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# Urban Air Quality Management Strategy in Asia

*Greater Mumbai Report*


*Edited by*
*Jitendra J. Shah*
*Tanvi Nagpal*

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*Edited by*
*Jitendra J. Shah*
*Tanvi Nagpal*

*The World Bank*
*Washington, D.C.*

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## LETTER FROM THE GOVERNMENT OF MAHARASHTRA
## DEPARTMENT OF ENVIRONMENT
## MUMBAI, INDIA

Many Asian cities are on the threshold of a major environmental crisis in the form of air pollution. The deteriorating air quality in cities is a result of rapid economic expansion, rise in population, increased industrial output and unprecedented growth of passenger vehicles. The impact of air pollution on public health and consequent rising health costs, damage to ecological and cultural properties, deterioration of built environment, etc. is well known.

In Mumbai (Bombay) the main contributor of air pollution is the transport sector, followed by power plants, industrial units and burning of garbage. Fuel quality and engine conditions significantly influence the level of air pollution. To arrest this growing problem, a concerted effort with public involvement is essential. Awareness of the issue, proactive policies, economically affordable standards and technologies and effective enforcement are key elements in any effective air quality management strategy. A long-term perspective shows that early adoption of policies for environmentally safer technologies can allow developing countries to resolve some of the most difficult problems of industrialization and growth at lower human and economic cost.

Mumbai (Bombay) joined the World Bank-aided Metropolitan Environmental Improvement Program (MEIP) in 1990. At the Inter-country workshop held in Hawaii in 1990, the cities facing air pollution problems sought MEIP intervention to assist in finding solutions. In response to this, Urban Air Quality Management Initiative (URBAIR) was conceived and launched in Mumbai (Bombay) in 1992.

URBAIR has assisted the Environment Department, Government of Maharashtra to develop a strategy and time-bound action plan for air quality management in Mumbai (Bombay). For the first time, it brought together the different stakeholders—sectoral agencies, private sector, NGOs, academics, research bodies and media to formulate a strategy. This group was met as a Technical Committee which deliberated over several months with support provided by a team of national and international experts. The outcome is the Action Plan that is presented here. The result is quite impressive and I believe that the Action Plan will catalyze continuous and sustained effort by all the concerned agencies which is absolutely essential to improve the ambient air quality of Mumbai (Bombay). The State Government through its various agencies will wholeheartedly participate and extend necessary support for the implementation of the plan. We will welcome the support of the international community in realizing the goals of the plan.

I would like to record our appreciation for the contributions made by various agencies in the development of the strategy and plan, especially to MEIP for facilitating the process.

**Asoke Basak**
Secretary to Government of Maharashtra
Environment Department
Mumbai, India

# FOREWORD

In view of the potential environmental consequences of continuing growth of Asian metropolitan areas, the World Bank and United Nations Development Programme launched the Metropolitan Environmental Improvement Program (MEIP) in six Asian metropolitan areas: Beijing, Mumbai (Bombay)[1], Colombo, Jakarta, Kathmandu Valley and Metro Manila. MEIP's mission is to assist Asian urban areas address their environmental problems.

Recognizing the growing severity of air pollution caused by industrial expansion and increasing numbers of vehicles, the World Bank through MEIP started the Urban Air Quality Management Strategy (URBAIR) in 1992. 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 developing action plans which would be an integral part of the air quality management system for the metropolitan regions. The approach used to achieve this objective involves the assessment of air quality and environmental damage (on health and 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 was set up containing the selected abatement measures for implementation in the short, medium, or long term.

The preparation of this city-specific report for Bombay is based on data collected and specific studies carried out by local consultants, and on workshops and fact-finding missions carried out in April and August 1993, and May 1994. The Norwegian Institute for Air Research (NILU) and Institute for Environmental Studies (IES) prepared a draft of the report before the first workshop based upon general and city-specific information available from earlier studies. A second draft was prepared before the second workshop with substantial inputs from the local consultants and assessment of air quality, damage and control options, and costs carried out by NILU and IES. The report concludes with an action plan for air pollution. NILU and IES carried out cost-benefit analysis of some selected abatement measures, showing the economic viability of many of the technical control options.

It is hoped that this report will form the basis for further analysis of air quality data, and formulation of strategies for air pollution control. Local institutions may refer to it as a preliminary strategy and use it in conjunction with the *URBAIR Guidebook* to formulate policy decisions and investment strategies.

**Maritta Koch-Weser**
Division Chief
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[1] While the consultants and the World Bank recognize the change of name to Mumbai, the city name Bombay is used in this study to more accurately reflect the data collection and the time period during which this study was conducted.

# ABSTRACT

Severe air pollution is threatening human health and the gains of economic growth in Asia's largest cities. This report aims to assist policy makers in the design and implementation of policies, monitoring and management tools to restore air quality in Mumbai (Bombay), India's financial and commercial capital.

Annual average TSP concentration has increased about 50 percent from 1981 to 1990, to reach 270 $\mu g/m^3$. World Health Organization (WHO) and national guidelines for $PM_{10}$ are frequently and substantially exceeded in Mumbai; 97 percent of the population lives in areas where the WHO air quality guideline for particulate is exceeded. Studies point to the resulting health effects—more cases of colds, chronic bronchitis, asthma and general decline in lung function. Using dose-response equations developed in the United States, this report estimates that air pollution causes 2,800 cases of excess mortality, 60 million respiratory symptom days, and 19 million restricted activity days, at a total cost of Rs.18 billion per year.

Applying the essential components of an air quality management system to the problem in Mumbai, this report suggests an action plan containing abatement measures for the short, medium and long terms. Recommended actions fall under two categories—institutional and technical. A single institution with a clear mandate and sufficient resources should be made responsible for air quality management in Mumbai. In addition, capabilities for data gathering and processing should be improved throughout the city. Technically, it is crucial that clean vehicle standards be established and strictly enforced. The switch from dirty to clean fuel, including to unleaded gasoline and low-sulfur diesel, should be completed. Another option for clean vehicles is the introduction of LPG- and CNG-powered vehicles. The use of low-smoke lubrication oil for 2-stroke engines is also an important policy measure. Gross polluters should be identified and penalized. In addition, general traffic management would reduce congestion and pollution. Awareness raising through public and private organizations including educational institutions is key to bringing about policy change on matters of air pollution.

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The city-level technical working groups and the steering committee members gave policy direction to the study team. The National Program Coordinator (NPC) of MEIP-Mumbai, G. N. Warade provided substantial contribution to the successful outcomes.

At the World Bank's Environment and Natural Resources Division, Asia Technical Department, URBAIR was managed by Jitendra Shah, Katsunori Suzuki, and Patchamuthu Illangovan, under the advice and guidance of Maritta Koch-Weser, Division Chief and David Williams, MEIP Project Manager. Colleagues from Country Departments (Robert Burns, Richard Cambridge, Harald Hansen, and Peter Nicholas) assisted with the program. Management support was provided by Sonia Kapoor, Ronald Waas, and Erika Yanick. Tanvi Nagpal and Sheldon Lippman were responsible for quality assurance, technical accuracy, and final production. Julia Lutz designed the layout.

Many international institutions (World Health Organization United States Environmental Protection Agency, United States Asia Environmental 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.

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **AADT** | annual average daily traffic |
| **AQG** | air quality guidelines |
| **AQIS** | Air Quality Information System |
| **AQMS** | Air Quality Management Strategy |
| **BARC** | Bhabha Atomic Research Centre |
| **BEST** | Bombay Electric Supply & Transport Undertaking |
| **BIS** | Bureau of Indian Standards |
| **BMRDA** | Bombay Metropolitan Region Development Authority |
| **CNG** | compressed natural gas |
| **CO** | carbon monoxide |
| **CDC** | Centers for Disease Control |
| **CPCB** | Central Pollution Control Board |
| **DOE** | Department of Environment |
| **FO** | fuel Oil; furnace Oil |
| **GAIL** | Gas Authority of India Ltd. |
| **GDP** | Gross Domestic Product |
| **GEMS** | Global Environmental Monitoring System |
| **HSD** | high speed diesel |
| **IIP** | Indian Institute of Petroleum |
| **IIT** | Indian Institute of Technology |
| **IMD** | India Meteorology Department |
| **LDO** | light diesel oil |
| **LPG** | liquid petroleum gas |
| **LSHS** | low sulfur high stock |
| **MCGB** | Municipal Council of Greater Bombay |
| **MEDA** | Maharashtra Energy and Development Authority |
| **MEIP** | Metropolitan Environmental Improvement Program |
| **μg** | micrograms ($10^{-6}$ grams) |
| **mg** | milligrams ($10^{-3}$ grams) |
| **MOEF** | Ministry of Environment and Forests |
| **MPCB** | Maharashtra Pollution Control Board |
| **MTBE** | Methyl Tertiary Butyl Ether |
| **MTNL** | Mahanagar Telephone Nigam Ltd |
| **NEERI** | National Engineering and Environmental Research Institute |
| **NGO** | nongovernment organization |
| **$NH_3$** | ammonia |
| **$NO_x$** | nitrogen oxides |
| **NPC** | National Program Coordinator |
| **ONGC** | Oil & Natural Gas Commission |
| **PM** | particulate matter |
| **$PM_{10}$** | particulate matter of 10 microns or less |
| **PPM** | parts per million |
| **PCRA** | Petroleum Conservation Research Association |
| **RAD** | restricted activity days |
| **RHA** | respiratory hospital admissions |
| **RON** | research octane number |
| **RPM** | respirable particles |
| **RTO** | Regional Transport Office |
| **SKO** | kerosene |
| **$SO_2$** | sulfur dioxide |
| **SSI** | small-scale industries |
| **TSP** | total suspended particles |
| **UNDP** | United Nations Development Programme |
| **URBAIR** | Urban Air Quality Management Strategy |
| **USEPA** | United States Environmental Protection Agency |
| **VSL** | value of statistical life |
| **WHO** | World Health Organization |
| **WLD** | work-loss days |
| **WTP** | willingness to pay |

# EXECUTIVE SUMMARY

**URBAIR-GREATER MUMBAI (BOMBAY).** Larger and more diverse cities are a sign of Asia's increasingly dynamic economies. Yet this growth has come at a cost. Swelling urban populations and increased concentration of industry and automotive traffic in cities has resulted in severe air pollution. Emissions from automobiles and factories; domestic heating, cooking and refuse burning are threatening the well being of city dwellers, imposing not just a direct economic cost on human health but also threatening long-term productivity. Governments, businesses, and communities face the daunting yet urgent task of improving their environment and preventing further air quality deterioration.

Urban Air Quality Management Strategy or URBAIR aims to assist in the design and implementation of policies, monitoring and management tools to restore air quality in the major Asian metropolitan areas. At several workshops and working group meetings, government, industry, local researchers, non-governmental organizations, international and local experts reviewed air quality data and designed action plans. These plans take into account economic costs and benefits of air pollution abatement measures. This report focuses on the development of an air quality management system for Greater Mumbai (Bombay) and the resulting action plan.

## THE DEVELOPMENT OF GREATER BOMBAY AND ITS POLLUTION PROBLEM

Greater Bombay's population grew by 38 percent from 1971 to 1981, and another 20 percent between 1981 and 1991 to reach 9.9 million. This growth was accompanied by an increase in the per capita gross domestic product. Expansion of industries, increased foundry production, and a 103 percent increase in vehicles has led to a severe air pollution problem in the city.

Annual average Total Suspended Particles (TSP) concentration has increased from about 180 $\mu g/m^3$ (particles per cubic meter) to approximately 270$\mu g/m^3$ between 1981 and 1990—an increase of almost 50 percent. Nitrous Oxide ($NO_x$) increased by about 25 percent, while sulfur dioxide ($SO_2$) concentrations declined due to increased use of natural gas and low-sulfur coal. The average lead (Pb) concentrations doubled from 1980 to 1987. In general, $SO_2$ and $NO_2$ pollution is not as serious an issue as TSP and $PM_{10}$ concentrations. The total annual emissions of TSP and $PM_{10}$ are estimated at 32,000 and 16,000 tons/year. The resulting annual average ambient concentration varies from 118 to 313 $\mu g/m^3$ at various locations. World Health Organization's Air Quality Guideline (WHO AQG), as well as the National guideline for $PM_{10}$ are frequently and substantially exceeded in Bombay; 97 percent of the population lives in areas where WHO AQG is exceeded. TSP exposure is mainly due to resuspension from roads caused by vehicles (40%), emissions from diesel and gasoline vehicles (14%), domestic wood and refuse burning (31%) and others (15%). Drivers, roadside residents and those who live near large sources are most severely affected.

Studies conducted between 1976 and 1990 conclude that growing concentrations of air pollutants have led to increased cases of chronic bronchitis, colds, and general decline in lung functions. A 1990 study observed that incidence of different respiratory symptoms and cardiac diseases, respiratory tract infections, and skin allergies was 5 to 10 percent higher in communities near factories in Chembur. Similarly, a study of two high density traffic areas in Bombay found a significant correlation between concentrations of air pollutants and frequency of colds and attacks of breathlessness. Past studies, as well as anecdotal evidence, suggest that Greater Bombay residents' health, especially in high density traffic areas or near industries, is under assault. The health impact is estimated at 2,800 cases of excess mortality, 60 million respiratory symptom days, and 19 million restricted activity days, with an estimated health damage cost of Rs18 billion, per year.

## CONCEPT OF AN AIR QUALITY MANAGEMENT SYSTEM

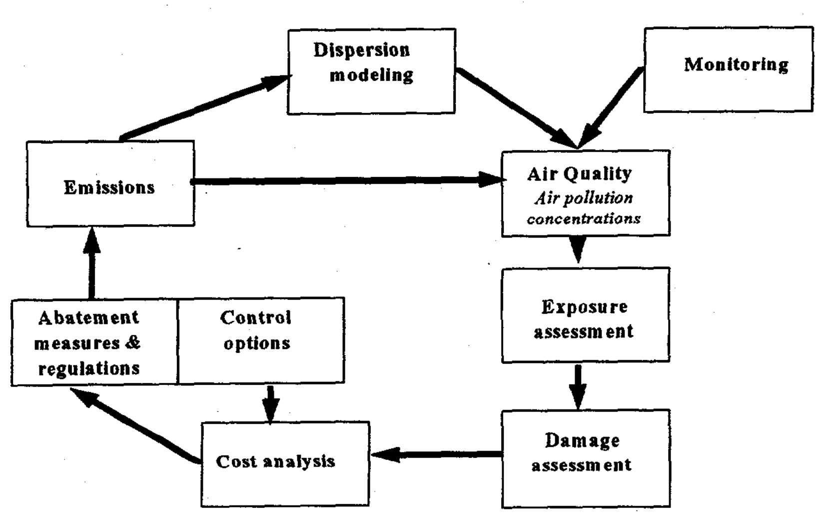
Assessment of pollution, and its control, form two prongs of an Air Quality Management System (AQMS). These components are inputs into a cost-benefit analysis. Air quality guidelines or standards, and economic objectives and constraints also guide the cost-benefit calculation. (See Figure ES.1) An Action Plan contains the optimum set of abatement and control measures for short-, medium- and long-term enactment.

Successful AQMS requires the establishment of an integrated system for continual air quality monitoring. Such a system involves:

- An 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, building materials and planned urban development;
- Calculation of the effect of abatement/control measures; and
- Establishment/improvement of air pollution regulations.

In order to ensure that an AQMS is having the desired impact, it is necessary to carry out surveillance or monitoring. This requires the establishment of an Air Quality Information System (AQIS) to inform authorities and the general public about air quality and

*Figure ES.1: Air Quality Management System*



assess results of abatement measures. AQIS should also provide continuous feedback to the abatement process.

## ABATEMENT MEASURES AND ACTION PLAN

Measures to reduce air pollution in Bombay focus on traffic. Traffic emissions are a clear and major source of air pollution exposure. Abatement measures which address other important pollution sources including refuse and wood burning and resuspension of road dust could not be addressed due to lack of data. While pollution control in industrial areas has not been discussed at length, it must also be promoted through enforcement and regulation.

Based on abatement measures, an Action Plan was designed through a consultative process with Bombay URBAIR working groups, the Municipal Council of Greater Bombay, Maharashtra Pollution Control Board, the Transport Commissioner, and local and foreign experts. See Table ES.1 for estimated costs and benefits of these measures. Recommended actions fall under two categories: (1) technical and other measures that will reduce exposure to and damage from pollution; and (2) improvements in the database and in the regulatory and institutional basis required to establish an operative system for air quality management in Greater Bombay.

It is proposed that the following technical and policy measures be given priority:

- **Address gross polluters**: Existing smoke opacity regulations for diesel vehicles must be strictly enforced. Successful action depends on routine maintenance and adjustment of engines.
- **Clean vehicle emission standard**: Establish state-of-the-art emission standards for gasoline cars, diesel vehicles, and motorcycles. Such standards would be better enforced with the assured availability of lead-free gasoline, at prices below that of leaded gasoline.
- **Switch to unleaded gasoline**: This is an early prerequisite for clean vehicle standards. The health benefits stemming from this action would be substantial.

***Table ES.1: Action Plan of abatement measures, Greater Bombay, based on cost-benefit analysis***

| Abatement measure | Avoided emissions *tons $PM_{10}$/yr* | Mortality reduction | Reduced RSD *million days* | Annual health benefits *million Rs* | Annual costs *million Rs* |
|---|---|---|---|---|---|
| Vehicles: | | | | | |
| Unleaded gasoline | * | * | * | * | 250–360 |
| Low-smoke, lub oil, 2-stroke | 450 | 65 | 1.5 | 150 | 30 |
| Inspection/maintenance | 800 | 110 | 2.5 | 250 | 150–300 |
| Gross polluters | 400 | 50 | 1.2 | 125 | * |
| Clean vehicle standards | | | | | |
| - cars and vans | 400 | 50 | 1.2 | 125 | 750 |
| - motor-, tricycles | 750 | 100 | 2.4 | 250 | 600 |
| Diesel quality | 250 | 35 | 0.75 | 80 | 300 |
| CNG replace gasoline 50% | 200 | 25 | 0.6 | 75 | * |
| Fuel combustion | | | | | |
| Cleaner fuel oil (to 2% S) | 150 | 22 | 0.5 | 50 | 450 |

# Time frame for starting the work necessary to introduce measure.

* Not quantified.

- **Use of low-smoke lubrication oil, 2-stroke**: Setting and enforcing a standard for oil quality and is important. Taxes and subsidies can be used to set the price of oil according to its quality.
- **Inspection and maintenance of vehicles**: More maintenance stations able to carry our annual or biannual inspections are needed for enforcement of clean vehicle standards. Basic legislation is already in place. The greatest potential to reduce emissions lies in diesel vehicles and initially, agencies could concentrate on these vehicles.
- **Improving diesel quality**: Indian refineries require modification in order to produce low sulfur (less than 0.2 percent) diesel. Economic instruments such as taxes and subsidies can be used to differentiate fuel price according to quality.
- **Fuel switching, gasoline to LPG/CNG in vehicles**: The tax or subsidy structure must be changed in order to make LPG/CNG the preferred fuel. The establishment of distribution and compression systems for CNG are also a key component of this action.
- **Cleaner fuel oil**: A reduction in the sulfur content of furnace oil, initially to less than 2 percent is a prerequisite.
- **Awareness raising:** Public awareness and participation are key to bringing about policy change. Widespread environmental education promotes understanding of linkages between pollution and health and encourages public involvement. Private sector participation through innovative schemes like accepting delivery only from trucks that meet government emission standards; Adopt-a-Street campaigns, and air quality monitoring displays should be encouraged. Media can also participate in awareness raising by disseminating air pollution-related data.

## RECOMMENDATIONS FOR STRENGTHENING AIR QUALITY MONITORING, AND INSTITUTIONS

A single coordinating institution with a clear mandate and sufficient resources must be made responsible for air quality management. In order to improve data, it is recommended that there be continuous, long-term monitoring at 5 or more general city sites (or city background sites), 1 to 3 traffic exposed sites, 1 to 5 industrial hot spots. Also, an on-line data retrieval system directly linked to a laboratory database either via modem or fax is recommended for modern surveillance.

The analysis in this report calculates health impacts based on average dose-effect relations derived from U.S. cities because of a lack of local data. Such epidemiological data for exposure calculations should be improved. It is suggested that dispersion modeling experts be identified in Bombay and their expertise used by the agencies responsible for air quality management.

Current restrictions on the use of coal, the Industrial Location Policy (1984), and the Central Action Plan (1992) to discourage non-compliance have been the most effective regulations. Restrictions on auto-rickshaws (three wheelers) and heavy commercial vehicles have had a positive effect on the air quality. It is important to ensure that institutions dealing with air quality be strengthened through clearer mandates and enforcing powers.

Clearly, environmental risks are escalating. If pollution sources are allowed to grow unchecked the economic costs of productivity lost to health problems and congestion will escalate. While working with sparse and often unreliable data, this report sets out a preliminary plan that has the potential to improve air quality and better manage the AQMS in the future.

# 1. BACKGROUND INFORMATION

## SCOPE OF THE STUDY[2]

This city report on air quality management for Greater Mumbai (henceforth referred to as Greater Bombay) has been produced as part of the URBAIR program. A major objective of the URBAIR program is to develop Air Quality Management Systems (AQMS) for Asian cities, and to apply such strategies in the development of Action Plans to improve urban air quality.

AQMS is based on a cost-benefit analysis of proposed actions, and measures for air pollution abatement. In general, costs relate to abatement measures while benefits include a potential reduction in the estimated costs of health damage resulting from air pollution. This study emphasizes the damage to the health of those who are exposed to air pollution. Population exposure is based on measured and calculated concentrations of air pollution through emission inventories and dispersion modeling.

A general strategy for AQMS is described in the *URBAIR Guidebook on Air Quality Management Strategy* published by MEIP. In addition to this Technical Paper, others based on city-specific analysis are produced for three MEIP cities: Kathmandu Valley, Jakarta, and Metro Manila (World Bank Technical Paper nos. 378, 379, and 380). These reports outline action plans for air quality improvement (Chapter 5), including estimates of cost-and-benefit figures. The action plans are based comprehensive lists of proposed measures and actions developed by local working groups in consultation with outside experts.

The appendices of the report contains more detailed description of the air quality data, the emissions inventory and emissions factors, population exposure calculations and local laws and regulations.

## GENERAL DESCRIPTION OF GREATER BOMBAY

*Geography.* Bombay is located on India's west coast, on a peninsula originally composed of seven islets. Drainage and concentration have caused the islets to join and form the present-day Bombay Island, with the Arabian Sea to the west, and Bombay Harbor 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)

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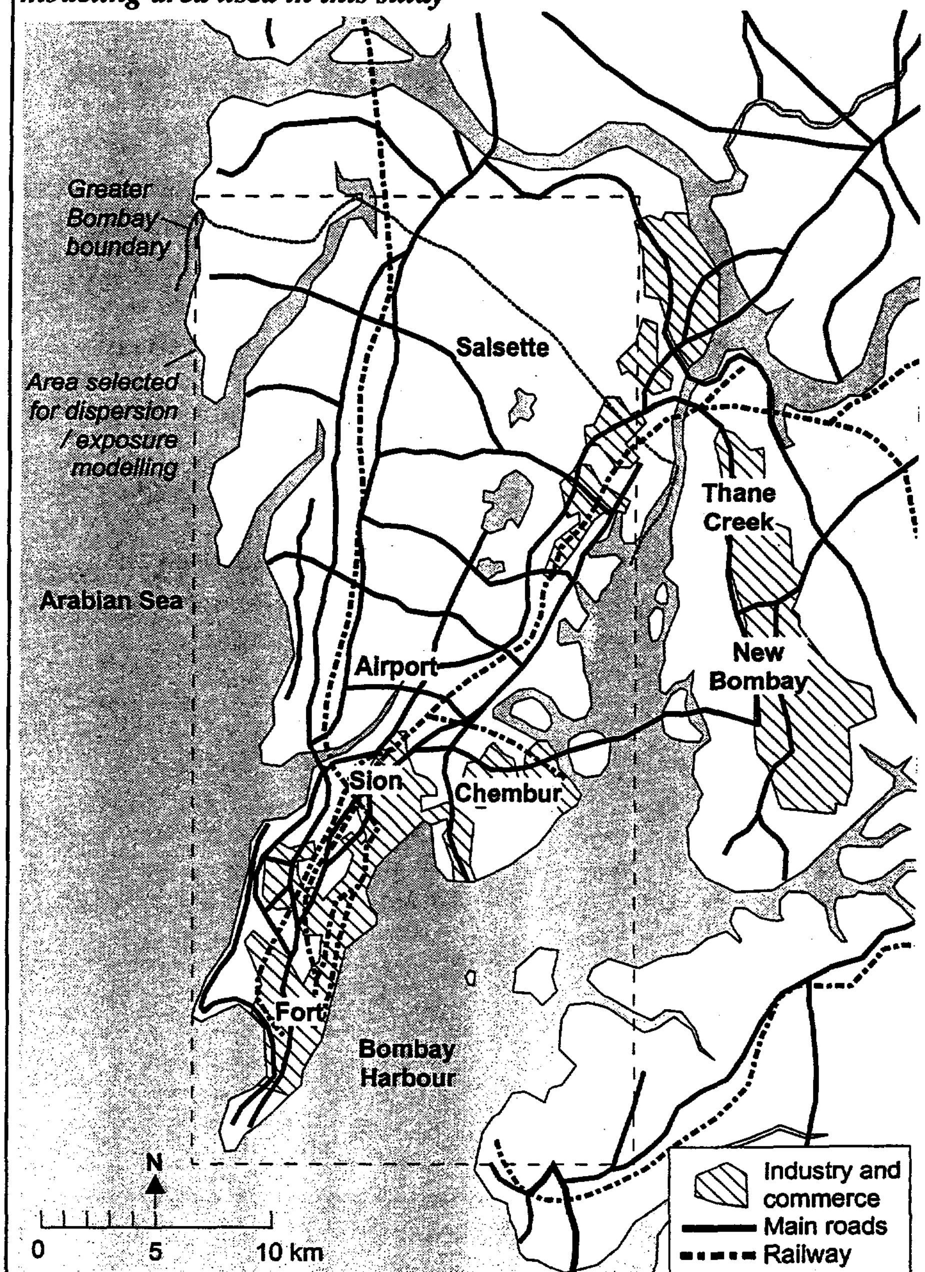
[2] Except as indicated, "dollars" refers to 1992–3 U.S. dollars.
All tables and figures, except as indicated, were created by the authors for this report.

continued to expand and now includes New Bombay to the east of Thana Creek, and Bombay Harbor and other areas further to the north and east. In the mid-1980s BMR covered an area of more than 600 square kilometers ($km^2$). Figure 1.1 shows a map of BMR. Much of Bombay is on a flat plain, one-fourth of which is below sea level. Two north-south ridges flank the flat area, the highest point being Malabar Hill to the south-west, 55 meters above sea level.

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




*Population.* The population density of Greater Bombay averages about 16,500 persons per $km^2$ (1991), with more than three times this figure in the older central parts of Bombay. The total population was about 9.9 million in 1991.

*Transportation.* Bombay is India's main industrial city with many air-polluting industries located in Chembur, in eastern Bombay. The main roads are congested most of the day, particularly the eastern and western express highways and the Thana Creek Bridge Road. Municipal and commercial activity is concentrated in the city's southern part. Commuting to and from populated areas to the north places a large burden on the road system. The capacity of the road and rail system to accommodate the increasing need for south-north commuting is much too small, leading to chronic day-time congestion. Maximum traffic flow (Annual Average Daily Traffic, AADT) at a road section is about 120,000 vehicles per day. Three suburban, surface, electric train systems provide the main public transportation, together with the municipally owned bus fleet. The former carries more than 4 million passengers per day, while the latter transports about 4.5 million people. Bombay Harbor is India's busiest, handling more than 40 percent of India's maritime trade.

The land use structure of Bombay has undergone major changes in the past decade. Massive housing developments have arisen in previously non-urban belts along the western corridor and the Bombay-Pune (eastern) rail corridor. New Bombay on the mainland, east of Thane Creek, has become a center of commercial activity. Commercial complexes have been developed in the reclamation area along Mahim Creek and Mithi River on the outskirts of the island city. A new district center—Oshiwara—has emerged in the northern suburbs. (Coopers & Lybrand and AIC, 1994)

## 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. The Bombay air pollution situation is briefly described by the World Health Organization and United Nations Environment Programme (WHO/UNEP, 1992) based mainly on the three Global Environmental Monitoring System (GEMS) monitoring sites in Bombay, operated by the National Environmental Engineering Research Institute (NEERI).

The MEIP study, "Environmental Management Strategy and Action Plan for Bombay Metropolitan Region," (Coopers & Lybrand and AIC, 1994) includes the air pollution sector and proposed management options, as it does for other environmental sectors. The recently reported Comprehensive Study of Bombay Metropolitan Region (Atkins, 1993) has provided essential data on the traffic activity in Greater Bombay.

*URBAIR data collection.* Further data on various aspects of population, pollution sources, dispersion, air quality, and health aspects were collected for URBAIR, starting in April 1993. ADITYA Environmental Services, Bombay, provided data on population, pollution sources, fuel, vehicle and traffic statistics, air quality measurements, and meteorological/dispersion conditions. Dr. A. A. Mahashur of the Environmental Pollution Research Center in Bombay contributed evidence of the health effects of air pollution on the Bombay population, and on associated health costs. (See Appendix 8 for further details.)

## THE GROWTH OF BOMBAY, 1981–1991

Bombay's population grew by 38 percent from 1971 to 1981, and another 20 percent between 1981 and 1991, to reach 9.9 million. The total number of vehicles increased by about 103 percent from 1981 to 1991, leading to increased consumption of gasoline and diesel oil. Between 1985–1990, gasoline and light diesel oil consumption increased by 26 percent and 24 percent respectively, while furnace oil use decreased significantly. The 1990 gross domestic product per capita (GDP/capita) figure for India is US$350, and the corresponding figure for Bombay is expected to have been much higher. Over the period 1965–1990, the growth rate of GDP/ per capita was 1.9 percent, about the same as for the U.S. Over the last decade the annual increase was 3.2 percent. Figure 1.2 gives a summary of the available data regarding population, vehicles, fuel consumption and air quality, and development over the last decade.

Air quality measurements over the last decade show a definite increase in average total suspended particles (TSP) and nitrogen oxides ($NO_X$) concentrations, while sulfur dioxide ($SO_2$ ) concentrations have decreased. This appears to correspond with the decrease in furnace oil consumption, and increase in traffic emissions. TSP concentrations (annual average, and maximum 24-hours) are much higher than WHO Air Quality Guidelines of 90 $\mu g/m^3$ at many measuring sites. At certain times WHO Air Quality Guideline for $SO_2$ (24-hour averages) is also exceeded.

***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 |

## POPULATION

Population data for 1981 and 1991 for Greater Bombay, the Island City, Western and Eastern Suburbs (1990) is summarized in Table 1.1. From 1980 to 1990 population grew by 20 percent . The average density in 1990 was about 16,500 inhabitants per km$^2$. The age distribution in Greater Bombay is given in Table 1.2 (1991). Almost a third of the population (31.5 percent) was under 15 years of age, and 66 percent were 15–65 years old.

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

| Age | % | Age | % |
|---|---|---|---|
| 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 |

## VEHICLE FLEET

The vehicle fleet in Bombay is categorized by cars (passenger, taxis, and light-duty vehicles); trucks and buses; motorcycles; and auto-rickshaws (tricycles). Of the 630 million vehicles in 1991, 48 percent were cars (including taxis), 39 percent were motorcycles, and 9 percent were trucks and buses. Table 1.3 provides the fleet data from 1981 to 1991.

***Table 1.3: Registered vehicle fleet data in Bombay).***

| | Vehicles *(Unit: 1,000)* | | | | | |
|---|---|---|---|---|---|---|
| | **Cars and taxis** | **Utility vehicles** | **Trucks/ Buses** | **Motor-cycles** | **Tricycles** | **Total** |
| 1981 | 180,334 | 3,677 | 41,931 | 78,474 | 4,465 | 308,881 |
| 1982 | 192,281 | 4,035 | 41,932 | 94,671 | 8,487 | 341,406 |
| 1983 | 204,228 | 4,393 | 41,933 | 110,868 | 12,510 | 373,932 |
| 1984 | 216,175 | 4,751 | 41,934 | 127,065 | 16,532 | 406,457 |
| 1985 | 228,122 | 5,109 | 41,935 | 143,262 | 20,555 | 438,983 |
| 1986 | 240,069 | 5,469 | 50,500 | 159,549 | 24,577 | 480,165 |
| 1987 | 253,215 | 5,646 | 51,515 | 177,577 | 24,577 | 512,530 |
| 1988 | 266,361 | 5,823 | 52,530 | 195,696 | 24,577 | 544,987 |
| 1989 | 279,507 | 6,000 | 53,545 | 213,814 | 24,577 | 577,443 |
| 1990 | 292,653 | 6,177 | 54,562 | 231,932 | 24,577 | 609,901 |
| 1991 | 299,289 | 6,501 | 56,086 | 242,008 | 24,577 | 628,461 |

**Source:** BMRDA (1990).

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

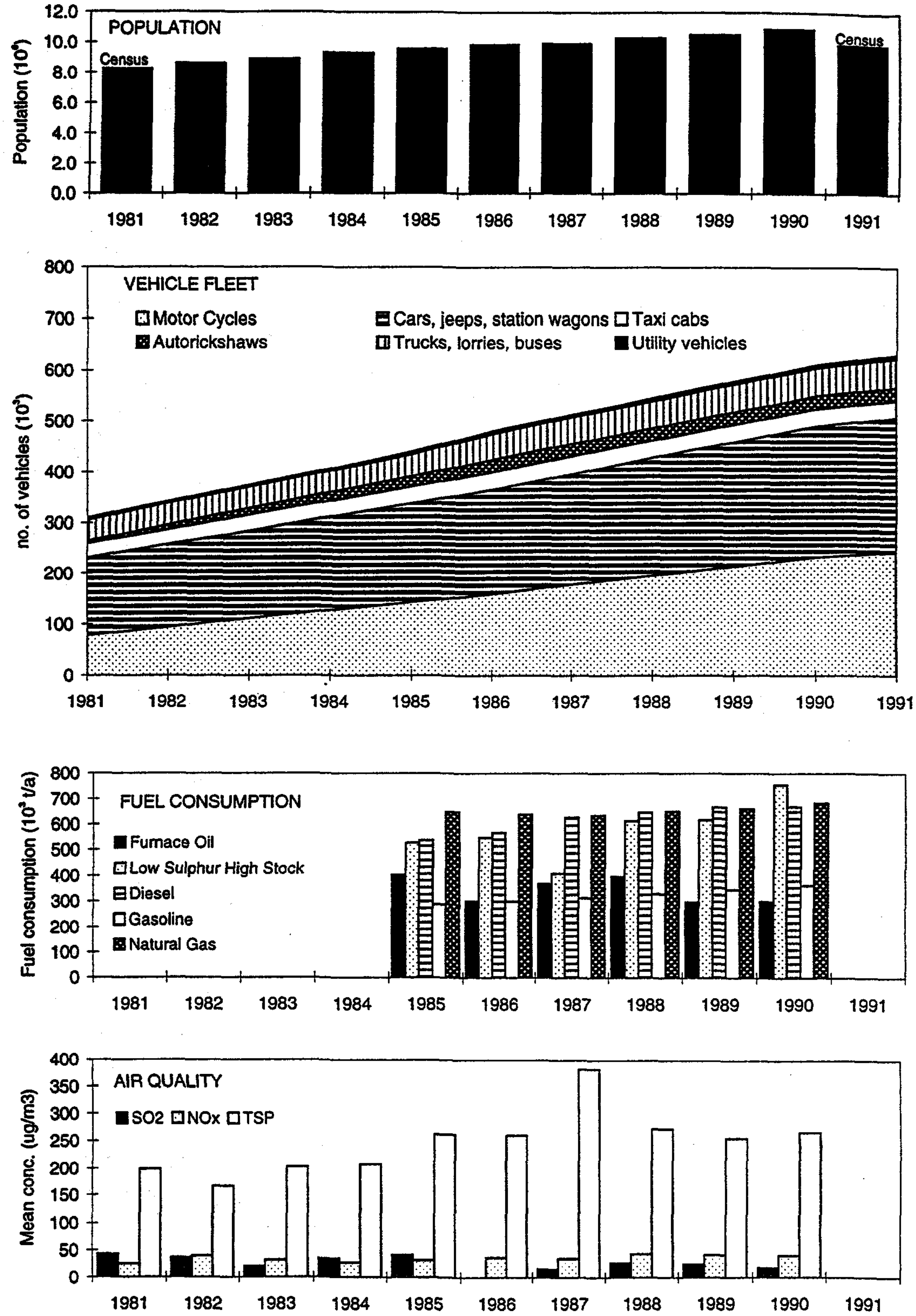


Table 1.4 shows that there was substantial growth in fleet size between 1981 and 1991. The average total annual increase was 7.3 percent, largest for tricycles and motorcycles (19 percent and 12 percent per year). The number of tricycles which had been stable between 1986 and 1991, has been on the rise since 1993.

