations by reducing and/or relocating some stations to provide increased frequency of monitoring and extended monitoring network to provide better coverage of impacted areas.	6-12 months	Dy. C.E. (C)E.S.P.
4.	Monitor additional parameters viz. PM10/CO/Pb/O3, optimise sampling station height and identify locations for extended monitoring through rapid surveys. Ensure better co-ordination among monitoring agencies and optimise resource use through sharing monitoring locations.	6-12 months	Dy. C.E. (C)E.S.P.
5.	Establish meteorological stations with automatic recording facility in the city to provide data for air quality modelling at four locations (Chembur, Central Bombay, Western suburb and Central suburb) as recommended by the expert sub-committee. Procure one SODAR for conducting low level inversion studies.	6-12 months	Dy. C.E. (C)E.S.P.
6.	Standardise data collection/analysis methods and reporting formats. Provide for better training facilities. Establish procedures for quality assurance. Arrange for data sharing and common processing facilities. Introduce quality audit for monitoring/analysis activities.	6-12 months	Dy. C.E. (C)E.S.P.

SR. NO.	ACTION	TIMEFRAME ESTIMATE	CONCERNED DEPARTMENTS
7.	Strengthen present health monitoring carried out by KEM Hospital. Provide necessary equipment to other hospitals in Bombay for monitoring health effects of air pollution throughout the city of Greater Bombay. Improve and standardise maintenance of records in hospitals. Make arrangements to pool the data collected and analysis of the same.	6-12 months	K.E.M./Dy. C.E. (C)E.S.P.
8.	Standardise reporting formats for industrial emission data. Standardise industry specific monitoring/analysis methods. Methods as per international procedure (for MPCB approved laboratories) introduce compulsory quality audit.	6-12 months	Dy. C.E. (C)E.S.P.
9.	Identify target industries to generate database of fugitive/ process emissions through rapid surveys to establish industry specific emission factors.	6-12 months	Dy. C.E. (C)E.S.P.
10.	Identify energy demand for domestic and commercial establishments. Quantify consumption of fuels (Wood/Charcoal/ Kerosene etc.). Generate adequate database for establishment of emission factors for Indian conditions.		
11.	Discourage practice of refuse burning on dumps through stricter vigilence. Conduct special surveys to determine magnitude of this problem and to establish emission factors for Indian conditions.	6-12 months	Solid Waste
12.	Stop unauthorised stone crushing units. Take punitive action against authorised units which violate environmental laws through better co-ordination among agencies.	6-12 months	Dy. C.E. (C)E.S.P.
13.	Conduct study to establish contribution of road dust resuspension in air pollution problem. Remove accumulated dirt from the road sides regularly.	6-12 months	Dy. C.E. (C)E.S.P.

SR. NO.	ACTION	TIMEFRAME ESTIMATE	CONCERNED DEPARTMENTS
14.	Establish contribution of road repair activity and construction debris in air pollution problem.	6-12 months	Dy. C.E. (C)E.S.P.
15.	Conduct rapid surveys to evaluate indoor air quality. Such data will have direct bearing on estimation of health damage.	6-12 months	Dy. C.E. (C)E.S.P.
16.	Increase use of electricity in crematoria. Invite participation of social organisations for increased awareness about need of forest conservation and to influence public opinion for change in religious practices. All crematoria should be provided with efficient pyres to reduce wood consumption.	6-12 months	Dy. C.E. (C)E.S.P./Chief Engg. M&E
17.	During the first phase of URBAIR, several datagaps were identified. Fill these datagaps by implementing the projects identified and actions recommended during the second phase so as to prepare a comprehensive emission inventory for the city of Greater Bombay. Such inventory should be kept updated so as to assist authorities in planning strategy for better Air Quality Management.	6-12 months	Dy. C.E. (C)E.S.P.