In 1991, Bombay had 63 vehicles per 1,000 inhabitants. This includes 30 cars per 1,000 persons; 5.5 trucks/buses per 1,000; and 24 motor- and tricycles per 1,000 inhabitants. The percentage of diesel-powered cars was estimated at 20 percent.

***Table 1.4: Vehicle growth rate, annual average, Bombay***

| | 1981–1991 % growth |
|---|---|
| Passenger cars | 5.2 |
| Utility vehicles | 5.9 |
| Trucks | 2.9 |
| Motorcycles | 11.8 |
| Tricycles | 19.0 |
| Total | 7.3 |

**Source**: BMRDA (1990).

## ROAD AND TRANSPORT

The growth in traffic activity in four cordons: Mid-city (by Mahalakshmi), Island (by Sion); Mid-suburban (by Malad Creek-Pavai Lake); and Outer cordon (by Dahisar-Thane, i.e. Greater Bombay limits), is recorded here. See Figure 1.3.

Data for growth in traffic and transport in Greater Bombay are taken from the Traffic Survey in Greater Bombay Report (1988) conducted by the Bombay Metropolitan Region Development Authority (BMRDA, 1990).

Traffic activity and growth during 1978–1988 is shown in Table 1.5. There has been a 5–6 percent growth in the outer cordons while the growth has been small on Island and Mid-city (1.5–5 percent per annum).

Growth across the outer cordon has mainly taken place along the western routes (Western Express Highway and Sion Panvel Roads, 192 percent and 124 percent 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 percent during 1978–1988.

***Table 1.5: Growth in traffic activities across four cordons across Greater Bombay, 1978–1988.***

| Traffic Cordon | Total daily vehicle 1988 | Increase % 1978–1988 | Increase % 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 |

**Source**: BMRDA (1990).

Motorized passenger traffic has increased the most, especially across outer and mid-suburban cordons. Goods traffic has actually declined in the Mid-City, possibly because some wholesale markets have moved out of the Island City.

The main increase in passenger vehicle traffic growth (more than 200 percent increase in the outer cordon during 1978–1988) has been due to two-wheeler traffic across all cordons. Private car traffic has increased moderately (20–30 percent over the decade), while auto-rickshaw traffic has to a large extent replaced taxis in the suburbs, indicated by the very large increase in number of auto-rickshaws early in the decade. The growth rate for various vehicle categories is presented in Table 1.6.

***Table 1.6: Growth rates in Greater Bombay traffic for vehicle categories***

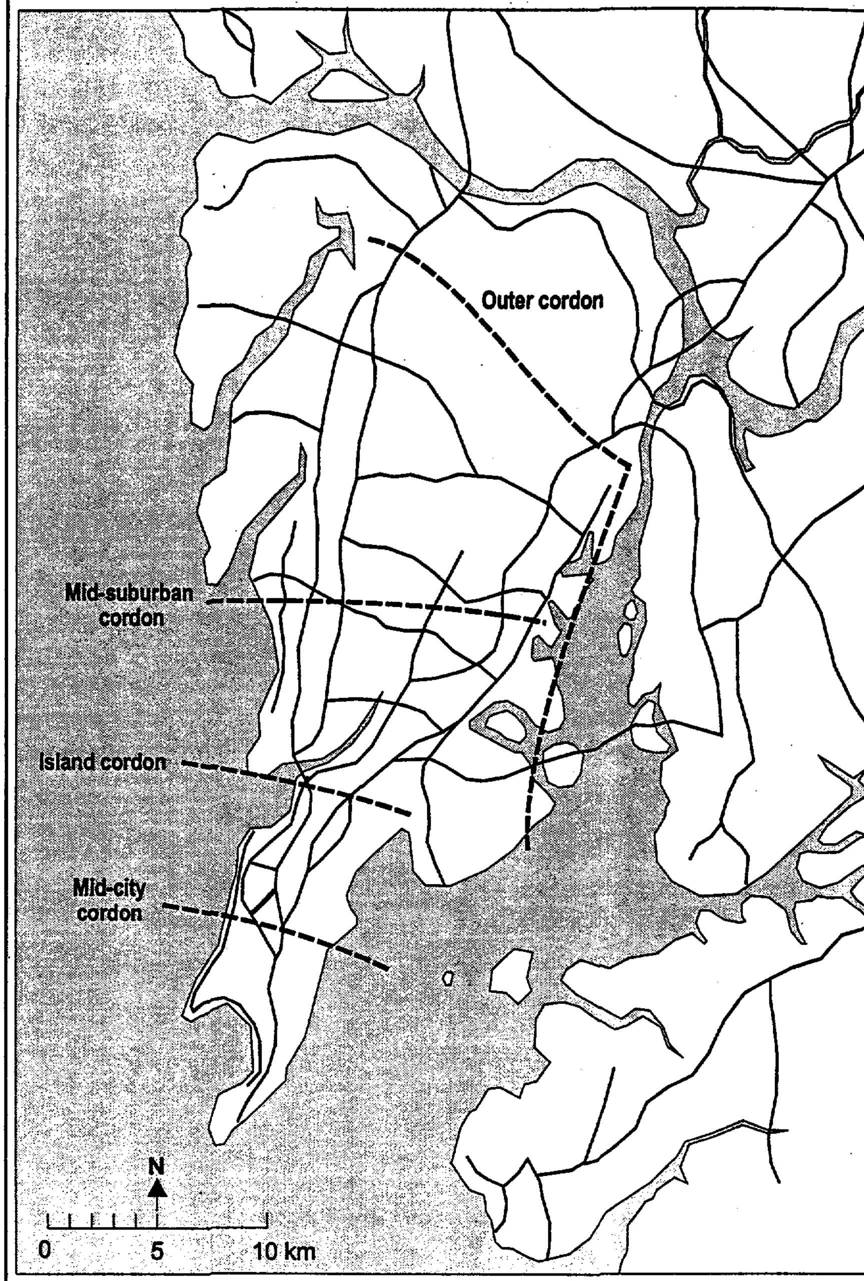
| | Growth rate % per annum | | |
|---|---|---|---|
| | Passenger vehicles | Goods vehicles | Cycles and other vehicles |
| Outer cordon | 6.0 | 4.5 | -2.8 |
| Mid-suburban | 6.8 | 1.5 | 2.7 |
| Island | 2.0 | 0.1 | -4.4 |
| Mid-city | 3.0 | -2.6 | -1.85 |

**Source**: BMRDA (1990).

Increased volume has resulted in a substantial slowing down of traffic, especially on the main corridors. Along the Eastern corridor, the speeds are low (15–30 km/h) and have not changed substantially. However, the average speed along the main Western corridor has declined from 50 km/h in 1962 to 30–40 km/h in the late 1970s, and 20–30 km/h in 1990. Similarly, the average speed in the Eastern corridor has fallen from 30 km/h in 1962 to 20–25 km/h in 1979, and 15 km/h in 1990 (Deshpande et al. 1993).

The BMRDA study of the rates of increase in population, registered vehicles, and traffic flow revealed that the large population growth in the suburbs, both immediate and extended, has caused a considerable increase in traffic flow in these areas. In the Island City, however, both population growth and traffic flow have stagnated (compared to 1962–78), although the number of registered vehicles has increased substantially (Table 1.7).

***Figure 1.3: Four cordons studied for growth traffic activity in Greater Bombay***




**Note:** Solid bold lines show the main road network of BMR.

## INDUSTRIAL SOURCES

*Table 1.7: Broad comparison of growth rates of population, registered vehicles and traffic flow*

| | Growth rates, 1978–1988 (% p.a.) | | |
|---|---|---|---|
| | Population | Registered vehicles | Traffic flow |
| Island City | 0.12 | 6.1 | 1.8 (Mid-City cordon)<br>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 |

**Source**: BMRDA (1990).

Aside from being India's financial and commercial center, Bombay is also the most industrialized Indian city. There are approximately 40,000 small and big industries in the city, of which 32 have been classified as hazardous (Table 1.8). Industries in the air polluting category include textile mills, chemical, pharmaceutical engineering, and foundry units. Process emissions, and those from fuel consumption, constitute the main sources of air pollution. This study does not account for industrial fugitive emissions. Major air pollution sources include a giant fertilizer/chemical complex; two oil refineries, and a thermal power plant, all based in Chembur, a suburb on the eastern coast of the Bombay Island.

*Table 1.8: Industrial classification in Greater Bombay*

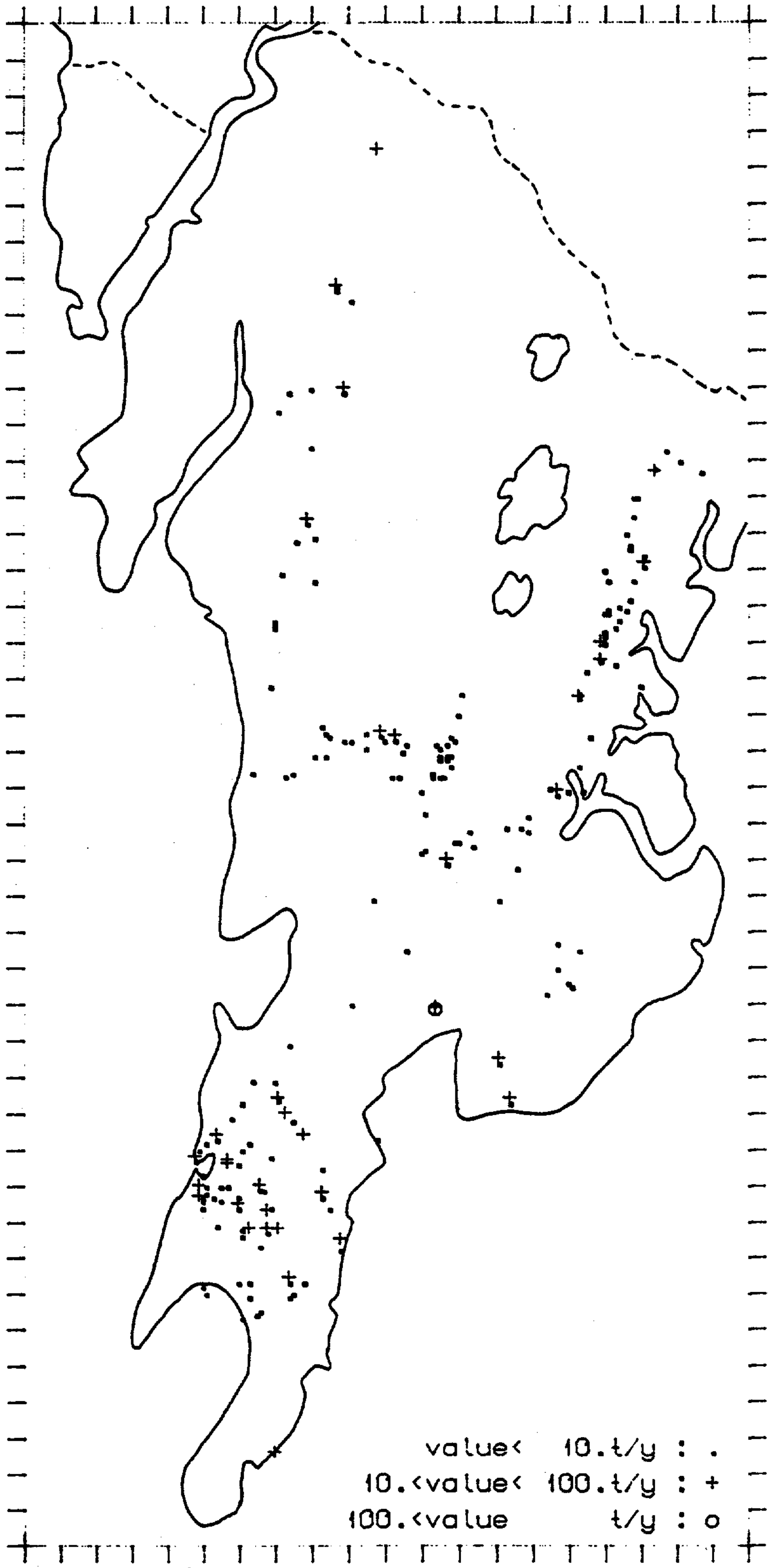
| Type of Industries | Number of Industries |
|---|---|
| Mechanical Workshop | 3,348 |
| Plastic and Rubber | 32 |
| Printing Press | 1,075 |
| Chemical | 523 |
| Textile | 531 |
| Pesticide | 9 |
| Miscellaneous | 33,790 |
| Thermal Power Plant | 1 |
| **Total** | 40,369 |

Industrial growth has been concentrated in the Tromby-Chembur and Lalbaug areas. In addition, industries have developed along Lal Bahadur Shastri Marg (Street) passing through the Central suburbs toward Thane; in the Andheri-Kurla area in Central Bombay, and along the Western Express highway leading out of Bombay. Figure 1.4 shows a map of major industrial sources in Bombay. As part of this URBAIR study, emissions data were collected for about 280 large and medium industries in Greater Bombay.

## FUEL CONSUMPTION

Over the period 1985–91, gasoline, high speed diesel (HSD) and low-sulfur high stock (LSHS) consumption increased by 26 percent, 28 percent, and 43 percent respectively. Furnace oil consumption decreased by 26 percent 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. Available fuel consumption data are presented in Table 1.9.

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



Coal consumption data for the same period are not available. Consumption in 1985–86 was 2,124,000 metric tons per year, with a sulfur content of 0.5 percent and ash content of 12 percent.

## 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. Wood combustion is an especially significant source of suspended particle pollution. About 1,100 of Bombay's 1,400 bakeries use wood for energy, as do the crematoria. The slum population also consumes a considerable volume of wood.

***Table 1.9: Fossil fuel consumption, Greater Bombay (million l/yr.)***

| | Furnace Oil | Low Sulfur High Stock | High Speed Diesel | Light diesel oil | Gasoline | LPG | Kerosene |
|---|---|---|---|---|---|---|---|
| 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.

**Source**: (i) E.S & P Dept; MCGB (for period 1985–91).
(ii) 1992–93 Data generated under URBAIR by ADITYA.

Sources responsible for such distributed consumption are termed "area sources," of which one, vehicular traffic, is already treated above. Fuel consumption for stationary area-distributed sources, for 1990, is shown in Table 1.10.

***Table 1.10: 1990 Fuel consumption for area-distributed sources ($10^3$ metric tons/year)***

| | 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 | | | |

**Note**:

1 Consumed by the non-slum population.

2 Consumed by the total population.

3 Consumed by the slum population.

**Source**: ADITYA for URBAIR.

# 2. AIR QUALITY ASSESSMENT

This chapter provides an estimate of the population exposure to air pollutants, and quantifies the contribution of various pollution source categories to this exposure.

This estimate of population exposure is arrived at through the following analysis:

- description of 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 modeling; and,
- calculation of the population exposure by combining spatial distributions of population and concentrations, and considering exposure on roads and in industrial areas.

## AIR POLLUTION CONCENTRATIONS

*Overview of database.* Air pollution measurement programs reveal that Bombay has a substantial particle pollution problem, with frequent and widespread exceeding of TSP and $PM_{10}$ air quality guidelines. According to the measurements, the $SO_2$ pollution problem seems less pronounced, although guidelines are sometimes exceeded. $NO_x$ concentrations are presently within WHO guidelines.

Monitoring networks and results of measurements are described in greater detail in Appendix 1. Assessments are based on data from various monitoring networks. MCGB has a network of 22 measurement stations in commercial, industrial, and residential areas. Levels of TSP, $SO_2$, $NO_x$, and Ammonia ($NH_3$) are measured as 8-hour averages (and a few 24-hour periods) per month. Most of the sites can be characterized as area-representative (city sites), while some are influenced by nearby traffic. At the GEMS network of three sites located south of Santa Cruz airport, and operated by NEERI, levels of TSP, $SO_2$, and nitrogen dioxide ($NO_2$) are measured a few days per month. 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 several sites at its plant by continuous analyzers and also monitors meteorological data at one site. The Indian Meteorological Department (IMD) operates meteorological stations at the Santa Cruz Airport and at the Colaba Observatory.

*TSP air quality guidelines.* The TSP Air Quality Guidelines applicable to Bombay are shown in Table 2.1 (also see Appendix 2 for details on WHO guidelines).

The annual average TSP values at all stations fall below the Indian (Bombay) air quality guidelines. The long- and short-term WHO guidelines are, however, exceeded at all stations. Although Indian (Bombay) guidelines are not exceeded, it should be noted that the Bombay guideline for TSP is considerably less stringent than those of WHO, as is apparent from the above Table. Considering the fact that TSP readings at MCGB are all recorded at heights ranging from 4–10 meters (on roof tops of buildings), these values are very high.

***Table 2.1: TSP air quality guidelines applicable to Bombay***

| | WHO (μg/m³) | Indian (Bombay) (μg/m³) |
|---|---|---|
| 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, see S.O. 384(E) under Air Pollution Control Act, Government of India 1981. For WHO guidelines see WHO/UNEP (1992).

**Note:** * Annual average mean of minimum 104 (24 hourly) measurements in a year.
** Should be met 98 percent of the time in a year. Should not be exceeded on two consecutive days.

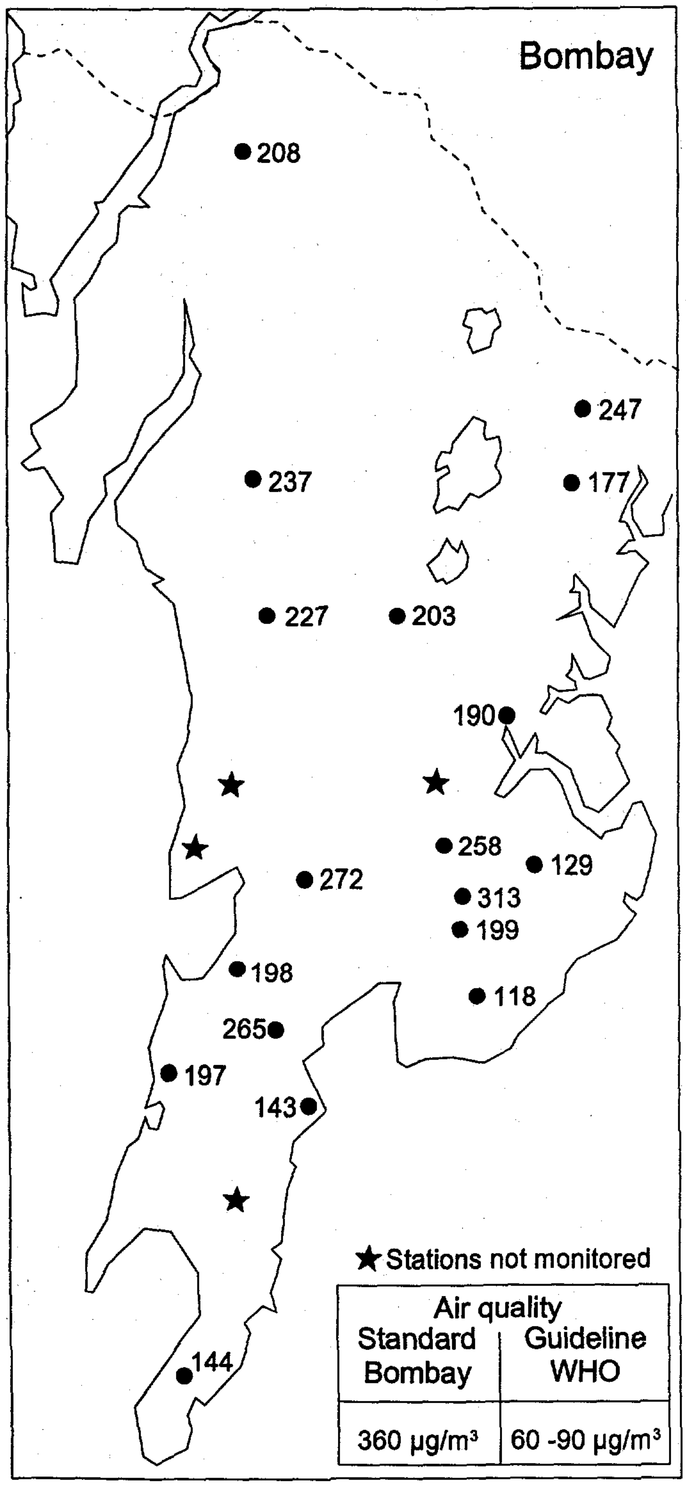
The sites with highest TSP concentrations are Maravali and Chembur Naka (both in Chembur), Sion, Parel, and Mulund. Maravali station has recorded very high 24-hour average TSP values (in the range 400–500 μg/m³) during dry seasons, while Chembur, Sion, Parel, and Mulund stations have recorded values between 250–400 μg/m³. These monitoring stations are located in industrial areas, and along highly trafficked roads.

Figure 2.1 shows annual average TSP concentrations at the 18 MCGB sites monitored in 1992-93. Figure 2.2 shows the monthly average at the Parel site. The annual average was 265 μg/m³, while the maximum monthly average of two to four 24-hourly values, was about 400 μg/m³.

The average TSP concentration in Bombay has increased considerably since 1980, from about 200 μg/m³ to about 250 μg/m³ in 1991. The year 1987 was exceptional with an annual average TSP concentration close to 400 μg/m³.

Data from Parel Station (Figure 2.2) show the typical annual variation observed at all MCGB 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 higher by as much as a factor of three. 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 causing dispersion during the monsoon. Extremely high TSP concentrations, up to 3,170 μg/m³, were measured at the Mahim Junction. Recorded maximum values exceed the WHO air quality guideline by a factor of up to 10, and the Bombay air quality guideline by a factor of 6. From the available evidence it can be concluded that TSP is a major air pollution problem in most of Bombay. It is worst near streets and industrial areas, and during the dry season. Measurements for TSP, $SO_2$, $NO_2$, and carbon monoxide (CO), taken at street junctions are presented in Table 2.2.

*Figure 2.1: Mean TSP concentrations at MCGB stations in the period June 1992–May 1993 (µg/m³)*




| Air quality Standard Bombay | Guideline WHO |
|---|---|
| 360 µg/m³ | 60 -90 µg/m³ |

**Note:** For site location, see Figure 1, Appendix 1.

*$PM_{10}$ air quality guidelines.* The $PM_{10}$ air quality guidelines applicable to Bombay, as well as the WHO standard, are given in Table 2.3.

$PM_{10}$ has not recently been measured in Bombay. However, a 1982–1983, respirable particles, human exposure study (WHO, 1984) is summarized in Table 2.4

The results of this study indicate that concentrations of, and exposure to, $PM_{10}$ in Bombay in 1982 were much higher than the WHO air quality guideline, with

***Figure 2.2: Monthly average TSP concentrations at the MCGB Parel site for 1987-1988 and 1992-1993(µg/m³)***

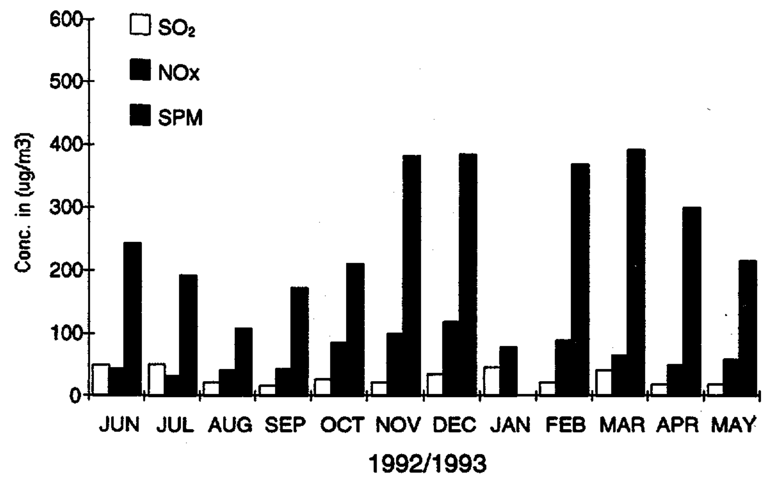



***Table 2.2: Results of ambient air monitoring (µg/m³) at different traffic junctions in Bombay.***

| Site | Monitoring Period | $SO_2$ # samples | $SO_2$ AVG | $SO_2$ MAX. | $NO_2$ # samples | $NO_2$ AVG | $NO_2$ 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 |

| Site | Monitoring Period | TSP # samples | TSP AVG | TSP MAX. | CO - PPM # samples | CO - PPM AVG | CO - PPM 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 |

**Source**: Correspondence with MCGB.

maximum values as high as 6 times the guideline. Although long-term concentrations were below the Bombay air quality guideline, short-term (24-hour) concentrations frequently exceeded the present standard.

***Table 2.3: $PM_{10}$ standards applicable to Bombay***

| | WHO (µg/m³) | Indian (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. Refer to S.O. 384(E) under Air Pollution Control Act, 1981, Government of India. For WHO Guidelines, see WHO/UNEP (1992).

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

** Should be met 98 percent of the time in a year. Should not be exceeded on two consecutive days.

***Table 2.4: Respirable particle concentrations measured in Bombay, 1982 (average and maximum 24-hour concentration)***

| | Winter | Summer | Monsoon |
|---|---|---|---|
| Person: personal monitor | 127/434 | 67/188 | 58/138 |
| Indoor: in the person's home | 118/327 | 65/231 | 62/131 |
| Outdoor: outside the person's home | 117/251 | 65/225 | 51/106 |
| Monitoring site: measurements at the nearest fixed monitoring site | 112/204 | 53/100 | 44/122 |

**Note:** Each average number represents about 100 samples.

*Lead.* Lead measurements at the 22 MCGB sites (1980–1987) indicate that it is a significant pollutant in Bombay. Annual average levels ranged from 0.5 µg/m³ to 1.3 µg/m³. These exceed the WHO guideline annual average (0.5–1 µg/m³, long-term) and the Bombay guideline (1.0 µg/m³, annual average and 1.5 µg/m³, 24-hour average), at all locations. From 1980 to 1987, average lead concentration in the air nearly doubled. Considering the frequency of measurements, these very high "monthly" averages are likely to represent single, 24-hour values. The Eastern Suburban zone was the most exposed area with monthly average concentrations as high as 17.9 µg/m³, recorded at the Mulund Site in October 1984. Lead concentrations in the Central Bombay area were also high, with the highest monthly average of 8.4 µg/m³ measured at Dadar in January 1985.

The Indian standard for maximum lead content of gasoline is 0.56 grams per liter in regular gasoline (Research Octane Number 87 or RON 87) and 0.80 grams per liter in premium gasoline (RON 93). In Bombay, most gasoline sold in the last 8–9 years has about 0.18–0.19 grams per liter. About 30 percent of the gasoline consumed has a high lead content, although it complies with the Indian standard.

*$SO_2$ and $SO_4$.* Indian (Bombay) and WHO air quality guidelines for $SO_2$ are given in Table 2.5. The annual average $SO_2$ concentration in Bombay (MCGB sites) has decreased since the 1980 average of about 45 µg/m³, to about 25 µg/m³ in 1992/93. This decrease is also apparent at the GEMS sites. Extremely high sulfate concentrations in particles were measured during the respirable particle 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. Contribution from sea aerosol may at times make considerable additions to these concentrations.

***Table 2.5: Bombay air quality guidelines for $SO_2$ and $SO_4$***

| | Indian (Bombay) | WHO |
|---|---|---|
| Long-term (annual) average | 80 µg/m³ | 50 µg/m³ |
| Short-term (24-hour) average | 120 µg/m³ | 125 µg/m³ |

**Source:** S.O. 384(E) under Air Pollution Control Act, 1981, Government of India, and WHO/UNEP (1992).

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

*$NO_x$.* Bombay air quality standards and WHO Guidelines for $NO_x$ are not directly comparable since the WHO guideline specifies $NO_2$, 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 $NO_2$ guidelines. The guidelines for $NO_2$ and $NO_x$ are given in Table 2.6.

***Table 2.6: Bombay air quality guidelines for $NO_x$***

| | Indian (Bombay) $NO_x$ as $NO_2$ | WHO $NO_2$ |
|---|---|---|
| Long term (annual) average | 80 µg/m3 | |
| Short term (24 hour) average | 120 µg/m3 | 150 µg/m3 |

**Source**: S.O. 384(E) under Air Pollution Control Act, 1981, Government of India, and WHO/UNEP (1992).

The annual average summary of $NO_x$ measurements in 1992–93 is shown in Figure 2.4. The highest concentration, 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. The summary of NOx concentrations at MCGB stations in the period June 1992–May 1993 is shown in Figure 2.4.

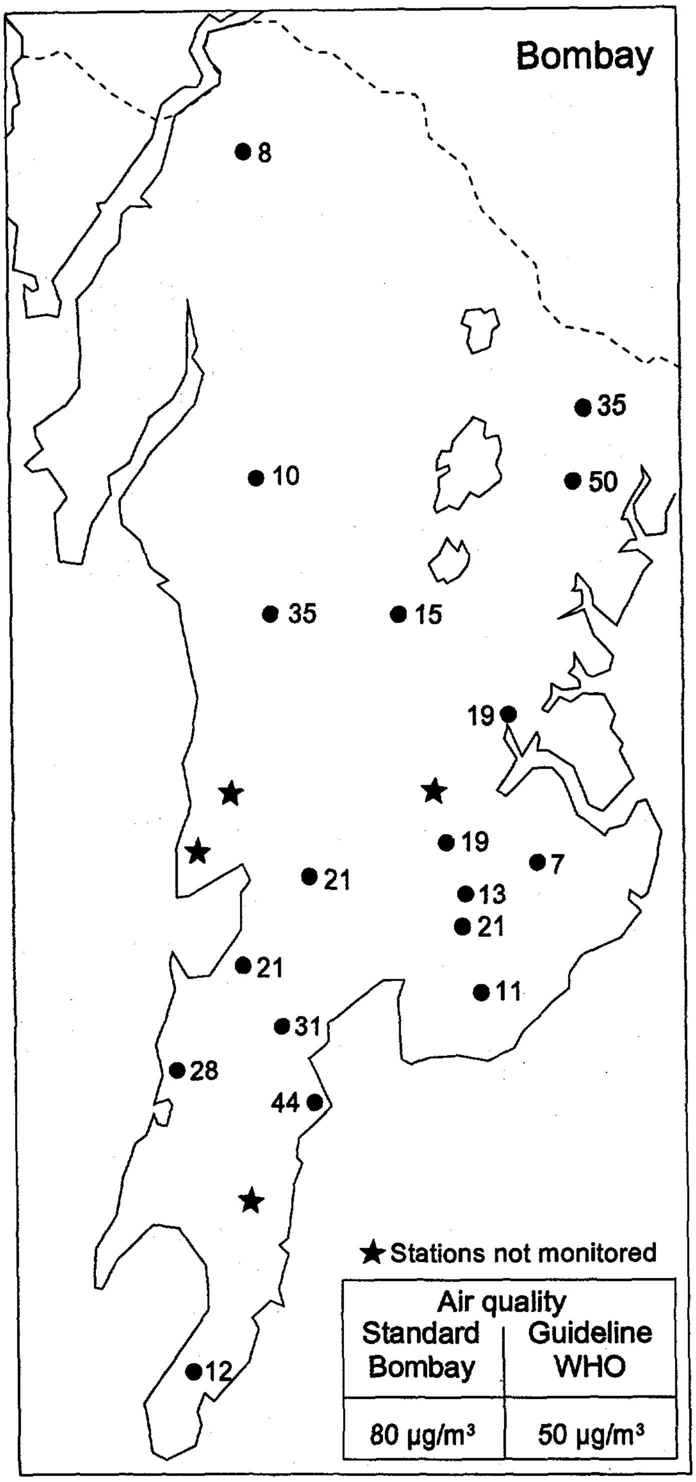
## AIR POLLUTANT EMISSIONS IN GREATER BOMBAY

*Total emissions.* A comprehensive emission inventory was developed for Bombay as part of the URBAIR project. The local URBAIR consultant collected the necessary input data, according to the project description (Appendix 8). The traffic emission distribution was developed on the basis of road and traffic data included in the Comprehensive Transport Plan for Bombay (Atkins, 1993).

Appendix 4 describes the development of the emission inventory. The results of the emission inventory are presented in Table 2.7. These are based on the emission factor data given in Table 2.8, and the fuel consumption data in Table 2.9. Traffic activity data are described in detail in Appendix 4. Emission factors for particles are described in Appendix 5. Appendix 7 contains the emission spreadsheet calculations.

The inventory covers the main source categories. Figure 2.5 shows the main source contributions. Emission factors recommended by WHO (1993), and United States Environmental Protection Agency (USEPA, 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). The working groups decided to use the WHO/EPA factors in this first phase of URBAIR. Accepted Indian factors should be used in subsequent analysis processes.

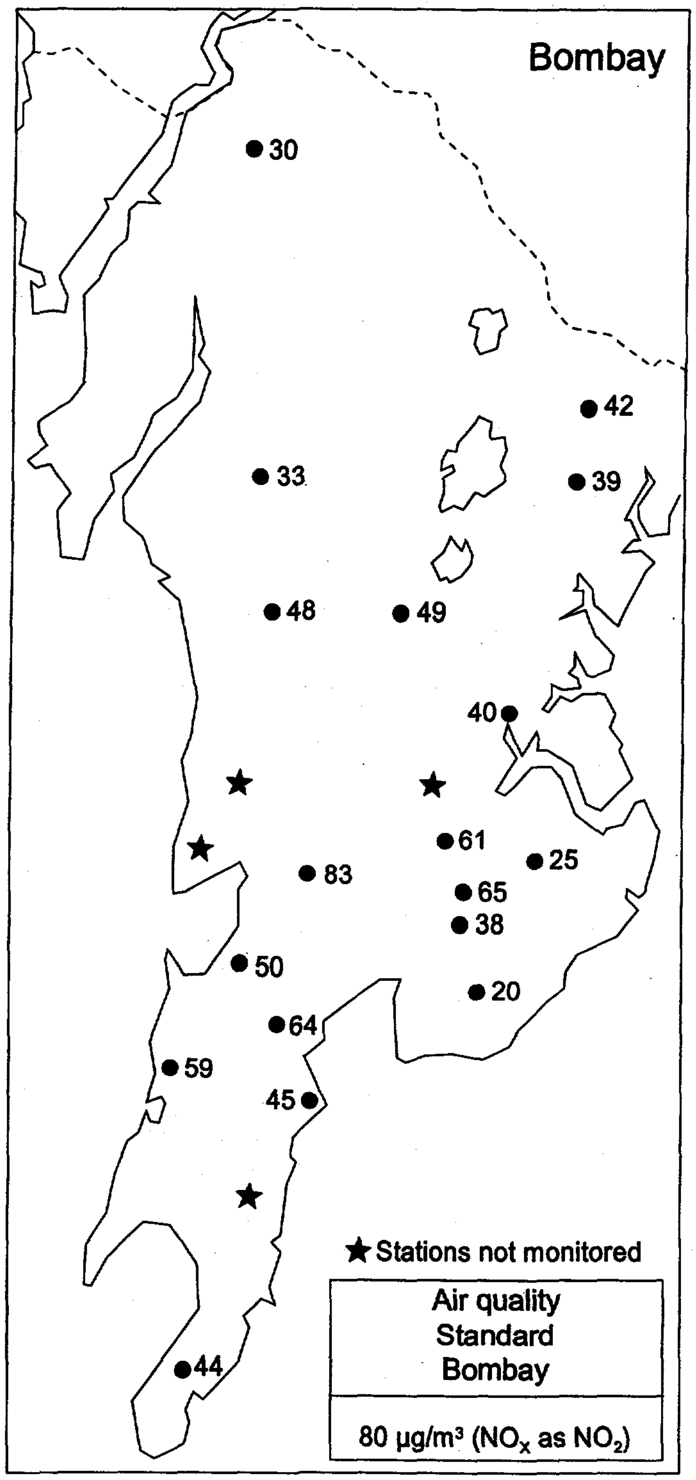
*Figure 2.3: Mean annual $SO_2$ concentrations at MCGB sites for 1992–1993 (μg/m³)*




| Air quality Standard Bombay | Guideline WHO |
|---|---|
| 80 μg/m³ | 50 μg/m³ |

**Source:** Communication with MCGB scientists.
**Note:** For site location see Figure 1, Appendix 1.

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




**Source:** Communication with MCGB scientists.
**Note:** For site location see Figure 1, Appendix 1.

*Table 2.7: Total annual emission in Greater Bombay, 1992–1993 (tons/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 | ~1500 | ~26,000 | ~11,200 | 24 |
| *Other fuel combustion* | | | | | |
| Industrial LSHS | 140[a] | 84 | 11,920[a] | 1,690 | 24 |
| FO | 1,652[a] | 1,399 | 24,480[a] | 2,140 | 24 |
| LDO | 12[1] | 6 | 1,510[a] | 120 | 24 |
| Diesel | 12[1] | 6 | 800[a] | 115 | 24 |
| LPG | 0,5 | 0.5 | - | 20 | 24 |
| Sum industrial | 1,817 | 1,496 | 38,710 | 4,085 | |
| *Domestic/commercial* [c] | | | | | |
| 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[b] | | | | | |
| 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** | |

a) Uncontrolled.
b) Process emissions are less important than fuel combustion emissions in Bombay.
c) Domestic coal/dung combustion not included, due to lack of volume data.

*Table 2.8: Emission factors used for URBAIR, Bombay, 1992*

| | TSP | $PM_{10}$/TSP | $SO_2$ | $NO_x$ | %S max. |
|---|---|---|---|---|---|
| **Fuel combustion (kg/t)** | | | | | |
| Coal, bituminous, power plant | | | | | |
| - uncontrolled | 5A[a] | | 19.5S[a] | 10.5 | |
| - cyclone | 1.25A | 0.95 | 19.5S | 10.5 | |
| - ESP | 0.36A | | 19.5S | 10.5 | |
| Residual oil (OF): ind./comm. | 1.25S+0.38 | 0.85 | 20S | 7.0 | 4 |
| Distillate oil: ind./comm. | 0.28 | 0.5 | 20S | 2.84 | LSHS: 1 |
| (LSHS, HSD, LDO): residential | 0.36 → 1.6[b] | 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 | 0.5 | 3.0 | |
| - dumps | 8 | | | | |
| Coal: domestic | 10 | | | | |
| Dung: domestic | 10 | | | | |
| **Road vehicles (g/km)** | | | | | |
| Gasoline: Cars | 0.2 | 1.0 | | 2.7 | 87:0.25 |
| - Trucks, light duty | 0.33 | 1.0 | | | 83:0.20 |
| - Buses and trucks, heavy duty | 0.68 | 1.0 | | | |
| - MC/TC | 0.5 | 1.0 | | 0.1 | |
| Diesel: Cars | 0.6 | 1.0 | | 1.4 | 1.0 |
| - Trucks, light duty | 0.9 | 1.0 | | | |
| - Buses and trucks, heavy duty | 2.0 | | | 13 | |

a) A: Ash content, in %; S: sulfur content, in %

b) Well → poorly maintained furnaces

**Note:** For additional information on the compilation of emission factors, see Appendix 5.

Emissions from the TATA power plant have been calculated based on the fuel consumption figures of Table 2.5, and assuming ESP emission control. The emissions do not contribute much to ground level exposure due to their tall stacks (278 meters).

Dockside emissions are primarily a result of petroleum products sold to ships. It is not known how much of this petroleum is actually burned in the docks. Emissions also come 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. They are 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 contains data from about 280 large/medium plants in Bombay. Process and fuel combustion emissions have not been separated. Also, the emission data for some of the plants are based on actual emission measurements, and may not be representative.

*TSP.* Total annual TSP emissions are estimated at about 32,400 tons per year for 1992–1993. Road traffic, particularly resuspension of road dust, wood burning, domestic refuse burning, and furnace oil use in industry are the largest sources of TSP emissions. Because these sources exhaust emissions at low heights, they contribute significantly to population exposure.

*Table 2.9: Fuel consumption data for Greater Bombay, 1992–1993 (April–March)*

| Category | Fuel type | $10^3$ metric tons/year | |
|---|---|---|---|
| TATA Power Plant | LSHS | 927 | |
| | Coal | 298 | |
| | Gas | 496 | |
| Industrial | LSHS | 499 | 279 in Petrochem. industry<br>164 in large/medium industry<br>56 in small scale industry |
| | FO | 306 | 183 in large/medium industry<br>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 | |

**Note**: For mobile sector fuel consumption and traffic activity, see Appendix 4.

In some areas, stone crushers expose nearby populations to TSP. Emissions from stone crushers are assumed to be uncontrolled and have been worked out separately. The emission figure for domestic refuse burning refers to commonly burned street litter and leaves, although little is known about the magnitude of the practice. A first gross estimate of one kilogram per household per week was used. The emission factor is highly uncertain. Based on WHO (1993) and NILU experiments (Semb, 1986), an emission factor of 37 grams per kilograms (g/kg) has been used. For burning at municipal refuse dumps, 8 g/kg has been used with reference to WHO (1993). An emission figure has not been developed for construction in Bombay due to lack of data, even though the experience of other Asian cities such as Manila leads us to believe that TSP emissions from construction tend to be substantial (Larssen et al., 1995).

Table 2.10 lists USEPA suggested emission factors (EPA AP 42) for road dust resuspension.

*Table 2.10: USEPA suggested road dust resuspension emission factors*

| Road class | AADT | Emission factor in g/km |
|---|---|---|
| Local streets | <500 | 15.00 |
| Collector streets | 500–10,000 | 10.00 |
| Major streets | 10,000–50,000 | 4.40 |
| Freeways/expressways | >50 000 | 0.35 |

**Source**: USEPA (1986).

These factors are valid for dry road conditions. Much of the traffic activity takes place on roads with annual average daily traffic (AADT) greater than 50,000. Assuming the traffic activity share on these road are 5 percent (local), 25 percent (collector), 30 percent (major), and 40 percent (freeway/expressway), and that the roads are wet 50 percent of the time, EPA emission factors give an average factor of a little more than 2 grams per kilometer. A recent evaluation of road emission rates supports, in general, the EPA emission factors for paved roads, although the study concludes that more investigation is needed (Claiborn et al., 1995). We select 2 grams per kilometer as an average resuspension emission factor.

*$PM_{10}$.* Total $PM_{10}$ emissions are calculated at about 16,000 tons per annum for 1992–1993. Refuse burning, resuspension, vehicle exhaust from diesel trucks, and fuel oil combustion in industry were the dominant $PM_{10}$ sources. Source distribution is shown in Figure 2.5.

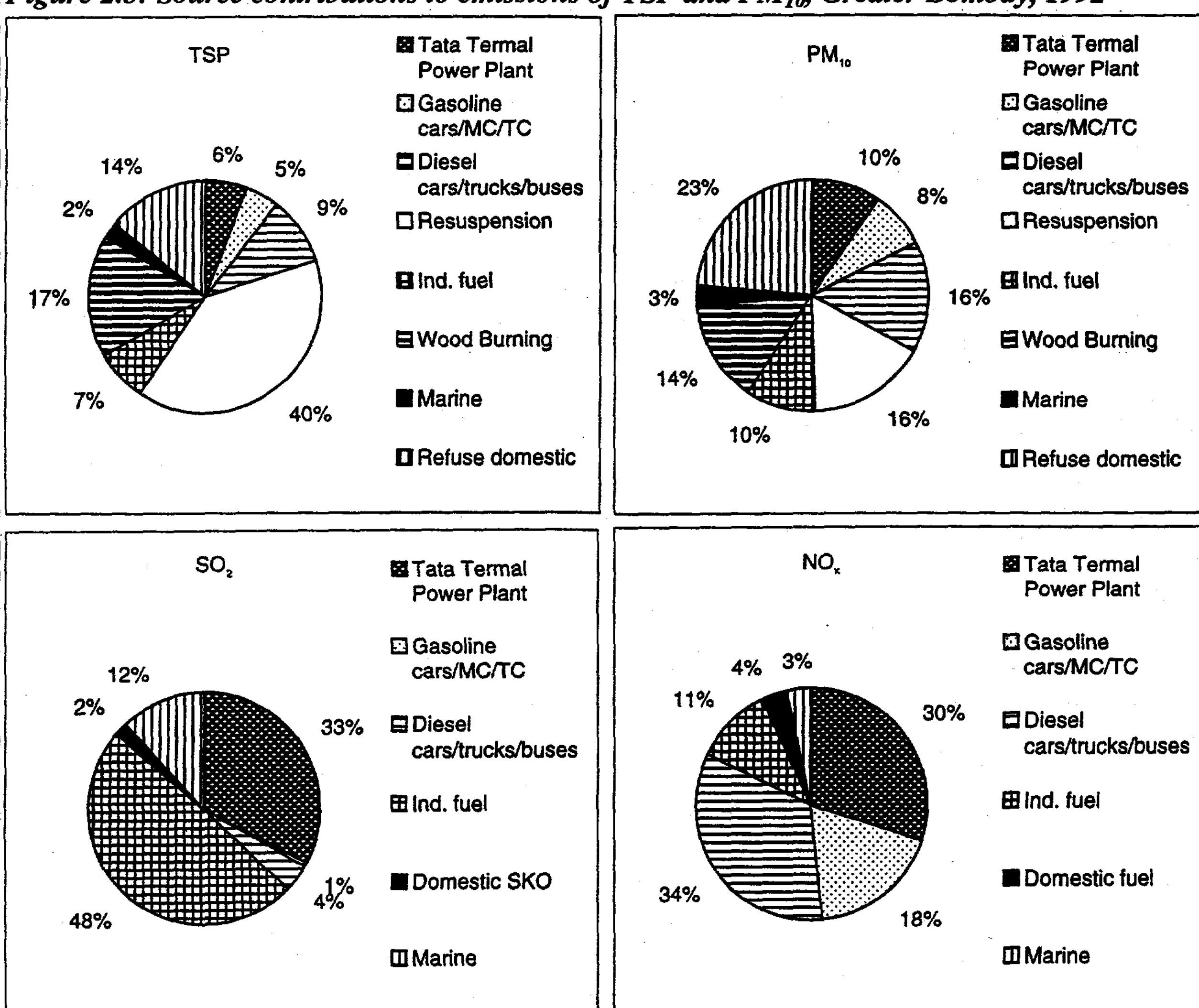
***Table 2.11: Typical fuel sulfur content***

| Fuel type | Sulfur content (%) |
|---|---|
| Fuel Oil (FO) | 4.0 |
| Light diesel oil (LDO) | 1.8 |
| Distillate (LSHS, HSD) | 1.0 |
| Motor diesel | 1.0 |
| Kerosene | 0.25 |
| Gasoline:87 RON | 0.25 |
| 93 RON | 0.20 |

*$SO_2$.* Emissions of $SO_2$ are calculated on the basis of the maximum sulfur contents of fuel as shown in Table 2.11.

Total $SO_2$ emissions are roughly 79,000 tons per annum. Industries, fuel oil, LSHS, and the TATA power plant are the main contributors. The actual sulfur content of fuels, and thus actual $SO_2$ emissions, may be lower.

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

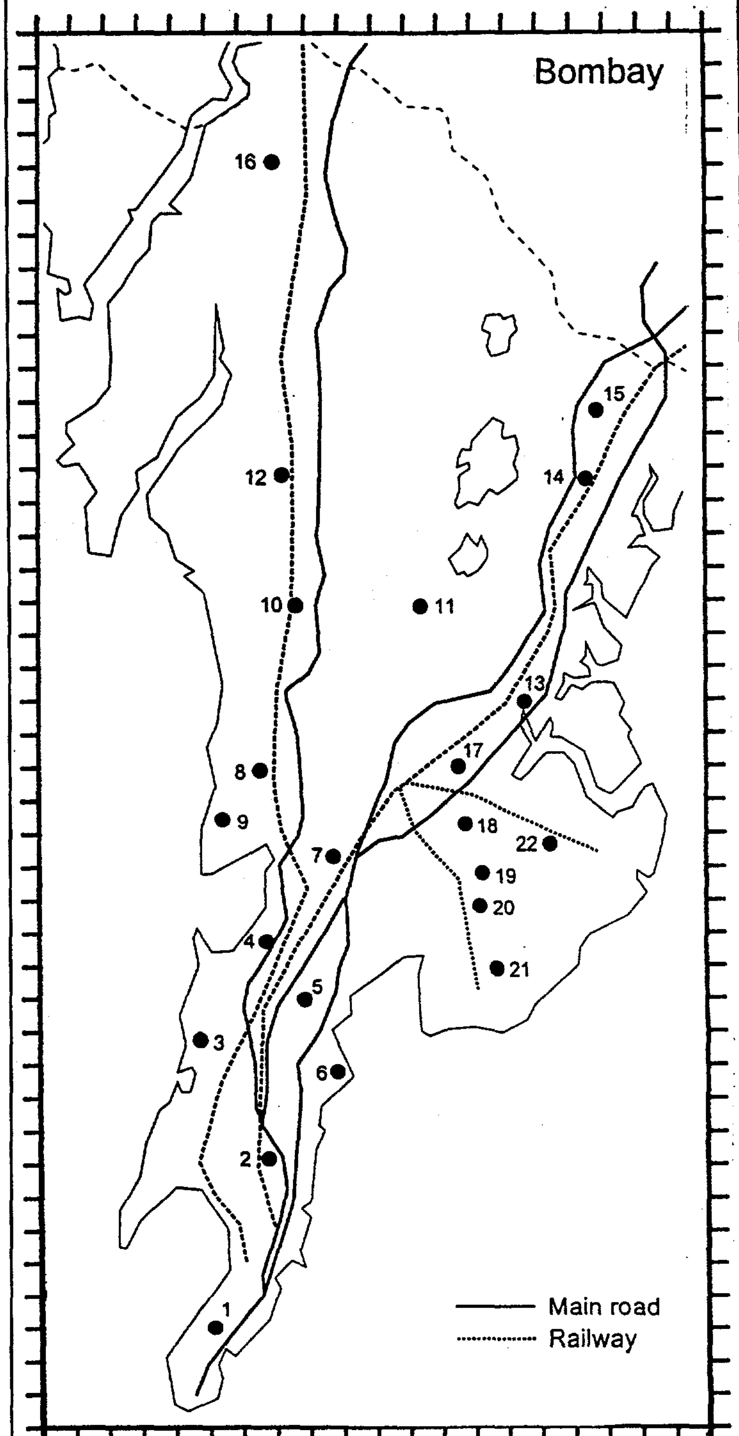


*$NO_x$.* Total annual $NO_x$ emissions are calculated at 37,000 tons per annum with vehicle exhaust, especially from diesel trucks and gasoline cars, and the TATA power plant being the main causes.

*Spatial emission distribution.* A base-line situation for air pollution exposure was established as a basis for a cost-benefit or cost-effectiveness analysis of abatement measures for Greater Bombay. In addition, spatial concentration fields over the urban area were demarcated. To model the spatial distributions, a grid-formed particle emission survey was designed to measure high particle concentrations—the main air pollution problem in Bombay. The calculated total emissions were distributed over a square kilometer ($km^2$) grid net of 42 by 20 $km^2$, covering the area shown in Figure 2.6.

Point source emissions were distributed according to their actual location. Fuel consumption in small industries, and in households, were distributed in relation to the population (See Appendix 4). Traffic emissions on the main road network were based on the locations of various corridors. The remaining diesel and gasoline used was distributed among the non-slum population distribution.

***Figure 2.6: Exposure modeling area, Greater Bombay***




**Note**: 42x20 $km^2$ grid net. Numbers correspond to MCGB monitoring sites. See Figure 1, Appendix 1 for site locations.

## DISPERSION MODEL CALCULATIONS FOR GREATER BOMBAY

### *Dispersion conditions*

*General description of topography, climate and dispersion.* Bombay has a mean elevation of 11 meters above sea level, and it consists of several islands on the Konkan coast. The city has a tropical savanna climate, with monthly mean humidity ranging between 57–87 percent. The annual average temperature is 25.3°C, rising to a maximum of 34.5°C in June and minimum of 14.3°C in January. Average annual precipitation is 2,078 millimeters with 34 percent (709 millimeters) falling in the month of July.

In the winter the predominant local wind direction is northerly, while in the summer monsoon season, north-westerly winds predominate. A sea breeze is usual during the day, with mean wind speeds between 1.5–2 meters per second. Nights, between the hours of 22:00 and 06:00, are calm. The mixing depth varies between 30 meters and 3,000 meters (NEERI, 1991).

Studies have shown that active monsoon conditions are 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. The reverse is observed on monsoon break days. In weak and break monsoon conditions there is a subsidence and feeding of dry air from the sky. In moderate to active monsoon conditions, the moisture reaches higher levels due to synoptic scale convergence.

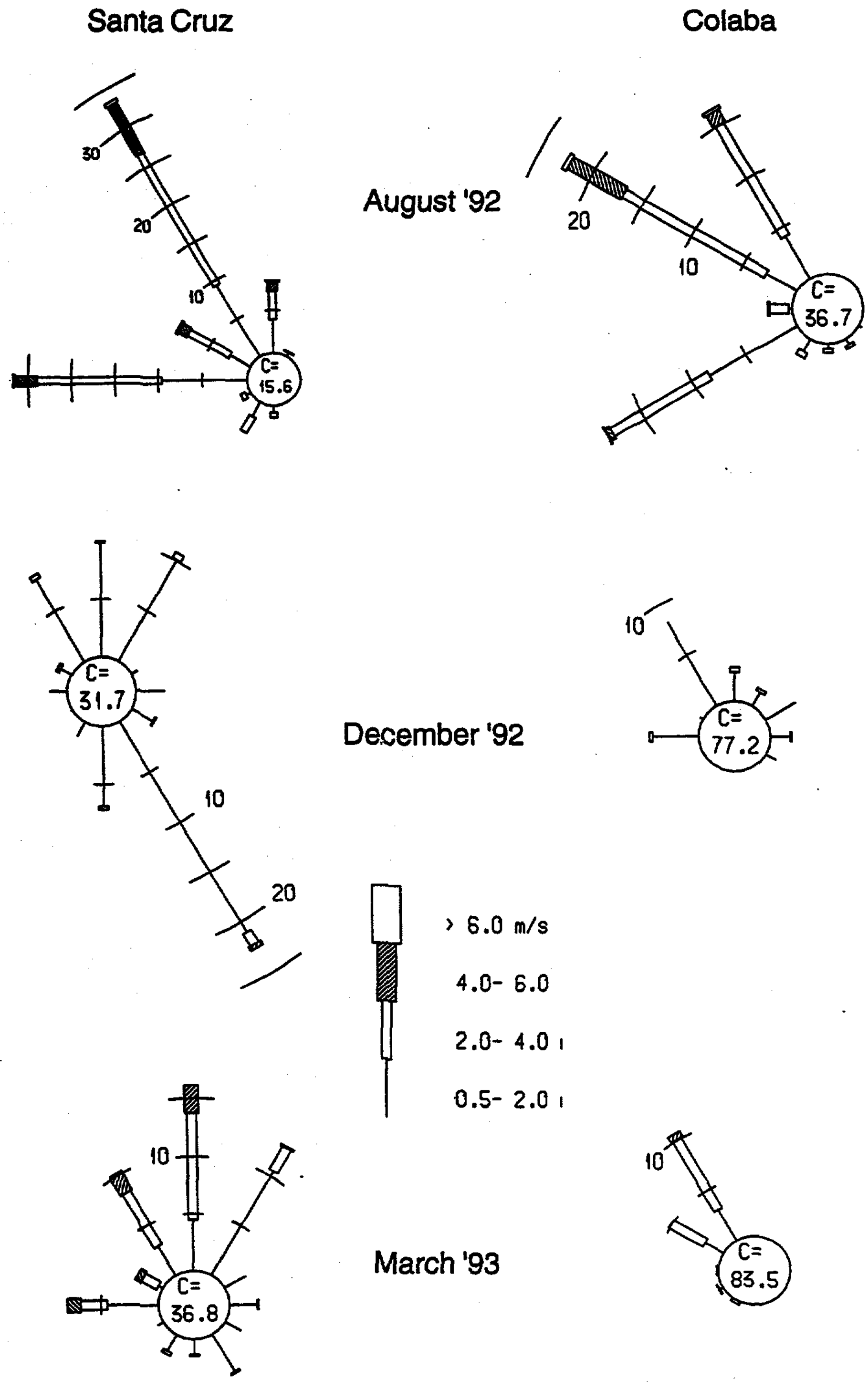
High pollution concentrations in Bombay usually occur in the winter when adverse meteorological situations, and weak and break monsoon conditions dominate. In the early mornings the inversion layer is lowest (closest to the ground), and leads to poor vertical mixing of pollutants. In the daytime when there is high insulation, a sea breeze blows inland. This wind direction may cause stagnation of the airmass when the monsoon winds run in the opposite direction. Such a condition can usually be seen on winter days and early summer mornings.

*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 Santa Cruz airport and Colaba Observatory, at Bombay's southern tip, have been obtained from the Indian Meteorological Department (IMD).

Winds are generally calmer at Colaba than at Santa Cruz indicating 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, the wind direction seems to be shifted some 30° counter-clockwise. During the winter (December) winds are very weak, and the main wind sectors are southeast and north. During the summer (March), the wind speed picks up again and the northerly sector dominates.

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

***Figure 2.7: Wind roses for 1992–1993, Santa Cruz Airport and Colaba***




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

From this 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. The combined matrix, based on the Santa Cruz data, is given in Table 2.12. This matrix is used for the dispersion conditions over the entire modeling area.

***Table 2.12: Wind/stability frequency matrix), Santa Cruz Airport, June 1992–May 1993 (% annual)***

| 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% |

**Note:** 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.

## *Dispersion model calculations, city background*

Model description. The dispersion modeling work in the first phase of URBAIR concentrates on the calculation of long-term (annual) average concentrations, representing averages within square kilometer grids (city concentrations). Contributions from nearby local sources in specific receptor points (streets, industrial hot spots) must also be evaluated. The model used is a multisource Gaussian model that treats 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 to be 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 square kilometer grid are simulated by 100 ground level point sources equally spaced over the grid.

McElroy-Pooler classification for low-level area sources, and Brookhaven classification for point sources (stacks) were used as the dispersion parameters. The software package used in the KILDER model system was developed at NILU (Gram and Bøhler, 1992).

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

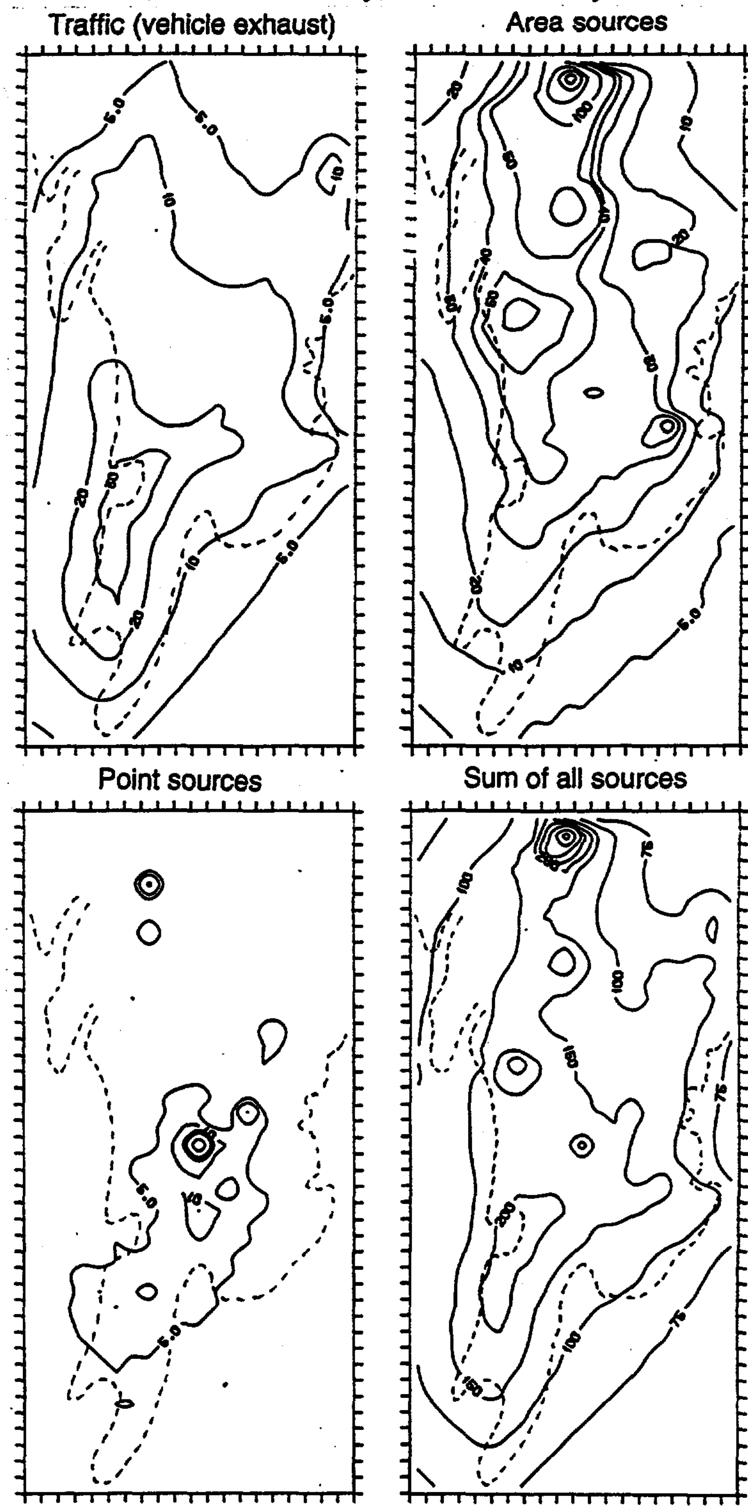
- road traffic (vehicle exhaust);
- area sources—domestic fuel combustion (wood, SKO, LPG), fuel combustion in small industries (LSHS, LDO), stone crushers, and burning in refuse dumps;
- point sources (emission from 280 large and medium size industrial plants); and,
- resuspension from roads.

A total background concentration of 60 $\mu g/m^3$ has been estimated based on measurements carried out near Vikram and Thal South of Bombay (data provided by M.G. Rao; Rashtriya Chemicals and Fertilizer, Ltd. and ADITYA). This total also includes resuspension from roads. The concentrations from resuspension are calculated to be about 2.5 times those from exhaust particles, based on emission factors. We estimate that resuspension of dust from roads is the most important source of TSP.

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. Contribution from refuse burning would be about the same as from traffic, about 20–30 μg/m3 in the maximum zone. The concentration peaks correspond to stone crushers (in the area source distribution), and to 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 generally of the same magnitude. Many of the sites with high measured values were seen to be situated in industrial areas, indicating possibilities of contributions from local sources. In this comparison it should be noted that TSP from refuse burning is in addition to the calculated concentrations.

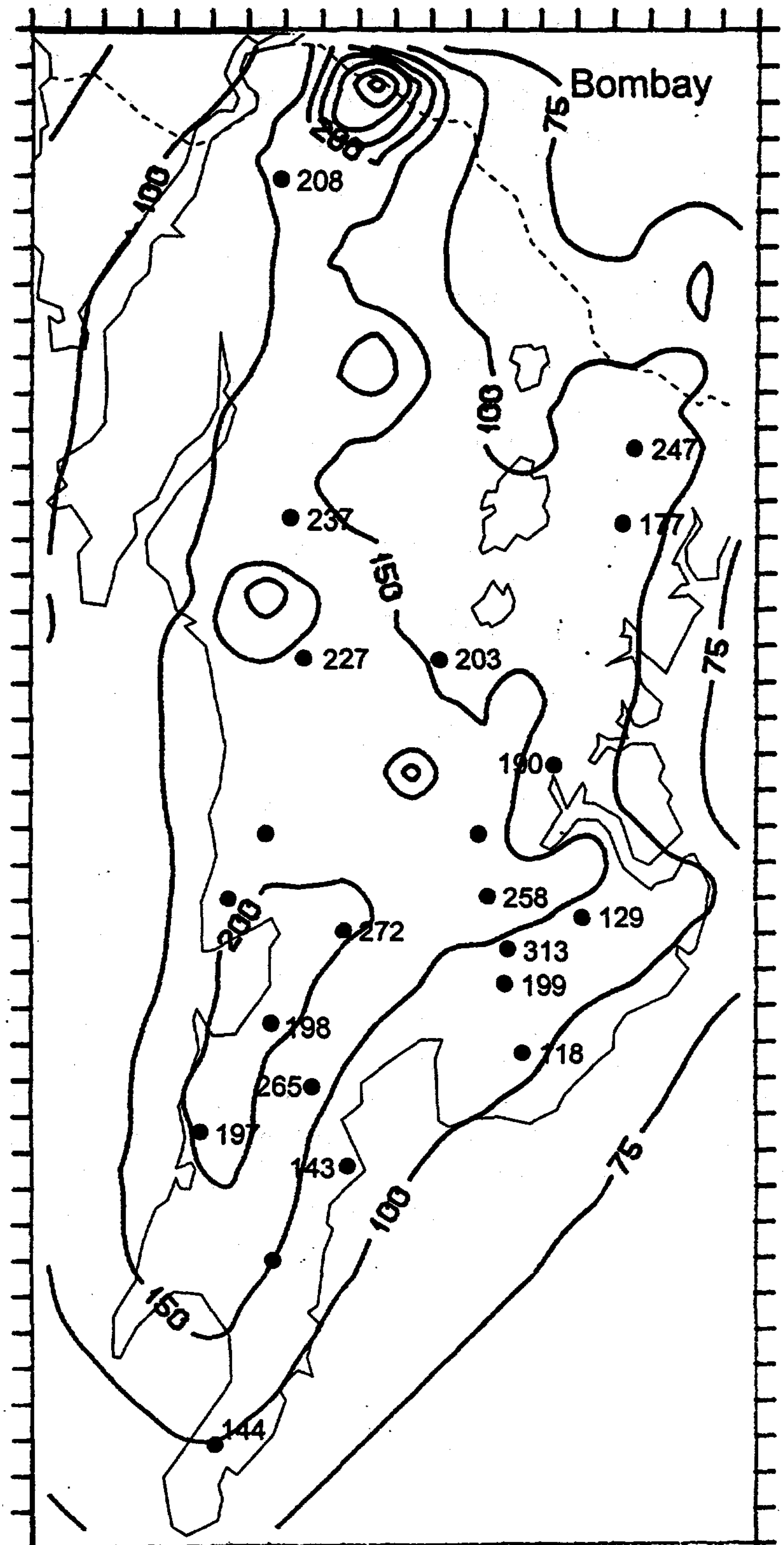
***Figure 2.8: Calculated average annual TSP concentration distributions, Greater Bombay, June 1992–May 1993***




**Note:** Calculated and measured values at MCGB and GEMS sites. See Figure 1, Appendix 1 for site locations.

*$PM_{10}$.* Concentration distributions for $PM_{10}$ have not been calculated, but can be estimated based on calculated TSP concentrations and $PM_{10}$/TSP ratios. Estimated $PM_{10}$ concentration contributions in the maximum concentration distribution zone (Dadar-Sion) are tabulated in Table 2.13.

***Figure 2.9: Annual average TSP, Greater Bombay, June 1992–May 1993***




**Note:** Calculated and measured values at MCGB and GEMS sites. See Figure 1, Appendix 1 for site locations.

*Table 2.13: Calculated TSP and $PM_{10}$ concentrations*

| | 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 |

Annual average $PM_{10}$ concentrations of about 100 µg/m³ represent about 50 percent of the TSP concentrations in the Dadar-Sion area for 1992. This is slightly higher than the $PM_{10}$ concentrations reported in Table 2.2, as measured in 1982. It can be expected that the $PM_{10}$ concentrations have increased since 1982.

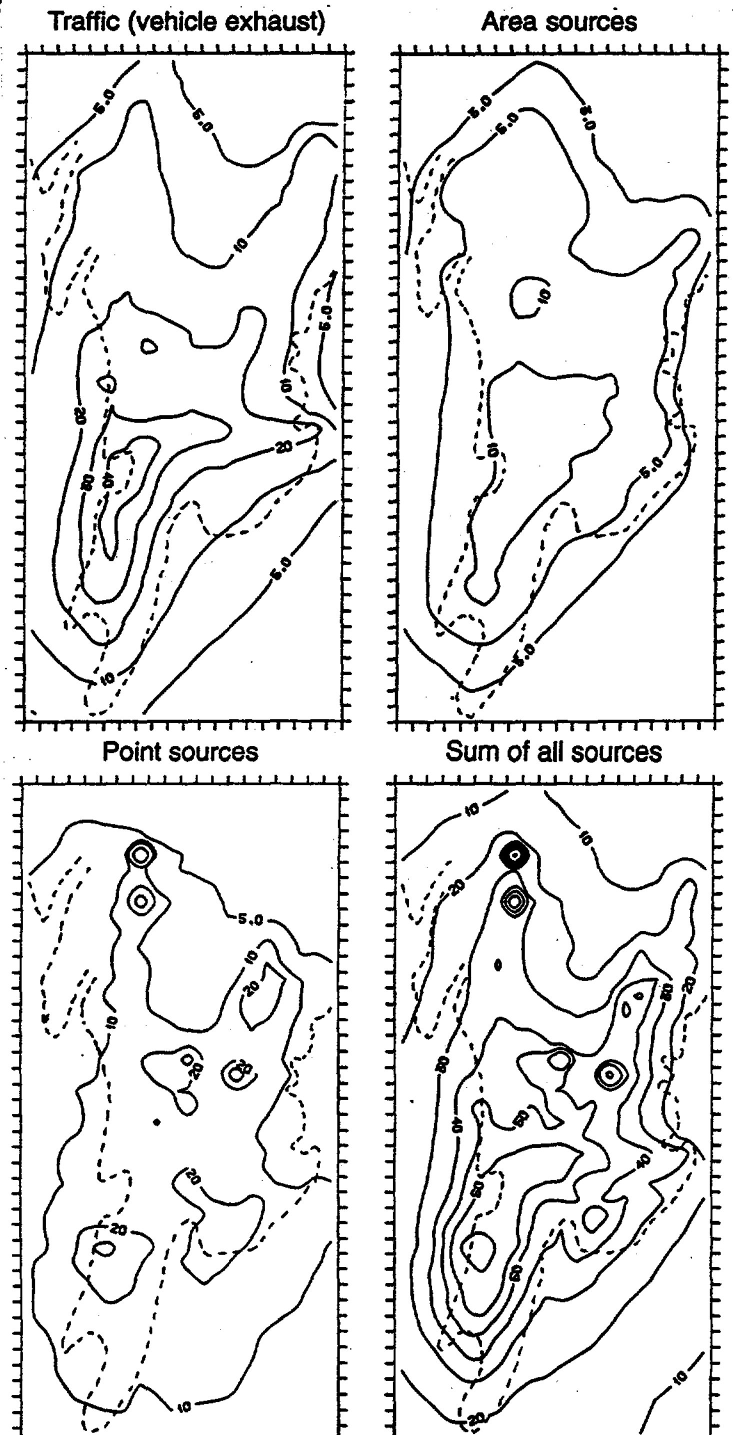
*$SO_2$.* Dadar-Parel (excluding peaks near specific industries) has the highest calculated annual average $SO_2$ at 70 µg/m³. This is significantly higher than the measured $SO_2$ concentration which ranges from 30–40 µg/m³. The discrepancy can be mostly accounted for by the maximum sulfur content of fuel. Actual sulfur content is less and, therefore, the $SO_2$ concentrations should also be less. Figure 2.10 shows calculated $SO_2$ concentration distributions (annual average, June 1992–May 1993). 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. Vehicle exhaust from traffic is the most important source for ground level $SO_2$ concentrations in Bombay.