Sr. No.	Activity	Action	Cost	Time Frame
1.	Standardise data collection/analysis methods and reporting formats. Provide for better training facilities. Establish procedures for quality assurance. Arrange for data sharing common processing facilities. Introduce quality audit for monitoring/analysis activities.	1) Standardise analysis methods for pollutants in Ambient Air.	50,000 M.P.C.B. Funded.	3 months
		2) Standardise data collection and reporting reporting formats. Circulate both to Industrial Associations and M.P.C.B., approved laboratories.		
		3) Arrange for data sharing and common proces--sing facilities.		
		After agency for co-ordinating the data collection e.g.: M.P.C.B. has B.M.R.D.A./ M.P.C.B. is selected earmarked facilities like computer hardware & software & related infrastructure will have to be developed.	3 Lakhs 1 Lakh	6 months
		Data supplied to agencies (other than contributors) shall be at nominal charge for genuine use.		
2.	Establish meteorological stations with automatic recording facility in the city to provide data for air quality modelling at four locations (Chembur, Central Bombay, Western suburb and Central suburb) as recommended by the expert sub-committee. Procure one SODAR for conducting low level inversion studies.	Site selection for establishing meteorological monitoring stations at four locations.	Capital:20 Lakhs Recurring : 1 Lakh/year (M&R of equipment; data collection and processing).	
		Sodar equipment installation and operation in co-operation with experts from Met Dept./ B.A.R.C. Frequency of operation : Once a week.	Capital: 5 Lakhs Recurring : 2 Lakhs/year.	

Sr. No.	Activity	Action	Cost	Time Frame
3.	Evaluate indoor air quality by rapid surveys to estimate health damage.	Project Proposal : I) Select about 100 families of lower income group for first year. II) Same number of families of middle income group for second year. III) Same number of families of higher income group for third year. Monitor 40 families/month and cover all every 3 months. Cost of monitoring of CO, RPM, PM, SO_2, NO_x is about Rs. 1000/- per set of sample. Consulting agency to be fixed for exe--cution of work.	5 Lakhs/year	14 months for each phase.
4.	Reporting Format	1) Identify type of industries. 2) Identify type of pollutants in each with point of emissions. 3) Standardise methods of monitoring/analysis. 4) Standardise formats for : i) Utilities ii) Process emissions iii) Fugitive emissions Circulate to concerned agencies.	50,000 M.P.C.B. Funded	
5	Identify target industries to generate database of fugi--tive/process emissions through rapid surveys to establish process emissions through rapid surveys to establish	1) Identify the type of indusustries & type of emissions. 2) Decide methodology to monitor the	5 lakhs C.P.C.B. Funded	3 years

Sr. No.	Activity	Action	Cost	Time Frame
	industry specific emission factors.	emissions. 3) Survey 3-4 industries of same type with different capacities with and without control equipments and different types of control systems. 4) Related data collection and compilation per type of industry @ Rs. 5000/-.		
6	Take punitive action against units which violate environ--mental laws through better coordination amongst agencies.	1) Preliminary survey to identify the no. of crushers. 2) Data collection for each crusher. 3) Survey areawise of crushers. 4) Employ staff/3 persons/crusher. Approx. 10 persons/day for one month/ward and pay @ Rs. 40/- day.	3,50,000	6 months

SR. NO.	ACTION		COST (Rs.)	TIMEFRAME ESTIMATE	REMARKS
VEHICULAR POLLUTION					
1)	Exhaust Monitoring	Stricter Enforcement of existing legal provisions			
		1) Four wheelers at annual tax payment.	342.81 Lakhs	1 year	There are 33 lakhs Motor Vehicle's (M.V.) in Maharashtra State on 31st March 1994. Earlier it was compulsory for M.V. Department to actually check exhaust emissions of M.V.'s but by amendment of C.M.V. Rules 1989 which came into effect from 26th March 1993, carrying of P.U.C. Certificate is made compulsory. The M.V. Dept. has to check validity of PUC Certificate and randum check of exhaust emissions.
		2) Three wheelers vigilance monitoring.			Although there is no legal provision to make it compulsory to check PUC Certificate at the time of acceptance of tax, however we insist production PUC at the time of payment of tax. We check PUC at the time of inspection of M.V. for fitness certificate.
		3) Two wheelers awareness campaign.			There are six mobile auto pollution control squads with two Motor Vehicles with one Inspector in each such squad. These squads check for PUC for all types of Motor Vehicles plying on roads (including three wheelers).