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

## *Pollution hot spots*

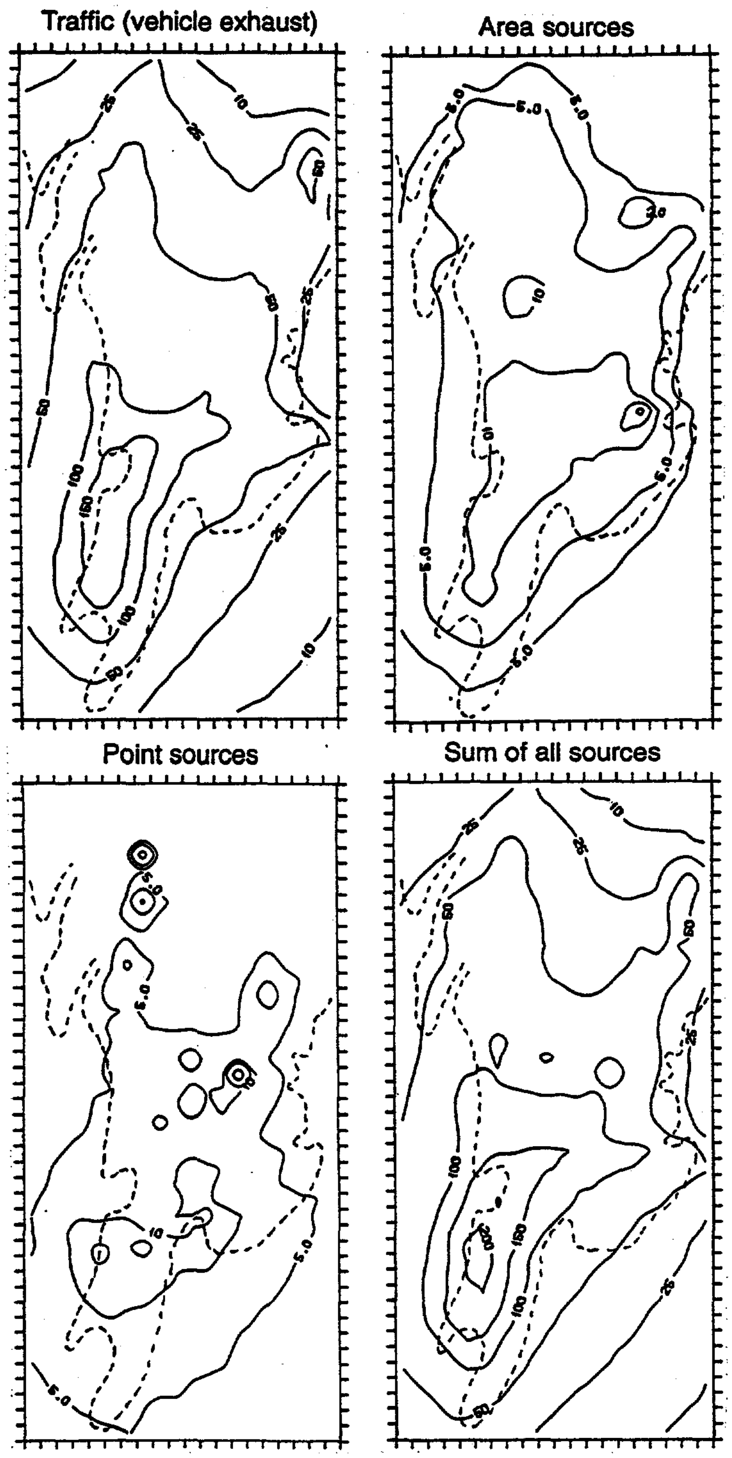
Pollution hot spots are areas with large concentration contributions. They are generally located along main roads, and near industrial areas with significant emissions from low stacks. The calculated concentration distributions of Figures 2.8, 2.9 and 2.10 indicate industrial pollution hot spots, including stone crushers. The measurements described in Figure 2.1 and in Table 2.2 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***




**Note:** Calculated and measured values at MCGB and GEMS sites. See Figure 1, Appendix 1 for site locations.

***Figure 2.11:*** ***Calculated annual average $NO_x$ concentration distributions, Greater Bombay, June 1992–May 1993***




**Note:** Calculated and measured values at MCGB and GEMS sites. See Figure 1, Appendix 1 for site location.

## POPULATION EXPOSURE TO AIR POLLUTION IN GREATER BOMBAY

People are generally exposed to air pollutants at home, on roads, and at work. *Population exposure* is defined as *the number of inhabitants experiencing concentrations of pollution compounds above certain concentrations.* The cumulative population exposure distribution gives the percentage of the total population exposed to concentrations above given values.

Correct mapping of pollution exposure requires data on:

- Concentration distributions and their variation with time—
  - at residences (general urban air pollution, city background);
  - along main roads;
  - near other hot spots, such as near industrial areas; and,
- Population distribution (residences and workplaces), the number of commuters and time-dependent travel habits.

The methodology used for calculating population exposure is described in Appendix 6. Briefly, it can be described as follows:

- calculate concentration distribution from all sources (except from domestic refuse burning);
- add exposure for residents close to the main roads;
- calculate residence exposure from this concentration distribution and the $km^2$ population distribution; and,
- add exposure for commuters and drivers traveling on roads.

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

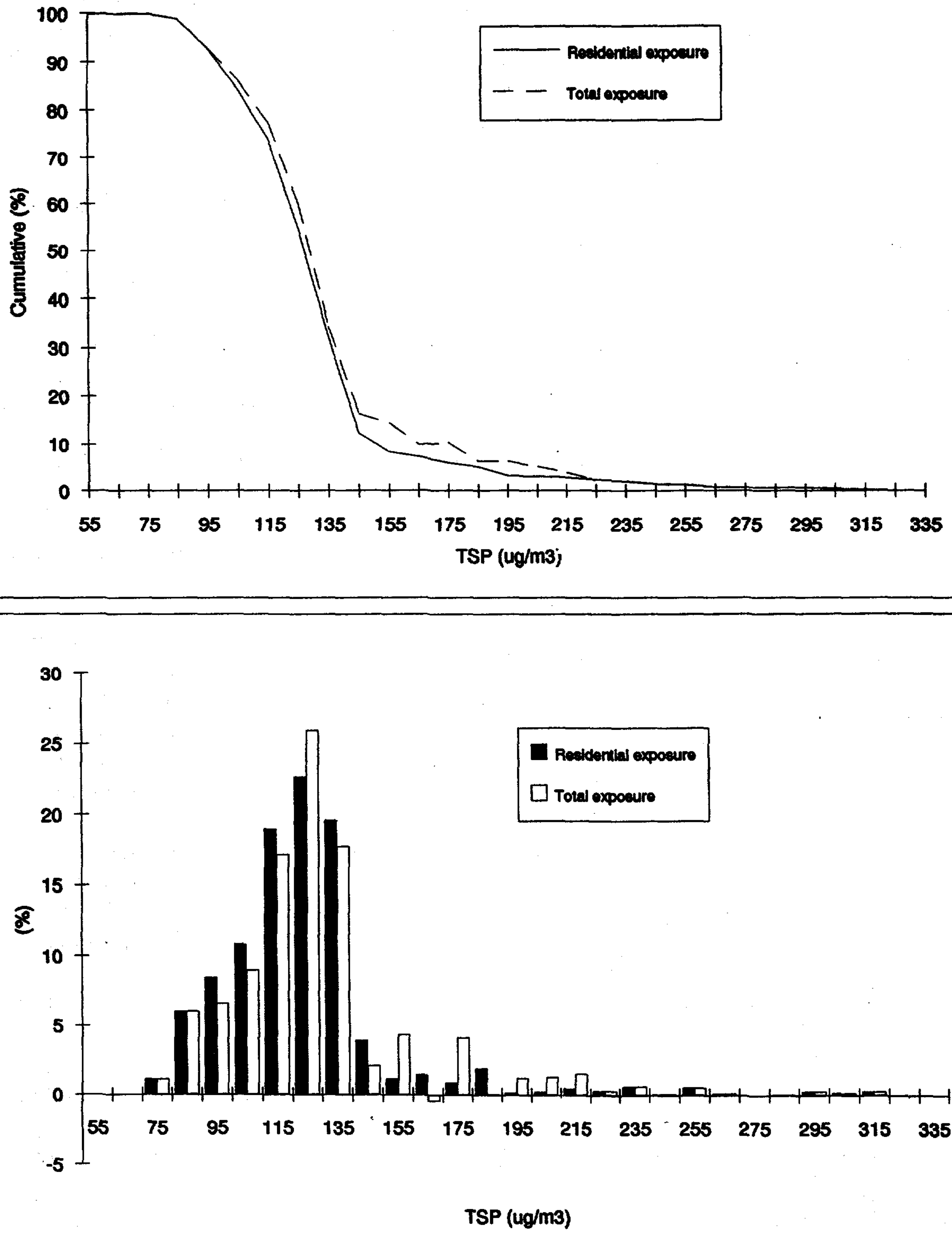
*TSP.* Population exposure to TSP, the major air pollution problem in Greater Bombay, is an input into health damage analysis. This is not to diminish the importance of exposure to high short-term concentrations of suspended particles and other pollution compounds in hot spots. Calculating such exposure requires a more extensive database than was available for Greater Bombay. In addition, although air quality guidelines have been set for short-term exposures, comprehensive dose-effect relationships regarding health have not yet been developed for such 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 and can be summarized as follows:

- about 97 percent of the population is exposed to TSP concentration above the WHO AQG (90 $\mu g/m^3$);
- approximately 8 percent of the population is exposed to TSP more than twice the WHO AQG (180 $\mu g/m^3$), including an estimated 300,000 drivers;
- most seriously exposed are roadside residents and public transport drivers, policemen and other roadside workers (estimated at 300,000 or 3 percent of the population), and residents near stone crushers.

Exposure to TSP in homes is due to resuspension from roads, domestic wood combustion and refuse burning, and exhaust from diesel vehicles.

*Figure 2.12: Calculated population exposure distribution, Greater Bombay modeling area, TSP, 1992–1993, annual average*



*$PM_{10}$*. Corresponding population exposure to $PM_{10}$ can be estimated by multiplying the TSP axis in Figure 2.12 by 0.5. The long-term WHO AQG for TSP, 90 µg/m³, is exceeded to a larger extent than the corresponding $PM_{10}$ guideline of 60 µg/m³. Thus, for long-term exposure to particles, TSP is the limiting parameter.

Main sources of $PM_{10}$ exposure at residences are diesel vehicles, domestic refuse and wood burning, and resuspension of road dust. Additional exposure in hot spot areas near industries may be significant.

## SUMMARY OF THE AIR QUALITY ASSESSMENT

*Greater Bombay air quality.* Total annual emissions (1992–93) are the following:

- 32,343 tons TSP
- 79,264 tons $SO_2$
- 37,547 tons $NO_X$
- 16,031 tons $PM_{10}$

For many years, concentrations of TSP, $SO_2$ and $NO_x$ have been measured regularly at more than 22 fixed locations for a few days each month. The locations are distributed among area-representative stations, street-side locations and in industrial areas. Despite its limitations, this database shows:

- TSP frequently exceeds the WHO air quality guideline at all stations;
- concentrations at street crossings are sometimes extremely high, exceeding the WHO air quality guideline by a factor of 10 or more;
- relative to their respective air quality guidelines, TSP and $PM_{10}$ are the most important pollution parameters in Bombay; and
- it is desirable to substantially improve the air quality monitoring system of Greater Bombay.

*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 dominate $SO_2$ emissions. Improvements are needed in the emissions inventory, especially with respect to industrial emissions, domestic refuse burning, resuspension, and construction. Estimated contributions from different sources are shown in Table 2.14.

***Table 2.14: Estimated contributions of emissions from differenct sources***

| | Source | Percentage |
|---|---|---|
| TSP | Resuspended road dust | 40 (rough estimate) |
| | Wood combustion | 17 |
| | Diesel vehicle exhaust | 9 |
| | Domestic refuse burning | 14 (rough estimate) |
| | Industrial fuel combustion | 7 |
| $PM_{10}$ | Diesel vehicle exhaust | 16 |
| | Domestic wood | 14 |
| | Domestic refuse burning | 23 |
| | Resuspension from roads | 16 |
| | Gasoline vehicle exhaust | 8 |
| $SO_2$: | Industrial fuel combustion | 82 (incl. power plant 33%) |
| | Diesel vehicle exhaust | 4 |
| | Marine fuel combustion | 12 |
| $NO_x$ | Industrial fuel combusion | 41 |
| | Gasoline vehicle exhaust | 18 |
| | Diesel vehicle exhaust | 34 |

*Population exposure.* Calculations show that about 97 percent of the population is exposed to annual average TSP concentrations exceeding the WHO air quality guideline. Of this, 8 percent of the population is exposed to TSP that is double the guideline. This includes approximately 300,000 drivers, other roadside workers, roadside residents, and those who live near stone crushers.

Main sources of TSP exposure are resuspension from roads, domestic wood combustion, diesel vehicles, and domestic refuse burning. Diesel vehicles, domestic wood and refuse burning, and resuspension are the main sources of $PM_{10}$ . Additional exposure in industrial hot spots may also be significant.

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

## IMPROVING AIR QUALITY ASSESSMENT FOR GREATER BOMBAY

### *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 $NH_3$ collected infrequently (1–4 days per month);
- $PM_{10}$, lead, CO and $O_3$ and other compounds not routinely measured;
- Monitoring on rooftops (4–12 meters above ground);
- No stations are monitored as frequently as required under the Indian AQG (at least 104 days per year); and,
- Many of the measurement sites are not clearly defined in terms of their representativeness, as:
  - city 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 analyses are good, financial constraints affect methodological and manpower capacities. It is important to improve air quality monitoring in Greater Bombay by including:

- at least 5 city 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;
- 1 background site;
- continuous monitors for $PM_{10}$, CO, $NO_x$, $SO_2$, $O_3$, depending upon the site; and,
- an online data retrieval system linked to a lab database, via telephone or modem.

*Emissions.* The main shortcomings of the emission inventory are:

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

*Population exposure.* Population exposure from various sources is determined by a combination of dispersion modeling and air pollution monitoring. It is vital that the population exposure distribution be reliable, since it forms the basis for assessing damage to health and the costs stemming from such damage. Further, it feeds into the cost-benefit analysis of measures to reduce exposure.

In order to make improvements to the population exposure calculations that have been developed in the first phase of URBAIR, dispersion modeling expertise in Bombay should be identified, and the use of dispersion modeling integrated into the control agencies' Air Quality Management work. Dispersion modeling expertise and appropriate models for air pollution management and control strategies should be based in Bombay.

Proposed actions to improve air quality assessment are summarized in Table 2.15.

***Table 2.15: 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<br>- evaluate sites; number (at least 10) and locations;<br>- select parameters (CO, $NO_x$, $O_3$,HC, TSP and $PM_{10}$ recommended) /methods/monitors/operation schedule;<br>- upgrade laboratory facilities, and manpower capacities. | This activity should start immediately, and a proposed schedule is as follows:<br>**Now**:<br>Finalize plan for an upgraded air quality monitoring system, including plans for laboratory upgrading.<br>**Within one year**:<br>Establish of 1–2 new modern monitoring stations; and<br>Carry out first phase of laboratory upgrading. |
| Design and establish a Quality Control/Quality Assurance System | This activity should also start immediately, phased in with the improved monitoring system, and the laboratory upgrading. |
| Design and establish an Air Quality Information System, including<br>- database; and<br>- information to control agencies; lawmakers; and public. | |
| ***Emissions*** | |
| • Improve emission inventory for Greater Bombay<br>a) Improve industrial emissions inventory (location, process, emissions, stack data)<br>b) Improve road and traffic data inventory<br>c) Improve domestic emissions inventory<br>d) Study resuspension<br>- from roads<br>- from other surfaces<br>e) Estimate contribution from construction and refuse burning.<br>f) Establish emission factors for Indian conditions. | • Priority:<br>- industrial emissions inventory<br>- study of resuspension from roads<br>- start developing an emission inventory procedure. |
| • Develop an integrated and comprehensive emission inventory procedure, include emission factor review, update and quality assessment procedures.<br>• 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. AIR POLLUTION: IMPACTS AND VALUATION

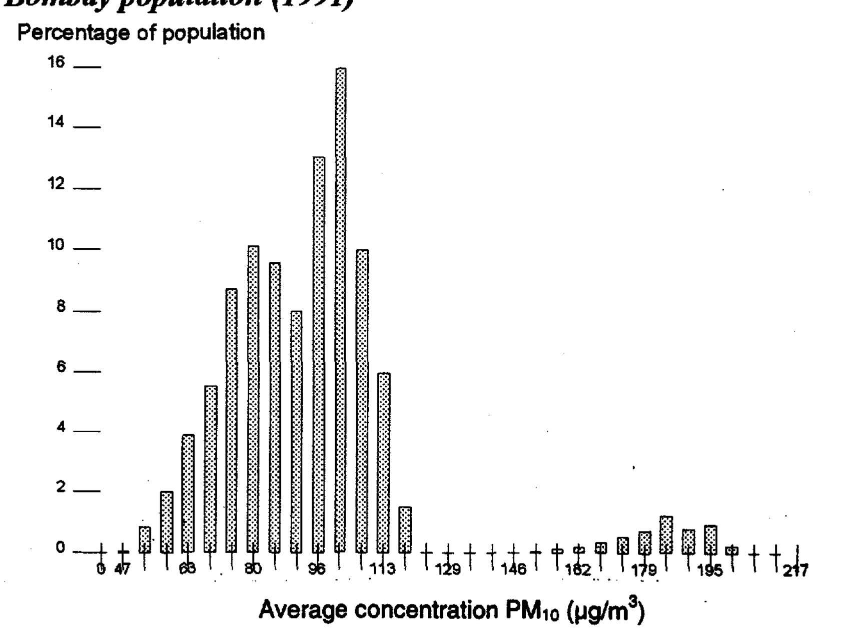
## INTRODUCTION

As large cities in Europe and North America industrialized, and the energy used by industries and homes increased, so did pollution. Air pollution in urban areas became a major public health concern, as exemplified by the killer fogs that claimed thousands of lives in London in 1952 and 1956 (Lave and Seskin, 1977). Economic development in Asia has had similar consequences, and air pollution problems have become endemic in Asian cities. This chapter presents an overview of major impacts of air pollution in Bombay, including a rough estimation of the monetary value of these damages. As concluded in Chapter 2, high concentrations of suspended particles and lead are the leading problems in air pollution. This chapter details the impact of $PM_{10}$. A frequency distribution of the $PM_{10}$ exposure of Bombay's population is summarized in Figure 3.1. Unfortunately, current data on lead exposure were not available.

Health impact estimates are based on research conducted in the United States(Ostro, 1994), and their methodology is described in the *URBAIR Guidebook*. Although damage to human health is not the only adverse effect of air pollution, lack of appropriate data prevented us from quantifying other impacts such as a reduction in the economic life of capital goods, tourism, crop production, and other intangible impacts.

This chapter summarizes health studies carried out in Bombay; addresses the calculated

***Figure 3.1: Frequency distribution of the $PM_{10}$ exposure of the Bombay population (1991)***



impacts on health and mortality in Bombay; and calculates the costs that can be attributed to these impacts.

## SUMMARY OF STUDIES BY ENVIRONMENTAL POLLUTION RESEARCH CENTER, (KEM HOSPITAL, BOMBAY)

In addition to inadequate housing and sanitation, Bombay's urban population (of which 50 percent lives in slums) is exposed to rising levels of air pollution. It has been experimentally established that air pollutants like $SO_2$, ozone, oxides of nitrogen, benzopyrene, and suspended particulate matter (SPM) result in incidence if respiratory diseases. High $SO_2$ levels have been shown to cause increased incidence of chronic bronchitis, frequent colds, and decline in lung functions. In order to determine the actual impact of pollution on health in Bombay, the Environmental Pollution Research Center (EPRC), KEM Hospital has conducted studies since 1976, correlating air pollution to morbidity.

In 1978, when automobile fuel had higher concentrations of lead and sulfur, EPRC conducted a study on 1,008 subjects (522 male and 486 female) from a residential community in Parel, in Central Bombay. Because of a coal gas factory and many textile mills, together with main arterial roads and heavy traffic, levels of pollution in Parel were very high. The incidence of respiratory symptoms (coughing and dyspnoea) was observed to be higher in this suburb than in Chembur. Chembur is surrounded by chemical and fertilizer factories, and a thermal power station, but has comparatively low vehicular traffic.

In 1990, following a decline in the sulfur content of fuel, and the closing of the coal gas factory and many textile mills, $SO_2$ levels in Parel dropped from 103 $\mu g/m^3$ to 29 $\mu g/m^3$. At the same time due to increases in vehicular traffic, $NO_2$ levels increased from 16 $\mu g/m^3$ to 54 $\mu g/m^3$, and SPM levels increased from 242 $\mu g/m^3$ to 304 $\mu g/m^3$. Different studies conducted in this area suggested that although frequent colds, headaches and eye irritation were less common, cough, dyspnoea and hypertension had increased. Similarly, while the prevalence of bronchitis had decreased, cardiac disease had increased. Table 3.1 shows $SO_2$, $NO_2$ and SPM mean levels in different years in Parel, along with the mortality rate due to respiratory diseases, heart diseases and cancer.

***Table 3.1: Pollution trend and mortality rates in Parel***

| | Pollution trends ($\mu g/m^3$) | | | |
|---|---|---|---|---|
| **Pollutants** | **1978** | **1982** | **1986** | **1990** |
| $SO_2$ | 102 | 62 | 37 | 29 |
| $NO_2$ | 16 | 41 | 52 | 54 |
| SPM | 242 | 219 | 326 | 304 |
| **Mortality rate** | **Affected Population (100,000)** | | | |
| 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 |

A 1988 cross sectional study examined symptom and disease patterns in four localities:

- 421 subjects (194 male and 227 females) of a community located about 2 kilometers from a large fertilizer factory (Tolaram Nagar);
- 397 subjects (185 males and 212 females) of a locality with comparatively low pollution (Telecom township);and

- 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, tuberculosis, cardiac diseases, and restrictive lung diseases were more prevalent among subjects of Parel and Tolaram Nagar as compared to the other two localities.

A 1978 study in Chembur examined 586 males and 536 females living near fertilizer and chemical factories and thermal power stations. Automobile traffic 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 kilometers 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 to 13 percent. Further, the incidence of bronchitis (4.5 to 7.6 percent), cardiac diseases (4.3 to 6.7 percent), and other chest disorders (0.1 to 4.4 percent) had also risen between 1978 and 1990 (Table 3.2). It was also observed that different respiratory symptoms and cardiac diseases, respiratory tract infection, and skin allergy were about 5 to 10 percent higher among people of the communities near the factory. The lung functions of study subjects in both these communities were about 5 to 8 percent lower than the subjects of the control community.

In 1990, an awareness survey was conducted in communities near the chemical and fertilizer factories of Chembur. More than 95 percent of the population complained of strong smells that caused discomfort. The incidence of symptoms declined as distance from the chemical factories increased. For example, 80 percent of the sample complained of headache and eye irritation in Maharashtra State Electricity Board (MSEB) colony, just about 100 meters away from the Oswal Agro chemical factory; 73 percent reported similar symptoms in Railway Colony, about 500 meters away from the Rashtriya Chemicals and Fertilizer, Ltd. factory; as did 50 percent in Tolaram Nagar about 2 kilometers away from the Rashtriya Chemicals and Fertilizer, Ltd. factory.

In 1980–1981, a similar study of food and water was carried out in two middle-class communities in central Bombay. A community of 552 subjects near a wholesale vegetable market with fairly dirty ground conditions and bad ventilation was 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 was about 3 to 4 percent higher in communities near the market, compared to the control site.

From 1986 to 1988, a three-year prospective study was conducted of two high-density traffic areas of Bombay (King Circle and Peddar Road) with 383 subjects (164 males and 219 females) from King Circle, and 473 subjects (241 males and 232 females) from Peddar Road. Observed mean levels of CO were 9 to 18 PPM, reaching a maximum of 63 PPM in these two areas, contributing to a high incidence of coughs, bronchitis, and cardio-respiratory disorders. A significant correlation was also observed between SPM levels, the frequency of colds, attacks of breathlessness, and $NO_2$ and SPM levels. The prevalence of cardiac diseases had increased in these localities (Table 3.2).

*Table 3.2: Summary of EPRC studies along with air pollutant levels*

| Locality | Year | Pollutant Levels | | | Symptoms | | | Disorder Prevalence | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | $NO_2$ | SPM | Cough | Colds | Dyspnoea | 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 ($\mu g/m^3$) | | | | | | | | |
| Amboli n=506 | 1988 | | 2,016 | | 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 | |

In 1988, 507 subjects (144 males and 203 females) who lived near Amboli quarry where mean SPM level is 2,016 μg/$m^3$, were studied. A similar study involving 587 subjects (246 males and 341 females) was conducted in 1991 near Kandivili quarry where the mean SPM level is 618 μg/$m^3$ . It was observed that the people living near these two quarries were more affected than the quarry workers. Although the incidence of respiratory symptoms like cough and dyspnoea were higher among workers, the lung functions of residents were about 5 to 15 percent lower than workers. About 10 percent of radiographs of workers showed either vascular markings or nodular shadows.

Dahisar and BPH employees were examined in 1992 to look for the effect of CO gas on carboxyhemoglobin. The study included 211 male employees from Dahisar and 198 male employees from BPH. 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 at Dahisar and BPH check posts was 1.7 percent, and that of traffic police was 2.3 percent. 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 3.2 summarizes EPRC studies, 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. Table 3.2 shows that, compared to residents of Navy Nagar, the incidence of various respiratory symptoms is higher in communities near quarries, and among traffic police, employees of check posts, and the residential Chembur population near chemical factories. Furthermore, the prevalence of bronchitis and cardiac diseases was significantly higher among traffic police, compared to other localities. Similarly, people living near fertilizer factories or heavy traffic had a higher incidence of bronchitis and cardiac diseases compared to the control area, Navy Nagar.

Table 3.3 shows that lung function levels of Telecom (the control area of Chembur) subjects were higher than Chembur subjects who lived near the fertilizer and other chemical factories. There was no difference observed in lung functions of Parel subjects over the years. Overall, however, Parel residents had significantly worse lung function than that of Navy Nagar subjects (the Bombay control area). Peddar Road and King Circle subjects showed significant deterioration in lung function levels (by 200 to 500 milliliter) 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 3.3: Gender distribution of age and summary of lung function levels***

| | | | Age Groups (%) | | | | FVC | | FEV1 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Locality** | **Year** | **Sex** | **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 | 8.1 | 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** | | | **Age Groups (%)** | | | | **FVC** | | **FEV1** | |
| **Check Posts** | **Year** | **Sex** | **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 | 2.28±0.60 | 2.76±0.65 |

## MORTALITY

Health impacts are divided into mortality (excess deaths) and morbidity (excess illness). Mortality and morbidity numbers are derived from air quality data using dose-effect relationships. In principle, such relations are found by statistically comparing 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 U.S. cities and it is speculative to apply them to Bombay. However, until specific dose-effect relations for tropical conditions are derived, Ostro's relations are useful for preliminary estimates. Further, while it is clear that indoor air pollution such as that caused by cooking, can also damage health, this analysis was limited to outdoor air pollution.

*Mortality due to* $PM_{10}$. The relationship between air quality and mortality, where $P$ equals the number of people exposed to a specific concentration; $c$ equals the crude rate mortality (0.0076 in Bombay); and $PM_{10}$ stands for its annual average concentration (μg/m³), can be represented as follows:

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

The $PM_{10}$ benchmark is 41. Above this benchmark, mortality increases corresponding to the WHO guideline of 75 μg/m³ TSP ($PM_{10}$ /TSP ratio of 0.55) on a yearly basis (section 2.1). From this relation and the data presented in Chapter 2 (also Figure 4.1), it was estimated that the excess mortality due to $PM_{10}$ (and TSP) was about 2,765 cases and of an exposed population of 9.8 million.

## MORBIDITY

Inhaling particles can lead to chronic bronchitis, restricted activity days, respiratory diseases that require hospitalization, emergency room visits, bronchitis, asthma attacks and respiratory symptoms days. The estimated impact of $PM_{10}$ on health in Bombay is illustrated in Table 3.4.

***Table 3.4: Estimated impact of $PM_{10}$ air pollution on health in Bombay, 1991***

| Type of health impact | Number of cases (thousands) |
|---|---|
| Chronic bronchitis | 20 |
| Restricted activity days | 18,680 |
| Emergency room visits | 76 |
| Bronchitis in children | 190 |
| Asthma | 741 |
| Respiratory symptom days | 60 (millions) |
| Respiratory hospital admissions | 4 |

The following dose-effect relationships for impact estimation are described in the *URBAIR Guidebook*.

- 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 thus 6.12 x ([$PM_{10}$] - 41).
- Change in *restricted activity days* per person, per year, per μg/m³ $PM_{10}$ is estimated at 0.0575. If the WHO standard is used, the change is 0.0575 x ([$PM_{10}$] - 41).

- 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).
- 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).
- Change in the annual risk of *bronchitis* in children below 18 years is estimated at 0.00169 x ([$PM_{10}$] - 41). Approximately 35 percent of the total population is under 18 years of age. 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 percent of the population.
- *Respiratory symptoms days* per person, per year, are estimated at 0.183 x ([$PM_{10}$] - 41).

## VALUATION OF HEALTH IMPACTS

*Mortality.* Placing a monetary value on mortality is admittedly debatable. Many argue that such a valuation cannot be made ethically. By deleting mortality, however, we would seriously underestimate the total damage that air pollution causes.

A case (single instance) of mortality can be valued in two ways. The first is based on "willingness to pay," the other on "income potential." The "willingness to pay" approach is described in detail in the *URBAIR Guidebook*. In the United States 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 another, an approximation can be derived by correcting the U.S. figure by a factor of purchasing power parity in India, divided by the purchasing power in the United States. This factor is 970/21,900 = 0.044 (Dichanov, 1994). At an exchange rate of Rs 1 = US$0.032, this results in a value of Rs 4.25 million per statistical life in India.

The second approach is based on income lost income due to mortality. The value of a statistical life (VSL) 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 VSL formula is:

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

In the formula, w = average annual income, and d = the discount rate (Shin et al., 1992). In this approach, 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) and assume 200 working days in a year, using d = 5 percent as the discount rate, the value of a statistical life is VSL = Rs 250,000. 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.* A summary of the valuation of illness is presented in Table 3.5. It presents estimated health cost figures and the evolving total costs, by combining the figures for mortality and illness.

***Table 3.5: 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 | 1,000 | 741 |
| Respiratory symptoms day | 20 | 1,189 |
| Hospital admission | 9,646 | 38 |
| Chronic Bronchitis | 161,000 | 3,201 |
| Total Cost | | 18,219 |

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

*Emergency room visit.* Private hospitals charge Rs 100 to 150 for an emergency room visit. This includes the doctor's bill, and medication. To this is added the cost of the loss of one work day (Rs 60), cost of transport (2 x Rs 50), resulting in a total of Rs 260 to 310.

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

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, and is valued at respiratory symptoms day (Rs 20). Ostro's figure of 2 days of a parent's restricted activity, valued at Rs 28 per day, was used. The total loss is calculated as follows: 13.2 x 20 + 2 x 28 = Rs 320.

A severe *asthma* attack lasts on average 9.1 days. The daily hospital fee in private hospitals is about Rs 1,000; to this we add 9.1 lost working days. The total for a severe attack is thus 9.1 x (1,060) = Rs 9,646. For a milder attack, the same figure as for an emergency room visit (Rs 260 to 310) could be used. For still milder attacks only the medication costs apply; aerosols and tablets cost approximately Rs 200. Depending on the severity, the cost of an asthma attack can range from Rs 200 to Rs 9,646. Considering that milder attacks are more frequent, the average valuation is estimated at Rs 1,000 per attack.

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

*Chronic bronchitis* becomes more serious as people age. Elderly people and younger smokers are especially vulnerable to chronic bronchitis. The average age at which people become chronically ill with bronchitis is 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. Work days lost are valued at Rs 60 per day, resulting in Rs 46,000 if discounted at 5 percent. To this we add 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 1,000 per day. Discounted at 5 percent, total hospital costs amount to Rs 100,000. Finally, yearly expenditure on medication is about Rs 1,000—totaling 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.

## CONCLUSIONS

Air pollution damages human health, vegetation and crops, buildings and monuments, ecosystems and tourism. Assessing these impacts is hampered by incomplete and missing data. Nevertheless, the mortality and morbidity resulting from excess concentrations of $PM_{10}$ have been estimated using dose-effect relationships derived for U.S. cities. The lack of data for airborne lead prevented an estimate of its health impact, which includes increased mortality, IQ point loss in children, hypertension, and coronary heart disease.

It is difficult to estimate the monetary value of a lost life. The value of a statistical life is Rs 250,000; a figure estimated by the human capital approach (earnings lost due to premature death) is used in this analysis. Costs of morbidity (illness) are relatively more reliable. They consist of foregone wages, and medical treatment costs. This valuation of damage to human health tends to underestimate the suffering due to illness or premature death.

Table 3.6 provides preliminary information for calculating the benefits of measures to reduce emissions. Benefits of the emission reduction are estimated by potential health costs avoided by the absolute emission reduction. The table shows also "marginal" benefits from addressing each category of emissions. It appears that addressing emissions from industry is the most effective in terms of benefits per ton of emission reduced. This relates to the high estimated $PM_{10}$

***Table 3.6: Reduction of emissions and related benefits. Situation 1991, 9.8 million inhabitants in Bombay modeling area***

| Source category | Emissions *(tons)* | Mortality *(cases)* | Respiratory symptom days *(million)* | Health costs *(Rs million)* | "Marginal" benefits *(Rs million per ton)* |
|---|---|---|---|---|---|
| All source reference | | 2,765 | 60 | 6,467 | |
| Industry | 706 | | | | |
| Domestic | 6,443 | | | | |
| Traffic | 6,286 | | | | |
| Reduction of industry sources | | Avoided | Avoided | Avoided | Avoided |
| 25% | 176.5 | 64 | 1.4 | 151 | 0.85 |
| 50% | 353.0 | 121 | 2.6 | 284 | |
| Reduction of domestic sources | | | | | |
| 25% | 1610.75 | 466 | 10 | 1091 | 0.34 |
| 50% | 3221.50 | 971 | 21 | 2271 | |
| Reduction of traffic sources | | | | | |
| 25% | 1571.50 | 216 | 4.6 | 505 | 0.67 |
| 50% | 3143.0 | 421 | 9 | 985 | |

**Note:** Mortality valued according to the lost salary method (see Table 3.5).

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, domestic emissions followed by traffic emissions should be targeted first.

# 4. ABATEMENT MEASURES: EFFECTIVENESS AND COSTS

## INTRODUCTION

This chapter outlines measures for reducing air pollution in Bombay, and for drafting an action plan that would translate these measures into practice. Information is organized by pollution source category: traffic, large point source power plants, fuel combustion other than in power plants, industrial/commercial sources, and refuse burning and domestic emissions. For the main source categories, characteristics of appropriate measures are described:

- *effectiveness* in terms of both emission reduction and reduced impacts in the year 1990 (using Table 3.6). On average, 1.35 excess deaths are avoided by reducing 10 tons of $PM_{10}$. The reference data include: mortality (2,765 due to $PM_{10}$), number of respiratory symptom days (60 million in 1990), and total health costs (Rs6.5 billion);
- *costs* (mostly annual costs at the societal level);
- *benefits* estimated by interpolating figures from the Table 3.6;
- *policy instruments* that might be used to implement measures; and
- *term for emissions reduction*: short-term (less than 2 years), mid-term (2–5 years), or long term (more than 5 years).

Identifying measures to address traffic emission, for example, is straightforward because the major causes of air pollution are commonly known. Policy measures that are especially cost efficient include: an inspection and maintenance scheme, and the introduction of unleaded gasoline and 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; increased consumption of natural gas for automotive and stationary use; and improving the public transportation system.

A similar list of measures addressing pollution sources, other than traffic, was not possible due to lack of information. In particular, refuse burning and cooking with wood, appear to be more important to $PM_{10}$ exposure in Bombay than traffic sources (Table 3.4). The list of measures is derived from the information presented by the local URBAIR working group, the *URBAIR Guidebook*, and from earlier plans (see Chapters 3 and 6) addressing problems in Bombay.

## TRAFFIC

This section describes the effectiveness of abatement measures for reducing emissions and, to the extent possible, the benefits of 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.

### *Introducing unleaded gasoline*

Unleaded gasoline addresses the ambient lead problem and is a prerequisite for introducing strict emission standards, and for the use of an exhaust catalyst (see summary in Table 4.1). 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 liter. The present level is 0.18 to 0.19 grams per liter for gasoline supplied from Bombay refineries, about 70 percent of the total supply. The remainder has a lead content of 0.56 to 0.80 grams per liter.

***Table 4.1: Introducing low lead and unleaded fuel***

| | |
|---|---|
| Effectiveness: | Depending on rate of introduction. |
| Costs: | Costs at refinery Rs 0.7 to 1 per liter unleaded fuel (corresponding with Rs 250–360 million—1990. |
| Benefits: | Unknown in Bombay;<br>Unleaded fuel required when catalytic-exhaust gas control is introduced;<br>Need to control of benzene and aroma tics, to not offset benefits. |
| Instruments/institutions: | |
| Term: | Two to five years. |
| Target groups: | Oil and gasoline industry. |

**Note**: Sales of gasoline in 1990 were 362 millions liters (Table 1.9), corresponding with Rs. 250–360 million.

Assuming simultaneous introduction of vehicles with catalytic converters, unleaded gasoline would require a 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 lubrication required for their valve seats, or because of its higher RON-number. Unleaded gasoline is widely available in many countries, so technical obstacles should not be a major constraint.

Removing the lead compound in gasoline may require reformulation in order to maintain 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 due to 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 the amount of benzene and total aromatics in gasoline is necessary. A decision on the scale of the limit requires data on benzene as it relates to current air quality (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, which may be imported or produced in India.

*Effectiveness*. Reduction in emissions is proportionate to the eventual market shares of unleaded and low-lead gasoline and, in case of low-lead gasoline, also to the lead content.

*Costs of the measure*. Reduced-lead gasoline must be reformulated in order to retain the RON number. The lead is replaced by oxygenated compounds; MTBE is a preferred substitute. These changes increase production costs by Rs 0.7–Rs 1 per liter of 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 the maximum allowed lead content of gasoline is the first step. In countries where gasoline is taxed, unleaded gasoline may be taxed less and leaded fuel taxed more so that the fiscal authority's net yield does not change. The oil industry and gasoline distribution firms will have to produce unleaded gasoline. The oil industry is the main actor in the process (AIAM, 1994).

*Term.* Since it is relatively simple to produce, unleaded fuel can be commonly available within 5 years.

## *Improving diesel quality*

Diesel's ignition and combustion properties are important parameters for $PM_{10}$ emissions from diesel engines (Hutcheson and van Paassen, 1990, Tharby et al, 1992). Its volatility (boiling range), viscosity, and cetane number (an indicator of its ignition properties) determine these properties and, consequently, $PM_{10}$ emissions. A minimum cetane number of 42 is required in Bombay for automotive purposes. In the United States, Western Europe, and Japan the corresponding quality varies from 48 to 50. Another factor is the presence of detergents and dispersants in diesel fuels. These additives keep injection systems clean and have discernible efficiency effects (Parkes, 1988). The Indian automobile manufacturing industry advocates an improvement in fuel quality (AIAM, 1994). See summary in Table 4.2.

*Table 4.2: Improving diesel fuel quality*

| | |
|---|---|
| Effectiveness: | 250 tons $PM_{10}$ (1990). |
| Costs: | Rs 0.3 per liter (about Rs 300 million annually). |
| Benefits: | Less mortality, 35; less RSD, 0.75 million; avoided health costs Rs 80 million; reduction of $SO_2$ emissions. |
| Instruments/institution: | Energy authorities. |
| Terms: | Two–five years. |
| Target groups: | Petroleum industry. |

*Effectiveness.* It is assumed that an improvement in fuel properties, as expressed by an increase in the cetane number[2] and the addition of detergents, results in a 10 percent or about 230 ton reduction (1990) in $PM_{10}$ emissions (AIAM, 1994, Mehta et al, 1993). A reduction in the sulfur content of fuel would not result in a proportional decline in $SO_2$ emissions, it would also lead to a fall in $PM_{10}$ emissions. This is because a part of the $PM_{10}$ particle consists of sulfates.

*Costs.* The cost 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 etc.), and Government. The latter eventually determines the at-the-pump-price for fuels.

The cost of reducing the sulfur content of diesel fuel stems from the extensive desulfurization that must occur at the refinery. The costs for a reduction from 0.7 percent to 0.2 percent sulfur are about Rs 0.3 per liter. Combustion of sulfur in diesel fuel also leads to the formation of corrosive sulfuric acid. Therefore, reducing the sulfur content also lowers the costs of vehicle maintenance and repair.

*Policy instruments and target groups.* Improving the quality of diesel fuel should be a part of India's energy policy. The oil industry should take the necessary steps to expand its capacity for producing better quality diesel fuel.

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

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

Bombay traffic has a large share of motorcycles and auto-rickshaws, both equipped with two-stroke mixed-lubrication engines. These vehicles cause about a third (2,700 tons) of $PM_{10}$ emissions from traffic exhaust. A substantial fraction of the particles emitted by these vehicles are micro-droplets of unburned lubrication oil. According to Shell Oil Company (private communication, 1993) the lubricating oil used in most Southeast Asian countries is cheap and has poor combustion qualities. See summary in Table 4.3.

***Table 4.3: Low-smoke lubricating oil for two-stroke, mixed-lubrication engines***

| | |
|---|---|
| Effectiveness: | 450 tons $PM_{10}$ (1990). |
| Costs: | Rs 30 million. |
| Benefits: | Less mortality,65; less RSD, 1.5 million; avoided health costs, Rs 150 million. |
| Instruments/institution: | |
| Term: | Two 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.

*Effectiveness.* It can be assumed that a better-quality lubrication oil will decrease emissions by half (1,350 tons reduction).

*Costs.* Annually, 1,000 cubic tons of poor quality lubricating oil is consumed. Introducing better oil is estimated to double the expenditure on lubricating oil. A rough estimate of the total costs of low-smoke oil is Rs 30 million.

*Policy instruments and target groups.* A standard should be set for the quality of lubricating oil. The oil industry and lubricating oil importers are the main target groups.

## *Implementation of an inspection and maintenance scheme*

*Effectiveness.* Maladjusted fuel injection systems or carburetors, and worn-out motor parts present a threat to traffic safety, increase fuel consumption and thus costs, and lead to traffic emissions. The semi-annual inspection and maintenance of vehicles will probably result in a substantial reduction of $PM_{10}$, 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.

***Table 4.4: Implementation of an inspection and maintenance scheme***

| | |
|---|---|
| Effectiveness: | 35% reduction, 800 tons $PM_{10}$. |
| Costs: | Rs 150–300 million. Maintenance costs are expected to be offset by improved fuel efficiency. |
| Benefits: | Less mortality, 110; less 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). |
| Term: | Two to five years. |
| Target groups: | The scheme could be carried out by the private sector. |

The proposed inspection and maintenance scheme, would lead to 35 percent reduction in tail pipe emissions of $PM_{10}$, VOC, and CO. This is in line with an estimate by the Association of Indian Automobile Manufacturers (AIAM, 1994) and the World Bank estimate for Manila (Mehta, 1993). See summary in Table 4.4.

*Costs of an inspection and maintenance scheme.* The present capacity for vehicle-emission testing is insufficient. In order to circumvent capacity problems in government agencies, testing can be done by private firms[4]. Such a scheme, involving all vehicles, may have a total cost of approximately US$5–10 million or Rs 150–300 million for vehicle owners (US$2–5 or Rs 60–

[4] Such a scheme might include the following actions:
- private firms would be licensed to carry out inspections.
- authorities would spot-check the firms to oversee inspections.
- vehicles that pass the test would get a sticker valid for a specific period, and drivers would show a test report on request.
- vehicles would be spot-checked.

150 per test[5], 1.5 million vehicles, environmental inspection part of roadworthiness test). Better engine performance and the resulting reduction in fuel costs would offset the maintenance cost.

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

## *Address the problem of excessively polluting vehicles*

Almost a quarter of all vehicles are estimated to emit excessive exhaust. These vehicles are badly maintained, use worn-out engines, or have maladjusted engine controls. A program focusing on these vehicles would result in an emissions reduction equaling 400 tons of $PM_{10}$ (15 percent reduction in 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 would enhance the feasibility of such a measure. See summary in Table 4.5.

***Table 4.5: Address excessively polluting vehicles***

| | |
|---|---|
| Effectiveness: | 400 tons $PM_{10}$. |
| Costs: | |
| Benefits: | Less mortality, 50; less RSD 1.2 million; avoided health costs, Rs 125 million. |
| Instrument/institution: | Motor Vehicles Act (1988) and Environment Protection Act (1986), second amendment Rule (1990), Ministry of Surface Transport and State Transport Department. |
| Term: | |
| Target groups: | Traffic authorities/Vehicle owners. |

## *Fuel switching in the transportation sector*

Using gaseous fuels such as LPG (Liquid Petroleum Gas) and CNG (Compressed Natural Gas) is an option for addressing air pollution from $PM_{10}$ emissions from vehicles. Liquid LPG is widely used in areas where supply is abundant and fuel taxes favor its use. The use of LPG or CNG requires adapting the engine and its controls. Such a switch will only pay off when LPG or CNG prices are lower than those of gasoline or diesel. CNG has already been introduced as an automotive fuel in Bombay. The lack of filling stations is a major impediment. See summary in Table 4.6.

***Table 4.6: Introduction of CNG to replace 50% of gasoline consumption (1990 situation) in passenger cars***

| | |
|---|---|
| Effectiveness: | 200 tons $PM_{10}$. |
| Costs: | Costs for vehicle owner depends on the price differential between gasoline and CNG (natural gas is cheaper). |
| Benefits: | Less mortality, 25; less RSD, 0.6 million; avoided health costs, 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. |

[5] Order of magnitude. Cost in Manila estimated at US$3. Cost in the Netherlands (including roadworthiness) is US$30.

LPG can be used as a clean alternative to both gasoline and diesel. Its advantage over CNG is that it can be more easily transported in tanks, and its energy density (energy per volume of fuel) is higher, resulting in better mileage. Its market price is a disadvantage.

*Effectiveness.* CNG is used as a fuel substitute in four-stroke gasoline cars. It can effectively reduce $PM_{10}$ emissions by 90 percent. If all gasoline cars had been modified to use CNG in 1990, $PM_{10}$ emissions would have been less by 400 tons.

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

*Policy instruments and target groups.* The main bottleneck for introducing CNG and LPG seems to be the lack of filling stations, which is in turn relates to a limited gas distribution system. Connecting a filling station to the gas distribution grid requires large investments. A scheme for subsidies or cheap loans might facilitate this. The viability of the scheme will increase as use of natural gas in other sectors increases, thus justifying extending the distribution grid. The country's energy policy will have a bearing on this measure.

## *Adoption of clean vehicle emission standards*

Many countries have adopted standards for permissible emissions from vehicles. These standards require that vehicles with four-stroke gasoline engines 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 motorcycle emissions, requiring two-stroke engine-powered vehicles to be equipped with open-loop catalysts. Such devices control VOC, $PM_{10}$ emissions, and CO, but not $NO_x$. See summary in Tables 4.7 and 4.8.

***Table 4.7: Adoption of clean vehicle standards. Gasoline passenger cars and vans***

| | |
|---|---|
| Effectiveness: | 80% effectiveness per (gasoline) vehicle (for 1990 in total 400 tons). |
| Costs: | Rs 3,000 per vehicle (including costs of unleaded fuel). In total, Rs 750 millions annually. |
| Benefits: | Less mortality, 50; less RSD, 1.2 million; avoided health costs, Rs 125 million (hypothetical situation in 1990). Reductions of emissions of lead, CO, $NO_X$ and VOC are the justification for introducing these systems, in other countries. |
| Instruments/institution: | |
| Term: | Two to 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. |

Diesel-powered vehicles are also subject to regulations. The emission requirements are met by adjusting the motor design. Tailpipe emission treatment may also be used, and existing buses retrofitted with new equipment. If the last method is employed, the diesel must be of a much better quality than is presently used in Bombay (sulfur content below 0.02 percent). This type of standard is now being introduced in some parts of the world.

The catalyst technology uses unleaded gasoline, the sulfur content of which should be less than 500 PPM. Therefore, introducing such standards requires infrastructure for producing and distributing unleaded gasoline[6].

***Table 4.8: Adoption of clean vehicle standards for motorcycles and tricycles***

| | |
|---|---|
| Effectiveness: | 80% effectiveness per vehicle (for 1990 in total 750 tons) |
| Costs: | Rs 230 per vehicle (including costs of unleaded fuel). In total, Rs 600 million |
| Benefits: | Less mortality, 100: less RSD 2.4 million; avoided health costs, Rs 250 million (hypothetical situation in 1990). Reductions of emissions of lead, CO, $NO_x$ and VOC are the main justification for introduction of these systems in other countries. |
| Instruments/institution: | |
| Term: | Two to five years. The result of such measures is the renewal of the fleet. |
| Target groups: | Petroleum industry, vehicle importers, vehicle manufacturers. |

**Note:** Standards include two-stroke engines, either requiring catalytic converters or four-stroke engines.

*Effectiveness.* Catalytic devices for treating exhaust gases require the use of unleaded gasoline. Thus such devices not only result in cleaner emissions but also in a reduction in lead pollution. With closed-loop catalytic treatment of exhaust gases (three-way catalysts) from gasoline-engine vehicles, emissions of $NO_x$, CO and VOC are reduced by about 85 percent. In addition lead emissions are reduced by 100 percent, as unleaded fuel is a prerequisite for this type of standards.

Open-loop catalytic treatment of exhaust gases from two-stroke motorcycles reduces CO, VOC, and $PM_{10}$ (oil mist) emissions, by as much as 90 percent. Successful use of these catalysts also requires unleaded gasoline. An alternative is using well designed and adequately maintained four-stroke engines. A similar emission reduction can be obtained by following this approach.

*Costs.* The cost of closed-loop catalytic treatment of exhaust gases stems from the increased purchasing costs of vehicles. In the United States, this increase averages about US$400, ranging from US$300 to $500 (Wang et al, 1993). While catalytic devices have minor adverse effect on fuel economy, this cost is compensated by an increase in the life-time of replacement parts such as the exhaust system. The total annual cost per automobile is estimated at US$100 (US$50 depreciation per car and US$50 extra fuel costs) or Rs 3,000.

The cost of open-loop catalytic treatment of exhaust gases of two-stroke motor cycles is related to increased equipment costs. Benefits include lower fuel cost due to improved engine operation. Taiwan adopted standards that require the use of open-loop catalytic devices which result in a US$60 to US$80 cost increase. This is offset by fuel savings (Binnie & Partners, 1992). Total annual cost is estimated at US$75 or Rs 230 per vehicle (depreciation plus increased fuel costs). It is assumed that the cost of motorcycles is similar to the cost of four-stroke engines.

The higher price of unleaded gasoline, due to increased production costs and adjustments to the logistic system (modification of pump nozzles) should also be included here. A very rough estimate of the cost is Rs 3,000 annually, per car (Rs 1,500 depreciation of control system, plus a Rs 1,500 increase in fuel costs, depending on subsidies and levies on gasoline).

[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.

Due to methodological problems it is not possible to calculate the total cost of introducing this standard in Bombay. However, as explained above, costs can be estimated on a vehicle-by-vehicle basis.

*Policy instruments and target groups.* The groups involved in introducing "clean" vehicles are:

- petroleum industry, and gasoline retailers (clean cars require unleaded gasoline);
- car and motorcycle industry;
- repair shops/garages (proper skills required 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 expensive to equip existing vehicles with the necessary devices. Practically all vehicles currently sold on the world market are designed to be equipped with catalytic converters. This will affect the replacement rate of existing vehicles.

## *Other options*

The United States and the European Union are discussing ways to tighten standards by:

- improving current abatement techniques;
- improving inspection and maintenance, since a small number of maladjusted and worn-out cars cause disproportionately large emissions; and
- enforcing the use of "zero-pollution" vehicles, especially electric vehicles, in downtown areas.

Diesel engines are a bottleneck in decreasing automotive air pollution. This is because treating exhaust from diesel engines is not easy.

## *Resuspension emission*

Resuspension of road dust is clearly a high-priority issue. Unfortunately, there is a lack of quantitative information about control measures appropriate to Bombay. Further analyses should give priority to measures dealing with resuspension. In general, all methods for reducing entrainment should be evaluated and applied. Controlling resuspension of road dust may be the most cost effective way of reducing TSP exposure.

## *Improving traffic management*

Traffic management includes a variety of measures including: traffic control by policemen or traffic lights, one-way streets, new roads, and road-pricing systems. One of the major aims of traffic management is to solve the problem of congestion. Curb-side traffic management may improve air quality[7], but it may also increase emissions because it usually results in increased use of the transport system. In terms of exposure, traffic management leads to an improvement in the

[7] Accelerating vehicles, a dominant feature of congested traffic, emit disproportionaly large amounts of pollutants.

downtown air quality, and a reduction in road exposure. In terms of total exposure, however, the net result may be small. 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.

### *Construction and improvement of mass-transit systems*

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

Assessing the costs and effectiveness of measures to improve the Bombay public transport system involves:

- describing a future system appropriate to Bombay;
- appraising the performance of a such system;
- assessing the construction costs;
- specifying the baseline (future situation without such system);
- avoiding emissions;
- calculating 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 from an air pollution point of view alone. However, mass-transit systems have a variety of other benefits, including a reduction in congestion.

## LARGE POINT SOURCES

*Cleaner fuels in existing power plants.* Under special weather conditions, power plants in Bombay may have a significant impact on concentrations. On a yearly average basis they do not contribute much to the air pollution problem. The use of cleaner fuel (low sulfur oil or coal) or natural gas might be contemplated, but the benefits relate to $SO_2$ or $CO_2$ emissions that are regional and global.

*Other point sources.* Furnace oil (residual fuel oil or bunker fuel) with a sulfur content of about 4 percent (by weight) contributes about 75 percent of emissions from large point sources. The obvious measure is to reduce the sulfur content. The order of magnitude of the costs to use 2 percent, instead of 4 percent sulfur fuel, is about Rs 750 million (fuel consumption 200,000 tons annually). As these point sources contribute little to ambient $PM_{10}$, the estimated benefits are small.

## Distributed Industrial/Commercial Sources

The combustion of furnace oil by small industries is the main source of $PM_{10}$ emissions (source category domestic). This emission is estimated at 300 tons (see Chapter 2). Halving these emissions by using 2 percent sulfur oil would cost approximately Rs 450 million. It would, however, lead to a decline in excess mortality by 22, 0.5 million fewer RSD, and Rs 50 million less in health damage (derived from Table 4.6, reduction of domestic and distributed sources).

## Refuse Burning and Domestic Emissions

Refuse burning and domestic emissions, together with resuspension, are the main sources of air pollution in Bombay. Refuse burning can be avoided by extending the public refuse collection system. This may require an increase in municipal taxes, or overall management. Domestic emissions are caused by cooking on traditional stoves or "chullas." These stoves are a major cause of indoor air pollution and pose a special threat to the health of women and children. In addition, they are energy inefficient, have an adverse impact on the overall air quality in the city.

## Conclusions

This chapter describes measures for improving Bombay's air quality, their effectiveness, costs, benefits, implementation, and the institutions and authorities that would be responsible for each of the measures. A comparison of the costs and benefits leads to the prioritization of the measures.

Identifying measures to address traffic emissions is straightforward because the major causes of air pollution are obvious. From a cost-benefit point of view the measures that should receive priority are:

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

Other measures for which it is difficult to tabulate cost-benefit ratios because of lack of data or methodological problems are:

- improving automotive diesel fuel quality;
- clean car standards;
- increased use of natural gas for automotive and other use; and
- improving the public transport system.

Although other sources of pollution such as domestic cooking with wood, appear to be very important, measures to deal with these are not reported due to a lack of data. Resuspension of road dust constitutes a large part of TSP and controlling it would probably be one of the most cost effective ways of reducing ambient TSP exposure.

# 5. ACTION PLAN

The following action plan is based on the cost-benefit analysis of various measures that reduce air pollution and the damages that result from it. This plan is based on available data, the shortcomings of which are identified throughout the text. Improving the database is necessary in order to extend the action plan to include additional measures.[8]

The "actions" fall into two categories:

- Technical and other measures that will reduce exposure and damage.
- Improving 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 (less than 5 years), medium (5 to 10 years) or long-term (more than 10 years).

## ACTIONS TO IMPROVE GREATER BOMBAY AIR QUALITY, AND ITS MANAGEMENT

### *Actions to improve air quality*

Actions and measures have been formulated and proposed by the Bombay URBAIR working groups (Table 5.1), and consultants.

Technical measures, to be introduced in the short term, are prioritized in Table 5.2. For most of these measures, the estimated benefits as well as the estimated costs are substantial. Clean vehicle standards for cars and vans are the exception. Lowering the lead content of gasoline is an important measure in

***Table 5.1: Measures proposed by the URBAIR working group***

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

8 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.

***Table 5.2: Action plan of abatement measures, based on cost-benefit analysis***

| Abatement measure | Avoided emissions (tons $PM_{10}$/yr) | Mortality reduction | Reduced RSD (million days) | Annual health benefits (million Rs ) | Annual costs (million Rs ) | Time frame: Introduction of measure[a] | Time frame: Effect of measure |
|---|---|---|---|---|---|---|---|
| **Vehicles** | | | | | | | |
| Unleaded gasoline: | NQ | NQ | NQ | NQ | 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 | NQ | 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 | NQ | Immediate | 5–10 years |
| **Fuel combustion** | | | | | | | |
| Cleaner fuel oil (FO to 2% S): | 150 | 22 | 0.5 | 50 | 450 | Immediate | 2–5 years |

a: Time frame for starting the work necessary to introduce measure.
NQ: Not quantified.

itself as it leads to a reduction in lead concentrations. In addition it is also a prerequisite for clean vehicle standards.

The success of these measures rests with enforcement. It is important to ensure that necessary technical improvements and adjustments such as workshop capacity and capability for adjusting engines, and the availability of reasonably priced spare parts can be assured.

The action plan incorporates the following measures (as discussed in Chapter 4):

- Introducing unleaded gasoline;
- Improving diesel quality;
- Introducing low-smoke lubrication oil for 2-stroke, mixed lubrication engines;
- Implementing an inspection/maintenance scheme;
- Addressing excessively polluting vehicles;
- Fuel switching in the transportation sector, gasoline to LPG or CNG in vehicles;
- Adopting clean vehicle emission standard;
- Improving diesel quality;
- Improving abatement and other propulsion techniques;
- Improving traffic management;
- Constructing, and improving mass-transit systems; and
- Using cleaner fuel oil:

Table 5.3 lists abatement measures for which cost-benefit analysis has not been performed. These could also be introduced in the short- to medium-term, and would benefit air quality.

*Table 5.3: 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<br>• remove obstacles<br>• 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<br>• improve junctions/stations<br>• make integrated plan | Short term | Medium term |
| Develop parking policy: | • restrictions in central area | Short term | Short term |
| | • parking near mass transit terminals | | Short term |
| | • car-pooling | | Short term |

Table 5.4 lists actions to improve the Air Quality Management System. These apply to:

- air quality assessment;
- assessment of damage and costs;
- the institutional and regulatory framework; and
- building social awareness.

*Table 5.4: Actions to improve the air quality assessment of Greater Bombay*

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

The list of measures proposed by the Bombay URBAIR working group is presented in Table 5.5. Table 5.6 lists additional measures suggested by consultants that are not in the Bombay Working Groups' action plan (Table 5.5). 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. The MCGB, MPCB and the Transport Commissioner have presented lists of additional action items. These are presented as Annexes to Table 5.5.

***Table 5.5: Categorized action plan for Greater Bombay***

| Issue | Action Required | Lead Agency | Cost Estimate (Rs Lakhs) | Time-frame | Priority Estimate |
|---|---|---|---|---|---|
| **VEHICULAR POLLUTION** | | | | | |
| 1. Exhaust Monitoring: | Stricter enforcement of existing legal provisions.<br>Compliance to be checked:<br>a) Four wheelers: at annual tax payment;<br>b) Three wheelers: vigilance monitoring;<br>c) Two wheelers: awareness campaign.<br>At all transactions, e.g. Transfer/Hypothecation tax payment, etc. | Transport Dept. | 342.81 | 1 year | |
| 2. Expiration of PUC Certificate | Month of expiration 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 vigilance to prevent sale of adulterated fuels. Set up a cell to receive complaints and take prompt action. Make public the names/ addresses of retail outlets found guilty. | Oil Cos.<br>BIS | | | |
| 4. High Polluting Vehicles | Identify high polluting vehicles (especially commercial transport vehicles such as trucks/tempos, etc.) and levy stiff penalties. 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 | Petrol:<br>(a) Reduce content of lead in petrol to 0.15g/lt;<br>(b) Provide lead free petrol (0.915g/lt.);<br>(c) Use of catalytic converters to be made compulsory for all vehicles;<br>(d) Reduce sulfur content to 0.15% as per US/European standards. | Oil Cos.<br>BIS | | | |
| 6. Use of CNG | Increase use in taxis/cars. Provide more filling stations. Increase awareness about its use. | GAIL | | | |
| 7. Traffic Flow | (a) Improve traffic speed by ensuring proper repairs/ maintenance of roads. Ensure better utilization of existing road network by clearing roads and footpaths. Ensure that utility companies carryout proper resurfacing of roads whenever any digging is carried out.<br>(b) Provide additional sets of signals at elevated locations to ensure free flow of traffic. | MCGB<br><br>Traffic police | | | |
| 8. Pedestrian Flow | Provide and maintain footpaths, remove hawkers and other encroachments. | | | | |

***Table 5.5: Categorized action plan for Greater Bombay***

| Issue | Action Required | Lead Agency | Cost Estimate (Rs Lakhs) | Time-frame | Priority Estimate |
|---|---|---|---|---|---|
| 9. Inspection & Maintenance | Lower time span for fitness certification of vehicles to 10 years from the present limit of 15 years.<br>In addition to existing requirement, specify engine performance criteria and establish standard practices for fitness testing.<br>Appoint/nominate private garages for fitness determination as authorized agencies, or initiate procedure for approval of garages to ensure quality and explore possibility of private agencies checking PUC Certificates. | Transport | 91.0 | 1 yr. | |
| 10. Mass Transit | Improve present Mass Transit facilities. Provide additional mode of mass transit that will effectively reduce vehicular emissions. | BMRDA/MCGB/ Railways | | | |
| **MONITORING** | | | | | |
| 11. Air Quality Monitoring | (a) Make daily monitoring data publicly available | | | | |
| | (b) Rationalize 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 CPCB standards | MCGB | | | |
| | (c) Optimize sampling station height and identify locations for extended monitoring through rapid surveys. Ensure better coordination among monitoring agencies and optimize resource use through sharing monitoring locations. Monitor additional parameters: HC & Pb at 2 locations. Locations to be determined through rapid surveys. Monitoring of $PM_{10}$ and CO should be carried out regularly. | MCGB | | | |
| | (d) Standardize 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. | MCGB | | | |
| 12. Meteorological Monitoring | Establish meteorological monitoring stations with automatic recording facility in the city to provide data for air quality modeling 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 Environ. Dept. | | | |

***Table 5.5: Categorized action plan for Greater Bombay***

| Issue | Action Required | Lead Agency | Cost Estimate (Rs Lakhs) | Time-frame | Priority Estimate |
|---|---|---|---|---|---|
| 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 standardize maintenance of records in hospitals. Make arrangements to pool and analyze the gathered data. | KEM Hospital | | | |
| | Evaluate indoor air quality by rapid surveys to estimate health damage. | MCGB MPCB | 5.0 | 14 mths | medium priority |
| **INDUSTRIAL POLLUTION** | | | | | |
| 14. Reporting format | Standardize formats for industrial emission data. Standardize industry specific monitoring/analysis methods as per international procedures. Introduce compulsory quality audit. | MPCB | | | |
| 15. Emission factors | Create database of fugitive/process emissions through rapid surveys of targeted industries to establish industry specific emission factors. Change to cleaner fuels. | MPCB MCGB CPCB | | | |
| 16. Stone crushers | Take punitive action against units that violate environmental laws through better coordination among agencies. | MPCB | | | |
| 17. Waste burning | Disallow industrial solid, hazardous waste burning by road sides or close to factory premises. | | | | |
| **COMMUNITY SOURCES** | | | | | |
| 18. 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 | | | |
| 19. Wood burning | Increase use of electricity in crematoria. Invite participation of social organizations 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 bakeries and other commercial establishments to switch to cleaner fuels. Provide incentives to so the same. | MCGB/ BMRDA | | | |
| 20. Dust resuspension | Establish contribution of road dust resuspension, road repair activity and construction debris in air pollution problem. Remove accumulated dirt from road side. | MPCB/ MCGB | | | |

*Table 5.5: Categorized action plan for Greater Bombay*

| Issue | Action Required | Lead Agency | Cost Estimate (Rs Lakhs) | Time-frame | Priority Estimate |
|---|---|---|---|---|---|
| 21. Decongestion | Decongest business areas through entry Levy a toll tax/high parking fees, and area licensing. An entry tax should be high enough to discourage use of private vehicles in busy districts. | MCGB/ BMRDA | | | |
| 22. Emission inventory | Complete and upgrade emission inventory for Bombay for $SO_2$, $NO_X$, TSP, HC, $PM_{10}$, etc. | MPCB/ MCGB | | | |
| 23. Energy Demand | Identify energy demand and consumption patterns for domestic (slum and non-slum) and commercial sectors. | MPCB/ MCGB | | | |
| 24. Organization | Designate coordinating agency for AQMS. Such an agency should coordinate the operations of concerned Govt./Semi-govt. agencies; should oversee this action plan's progress and implementation. | MPCB/ MCGB/ BMRDA/ Transport Dept. | | | |
| Signatures of concerned major agencies: | Maharashtra Pollution Control Board (MPCB)<br>Municipal Corporation of Greater Bombay (MCGB)<br>Environment Department<br>Bombay Metropolitan Region Development Authority (BMRDA)<br>Transport Department<br>Traffic Police<br>Bhaba Atomic Research Centre | | | | |

*Table 5.5: Annex I*

| Action | Timeframe Estimate (months) | Concerned Departments |
|---|---|---|
| 1. Improve traffic speed by ensuring proper repairs, and maintenance of roads, and better utilization of available roads through removal of vehicles that have broken down. | 6–12 | Traffic & Roads |
| 2. Decongest business areas through entry tax/cordon pricing and area licensing. Such entry tax should be high enough to discourage use of private vehicles in busy districts. | 6–12 | Traffic & Roads |
| 3. Reduce and/or relocate some stations to provide increased frequency of monitoring and extended monitoring network to provide better coverage of impacted areas. | 6–12 | Dy. C.E. (C) E.S.P. |
| 4. Monitor additional parameters viz. $PM_{10}$/CO Pb/$0_3$, optimize sampling station height and identify locations for extended monitoring through rapid surveys. Ensure better coordination among monitoring agencies and optimize resource use through sharing monitoring locations. | 6–12 | Dy. C.E. (C) E.S.P. |
| 5. Establish meteorological stations with automatic recording facility for air quality modeling data at four locations (Chembur, Central Bombay, Western suburb, and Central suburb) as recommended by expert sub-committee. Procure one SODAR for conducting low-level inversion studies. | 6–12 | Dy. C.E. (C) E.S.P. |

*Table 5.5: Annex I*

| Action | Timeframe Estimate (months) | Concerned Departments |
|---|---|---|
| 6. Standardize 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 | Dy. C.E. (C) E.S.P. |
| 7. Strengthen present health monitoring carried out by KEM Hospital. Provide necessary equipment to other Bombay hospitals for monitoring health effects of air pollution. Improve and standardize maintenance of hospital records. Make arrangements to pool and analyze the data. | 6–12 | Dy. C.E. (C) E.S.P. |
| 8. Standardize reporting formats for industrial emission data. Standardize industry specific monitoring/analysis methods. Methods as per international procedure (for MPCB approved laboratories) introduce compulsory quality audit. | 6–12 | 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 | Dy. C.E. (C) E.S.P. |
| 10. Identify energy demand for domestic and commercial establishment. Quantify consumption of fuels (Wood/Charcoal/Kerosene etc.). Generate adequate database for establishment of emission factors for Indian conditions. | 6–12 | Dy. C.E. (C) E.S.P. |
| 11. Discourage practice of refuse burning on dumps through stricter vigilance. Conduct special surveys to determine magnitude of this problem and to establish emission factors for Indian conditions. | 6–12 | Solid Waste |
| 12. Stop unauthorized stone crushing units. Take punitive action against authorized units which violate environmental laws through better coordination among agencies. | 6–12 | 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 roadsides regularly. | 6–12 | Dy. C.E. (C) E.S.P. |
| 14. Establish contribution of road repair activities and construction debris in air pollution problem. | 6–12 | 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 | Dy. C.E. (C) E.S.P. |
| 16. Increase use of electricity in crematoria. Invite participation of social organizations 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 | Dy. C.E. (C) E.S.P. Eng. M&E |
| 17. Fill data gaps by implementing the projects and actions recommended during the second phase of URBAIR to prepare a comprehensive emission inventory for Greater Bombay. Update inventory to assist authorities in planning strategy for better Air Quality Management | 6–12 | Dy. C.E. (C) E.S.P. |

*Table 5.5: Annex II*

| Activity | Action | Cost | Time Frame |
|---|---|---|---|
| 1. Standardize 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) Standardize analysis methods for pollutants in ambient air;<br>(2) Standardize data collection and reporting formats. Circulate both to Industrial Association and MPCB, approved laboratories; | 50,000 MPCB-funded | 3 months |
| | (3) Arrange for data sharing and common processing facilities. | 3 lakhs | 6 months |
| | After agency for coordinating the data collection, e.g.: MPCB has BWRDA/MPCB is selected earmarked facilities like computer hardware & software & related infrastructure will have to be developed.<br>Data supplied to agencies (other than contributors) shall be at nominal charge for genuine use. | 1 lakh | |
| 2. Established meteorological stations with automatic recording facility in the city to provide data for air quality modeling at four locations (Chembur, Central Bombay, Western suburb, and Central suburb) as recommended by the expert subcommittee. | Site selection for establishing meteorological monitoring stations at four locations. | Capital: 20 lakhs<br>Recurring: 1 lakh/yr.<br>(M&R of equipment; data collection and processing). | |
| Procure one SODAR for conducting low level inversion studies. | SODAR equipment installation and operation in cooperation with experts from Met Dept./BARC<br>Frequency of operation: Once a week. | Capital: 5 lakhs<br>Recurring: 2 lakhs/ year | |
| 3. Evaluate indoor air quality by rapid surveys to estimate health damage | Project Proposal:<br>(1) Select about 100 families of lower income group for first year;<br>(2) Same number of families of middle income group for second year;<br>(3) Same number of families of higher income group for third year.<br>Monitor 40 families/month and cover all every 3 months.<br>Cost of monitoring of CO, RPM, PM, $SO_2$, $NO_X$ is about Rs 1,000 per set of samples. | 5 lakhs/ year | |
| 4. Reporting Format | (1) Identify type of industries;<br>(2) Identify type of pollutants in each with point of emissions;<br>(3) Standardize methods of monitoring/analysis;<br>(4) Standardize formats for:<br>(i) Utilities,<br>(ii) Process emissions,<br>(iii) Fugitive emissions.<br>Circulate to concerned agencies. | 50,000 MPCB funded | |

*Table 5.5: Annex II*

| Activity | Action | Cost | Time Frame |
|---|---|---|---|
| 5. Identify target industries to generate database of fugitive/process emissions through rapid surveys to establish industry specific emission factors. | (1) Identify the type of industries & type of emissions;<br>(2) Decide methodology to monitor the missions;<br>(3) Survey 3–4 industries of same type with different capacities with and without control equipment and different types of control systems;<br>(4) Related data collection and compilation per type of industry @ Rs 5,000. | 5 lakhs CPCB funded | 3 years |
| 6. Take punitive action against units which violate environmental laws through better coordination amongst agencies. | (1) Preliminary survey to identify the no. of crushers;<br>(2) Data collection for each crusher;<br>(3) Survey area-wise of crushers;<br>(4) Employ staff of 3 persons/crusher; Approx. 10 persons/day for one month/ward and pay Rs 40/day. | 350,000 | 6 months |

*Table 5.5: Annex III*

| Sr. No. Action | Cost (Rs) | Timeframe Estimate | Remarks |
|---|---|---|---|
| **VEHICULAR POLLUTION**<br>1. **Exhaust Monitoring**<br>Stricter enforcement of existing legal provisions. | | | |
| (1) Four wheelers at annual tax payment | 342.81 lakhs | 1 year | There are 33 lakhs Motor Vehicles (MV) in Maharashtra State as of 31 March 1994. Earlier it was compulsory for MV Department to routinely check exhaust emissions, but by amendment of CMV Rules 1989 which came into effect from 28th March 1993, carrying of PUC Certificate has been made compulsory. The MV Dept. now has to check validity of PUC Certificate, and only randomly check exhaust emissions. |
| (2) Three wheelers vigilance monitoring | | | Although there is no legal provision to make it compulsory to check the PUC Certificate at the time of acceptance of tax, this is usually done. PUC s are checked when MVs are inspected for a fitness certificate. |
| (3) Two wheelers awareness campaign | | | There are six mobile auto pollution control squads. These squads check the PUCs of all Mvs, including three wheelers. |
| (4) At all transactions e.g. transfer, hypothecation, tax payment, etc. | | | All offices of MV Department conduct awareness campaigns in respect of auto-pollution. Press notes are issued and banners are exhibited. Publicity is given through radio and television media. Instructions are being issued to all concerned officers to check PUC Certificate before any transaction (transfer, HPA etc.) pertaining to MV is effected in MV Dept. |

*Table 5.5: Annex III*

| Sr. No. | Action | Cost (Rs) | Timeframe Estimate | Remarks |
|---|---|---|---|---|
| | | | | 39 more mobile auto pollution control squads are needed. The details are as under:<br><br>PUC SQUADS / RTO OFFICES — EXISTING: 10; REQUIRED: 2 x 10 = 20; PROPOSED SQUADS: 6; REMAINING SQUADS: 14<br>AKTO/Dy.RTO OFFICES — EXISTING: 25; REQUIRED: 1 x 25 = 25; PROPOSED SQUADS: 0; REMAINING SQUADS: 25<br>Total: 39<br><br>Constitution of one PUC Squad — Average Cost (Rs).<br>1 Motor Vehicle 300,000<br>2 Inspectors of Motor Vehicles 130,000<br>1 Driver 34,000<br>1 Operator 28,000<br>1 Jr. Gr. Clerk 34,000<br>1 Petrol Equipment (testing machine) 130,000<br>1 Diesel Equipment (testing machine) 225,000<br>Total Average cost of one PUC squad 879,000<br>Total cost for 39 PUC squads 342.81 lakhs |
| 2. | **Expiration of PUC Certificates** Month of expiration of validity should be prominently displayed on PUC Certificate. This will enable the enforcement agency to detect defaulters. | | | Transport Commission's Office has already initiated 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 Authorized Pollution testing stations along with PUC certificates. With this scheme it will be possible to check more vehicles with limited staff.<br>Comparative Figures<br>Before introduction stickers (1–5-93 to 30-11-93): Mvs. Checked 108,850; Mvs. Detected 8,228<br>After introduction of stickers (1-5-94 to 30-11-94): Mvs. Checked 267,778; MVs. Detected 11,912 |
| 3. | **High Polluting Vehicles** Identify high polluting vehicles (especially commercial vehicles such as truck/tempos, etc.) and levy stiff penalties. 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 court imposes a penalty of Rs 1,000. For a second offense, the fine is Rs 2,000, and the vehicle cannot operate on the operate pending a PUC certificate. Non-production of valid PUC certificate at the time of checking is punishable under section 177 with fine up to Rs 100 for first offense, and up to Rs 300 for subsequent offenses. |

*Table 5.5: Annex III*

| Sr. No. Action | Cost (Rs) | Timeframe Estimate | Remarks |
|---|---|---|---|
| 4. **Inspection and Maintenance** Lower time span for fitness certification of vehicles to 10 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 as authorized agencies for determination of fitness, or initiate procedure for approval of garages to ensure quality. | 91 lakhs | 1 year | Registration certificate issued to vehicles other that transport vehicles is valid for 15 years from the date of issue. For renewal or registration, application shall be made not more than 80 days before the date of expiration of registration. (See section 30 of Motor Vehicle Act, 1988 and Rule 52 of Central Motor Vehicle Rules, 1989). |

*Table 5.6: Additional proposed actions and measures, introduced by the URBAIR consultants.*

| |
|---|
| Introduce policies to increase use of low-smoke lubrication oil in 2-stroke motorcycles. |
| Ban further sales of new 2-stroke motorcycles. |
| Begin 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 sulfur contents of fuel oils and motor diesel. |
| Price fuels to reflect their 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 behavioral options. |
| Develop the dispersion/exposure model capability and capacity by investing in local institutions and consultants. |

# 6. INSTITUTIONAL FRAMEWORK

## ENVIRONMENTAL INSTITUTIONS IN BOMBAY

At the Central Government level, the main law-enforcing body is the Central Pollution Control Board (CPCB), in 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. Motor vehicle regulations are an exception. They are enforced by the Transport Commissioner. At the city level, responsibility for monitoring air quality is shared by the MPCB and the Municipal Corporation of Greater Bombay (MCGB), with the latter monitoring within the city limits. Figure 6.1 depicts a flowchart of environmental institutions in Bombay. Functions of various boards are described in the following section.