SR. NO.	ACTION	COST (Rs.)	TIMEFRAME ESTIMATE	REMARKS
	4) At all transactions e.g. transfer/hypothecation/ tax payment etc.			All offices of M.V. Department conduct awareness campaigns in respect of auto-pollution. Press notes are issued and banners are exibited. Publicity is given through radio and television media. Instructions are being issued to all concerned officers to check PUC Certificate before any transaction pertaining to M.V. is effected in M.V. Dept. such as transfer, HPA etc. We need 39 more mobile auto pollution control squads. The details are as under :

RTO OFFICES	PUC SQUADS REQUIRED	EXISTING SQUADS	PROPOSED REMAINING SQUADS
10 AKTO/Dy.RTO OFFICES	2 x 10 = 20	6	14
25	1 x 25 = 25	0	25
TOTAL :			39

SR. NO.	ACTION		COST (Rs.)	TIMEFRAME ESTIMATE	REMARKS

Constitution of one PUC Squad	Average Cost(Rs.)
1 Motor Vehicles	3,00,000
2 Inspector of Motor Vehicles	1,30,000
1 Driver	34,000
1 Operator	26,000
1 Jr.Gr. Clerk	34,000
1 Petrol Equipment (testing machine)	1,30,000
1 Diesel	2,25,000
Total average cost of one PUC squad	8,79,000
Total cost for 39 PUC squads	342.81 Lakhs

SR. NO.	ACTION		COST (Rs.)	TIMEFRAME ESTIMATE	REMARKS
2)	Expiry of PUC Certificate	Month of expiry of validity should be prominently dis--played on PUC Cerficate. This will enable the enforcement agency to detect defaulters.			Transport Commissioner's Office has already initia--ted new PUC sticker scheme. Under this scheme sticker with digit of month showing validity of PUC is displayed on Motor Vehicle. These stickers are issued by Authorised Pollution testing stations alongwith PUC certificates. With this scheme it will be possible to check more vehicles with limited staff.

SR. NO.		ACTION	COST (Rs.)	TIMEFRAME ESTIMATE	REMARKS
					Comparative Figures

Comparative Figures

Before introduction of stickers (1-5-93 to 30-11-93)		After introduction of stickers (1-5-94 to 30-11-94)	
MVs. Checked	MVs. Detected	MVs. Checked	MVs. Detected
1,08,850	8,228	2,67,778	11,912

SR. NO.		ACTION	COST (Rs.)	TIMEFRAME ESTIMATE	REMARKS
3)	High Polluting Vehicles	Identify high polluting vehicles (especially com--mercial vehicles such as truck/tempos etc.) and levy stiff penalities. Also prevent entry of such vehicles into the city by posting staff at entry points.			As per legal provisions in case a vehicle is found without PUC Certificate seven days show cause notice is issued directing the vehicle owner to produce the PUC Certificate. In case of the owner's non response,the penalty by court is Rs.1000/- for first owner seperately. During the pendancy of valid PUC offence & Rs. 2000/- for second offence for driver & Certificate the vehicle cannot ply on road. Non production of valid PUC certificate at the time of checking is punishable under section 177 with fine upto Rs.100/- for 1st offence and upto Rs. 300/- for subsequent offence.

SR. NO.	ACTION		COST (Rs.)	TIMEFRAME ESTIMATE	REMARKS
4)	Inspection & Maintenance	Lower time span for fitness certification of vehicles to 10 Dept. years from the present limit of 15 years. In addition to existing requirement, specify engine performance criteria and establish standard practices for fitness testing. Appoint/nominate private garages for fitness determination as authorised agencies or initiate procedure for approval of garages to ensure quality.	91 Lakhs	1 year	Certificate of registration issued in respect of a Motor vehicle other than transport vehicles is valid for a period of fifteen years from the date of issue of such certificate and shall be renewable. For renewal or Registration application shall be made not more than 60 days before the date of expiry of registration. (See Section 30 of Motor Vehicle Act, 1988 and Rule 52 of Central Motor Vehicle Rules, 1989).

Table 7.5: Additional proposed actions and measures, introduced by the URBAIR consultants.

- Effective policy to increase use of low-smoke lubrication oil in 2-stroke motorcycles.
- Ban of further sales of new 2-stroke motorcycles.
- Public campaign to educate owners to maintain their vehicles to reduce smoke emissions (e.g. cleaning fuel injectors, etc.), resulting in fuel cost savings.
- Reduce sulphur contents of fuel oils and motor diesel.
- Fuel pricing policy reflecting fuel quality.
- Restrict lifetime of public utility vehicles, and buses.
- Develop parking policy for Central and South Bombay business districts.
- Develop public awareness campaigns regarding the effects of air pollution, and individuals' responsibility and behavioural options.
- Develop the dispersion/exposure model capability and capacity by Bombay institutions and consultants.