## AIR POLLUTION LEGISLATION

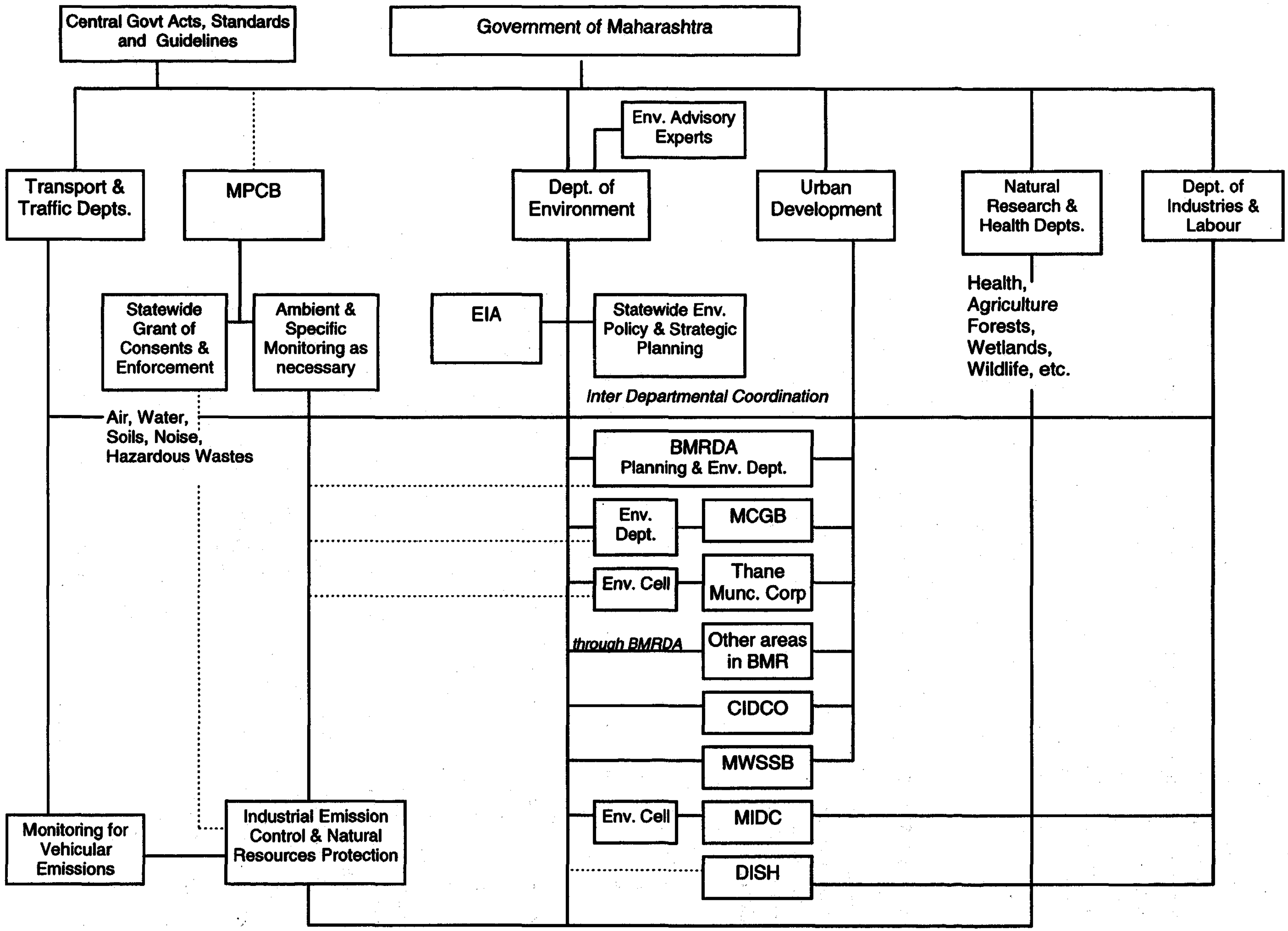
The Government of India has legislated constitutional provisions for protecting and improving the environment. The Indian Penal Code, Criminal Procedure Code, Factories Act, Wild Life Protection Act, Forests Conservation Act, Merton Shipping Act, Mines and Minerals (Regulation & Development) Act, Atomic Energy Act, as well as laws relating to local bodies and corporations, etc. contain provisions to regulate and take legal action with respect to specific environmental issues. All these enactments include specific provisions for environmental regulation and legal action. As India continues to experience industrialization, modernization, and urbanization, the existing laws have proven to be ineffective in controlling environmental degradation.

Following the Stockholm Conference on Human Environment in June 1972, it was considered appropriate to create a uniform national legal code that would tackle environmental problems. The Indian Parliament brought into operation specific and comprehensive legislation simultaneously institutionalizing the regulatory agencies for controlling pollution of various categories. 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.

Environmental legislation falls under:

- Water (Prevention & Control of Pollution) Act, 1974.
- Water (Prevention & Control of Pollution) Cess Act, 1977.
- Air (Prevention & Control of Pollution) Act, 1981.

***Figure 6.1: Organizational schedule***




**Source:** Coopers & Lybrand and AIC (1994).

- Environment (Protection) Act, 1986.
- Public Liability Insurance Act, 1991.

These Acts prescribe the Environment and Forests Agency as the nodal regulatory agency at the central level. It is in charge of policy formulation, planning, and coordination of all issues and programs related to environmental protection. The Central Pollution Board is the law-enforcing body at the Central level. It is entrusted with the work of enforcement of environmental legislations in Union Territories. It also has the role of coordinating the activities of State Boards, establishing environmental standards, planning, and executing a nationwide program for prevention control and abatement of pollution, etc. Pollution Control Boards, under the administrative control of various Departments of Environment, enforce environmental legislations at the state level.

## *The laws and regulations for air environment*

*The Air (Prevention & Control of Pollution) Act, 1981.* This Act provides for prevention, control, and abatement of air pollution. It can apply to a specific area by issuing a gazette notification. Once an area is notified under this Act, no industrial or other pollution-causing activity can commence or be carried out without the permission of the concerned State Pollution Control Board.

*Functions of the Central Board*

- Advise the Central Government on matters concerning air quality improvement, and the prevention, control, or abatement of air pollution.
- Plan and arrange to execute a nationwide program for the prevention, control, or abatement of air pollution.
- Coordinate the activities of the State Boards.
- 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.
- Establish air quality standards.

*Functions of State Boards*

- Plan a comprehensive program for the prevention, control or abatement of air pollution, and secure its execution.
- Advise the State Government on matters concerning the prevention, control, or abatement of air pollution.
- Collect and disseminate information relating to air pollution.
- Collaborate with the Central Board to organize training for people who are, or will be, engaged in air pollution prevention and control programs; and organize related mass-education programs.
- Inspect control equipment, industrial plants, or manufacturing processes, and give directions to responsible persons to take necessary steps for the prevention, control or abatement of air pollution.
- Inspect air pollution control areas at such intervals as necessary, assess the quality of air and take steps for the prevention, control or abatement of air pollution in such areas.

- Establish emission standards for industrial plants, automobiles, or other sources (with the exception of ships and aircraft) that discharge any pollutant into the atmosphere. This is done in consultation with the Central Board and its standards for air quality. Under this clause, different emission standards may be established for different industrial plants, depending on the quantity and composition of pollutants emitted into the atmosphere.
- Advise the State Government on the geographic location of a potentially pollution-generating industry.
- Perform such other functions as may be prescribed, or as may be entrusted to it by the Central Board or the State Government, from time to time.

*The Environment (Protection) Act, 1986, and Environment Protection rules formed under the Act.* The Environment (Protection) Act is an umbrella Act. It empowers the Central Government to take necessary measures for a) protecting and improving the environment; and for b) prevention, control and abatement of pollution. Under the provisions of this Act, the Government is empowered to set standards for environmental quality, and limits for emissions/discharges of pollutants from various specified sources.

This Act also empowers the Government to prohibit and/or restrict certain activities, industrial or otherwise, in specified areas to ensure protection of environment; and it also confers enforcement agencies with necessary punitive powers to restrict any activity detrimental to environment.

*The Motor Vehicles Act 1988, and The Central Motor Vehicles Rules 1989.* Although the Air Act, and the Environment (Protection) Act provide for the prescription of automobile emissions standards by the Central Pollution Control Board, or Ministry of Environment and Forests, implementation and enforcement of these standards is the responsibility of the transport commissioner. (His office is responsible for registration of motor vehicles, and hence better equipped for enforcement.)

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

- No stack can be erected or modified unless it conforms to the regulations of the above Act.
- No furnace, flue, or chimney may 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 shall be used for a purpose other than that which has been approved by the commission. Exceptions may be granted by the Commission for particular cases.
- A furnace at a lower altitude than 100 feet (30 m.) is not permitted to emit smoke from the firing floor level (unless specifically exempted).

*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.

## *Air pollution standards and regulations*

*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 are industry specific, and include stack height. These standards are mandatory for industries. As of June 1992, the Maharashtra Pollution Control Board had granted about 7,500 permits to industries in Bombay. Vehicle emission standards are implemented by the Office of the Transport Commissioner. Regular emission tests, performed by authorized agents, are mandatory (Appendix 3).

*Environmental audit*. Industries are required to submit an annual "Environmental Audit" report whose purpose is to improve compliance survey techniques.

*Central Action Plan* (1992) has been promulgated by the Government of India to speed up enforcement against non-compliance with emission standards. Chembur, Bombay, has been selected one of the 15 sensitive areas that fall under the "Sensitive Area Approach" of this plan. Eight industry categories have been identified as highly polluting. These are: cement, thermal power plants, iron and steel, fertilizer, zinc/copper/aluminum smelters, oil refineries.

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.

*Licensing of industries*. According to the Pollution Acts, industry-specific discharge and emission standards commonly referred to as MINAS (Minimum National Standards), have been prescribed. All industries, including small scale units, must comply with MINAS. State Pollution Control Boards have the responsibility of enforcing compliance with the Acts. The units under their jurisdiction obtain either a permission to operate, or a consent to discharge pollutants.

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

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

The Boards have declared some areas as "sensitive regions" 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, national wildlife parks or sanctuaries are also reasons for industries to seek out a prior site clearance.

Non-compliance invites prosecution, fines, penalties, and even imprisonment. Under the Environmental Protection Act of 1986, Pollution Control Boards are empowered to close a unit if they believe it is in the public interest to do so. 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 institutions and policies* on environmental protection in Maharashtra and Bombay include:

- *The Environmental Safety Committee,* established after the Bhopal accident, provides experts for safety inspection of major plants;
- *Industrial Location Policy,* 1984, for Bombay Metropolitan Region. This policy disallows the expansion of large and medium scale units in Bombay. Restrictions also exist for small-scale unit development; and
- *Restriction on the Use of Coal,* 1979, Urban Development Department, Government of Maharashtra. Ban on issuing new permits for using coal in Bombay.
- Ban on operation of three wheelers in Central Mumbai.

## SUGGESTIONS FOR IMPROVING INSTITUTIONS AND POLICIES

The following suggestions for improvement are extracted from the Bombay EMS Study (Coopers & Lybrand and AIC [1994], Preferred Options for EMS), and discussions held by URBAIR working groups in Bombay.

- The State Environment Department should have a stronger role in environmental policy making.
- The environmental wing within BMRDA must have the responsibility for environmental planning.
- Establish, at the metropolitan level, an organization responsible for strategic environmental planning for BMR.
- Create "environmental cells" in all sectoral organizations to include environmental considerations in their decision making.
- Establish a dedicated BMR transportation authority with representation from all relevant agencies and organizations.
- Use a charge on fuels to raise environmental management funds.
- Make environmental regulation more effective by tightening emission standards, and introducing fees and fines for pollution offenses.
- Give the Department of Environment a role in the BMRDA Policy/Executive Committee so that environmental issues will receive proper consideration at the planning stage. *(Note: This has already been implemented.).*
- The State Environment Department 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. The Department of Environment should provide leadership and professional management to achieve these goals.
- The activities of MPCB, MCGB, and other organizations concerned with air quality monitoring and air pollution control are uncoordinated, largely sector-driven, not systematically integrated, and often duplicated. Cross-sectoral issues between environment, development and investment are not properly addressed. As a nodal agency, this should be done by the State Environment Department.

- MPCB needs finance, equipment, and adequately trained and technically qualified personnel.
- The Department of Environment would benefit from a special Advisory Committee to help with policymaking and program development. The same Committee can also help to coordinate the functions of air quality management agencies.
- The Air Act (1981) permits action against defaulting industries. However, this action is time consuming since the complaints filed in law courts are not dealt with expeditiously. Closing polluting industries may be too harsh and other departments, especially Labor, often oppose such action. It is therefore necessary that MPCB should be able to penalize the defaulter on the spot, in keeping with the "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).
- There is a dire need to establish an "Environmental Training and Information Center" for decision makers and managers in governmental departments, industries and NGOs. Such a Center should be equipped with a database, environmental status and survey reports, and other information that may be vital to decision making by the Department of Environment and other agencies.
- MCGB's air quality monitoring and research laboratory needs strengthening. This is necessary in order to undertake the monitoring of air pollutants related to global warming and ozone depletion. This would require staff training, and the provision of sophisticated instruments and equipment.
- Effective monitoring and work reviews are necessary to improve MPCB and MCGB operations.
- Present procedure requires checking vehicles and issuing "Pollution Under Control" certificates only through approved centers. These centers should be checked unannounced by the Regional Transport Office, at least occasionally. This would increase identification of defaulters and help create awareness. The Transport Department would need more manpower and equipment to carry this out.

# REFERENCES


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

Atkins International (1993). "Comprehensive Transport Plan for the Bombay Metropolitan Region." Report submitted to BMRDA, Bombay, Atkins International, Mumbai.

Baker J. et al. (1992). "Final Report for Vehicular Emission Control Planning in Metro Manila." T.A. No. 1414 - PHI, Asian Development Bank, Manila.

Baker, J., R. Santiago, T. Villareal, and M. Walsh. (1993). "Vehicular Emission Control in Metro Manila." Report PPTA 1723, Asian Development Bank, Manila.

Binnie and Partners. (1992). "Modernization of Environmental Monitoring Facilities and Capabilities in Response to Philippines' Energy Development Project." Interim Report to EMB, Binnie and Partners, Mumbai.

Bombay Metropolitan Region Development Authority (BMRDA). (1990). *Traffic Survey in Greater Bombay (1988). Volume I: Classified Traffic Volume Survey, Part 1: The report.* BMRDA, Transport & Communication Division, Mumbai.

Central Pollution Control Board. (1993). Communication to the World Bank dated 20/08/1994, CPCB, New Delhi.

Claiborn, C. et al. (1995). "Evaluation of $PM_{10}$ Emission Rates from Paved and Unpaved Roads using Tracer Techniques." *Atmospheric Environment* 29:1075–1089.

Coopers and Lybrand, and Associated Industrial Consultants (1994) "Preferred Options for Environmental Management Strategy." Report to the Government of Maharashtra, Bombay, Coopers and Lybrand, London.

Despande et al. (1993). Reports on Air Pollution Related to activities by Bombay Municipal Corporation (Internal Reports).

Dichanov, Y. (1994). *Sensitivity of PPP-based Income Estimates to Choice of Aggregation Procedures.* Washington D.C.: 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 T. Bøhler. (1993). "User's Guide for the "KILDER" Dispersion Modeling System." Report TR 5/92, Norwegian Institute for Air Research, Lillestrøm, Norway.

Hutcheson, R. and C. van Paassen. (1990). "Diesel Fuel Quality into the Next Century." Shell Public Affairs, London.

Lave, L.B. and E.S. Seskin. (1977). *Air Pollution and Human Health.* Baltimore/London: Johns Hopkins University Press.

McGregor, D.B. and C.S. Weaver. (1992). "Vehicle I/M test Procedures and Standards." Draft Report. Engine, Fuel and Emissions Engineering, Sacramento, California.

Mehta, K.H. (1993). "Air Pollution Control Measures and Strategies for Bombay." Paper presented at the International Conference on Computerized Air Quality Management: Monitoring, Modeling and Emission control strategies, Bangkok 1993. Available from Maharashtra Pollution Control Board, Bombay.

Midgely, Peter. (1993). *Urban transport in Asia: An Operational Agenda for the 1990s.* Technical Paper No. 224. Asia Technical Department Series. Washington D.C.: World Bank.

Ostro, Bart. (1994). Estimating the Health Effects of Air Pollutants: A Method with Application to Jakarta." Policy Research Working Paper 1301, The World Bank, Washington, D.C.

Ostro, Bart. (1992). "Estimating the Health and Economic Effects of Air Pollution in Jakarta: A Preliminary Assessment." Paper presented at the Fourth Annual Meeting of the International Society of Environmental Epidemiology, Cuernavaca, Mexico.

Paassen, C.W.C. van et al. (1992). "The Environmental Benefits and Cost of Reducing Sulfur in Gas Oils." Oil Companies European Organization for Environmental Protection and Health (CONCAWE), Brussels.

Parkes, D. (1988) "Matching Supply and Demand for Transportation in the Pacific Rim Countries post-1990." Selected Papers. Shell Oil Company, London.

Perissich, R. (1993) "Auto Emissions 2000: "Stage 2000" of the European Regulations on Air Polluting Emissions of Motor Vehicles." Proceedings of the Symposium, Commission of the European Communities UCSC-EEC-EAEC, Brussels.

Semb, A. (1986). "Measurement of Emissions from Open Burning." NILU Report AS/SBH/0-8622/10, Lillestrøm, Norway.

Shah, Jitendra, Tanvi Nagpal and Carter Brandon eds. (1997*) Urban Air Quality Management Strategy in Asia (URBAIR), Guidebook.* Washington, D.C.:World Bank.

Shah, Jitendra and Tanvi Nagpal eds. (1997*) Urban Air Quality Management Strategy in Asia (URBAIR): Metro Manila Report*, Technical Paper No. 380. Washington, D.C.: World Bank.

Shin, E., R. Gregory, M. Hufschmidt, Y-S Lee, J.E. Nickum, and C. Umetsu. (1992). *Economic Valuation of Urban Environmental Problems.* Washington D.C.:World Bank.

Tharby, R.D., W. Vandenhengel, and S.Panich. (1992). "Transportation Emissions and Fuel Quality Specification for Thailand." Draft Report, Monenco Consultants Ltd., Oakville, Canada.

Tims, J.M. et al. (1981*). Exposure to Atmospheric Benzene Vapor Associated with Motor Gasoline*. CONCAWE Report 2/81, Brussels: CONCAWE.

Tims, J.M. (1983). *Benzene Emissions from Passenger Cars.* CONCAWE Report 12/83, Brussels: CONCAWE.

Turner et al. (1993). "Cost and Emissions Benefits of Selected Air Pollution Control Measures for Santiago, Chile." Report to the World Bank. Engine, Fuel and Emissions Engineering, Sacramento, California.

United State Environmental Protection Agency (EPA) (1986). "Fuel Oil Combustion." In: *Compilation of Air Pollutant Emission Factors, 4th ed., Suppl. A.* Research Triangle Park, NC:EPA. pp. 1.3-1- 1.3-11.

Wang, Q., C. Kling and D. Sperling. (1993). "Light-duty Vehicle Exhaust Emission Control cost Estimates Using a Part-pricing Approach." *Journal of Air Waste Management Association.* 43: 1461–1471.

Weaver, C.S. and P.E. Lit-Mian Chan. (1993). "Motorcycle Emission Standards and Emission Control Technology." Draft Report Submitted to the World Bank and the Thai Government. Engine Fuel and Emissions Engineering, Sacramento, California.

World Bank (1993). Philippines Environmental Sector Study: Toward Improved Environmental Policies and Management. Sector Report No. 11852-PH, East Asia, Country Department 1, World Bank, Washington D.C.

World Health Organization (WHO)/United Nations Environment Programme (UNEP). (1992). *Urban Air Pollution in Megacities of the World.* Oxford, U.K.: Blackwell Publishers.

W.S. Atkins International. (1993). "Comprehensive Transportation Study for Bombay Metropolitan Region." Technical Working Paper No. 3, Mumbai.

# APPENDIX 1
# AIR QUALITY STATUS, GREATER BOMBAY

CONTENTS

## DESCRIPTION OF PAST AND PRESENT MEASUREMENT PROGRAMS

*Stations and parameters.* The Municipal Corporation of Greater Bombay (MCGB) monitors air quality within the city limits, and Maharashtra Pollution Control Board (MPCB) monitors air quality in the rest of Bombay Metropolitan Region (BMR). MCGB has adapted the method designed by the United States Environmental Protection Agency (USEPA) to establish an air quality monitoring program. This includes determining the frequency and procedure of sampling and analysis of the samples.

MCGB has measured ambient air quality regularly at 22 stations in Greater Bombay over 15 years now. The pollutants measured are sulfur dioxide ($SO_2$), total suspended particles (TSP), oxides of nitrogen ($NO_x$) and ammonia ($NH_3$). Ambient air quality is also occasionally measured at selected traffic junctions in Bombay for $SO_2$, $NO_x$, carbon monoxide (CO) and benzo(a)pyrenes from total and respirable particulates.

The MCGB air quality monitoring network in Bombay is shown in Figure 1. There are few details available as to the location of these measuring sites, except that they are located at fixed points, most of them on terraces of municipal buildings, 10 to 12 meters above the ground. A few stations are located 3–4 meters above the ground. The stations are visited once a week and operated continuously for 24 hours, but the sampling period is 8 hours, giving three samples in 24 hours. Sampling is performed 1–4 days a month and not necessarily on a fixed weekday.

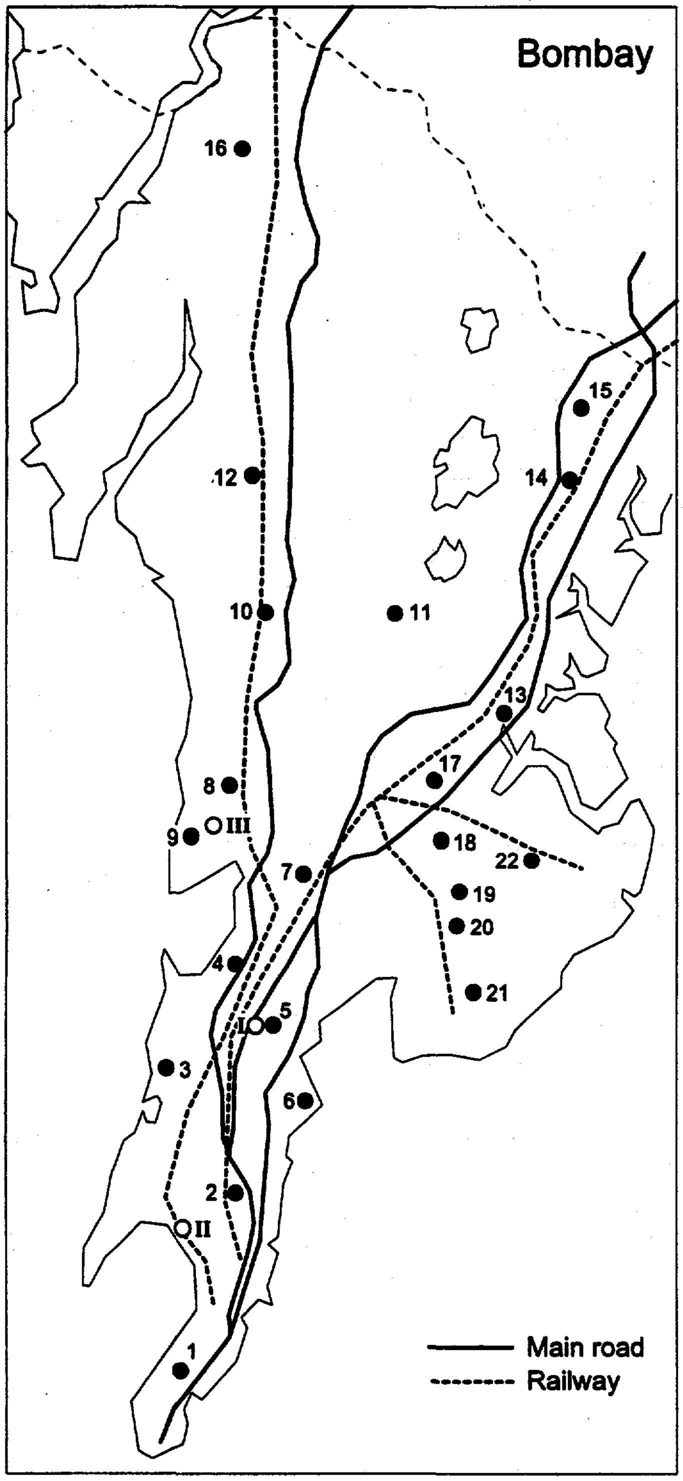
Since 1978 NEERI (National Environmental and Engineering Research Institute) has operated United Nations GEMS (Global Environment Monitoring System) air monitoring stations in Bombay. These sites are also shown in Figure 1. At these sites $SO_2$, TSP and $NO_2$ is measured. Monitoring was discontinued in 1988 and recommenced in January 1990.

Both MCGB and NEERI monitor at Parel. The results are somewhat different, as shown e.g. in Annex I, since the sites are not exactly the same, measurements are done on different days, and analysis is done in different laboratories.

In 1991 and 1992 an air quality monitoring program was performed at 7 stations around the Thal RCF industrial complex south of Bombay. This study was coordinated by Projects and Development India (PDIL) and RCF. The measurements included TSP, $SO_2$, $NO_x$ and $NH_3$ on an 8 hourly basis.

Also in 1991 and 1992 measurements of air quality was performed at 5 stations even further to the south around the Vikram Ispat Ltd, Salav Project site. The measurements included TSP, $SO_2$, $NO_x$, THC and CO on an 8 hourly basis 8 days in each two month periods. The measurement stations were located 1–7 kilometers from the plant. There are no information as to which agency actually did the analysis.

*Figure 1: MCGB and GEMS air quality monitoring network in Greater Bombay*




MCGB
1. Colaba (C/R)
2. Babula Tank (I/R)
3. Worli Naka (C)
4. Dadar (C)
5. Parel (I/C/R)
6. Sewree (I)
7. Sion (C)
8. Khar (C/R)
9. Supari Tank (R)
10. Andheri (I/C)
11. Saki Naka (I)
12. Jogeshwari (I)
13. Ghatkopar(I/C/R)
14. Bhandup (I)
15. Mulund (I)
16. Borivali (R)
17. Ţilaknagar (C)
18. Chembur Naka (C/R)
19. Maravali (I)
20. Aniknagar (I)
21. Mahul (I)
22. Mankhurd (R)

GEMS
I: Parel
II: Kalbadevi
III: Bandra

I: Industrial
C: Commercial
R: Residential

*Measurement and analysis methods.* The measurement methods used by MCGB are listed in Table 1.

***Table 1: Measurement methods used by MCGB in Bombay***

| Parameter | Analysis method |
|---|---|
| Suspended particulates (TSP) | Gravimetric. High volume sampler. |
| Sulfur dioxide ($SO_2$) | Pararosaniline method. $SO_2$ is collected in midget impinger and absorbed in a solution of TCM (Potassium Tetrachloromercurate) |
| Nitrogen oxides as $NO_2$ | TGS Ansa Method. Midget impinger. |

As part of the URBAIR study, a comparison of results of gravimetric weighing of glass-fibre high-volume filters were carried out. Pre-weighted filters from NILU were brought to Bombay, weighted, exposed (24-hour sampling), weighted again and returned to NILU for last weighting. Also MCGB-type filters went through the same procedure. The results were quite good, in that the net particle weight on 6 filters (net weight range 66.4–131.6 mg) (NILU figures) deviated on the average about 4 percent (highest at NILU). Maximum difference was about 15 percent.

## ANALYSIS OF MEASUREMENT RESULTS

The Municipal Corporation of Greater Bombay (MCGB) has operated 22 measuring stations in Greater Bombay for the last 15 years. In addition NEERI has operated 3 GEMS stations in the same period. At all stations $SO_2$, TSP and $NO_x$ is measured and in addition $NH_3$ at the MCGB stations. The MCGB stations are operated once a week, 1–4 days a month.

There are few details about the results other than annual mean concentrations. Annual mean values for fixed 8 hour periods (1200–2000 hrs, 2000–0400 hrs, 0400–1200 hrs) for the period June 1992–May 1993 are also given.

*Total suspended particles (TSP).* Annual mean and 98th percentile TSP levels from the GEMS/NEERI stations are shown in Figures 2 and 3. The TSP concentrations are well above the WHO guidelines. In 1990 annual TSP levels were about 170–220 $\mu g/m^3$ and 98th percentile levels about 400–500 $\mu g/m^3$ at these stations.

Annual TSP levels at the MCGB stations are shown in Figure 4, for the period 1978–1990. These values are probably mean values from all the 22 stations in operation. The 1990 level was 243 $\mu g/m^3$, a little higher than at the NEERI stations. The 1990 level was the lowest since 1984. The highest level, 383 $\mu g/m^3$, was recorded in 1987.

Data from 18 stations from the period June 1992–May 1993 show a mean value of 207 $\mu g/m^3$, that means an even lower level than in 1990, and about the same level as during the period 1978–1984, see Figure 5.

*Figure 2: Annual mean suspended particulate matter (TSP) at GEMS/NEERI stations (µg/m³)*

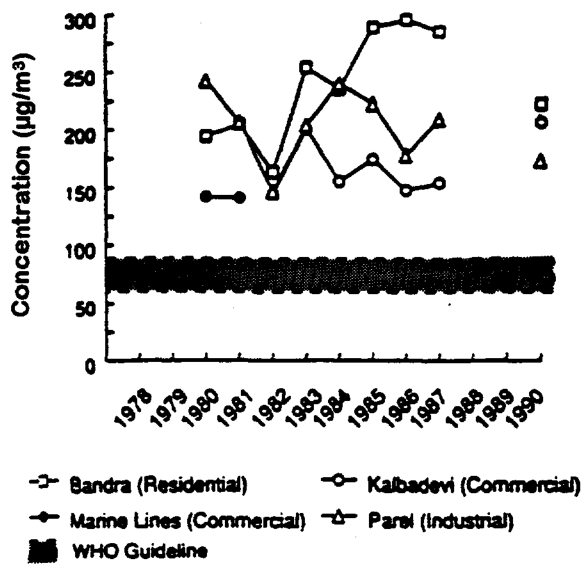



*Figure 3: Annual 98 percentile suspended particulate matter (TSP) concentrations at GEMS/NEERI stations (µg/m³)*

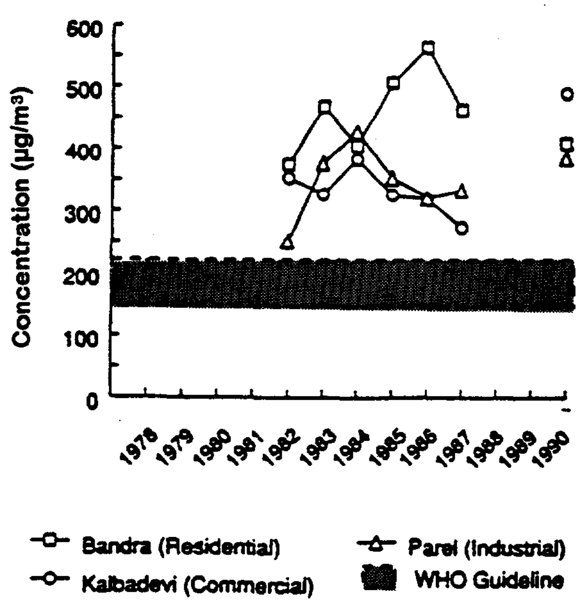
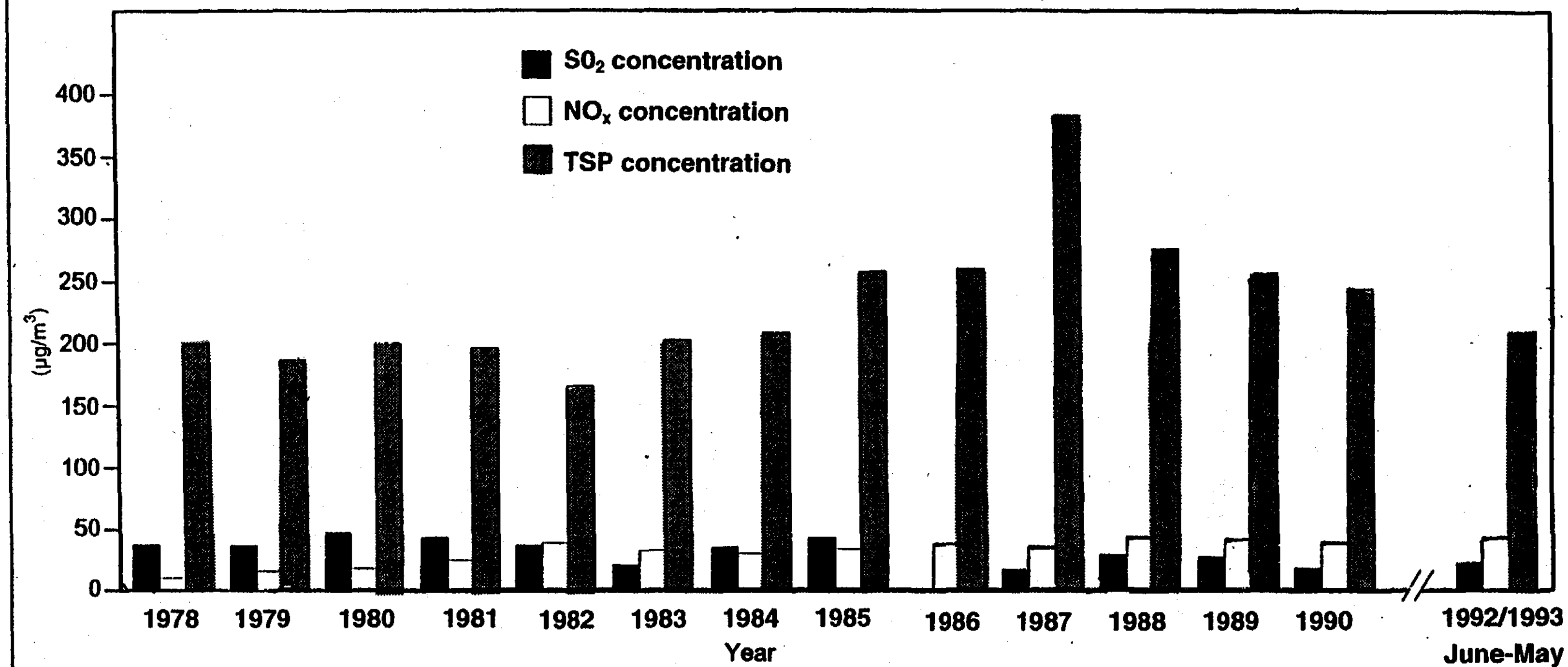


*Figure 4: Annual mean concentrations of $SO_2$, $NO_2$, and TSP at MCGB stations (µg/m³)*



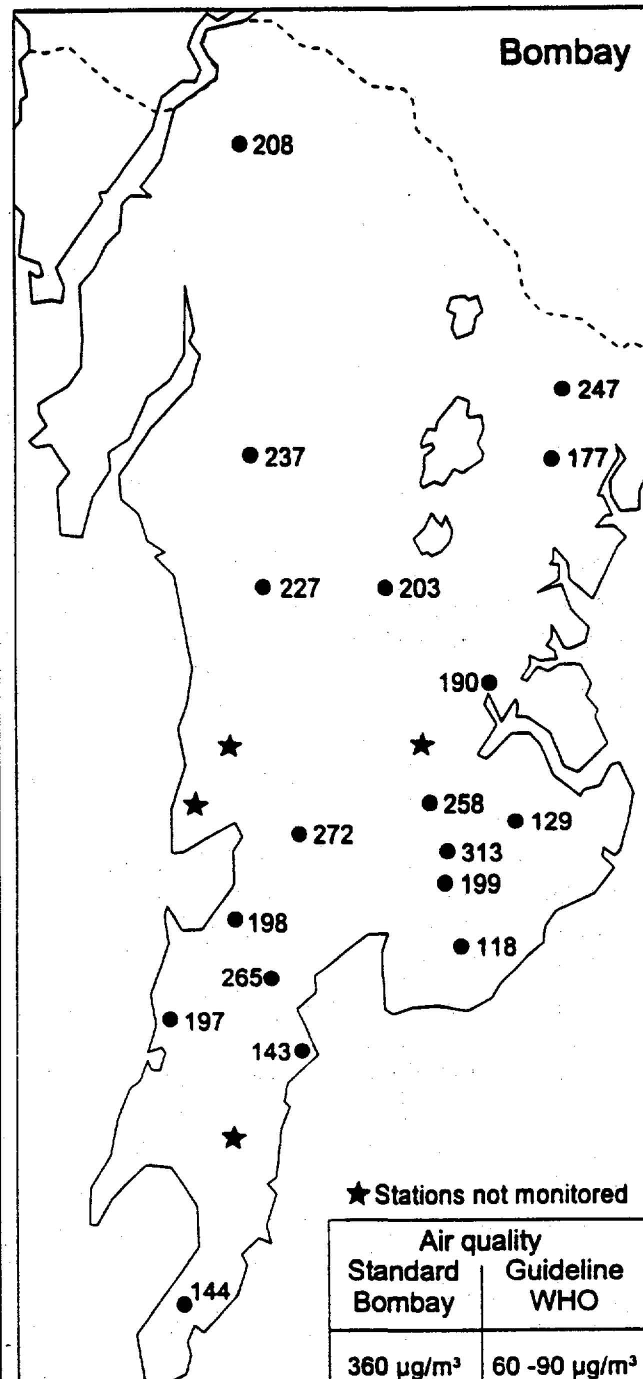
Data tables for all stations, with monthly average $SO_2$, TSP, $NO_x$ and $NH_3$ values are enclosed as Annex II to this Appendix.

Figure 5 shows the highest annual concentration at the Maravali station (313 µg/m³) situated in an industrial area. The Colaba, Sewree, Mahul and Mankhurd stations observed the lowest concentrations (118–144 µg/m³). Compared to the year 1987, 1993–92 TSP concentrations has fallen 20–30 percent at the Worli Naka, Dadar, Parel, Sewree and Saki Naka stations, while there is no change in the TSP level at the Sion and Chembur Naka stations.

Figures 6 and 7 show, as examples, the monthly averages at two selected sites, Parel and Saki-Naka, for 1987/88 and 1992/93. Similar figures for all available MCGB sites for 1992/93 are enclosed in Annex III to this Appendix. There is a considerable variation in the monthly mean TSP concentrations as shown in Figures 6 and 7. The lowest concentrations are measured during the months July–September, the monsoon season. The highest concentrations are usually measured during the months November–March. During the rainy season mean concentrations are usually lowered by a factor between 2 and 3 compared to the dry season.

There is a very little information available as to maximum 8 hour TSP levels. Data from April 1992, however, show maximum values much higher than the monthly mean values, see Table 2. During April 1992 maximum 8 hour values varied between 265 µg/m³ and 1 365 µg/m³. Maximum values seems to be between 1.5 and 3 times higher than monthly mean values.

***Figure 5: Mean TSP concentrations at MCGB stations during June 1992–May 1993 (µg/m³)***




**Note:** For site locations, see Figure 1, Appendix 1.

Figure 8 shows that TSP concentrations usually is about 30 percent higher during the hours 1200–2000 than during the night time and during the morning period. This is probably due to the general activity pattern. Why $NO_x$ and $SO_2$ do not follow this pattern, cannot be explained by available information.

***Figure 6: Monthly mean $SO_2$, $NO_x$ and TSP concentrations at the Parel station during the periods June 1987–May 1988 and June 1992–May 1993***

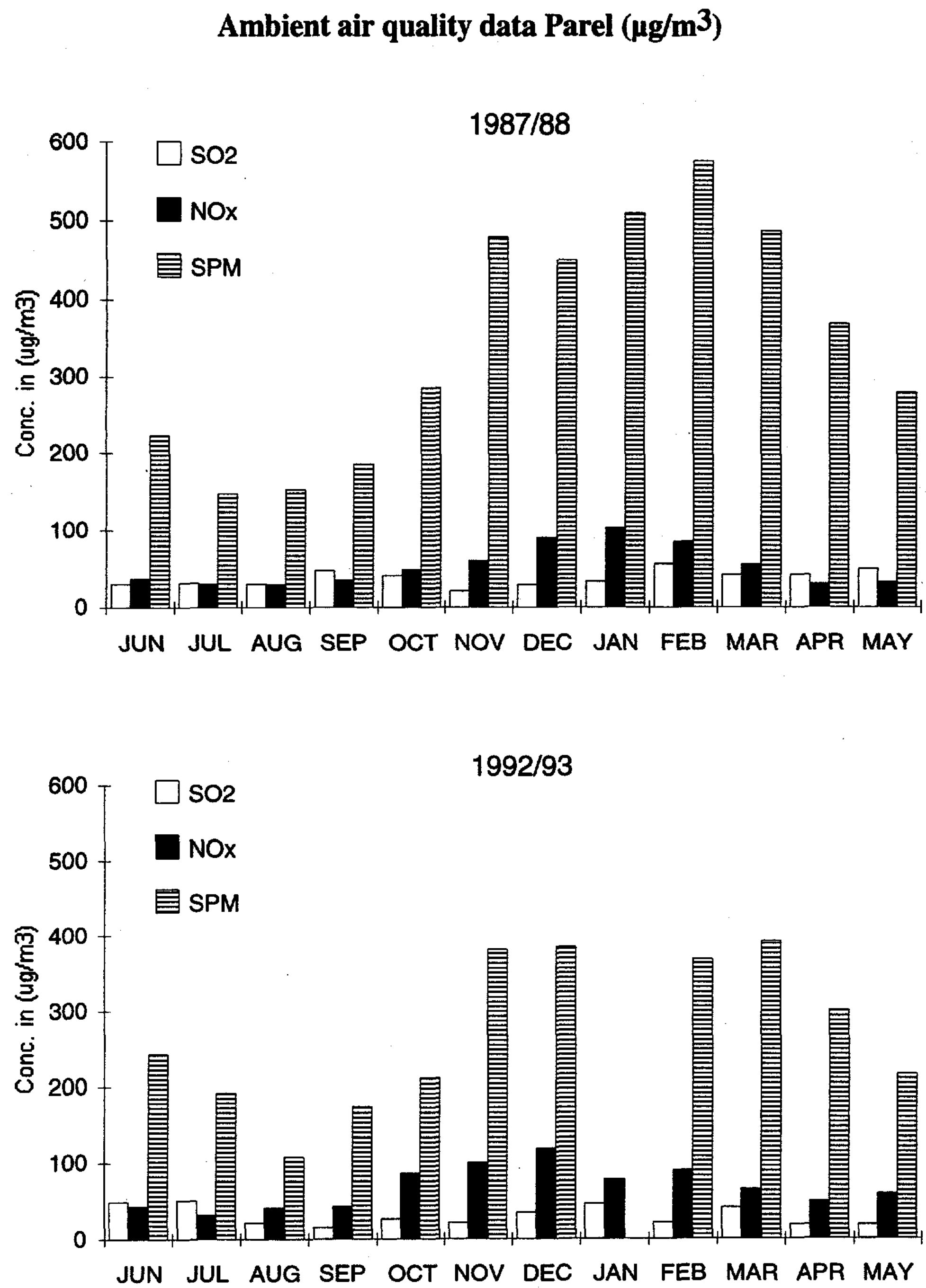


*Figure 7: Monthly mean $SO_2$, $NO_x$ and TSP concentrations at the Saki Naka station during the periods June 1987–May 1988 and June 1992–May 1993*

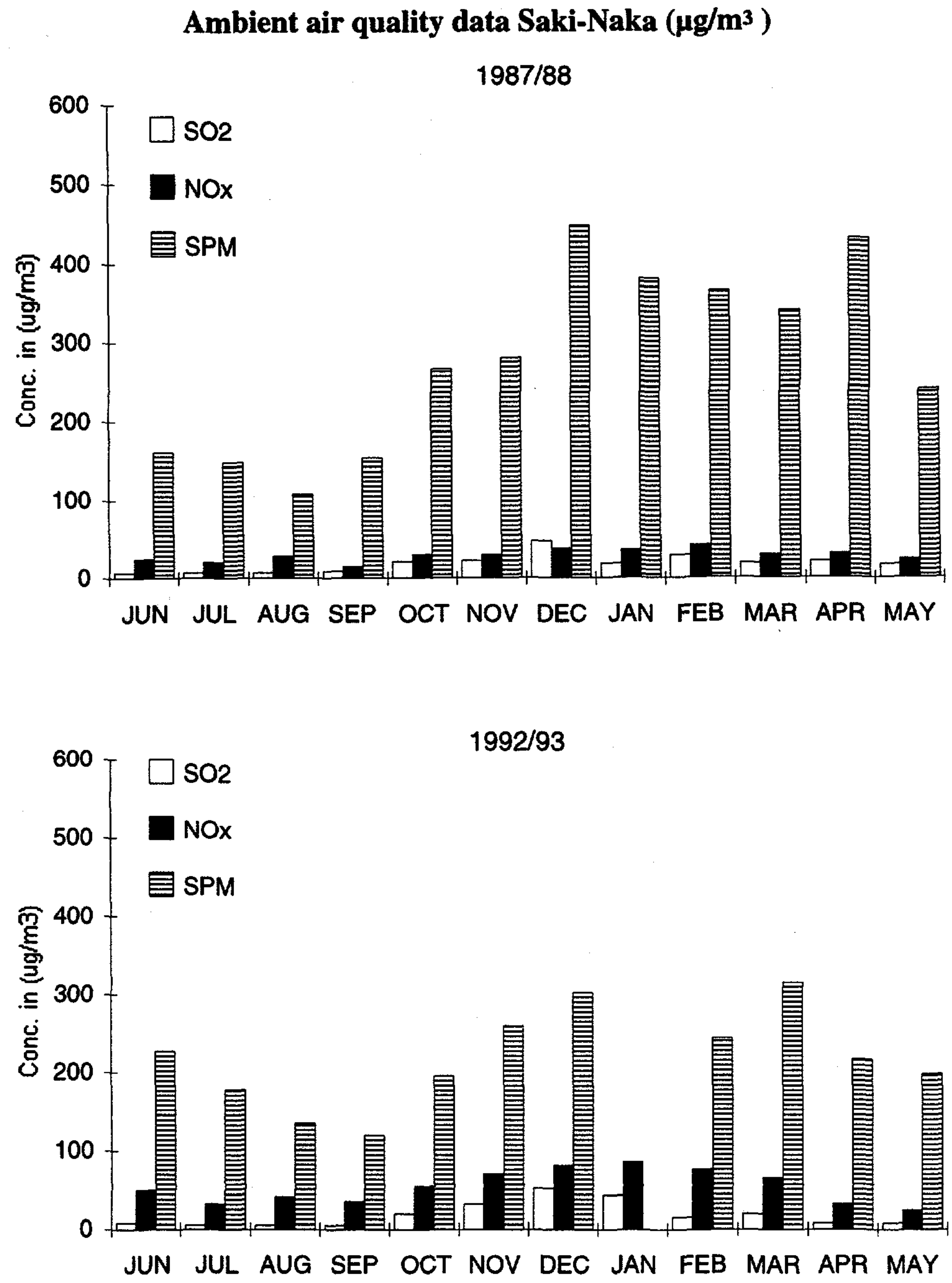


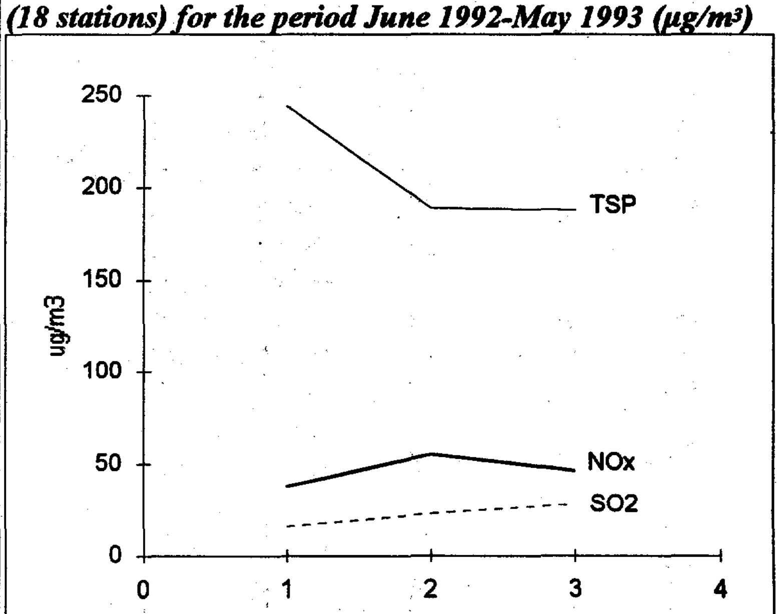
***Table 2: Concentrations of $SO_2$, $NO_2$, $NH_3$ and TSP from MCGB stations in April 1992 (μg/m³)***

| Sites | $SO_2$ | | $NO_2$ | | $NH_3$ | | TSP | |
|---|---|---|---|---|---|---|---|---|
| | A.M. | MAX | A.M. | MAX | A.M. | MAX | A.M. | MAX |
| 1. Colaba | 8 | 20 | 26 | 36 | 37 | 57 | 176 | 265 |
| 2. Babula Tank | - | - | - | - | - | - | - | - |
| 3. Worli | 13 | 90 | 43 | 78 | 56 | 96 | 281 | 645 |
| 4. Dadar | 9 | 28 | 31 | 54 | 60 | 79 | 238 | 408 |
| 5. Parel | 23 | 72 | 37 | 61 | 41 | 65 | 360 | 834 |
| 6. Sewree | 39 | 91 | 31 | 59 | 50 | 82 | 225 | 393 |
| 7. Sion | 18 | 60 | 89 | 126 | 59 | 87 | 465 | 1,365 |
| 8. Khar | - | - | - | - | - | - | - | - |
| 9. Supari Tank | - | - | - | - | - | - | - | - |
| 10. Andheri | 20 | 55 | 32 | 90 | 55 | 97 | 348 | 659 |
| 11. Sakinaka | 16 | 28 | 41 | 93 | 38 | 77 | 273 | 504 |
| 12. Jogeshwari | 7 | 13 | 26 | 49 | 61 | 109 | 337 | 495 |
| 13. Ghatkopar | 11 | 29 | 25 | 52 | 48 | 104 | 353 | 556 |
| 14. Bhandup | 50 | 96 | 29 | 62 | 56 | 106 | 320 | 662 |
| 15. Mulund | 7 | 20 | 20 | 38 | 43 | 65 | 275 | 533 |
| 16. Borivali | 6(?) | 6 | 15 | 28 | 37 | 44 | 199 | 291 |
| 17. Tilaknagar | - | - | - | - | - | - | - | - |
| 18. Chemburnaka | 14 | 31 | 45 | 83 | 57 | 88 | 319 | 496 |
| 19. Maravali | 12 | 54 | 55 | 119 | 73 | 165 | 207(?) | 381 |
| 20. Anik Nagar | 23 | 63 | 36 | 59 | 97 | 168 | 259 | 379 |
| 21. Mahul | - | - | - | - | - | - | - | - |
| 22. Mankhurd | 14 | 56 | 39 | 85 | 46 | 94 | 250 | 395 |

**Note:** A.M.: Monthly average conc. Max.: Maximum 8-hour conc.

There are only a few TSP data available from highly exposed traffic sites in Bombay. In 1991 and 1992, 3 or 4 days measurements of $SO_2$, $NO_x$, TSP and CO were performed at 6 traffic junctions in Greater Bombay. TSP mean values ranged from 480 μg/m³ to more than 1,300 μg/m³ and maximum 8 hour values ranged from about 550 μg/m³ to more than 3,100 μg/m³. These values are considerably higher than from the stations in the MCGB air quality monitoring network and show that TSP could be a very serious problem close to the main roads. These high values

***Figure 8: 8-hour mean annual TSP, $NO_x$ and $SO_2$ values (18 stations) for the period June 1992-May 1993 (μg/m³)***




**Note:** 1 = 1200-2000 hrs, 2 = 2000-0400 hrs, 3 = 0400-1200 hrs are probably caused by resuspension of road dust and not so much by direct exhaust emissions from the cars.

In 1989–1990 Sharma and Patil (1991, 1992) did some measurements of mass concentration of size-distributed aerosols using a quartz crystal microbalance cascade impactor (QCM-CI). The instrument operates at a low flow rate (0.24 l/min) and separates the aerosols into 10 size fractions. The 50 percent cut-off sizes varies from 25 µm to 0.05 µm. For comparison conventional High Volume Sampler was also used. These samples were analyzed for size distribution by a Centrifugal Analyzing System (CAS) and Image Analyser System (IAS).

Samples were taken one day on hourly basis each week at two sites. Site 1 (CESE, IIT, Bombay) is a relatively clean area and Site 2 (Hindustan Ciba-Geigy Ltd, Bhandup) is a "mixed region" with highly polluting industries surrounded with dense population. Site 2 was along the highway Lal Bahadur Shastri (LBS) Marg with a peak traffic density of about 2 000 vehicles per hour. It is not clear if the Bhandup site is the same as the Bhandup site in the BMC network, but from maps it is obviously in the same region.

The TSP values collected by the high volume sampler were much higher than total particulate collected by QCM-CI (≤ 25 µm) for both sites: 180 and 541 µg/m³ by high volume sampler as compared to 86 and 110 µg/m³ by QCM-CI. But the cumulative percentage of particulates ≤ 25 µm was approximately equal by the two instruments.

$PM_{10}$ values (particles with diameter ≤ 10 µm) were about 85–90 percent of total mass collected by the QCM-CI measurement method and the mass segregated by the CAS/IAS analyzer system (≤ 45 µm) on high volume samples. This shows that $PM_{10}$ levels are much lower than TSP levels and that the difference is highest in the most polluted areas where the mass of particles ≥ 45 µm dominates.

TSP high volume samples at Site 1 and Site 2 in 1989 were analyzed for 27 chemical species using inductively coupled plasma emission spectroscopy (ICP-MS), energy dispersive x-ray fluorescence spectroscopy (XRF) and UV/VIS spectrophotometry. Factor analysis applied on 19 marker elements extracted 7 factors indicating 7 major source types contributing to aerosol mass at the sampling sites. It was found that soil related elements were attached with more than one factor indicating collinearity of sources. However, results obtained indicated many anthropogenic sources present in the region like ferrous and non-ferrous industrial emissions, combustion processes such as refuse burning, oil and coal burning, road transport and secondary emissions.

Table 3 shows the annual average concentrations of TSP and the 27 analyzed elements at the two sites for 1989. The concentrations were much higher at Site 2 than at Site 1, especially for TSP, Al, Cr, S, Si, V, and Zn.

***Table 3: Annual average TSP and its components ($ngm^{-3}$)***

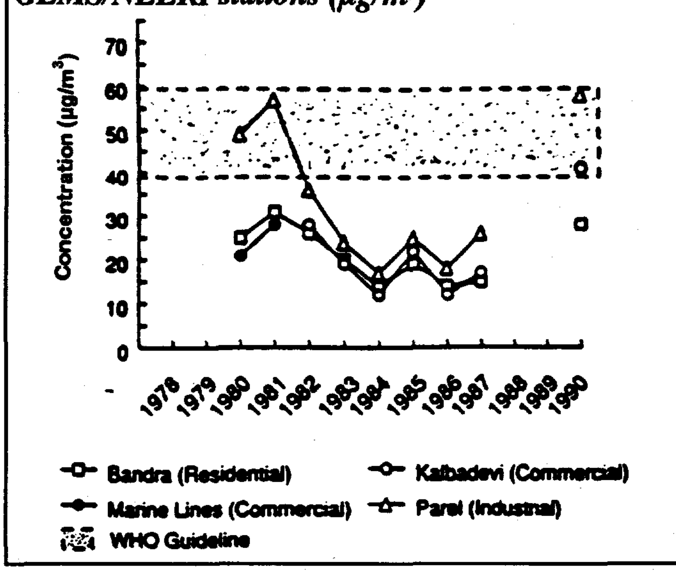
| Component | Site 1 Mean | Site 2 Mean |
|---|---|---|
| TSP* | 130.21 | 800.71 |
| Al* | 2.31 | 10.54 |
| As | 273.60 | 695.50 |
| Br | 244.20 | 384.40 |
| Ca* | 4.82 | 8.43 |
| Cd | 35.70 | 75.70 |
| Cl* | 9.13 | 11.08 |
| Co | 25.70 | 30.50 |
| Cr | 39.00 | 104.10 |
| Cu | 290.80 | 436.20 |
| Fe* | 2.95 | 5.06 |
| K* | 1.27 | 2.27 |
| La | 36.70 | 48.20 |
| Mg | 705.60 | 802.05 |
| Mn | 401.90 | 635.00 |
| Na* | 5.87 | 8.20 |
| Ni | 35.00 | 79.10 |
| Pb* | 0.55 | 1.21 |
| S* | 0.94 | 4.75 |
| Sb | 86.80 | 104.00 |
| Si* | 3.59 | 9.48 |
| Sn | 95.10 | 189.10 |
| Ti | 471.50 | 661.00 |
| V | 109.50 | 311.00 |
| Zn | 204.90 | 785.50 |
| $SO_4^{--}$* | 1.59 | 1.77 |
| $NO_3^{-}$* | 1.03 | 1.14 |
| $NH_4^{+}$ | 739.90 | 868.90 |

*Background TSP levels.* There are no data available from real background stations, but measurements are performed south of Bombay both around the Thal RCF industrial Complex and during the Vikram Ispat Ltd. Salav Project. Especially the Thal RCF data are interesting.

During the 1991/92 Thal RCF project TSP, $SO_2$, $NO_x$ and $NH_3$ were measured at 7 locations. The number of 8 hour observations ranged between 84 and 141. Arithmetic mean TSP values ranged between 79.8 μg/m³ and 117.6 μg/m³ and maximum 8 hour mean values ranged from 164 μg/m³ to 234 μg/m³. Even though local industrial emissions are supposed to contribute, the measured TSP levels around the Thal RCF Complex are quite lower than at all MCGB stations in Greater Bombay, pointing out the great importance of local emission sources in Bombay.

*Sulfur dioxide ($SO_2$).* Annual mean $SO_2$ concentrations from the GEMS/NEERI sites are shown in Figure 9. The concentrations dropped significantly between 1980 and 1987 to well below WHO annual guideline levels, and increased substantially again in 1990, but are still within the WHO guideline range.

***Figure 9: Annual mean sulfur concentrations at GEMS/NEERI stations (μg/m³)***




Annual $SO_2$ levels at the MCGB sites are shown in Figure 4. These values are mean values from all the 22 stations in operation. The 1990 level was 18 μg/m³, well below that at the NEERI stations. The 1990 level was the same as in 1987, while the $SO_2$ concentrations at the NEERI sites increased substantially from 1987 to 1990. The reason for this difference between NEERI and MCGB sites is not known. The MCGB data from the period June 1992–May 1993 show a mean value of 22 μg/m³, that is a little bit higher than in 1990.

Figure 10 shows annual mean $SO_2$ levels for the period June 1992–May 1993. These levels are ranging from 7 μg/m³ at the Mankhurd station to 50 μg/m³ at the Bhandup site. These values are all within the WHO guideline of 50 μg/m³.

As shown in Figures 6 and 7, there is a quite similar seasonal variation for $SO_2$ and TSP at the Saki Naka station, while this seasonal variation is not so clear for $SO_2$ at the Parel station. The reason for this is not known. It is also difficult to explain why $SO_2$ levels at most stations usually are higher during the late night and morning period than during the rest of the day as shown in Figure 8.

Available data from April 1992 from 17 MCGB stations show maximum $SO_2$ values (8 hour mean values) between 13 μg/m³ and 96 μg/m³, see Table 2.

A few measurements at traffic junctions in 1991 and 1992 show mean values ranging from 38 μg/m³ to 117 μg/m³ at 6 stations and maximum 8 hour values from 80 μg/m³ to 162 μg/m³. $SO_2$ concentrations at traffic junctions therefore seem to be considerably higher than at the MCGB network. The Indian Guideline value for short-term (24 hourly) in Industrial & Mixed Use areas is 120 μg/m³.

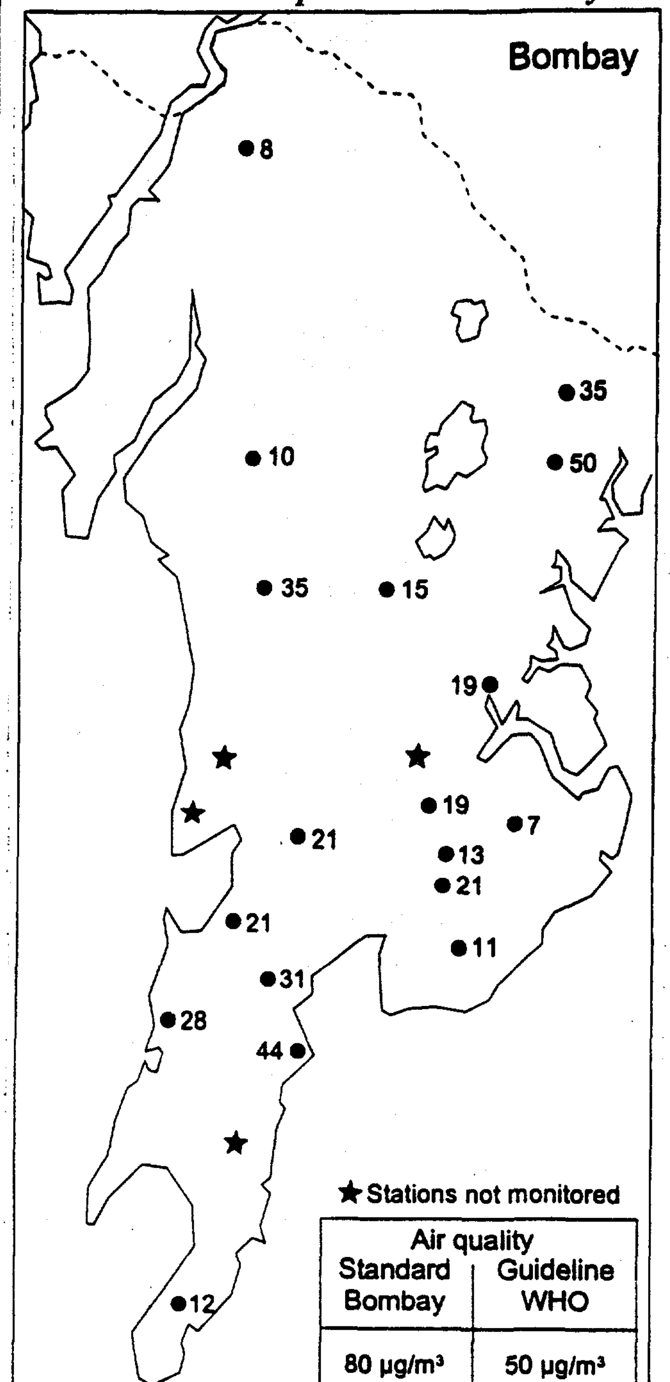
Air quality data around the Thal RCF Complex in 1991 and 1992 show mean values from 2.3 μg/m³ to 5.7 μg/m³ and maximum 8 hour values from 11.4 μg/m³ to 24.8 μg/m³ at 7 stations. These values are considerably lower than in the Greater Bombay area.

*Nitrogen oxides ($NO_x$ as $NO_2$).* Annual 98th percentile $NO_2$ levels at GEMS/NEERI sites are shown in Figure 11 (annual mean levels are not shown in reports available at NILU). Annual 98th percentile levels have dropped significantly from 1987 to 1990. Concentrations are relatively consistent suggesting $NO_2$ concentrations to be evenly distributed throughout the city.

Annual mean concentrations at MCGB sites are shown in Figure 4. These values are probably mean values from all 22 stations. The mean value in 1990 was 40 μg/m³, and the level has varied between 30 μg/m³ and 44 μg/m³ the last ten years. MCGB sites $NO_x$ level has increased about 10 percent from 1987 to 1990, while 98th percentile values at GEMS/NEERI sites have dropped significantly from 1987 to 1990. As very little details about monitoring methodology and site location are available for both monitoring networks, direct comparison of the data is not attempted. MCGB data from June 1992–May 1993 show a mean of 46 μg/m³ indicating that the $NO_x$ level still is rising.

Figure 12 shows mean $NO_x$ concentrations for the period June 1992–May 1993. The levels are ranging from 20 μg/m³ at the Mahul site to 83 μg/m³ at the Sion site.

***Figure 10: Mean $SO_2$ concentrations (μg/m³) at MCGB stations in the period June 1992–May 1993***



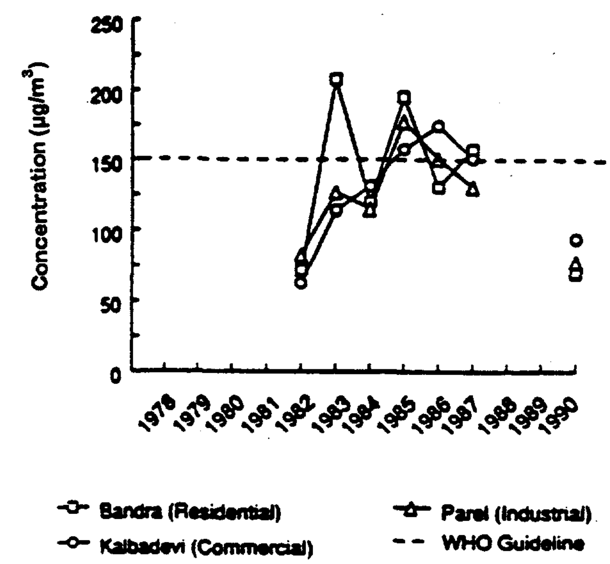

Note: For site location, see Figure 1, Appendix 1

As shown in Figures 6 and 7 the seasonal $NO_x$ variation seems to be quite similar as for TSP. The $NO_x$ levels usually are highest during the night time (Figure 8), while TSP concentrations are highest at daytime and $SO_2$ concentrations are highest at late night and morning hours.

Available data from April 1992 from 17 MCGB stations show maximum $NO_x$ values (8 hour mean values) between 28 µg/m³ and 126 µg/m³, see Table 2. The Indian guideline value for 24 hours in industrial areas is 120 µg/m³.

1991 and 1992 $NO_x$ measurements at some traffic junctions show mean values from 56 µg/m³ to 175 µg/m³ and maximum 8 hour values from 83 µg/m³ (Worli Naka site) to 296 µg/m³ (VT site). As for TSP and $SO_2$ these values are much higher than at the MCGB monitoring stations, indicating traffic emissions to be very important.

***Figure 11: Annual 98 percentile nitrogen oxide concentrations (µg/m³) at GEMS/NEERI stations***




Air quality data around the Thal RCF Complex in 1991 and 1992 show mean $NO_x$ values between 10.2 µg/m³ and 17.0 µg/m³ and maximum 8 hour mean values between 28.0 µg/m³ and 52.2 µg/m³ at 7 stations. These values are considerably lower than in the Greater Bombay area.

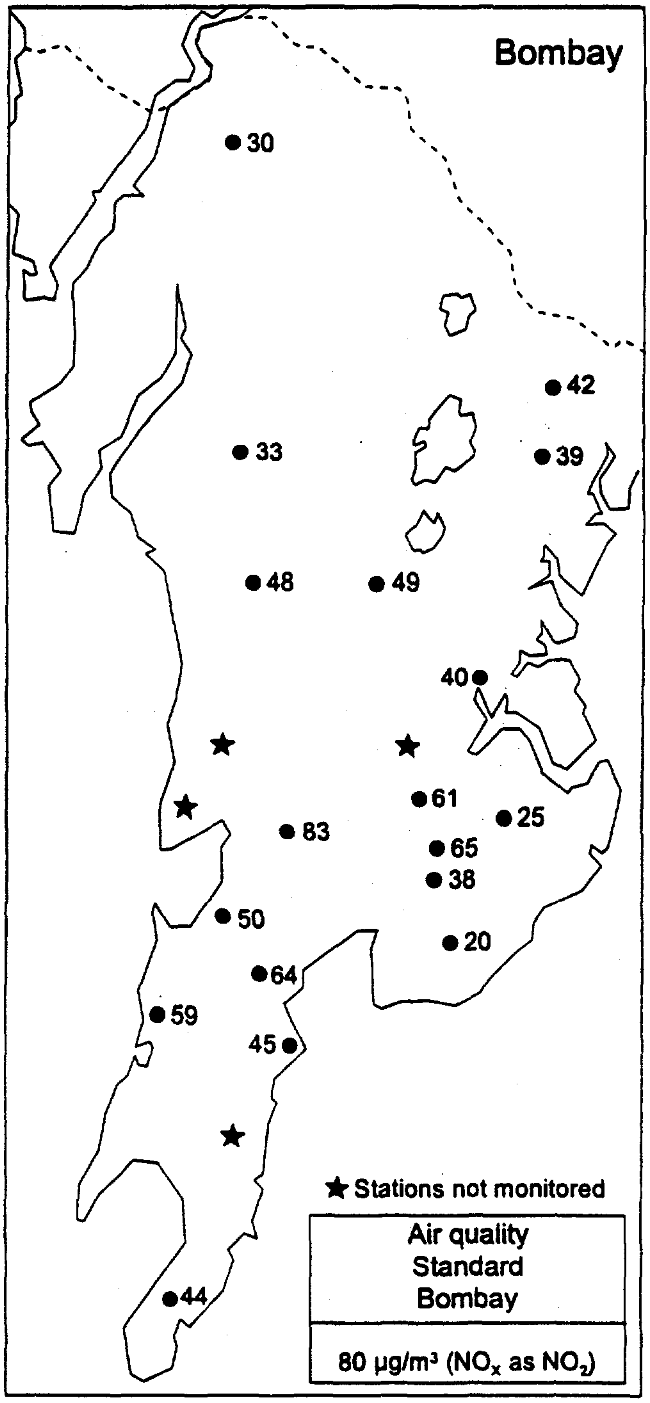
*Lead (Pb).* Monthly mean concentrations of lead during the Air pollution survey of Greater Bombay in 1971–1973 ranged from 0.4 µg/m³ to 2.4 µg/m³.