URBAIR
List of abbreviations for Draft Action Plan

1. B.M.R.D.A. = Bombay Metropolitan Region Development Authority
2. B.I.S. = Bureau of Indian Standards
3. B.E.S.T. = Bombay Electric Supply & Transport Undertaking
4. C.P.C.B. = Central Pollution Control Board
5. D.O.E. = Department of Environment
6. G.A.I.L. = Gas Authority of India Ltd.
7. I.I.P. = Indian Institute of Petroleum
8. I.M.D. = India Meteorology Department
9. M.C.G.B. = Municipal Corporation of Greater Bombay
10. M.O.E.F. = Ministry of Environment and Forests
11. M.T.N.L. = Mahanagar Telephone Nigam Ltd.
12. M.P.C.B. = Maharashtra Pollution Control Board
13. N.G.O. = Non Government Organisation
14. R.T.O. = Regional Transport Office
15. B.A.R.C. = Bhabha Atomic Research Centre
16. I.I.T. = Indian Institute of Technology
17. O.N.G.C. = Oil & Natural Gas Commission
18. P.C.R.A. = Petroleum Conservation Research Association
19. M.E.D.A. = Maharashtra Energy and Development Authority

8. References

AIAM (1994) Letter from Association of Indian Automobile Manufacturers to various Indian Ministries 28/02/1994.

Baker et al. (1992) Final report for vehicular emission control planning in Metro Manila. Asian Development Bank (T.A. No. 1414 - PHI).

Baker, J., Santiage, R., Villareal, T. and Walsh, M. (1993) Vehicular emission control in Metro Manila. Draft final report. Asian Development Bank (PPTA 1723).

Binnie & Partners (1992) Modernization of environmental monitoring facilities & capabilities in response to Philippines' Energy Development Project. Interim report. Binnie & Partners, Consulting Engineers. Report to the EMB.

Bombay Metropolitan Region Development Authority (1990) Traffic survey in Greater Bombay (1988). Volume I: Classified traffic volume survey, part 1: The report. Bombay, BMRDA, Transport & Communication Division.

Central Pollution Control Board (1993) Communication to the Worldbank d.d 20/08/1994, Delhi.

Claiborn, C. et al. (1995) Evaluation of PM_{10} emission rates from paved and unpaved roads using tracer techniques. *Atmos. Environ.*, *29*, 1075-1089.

Coopers & Lybrand, and AIC (1994) Preferred options for environmental management strategy, Report to the Government of Maharashtra, Bombay.

Dichanov, Y. (1994) Sensitivity of PPP-based income estimates to choice of aggregation procedures. Washington, World Bank.

Economopoulos, A. P. (1993) Assessment of sources of air, water and land pollution. A guide to rapid source inventory techniques and their use in formulating environmental control strategies. Part I: Rapid inventory techniques in environmental pollution. Geneva, World Health Organization (WHO/PEP/GETNET/93.1-A).

Gram, F. and Bøhler, T. (1993) User's guide for the "KILDER" dispersion modelling system. Lillestrøm (NILU TR 5/92).

Hutcheson, R. and Paassen, C. van (1990) Diesel fuel quality into the next century. London, Shell Public Affairs.

Larssen, S., Gram, F., Hagen, L.O., Jansen, H. and Olsthoorn, X. (1995) Urban air quality management strategy in Asia. URBAIR. Metro Manila city specific report. Kjeller (NILU OR 57/95).

Lave, L.B. and Seskin, E.S. (1977) Air pollution and human health. Baltimore/ London. Johns Hopkins University Press.

McGregor, D.B. and Weaver, C.S. (1992) Vehicle I/M test procedures and standards. Draft interim report. Sacramamento, Engine, Fuel and Emissions Engineering.

Mehta, K.H. et al. (1993) Philippines. Environmental sector study. Toward improved environmental policies and management. World Bank (Report No. 11852-PH).

Mehta, K.H. (1993) Air pollution control measures and strategies for Bombay. International conference on computerised air quality management: Monitoring, modelling and emission control strategies, Bangkok 1993. Bombay, Maharashtra Pollution Control Board.

Midgely, P. (1993) Urban transport in Asia. An operational agenda for the 1990s. (World Bank technical paper number 224).

Ostro, B. (1992) Estimating the health and economic effects of air pollution in Jakarta: a preliminary assessment (Draft). Paper presented at the Fourth Annual Meeting of the International Society of Environmental Epidemiology, Cuernavaca, Mexico, August 1992.

Ostro, B. (1994) Estimating health effects of air pollution, a methodology with application to Jakarta. PRDPE's Research Project (676-43).

Paassen, C.W.C. van et al. (1992) The environmental benefits and cost of reducing sulphur in gas oils. Brussels, Concawe (Concawe report 3/92).

Parkes, D. (1988) Matching supply and demand for transportation in the Pacific Rim countries post 1990. Selected papers. London, Shell.

Perissich, R. (1993) "Auto emissions 2000", "Stage 2000" of the European regulations on air polluting emissions of motor vehicles. Written proceedings of the symposium. Brussels, Commission of the European Communities, UCSC-EEC-EAEC.

Semb, A. (1986) Measurements of emissions from open burning. Lillestrøm (AS/SBH/O-8622/10 June 1986). (In Norwegian).

Shin, E., Gregory, R., Hufschmidt, M., Lee, Y.-S., Nickum, J.E., and Umetsu, C. (1992) Economic valuation of urban environmental problems. Washington D.C., World Bank.

Tharby, R.D., Vandenhengel, W. and Panich, S. (1992) Transportation emissions and fuel quality specification for Thailand (draft report Feb. 1992). Monenco Consultants.

Tims, J.M. (1983) Benzene emissions from passenger cars. Brussels, Concawe (Concawe report 12/83).

Tims, J.M. et al. (1981) Exposure to atmospheric benzene vapour associated with motor gasoline. Brussels, Concawe (Concawe report 2/81).

Turner et al. (1993) Cost and emissions benefits of selected air pollution control measures for Santiago, Chile. Report to the Worldbank. Sacramento, EF & EE.

U.S. Environmental Protection Agency (1986) Fuel oil combustion. In: *Compilation of air pollutant emission factors, 4th ed., Suppl. A.* Research Triangle Park, NC, EPA (Environmental Protection Agency ; AP-42) pp. 1.3-1 - 1.3-11.

Wang, Q., Kling, C. and Sperling, D. (1993) Light-duty vehicle exhaust emission control cost estimates using a part-pricing approach. *J. Air Waste Manage. Assoc., 43*, 1461-1471.

Weaver, C.S. and Lit-Mian Chan, P.E. (1993) Motorcycle emission standards and emission control technology. Draft report. Report to the Worldbank and The Thai Government. Sacramento, EF & EE.

WHO/UNEP (1992) Urban air pollution in megacities of the world. Earthwatch: Global environment monitoring system. Oxford, Blackwell.

WHO (1993) Assessment of sources of air, water, and land pollution. 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. Economopoulos. Geneva (WHO/PEP/GETNET/93.1-A).

WS Atkins International (1993) Comprehensive transportation study for Bombay Metropolitan Region. Development scenarios. Bombay (Technical working paper, 3).

Norsk institutt for luftforskning (NILU)

P.O. Box 100, N-2007 Kjeller - Norway

REPORT SERIES OPPDRAGSRAPPORT	REPORT NO. OR 56/95	ISBN-82-425-0717-1	
DATE 19/3-96	SIGN.	NO. OF PAGES 135	PRICE NOK 180,-
TITLE URBAIR Urban Air Quality Management Strategy in Asia GREATER BOMBAY City Specific Report		PROJECT LEADER Steinar Larssen NILU PROJECT NO. O-92117	
AUTHOR(S) Steinar Larssen, Frederick Gram and Leif Otto Hagen Norwegian Institute for Air Research (NILU) Kjeller, Norway Huib Jansen and Xander Olsthoorn Instituut voor Milieuvraagstukken (IVM) Vrije Universiteit, Amsterdam, the Netherlands Rajiv V. Aundhe and Ulhas Joglekar ADITYA Environmental Services, Bombay K.H. Mehta, Maharashtra Pollution Control Board, Bombay A.A. Mahashur, KEM Hospital, Bombay		CLASSIFICATION * A CONTRACT REF. Mr. Jitendra Shah	
REPORT PREPARED FOR:	International Bank for Reconstruction and Development (the World Bank), Asian Techn. Dept., 1818 H Street NW, Wash. D.C., 20433 USA		

ABSTRACT

The report describes the development of an action plan for air quality improvement in Greater Bombay, based upon the assessment of emissions and air quality in the metropolitan area, population exposure and health effects (damage), the assessment of costs related to the damage and to a number of proposed abatement measures, and a cost-benefit analysis.

NORWEGIAN TITLE

KEYWORDS		
Air Pollution	Management	Greater Bombay

ABSTRACT (in Norwegian)

** Classification*	A	*Unclassified (can be ordered from NILU)*
	B	*Restricted distribution*
	C	*Classified (not to be distributed)*