Lead was monitored at the 22 MCGB sites during the years 1980–1987. The Greater Bombay area was divided into 6 sub-areas; South Bombay, Central Bombay, Western Suburb, Eastern Suburb, Petrochemical Complex and Urban Clean (Borivali station).

This study showed an increasing trend in the whole area and the highest levels in the Eastern Suburb zone. The annual mean levels ranged from 0.5 µg/m³ to 1.3 µg/m³. The highest monthly mean level was 17.9 µg/m³ at the Mulund site in October 1984.

As an example annual mean Pb concentrations in the Central Bombay area are shown in Figure 13. Annual mean concentrations for 4 stations range from 0.2 µg/m³ to 1.1 µg/m³. The highest level (probably mean monthly value) was 8.4 µg/m³ at Dadar in January 1985. The second highest level of 6.2 µg/m³ was recorded during February 1987 at Parel. The annual mean levels of Pb in this area showed an increasing trend during the years 1980–1987. From 1980 to 1987 the annual mean Pb level nearly doubled.

*Figure 12: Mean $NO_x$ concentrations at MCGB stations in the period June 1992–May 1993 ($\mu g/m^3$)*



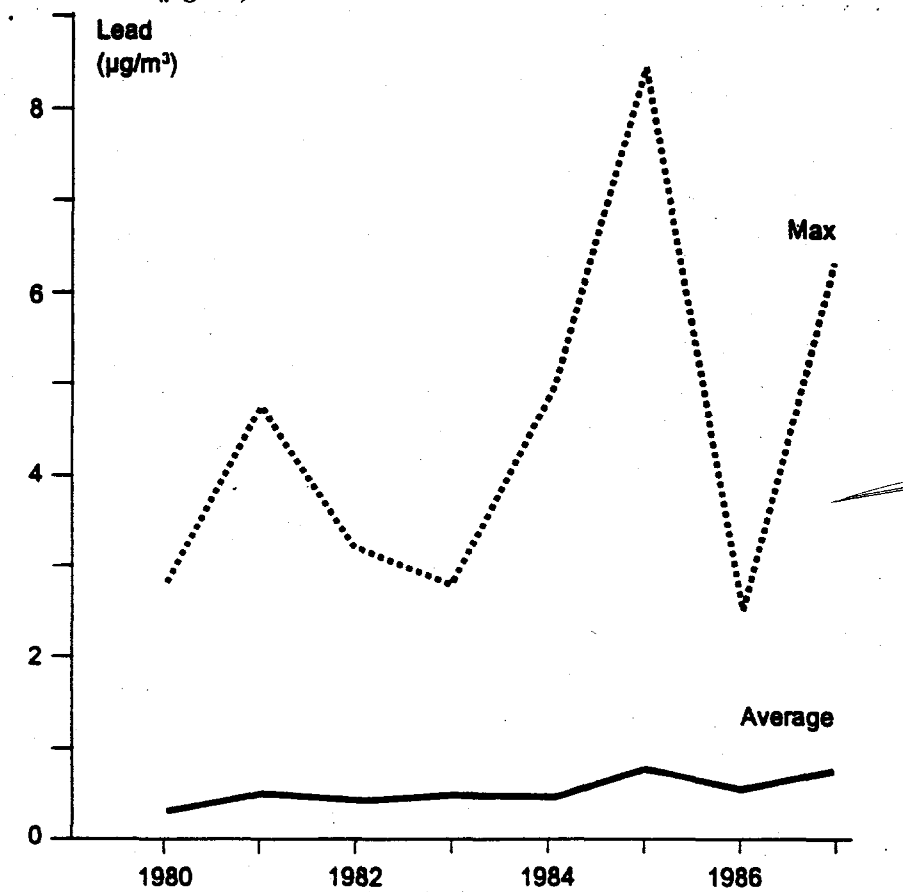

**Note:** Site locations are given in Figure 1, Appendix 1.

There is no information available about Pb monitoring at the MCGB stations after 1987.

Monitoring undertaken in 1990 at the GEMS/NEERI sites indicates that annual airborne Pb levels have fallen significantly since the 1970's to between 0.25 µg/m3 and 0.33 µg/m3, well below the WHO guideline of 1 µg/m3. It is likely that curbside levels will be much higher.

As shown in the TSP paragraph annual Pb levels at two sites in 1989 were 0.55 µg/m3 and 1.21 µg/m3, the latter site being close to a road. In the most heavily traffic-exposed city center streets it is likely that Pb levels are even higher.

***Figure 13: Annual trend of lead in Central Bombay during the years 1980–1987 (µg/m³)***




Note: Data is from Worli Naka, Dadar, Parel and Sewree stations.

*Carbon monoxide (CO).* Some short-term CO roadside surveys have been undertaken between 1984 and 1987. Monitoring was performed at several roadside sites during periods of peak traffic flow. 8 hour mean values ranged between 4 mg/m3 and 21 mg/m3. A maximum hourly concentration of 50 mg/m3 was recorded at the Haji Bachoo Ali Hospital. Maximum hourly concentrations were generally around 23–29 mg/m3, close to the WHO guideline of 30 mg/m3. These roadside surveys are not representative of ambient background levels which are likely to be much lower.

CO has also been measured at 6 traffic junctions on a few days in 1991 and 1992. Mean values ranged from 5.1 mg/m3 (Worli Naka) to 11.1 µg/m3 (VT station) and maximum values ranged from 7 mg/m3 (Nana Chowk) to 15.6 mg/m3 (Mahim).

CO was also measured during the Vikram Ispat Ltd. Salav project south of Bombay in the period January 1991–June 1992. The values usually ranged from 0.3 mg/m3 to 0.5 mg/m3, and only a few 8 hour values were above 1 mg/m3. These values seem to represent ambient background levels.

*Ozone ($O_3$).* Ozone is not measured in Bombay. Some monitoring should be started to identify the levels of ambient urban $O_3$ in and near Bombay.

*Ammonia ($NH_3$).* Ammonia is routinely measured at the MCGB sites, but information about the results are very limited. The April 1992 report shows mean values between 37 $\mu g/m^3$ and 97 $\mu g/m^3$ and maximum values between 44 $\mu g/m^3$ and 168 $\mu g/m^3$. The highest observed 24 hour maximum $NH_3$ value was 1 995 $\mu g/m^3$ at the Maravali station in 1985. There is no available information on $NH_3$ standards.

Air quality data at 7 stations around the Thal RCF Complex in 1991 and 1992 show mean $NH_3$ values ranging from 5.5 $\mu g/m^3$ to 46.7 $\mu g/m^3$. Maximum 8 hour values ranged from 15 $\mu g/m^3$ to 233 $\mu g/m^3$. These values are somewhat lower than in the Greater Bombay area.

*Benzo(a)pyrenes.* Occasionally samples of total and respirable TSP are taken at traffic junctions with heavy traffic. The level of benzo(a)pyrenes from total TSP ranges between 2.7 $\mu g/m^3$ and 13 $\mu g/m^3$, and the level of benzo(a)pyrenes from respirable TSP ranges between 2.3 $\mu g/m^3$ and 8.4 $\mu g/m^3$. There are no information on standards for benzo(a)pyrenes, but the measured levels seem to be quite high.

## REFERENCES

Sharma, V.K. and R. S. Patil. (1991). "In situ Measurements of Atmospheric Aerosols in an Industrial Region of Bombay." *Journal of Aerosol Science.* 22:501–507.

Sharma, V.K. and R. S. Patil. (1992). "Size Distribution of Atmospheric Aerosols and their Source Identification using Factor Analysis in Bombay, India." *Atmospheric Environment.* 26B: 135–140.

Sharma, V.K. and R.S. Patil. (1992). "Chemical Composition and Source Identification of Bombay Aerosol." *Environmental Technology.* 13:1043–1045.

# ANNEX I
# INTERCOMPARISON OF GRAVIMETRIC WEIGHING ANALYSIS OF GLASS-FIBRE HIGH-VOLUME FILTERS BETWEEN MCGB AND NILU LABORATORIES

NORSK INSTITUTT FOR LUFTFORSKNING - NORWEGIAN INSTITUTE FOR AIR RESEARCH
POSTBOKS 64, N-2001 LILLESTRØM

NILU

Office of the Dy. City Engineer (Civil)
Env. Sanitation & Projects
New Transport Garage Bldg. 3rd Floor
Dr. E. Moses Rd.
Worli
BOMBAY 400 018
INDIA

Att.: Mr. V.S. Mahajan, Dy. City Engineer

| Deres ref./*Your ref.*: | Vår ref./*Our ref.*: | Dato/*Date:* |
|---|---|---|
| | STL/EMN/O-92117 | 20 August 1993 |

*Dear Sir,*

with reference to your letter of 4 May this year I hereby enclose Tables and Figures giving the results of our comparison of weighing results on the High volume sampler filters performed by your laboratory, and by NILU, as also handed over to you in Bombay on 4 August.

The comparison of weighing results comes out quite favourably. The results show the following main features:

- The weights recorded at your laboratory are on the average about 4 mg higher than those recorded at NILU, varying between -15 mg and +11 mg
- The net weights recorded at NILU were also on the average somewhat higher than recorded by MCGB. NILU net weights were on the average 4.9% higher than MCGB net weights (for 6 samples), varying between +15.3% and -8.8%.
- Comparison of results from co-located samplers, one with MCGB filter paper, and one with Whatman GF/A filter paper (used by NILU) show that the MCGB filters give somewhat higher concentrations.
  This is an interesting result. The reason for this effect cannot be determined from this experiment. It may possibly be connected with irreversible absorption of water wapor in the MCGB filters, or to loss of fibers from the Whatman filters.

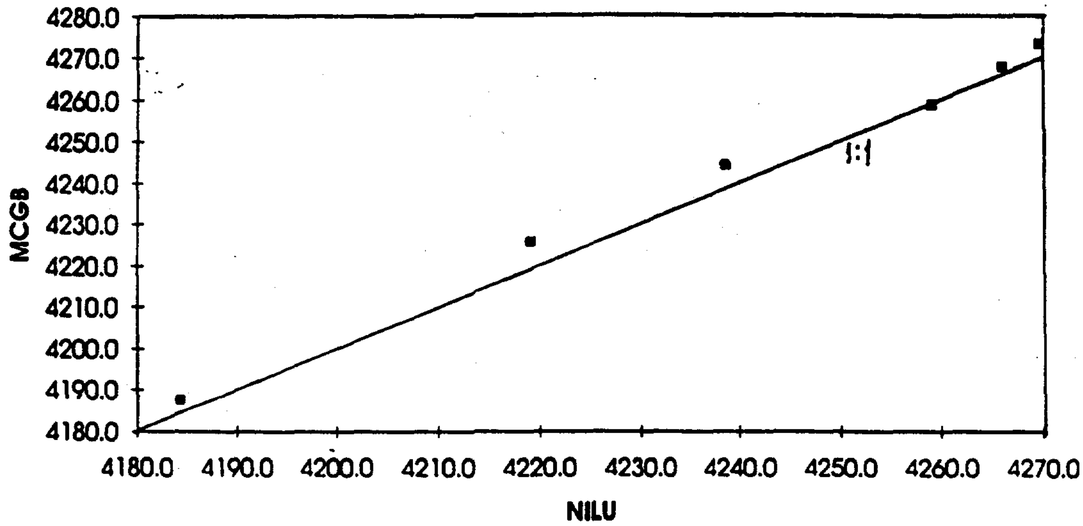
The results from this limited experiment supports the good quality of the particle weight data given by your laboratory.

Sincerely yours,

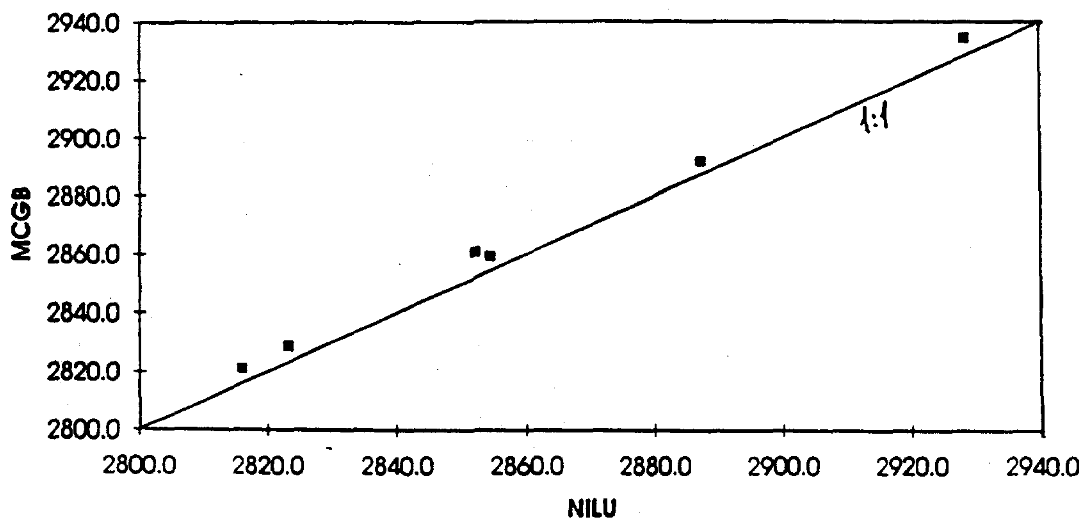
Steinar Larssen
Head of department
LOCAL AIR QUALITY

| BOMBAY TSP, Test filters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Weight before | | Weight after | | Net weight, mg | | m³ | µg/m3 | Station |
| Filter no. | NILU | MCGB | NILU | MCGB | NILU | MCGB | | MCGB | |
| 1 | 4219.1 | 4225.6 | 4308.3 | 4309.2 | 89.2 | 83.6 | 303.6 | 275 | SION |
| 2 | 4184.3 | 4187.5 | 4250.7 | 4247.8 | 66.4 | 60.3 | 331.2 | 182 | SION |
| 3 | 4259.1 | 4259.0 | 4369.1 | 4354.4 | 110.0 | 95.4 | 393.6 | 242 | JOGESHWARI |
| 4 | 4269.6 | 4273.3 | 4355.1 | 4367.0 | 85.5 | 93.7 | 412.8 | 227 | JOGESHWARI |
| 5 | 4266.0 | 4267.9 | 4397.6 | 4397.9 | 131.6 | 130.0 | 379.2 | 343 | MARAVLI |
| 6 | 4238.6 | 4244.4 | 4328.9 | 4330.2 | 90.3 | 85.8 | 379.2 | 226 | MARAVLI |
| 7 | 4245.3 | 4253.4 | 4249.8 | | 4.5 | | | | unexposed |
| 8 | 4202.8 | 4213.7 | 4210.9 | | 8.1 | | | | • |
| 9 | 4224.3 | 4234.5 | 4232.7 | | 8.4 | | | | • |
| 10 | 4228.8 | 4236.5 | 4234.3 | | 5.5 | | | | • |
| | | | | | | | | | |
| K-488 | | 2712.8 | 2854.4 | 2859.4 | | 146.6 | 493.5 | 297 | JOGESHWARI |
| K-489 | | 2708.9 | 2815.9 | 2821.3 | | 112.4 | 528.0 | 213 | JOGESHWARI |
| K-500 | | 2735.9 | 2928.0 | 2934.8 | | 198.9 | 475.2 | 419 | MARAVLI |
| K-501 | | 2733.3 | 2852.1 | 2860.9 | | 127.6 | 480.0 | 266 | MARAVLI |
| K-506 | | 2742.6 | 2887.1 | 2892.2 | | 149.6 | 435.6 | 343 | SION |
| K-507 | | 2740.0 | 2823.1 | 2828.8 | | 88.8 | 480.0 | 185 | SION |
| K-544 | | | 2762.0 | 2766.9 | | | | | unexposed |
| K-545 | | | 2753.3 | 2756.5 | | | | | • |

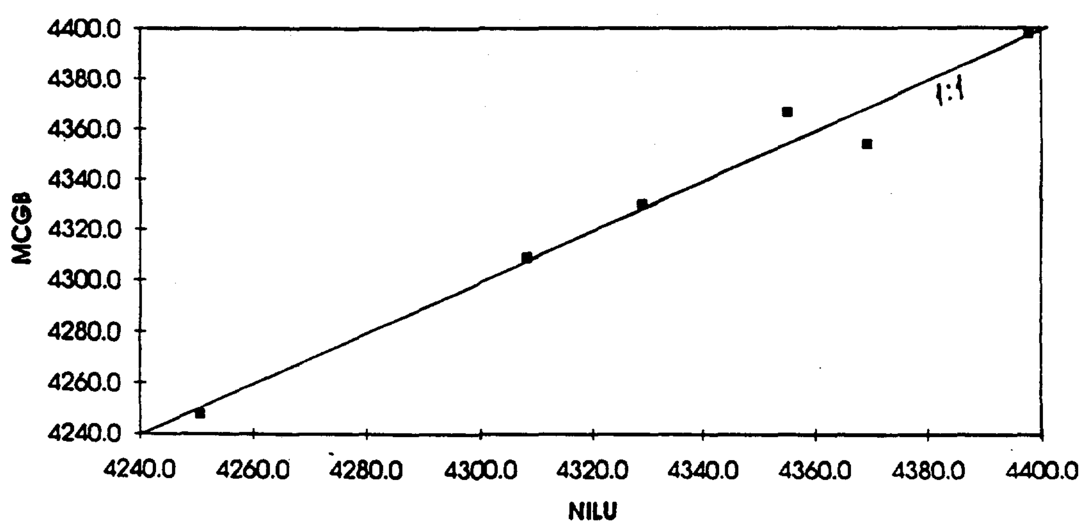
Weight before, filter 1 - 6

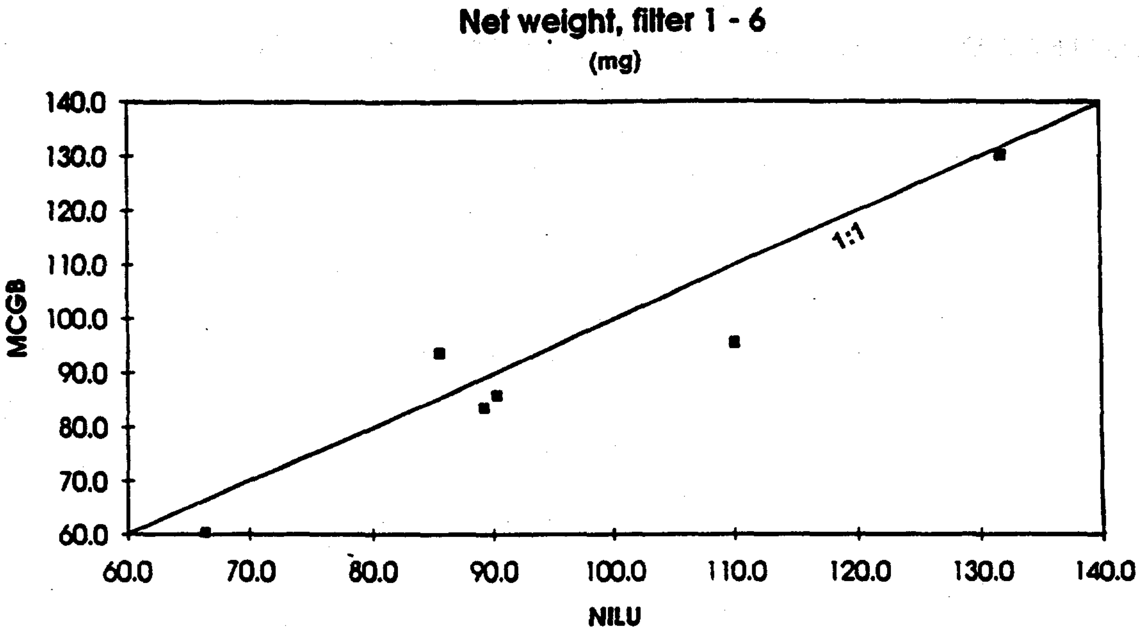


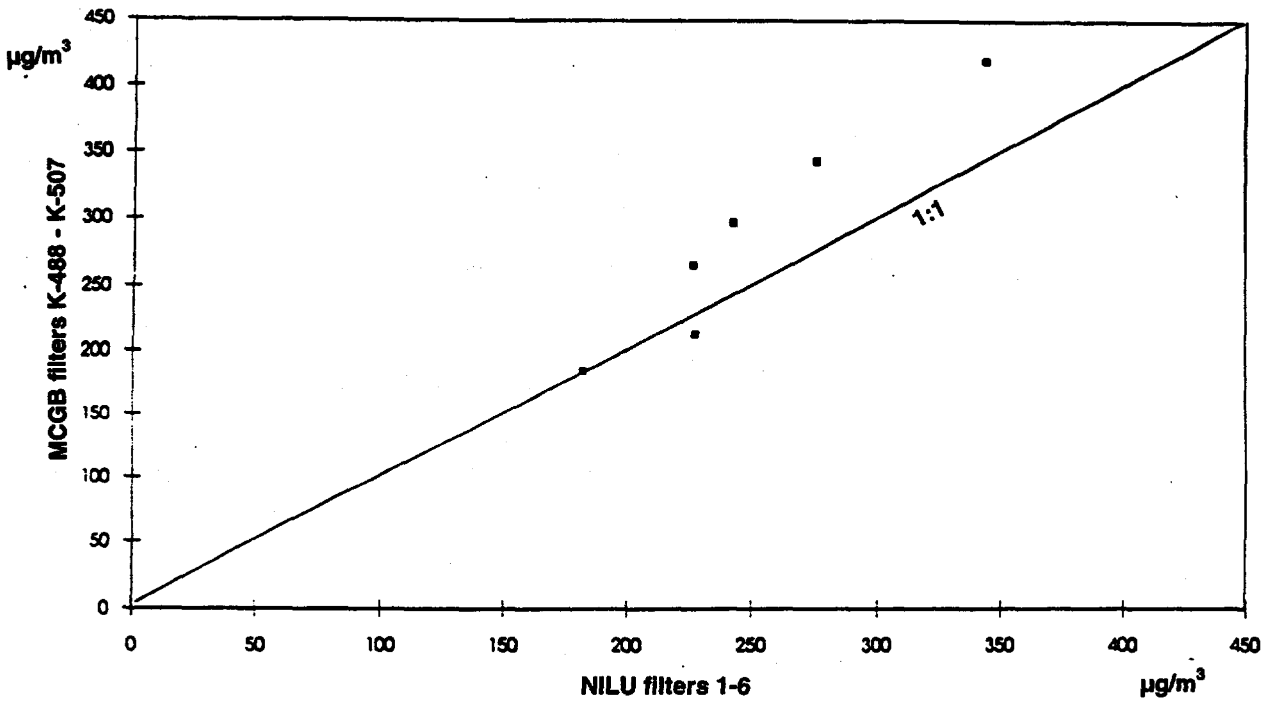

Weight after, filter K-488, K-489, K-500, K-501, K-506 and K-507




Weight after, filter 1 - 6




Net weight, filter 1 - 6
(mg)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
MCGB
1:1
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
NILU


µg/m³
450
400
350
300
250
200
150
100
50
0
MCGB filters K-488 - K-507
1:1
0
50
100
150
200
250
300
350
400
450
NILU filters 1-6
µg/m³

# ANNEX II
# MONTHLY AVERAGES FOR $SO_2$, TSP, $NO_X$ AND $NH_3$, MCGB SITES, FOR THE PERIOD 1978–1990

*Ambient Air Quality in Bombay Station: Colaba (A1)*

**Units**: μg/m³

| January | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1981 | 36 | 159 | 42 | |
| 1982 | 44 | 157 | 56 | |
| 1983 | 105 | 249 | 69 | |
| 1984 | 69 | 195 | 93 | |
| 1985 | 50 | 216 | 50 | |
| 1986 | 39 | 264 | 64 | 96 |
| 1987 | 12 | 235 | 64 | 131 |
| 1988 | 21 | 240 | 93 | 64 |
| 1989 | 13 | 238 | 87 | 68 |
| 1990 | 26 | 299 | 93 | 70 |

| February | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1981 | 70 | 283 | 55 | |
| 1982 | 35 | 143 | 33 | |
| 1983 | 31 | 142 | 44 | |
| 1984 | 73 | 211 | 77 | |
| 1985 | 49 | 218 | 63 | |
| 1986 | 13 | 210 | 71 | 82 |
| 1987 | 12 | 297 | 60 | 171 |
| 1988 | 21 | 302 | 68 | 88 |
| 1989 | 16 | 273 | 74 | 70 |
| 1990 | | | | |

| March | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1981 | | | | |
| 1982 | 30 | 132 | 39 | |
| 1983 | 17 | 137 | 21 | |
| 1984 | 31 | 241 | 48 | |
| 1985 | 25 | 233 | 32 | 87 |
| 1986 | 20 | 225 | 43 | 87 |
| 1987 | 8 | 271 | 32 | 108 |
| 1988 | 8 | 227 | 40 | 67 |
| 1989 | 9 | 260 | 53 | 35 |
| 1990 | | | | |

| April | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1981 | | | | |
| 1982 | 9 | 95 | 11 | |
| 1983 | 21 | 133 | 19 | |
| 1984 | 9 | 175 | 37 | |
| 1985 | 35 | 205 | 29 | 52 |
| 1986 | 17 | 154 | 39 | 96 |
| 1987 | 10 | 240 | 35 | 90 |
| 1988 | 11 | 225 | 17 | 54 |
| 1989 | 10 | 174 | 29 | 67 |
| 1990 | | | | |

| May | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1981 | | | | |
| 1982 | 9 | 86 | 14 | |
| 1983 | 14 | 98 | 13 | |
| 1984 | 12 | 157 | 18 | |
| 1985 | 10 | 120 | 13 | 43 |
| 1986 | 16 | 205 | 27 | 72 |
| 1987 | 6 | 218 | 29 | 129 |
| 1988 | 19 | 116 | 10 | 56 |
| 1989 | 14 | 176 | 23 | 47 |
| 1990 | | | | |

| June | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1981 | | | | |
| 1982 | 13 | 89 | 10 | |
| 1983 | 15 | 90 | 12 | |
| 1984 | 9 | 91 | 10 | |
| 1985 | 6 | 82 | 11 | 23 |
| 1986 | 8 | 126 | 32 | 75 |
| 1987 | 6 | 144 | 20 | 81 |
| 1988 | 6 | 126 | 20 | 42 |
| 1989 | 6 | 112 | 18 | 29 |
| 1990 | | | | |

*Ambient Air Quality in Bombay Station: Colaba (A1)*

**Units**: μg/m³

| July | | | | |
|---|---|---|---|---|
| **Year** | **$SO_2$** | **SPM** | **$NO_x$** | **$NH_3$** |
| 1981 | 6 | 91 | 5 | |
| 1982 | 6 | 82 | 6 | |
| 1983 | 13 | 119 | 15 | |
| 1984 | 9 | 92 | 11 | |
| 1985 | 6 | 113 | 10 | 37 |
| 1986 | 7 | 151 | 14 | 64 |
| 1987 | 9 | 89 | 18 | 20 |
| 1988 | 7 | 133 | 14 | 33 |
| 1989 | 6 | 88 | 17 | 27 |
| 1990 | | | | |

| August | | | | |
|---|---|---|---|---|
| **Year** | **$SO_2$** | **SPM** | **$NO_x$** | **$NH_3$** |
| 1981 | 6 | 71 | 6 | |
| 1982 | 6 | 74 | 8 | |
| 1983 | 10 | 112 | 15 | |
| 1984 | 12 | 118 | 8 | |
| 1985 | 6 | 115 | 9 | 20 |
| 1986 | 7 | 102 | 20 | 89 |
| 1987 | 6 | 77 | 17 | 74 |
| 1988 | 6 | 106 | 10 | 32 |
| 1989 | 6 | 66 | 14 | 30 |
| 1990 | | | | |

| September | | | | |
|---|---|---|---|---|
| **Year** | **$SO_2$** | **SPM** | **$NO_x$** | **$NH_3$** |
| 1981 | 22 | 83 | 17 | |
| 1982 | 7 | 74 | 14 | |
| 1983 | 11 | 105 | 12 | |
| 1984 | 17 | 90 | 29 | |
| 1985 | | | | |
| 1986 | 7 | 115 | 29 | 82 |
| 1987 | 19 | 81 | 32 | 52 |
| 1988 | 8 | 62 | 29 | 22 |
| 1989 | 12 | 95 | 29 | 25 |
| 1990 | | | | |

| October | | | | |
|---|---|---|---|---|
| **Year** | **$SO_2$** | **SPM** | **$NO_x$** | **$NH_3$** |
| 1981 | 48 | 99 | 35 | |
| 1982 | 52 | 128 | 61 | |
| 1983 | 19 | 134 | 30 | |
| 1984 | 33 | 131 | 51 | |
| 1985 | 27 | 149 | 27 | 55 |
| 1986 | 6 | 158 | 30 | 20 |
| 1987 | 6 | 154 | 35 | 78 |
| 1988 | 12 | 188 | 69 | 31 |
| 1989 | 13 | 133 | 42 | 44 |
| 1990 | | | | |

| November | | | | |
|---|---|---|---|---|
| **Year** | **$SO_2$** | **SPM** | **$NO_x$** | **$NH_3$** |
| 1981 | 58 | 105 | 48 | |
| 1982 | 49 | 113 | 58 | |
| 1983 | 57 | 227 | 74 | |
| 1984 | 57 | 160 | 62 | |
| 1985 | 50 | 219 | 40 | 110 |
| 1986 | 14 | 284 | 52 | 178 |
| 1987 | 10 | 242 | 71 | 68 |
| 1988 | 13 | 215 | 89 | 24 |
| 1989 | 22 | 178 | 61 | 78 |
| 1990 | | | | |

| December | | | | |
|---|---|---|---|---|
| **Year** | **$SO_2$** | **SPM** | **$NO_x$** | **$NH_3$** |
| 1981 | 72 | 193 | 56 | |
| 1982 | 71 | 233 | 60 | |
| 1983 | 71 | 206 | 92 | |
| 1984 | 68 | 210 | 76 | |
| 1985 | 41 | 234 | 45 | 35 |
| 1986 | 10 | 269 | 77 | 152 |
| 1987 | 9 | 313 | 60 | 66 |
| 1988 | 28 | 214 | 57 | 28 |
| 1989 | 24 | 209 | 70 | 82 |
| 1990 | | | | |

***Ambient Air Quality in Bombay Station: Babula Tank (A2)***

**Units**: µg/m³

January

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 112 | 548 | 49 | |
| 1981 | 95 | 328 | 60 | |
| 1982 | 11 | 274 | 39 | |
| 1983 | 213 | 380 | 92 | |
| 1984 | 109 | 298 | 95 | |
| 1985 | 88 | 323 | 56 | |
| 1986 | 56 | 521 | 68 | 158 |
| 1987 | 66 | 388 | 92 | 125 |
| 1988 | 26 | 476 | 90 | 92 |
| 1989 | 27 | 400 | 94 | 74 |
| 1990 | 20 | 458 | 101 | |

February

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 70 | 283 | 55 | |
| 1982 | 35 | 143 | 33 | |
| 1983 | 31 | 142 | 44 | |
| 1984 | 73 | 211 | 77 | |
| 1985 | 49 | 218 | 63 | |
| 1986 | 13 | 210 | 71 | 82 |
| 1987 | 12 | 297 | 60 | 171 |
| 1988 | 21 | 302 | 68 | 88 |
| 1989 | 16 | 273 | 74 | 70 |
| 1990 | | | | |

March

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | | | | |
| 1982 | 30 | 132 | 39 | |
| 1983 | 17 | 137 | 21 | |
| 1984 | 31 | 241 | 48 | |
| 1985 | 25 | 233 | 32 | 67 |
| 1986 | 20 | 225 | 43 | 87 |
| 1987 | 8 | 271 | 32 | 108 |
| 1988 | 8 | 227 | 40 | 67 |
| 1989 | 9 | 260 | 53 | 35 |
| 1990 | | | | |

April

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | | | | |
| 1982 | 9 | 95 | 11 | |
| 1983 | 21 | 133 | 19 | |
| 1984 | 9 | 175 | 37 | |
| 1985 | 35 | 205 | 29 | 52 |
| 1986 | 17 | 154 | 39 | 96 |
| 1987 | 10 | 240 | 35 | 90 |
| 1988 | 11 | 225 | 17 | 54 |
| 1989 | 10 | 174 | 29 | 67 |
| 1990 | | | | |

May

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | | | | |
| 1982 | 9 | 86 | 14 | |
| 1983 | 14 | 98 | 13 | |
| 1984 | 12 | 157 | 18 | |
| 1985 | 10 | 120 | 13 | 43 |
| 1986 | 16 | 205 | 27 | 72 |
| 1987 | 6 | 218 | 29 | 129 |
| 1988 | 19 | 116 | 10 | 56 |
| 1989 | 14 | 176 | 23 | 47 |
| 1990 | | | | |

June

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | | | | |
| 1982 | 13 | 89 | 10 | |
| 1983 | 15 | 90 | 12 | |
| 1984 | 9 | 91 | 10 | |
| 1985 | 6 | 82 | 11 | 23 |
| 1986 | 8 | 126 | 32 | 75 |
| 1987 | 6 | 144 | 20 | 81 |
| 1988 | 6 | 126 | 20 | 42 |
| 1989 | 6 | 112 | 18 | 29 |
| 1990 | | | | |

***Ambient Air Quality in Bombay Station: Babula Tank (A2)***

Units: µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 6 | 91 | 5 | |
| 1982 | 6 | 82 | 6 | |
| 1983 | 13 | 119 | 15 | |
| 1984 | 9 | 92 | 11 | |
| 1985 | 6 | 113 | 10 | 37 |
| 1986 | 7 | 151 | 14 | 64 |
| 1987 | 9 | 89 | 18 | 20 |
| 1988 | 7 | 133 | 14 | 33 |
| 1989 | 6 | 88 | 17 | 27 |
| 1990 | | | | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 6 | 71 | 6 | |
| 1982 | 6 | 74 | 8 | |
| 1983 | 10 | 112 | 15 | |
| 1984 | 12 | 118 | 8 | |
| 1985 | 6 | 115 | 9 | 20 |
| 1986 | 7 | 102 | 20 | 89 |
| 1987 | 6 | 77 | 17 | 74 |
| 1988 | 6 | 106 | 10 | 32 |
| 1989 | 6 | 66 | 14 | 30 |
| 1990 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 22 | 83 | 17 | |
| 1982 | 7 | 74 | 14 | |
| 1983 | 11 | 105 | 12 | |
| 1984 | 17 | 90 | 29 | |
| 1985 | | | | |
| 1986 | 7 | 115 | 29 | 82 |
| 1987 | 19 | 81 | 32 | 52 |
| 1988 | 8 | 62 | 29 | 22 |
| 1989 | 12 | 95 | 29 | 25 |
| 1990 | | | | |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 48 | 99 | 35 | |
| 1982 | 52 | 128 | 61 | |
| 1983 | 19 | 134 | 30 | |
| 1984 | 33 | 131 | 51 | |
| 1985 | 27 | 149 | 27 | 55 |
| 1986 | 6 | 158 | 30 | 20 |
| 1987 | 6 | 154 | 35 | 78 |
| 1988 | 12 | 188 | 69 | 31 |
| 1989 | 13 | 133 | 42 | 44 |
| 1990 | | | | |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 58 | 105 | 48 | |
| 1982 | 49 | 113 | 58 | |
| 1983 | 57 | 227 | 74 | |
| 1984 | 57 | 160 | 62 | |
| 1985 | 50 | 219 | 40 | 110 |
| 1986 | 14 | 284 | 52 | 178 |
| 1987 | 10 | 242 | 71 | 68 |
| 1988 | 13 | 215 | 89 | 24 |
| 1989 | 22 | 178 | 61 | 78 |
| 1990 | | | | |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 72 | 193 | 56 | |
| 1982 | 71 | 233 | 60 | |
| 1983 | 71 | 206 | 92 | |
| 1984 | 68 | 210 | 76 | |
| 1985 | 41 | 234 | 45 | 35 |
| 1986 | 10 | 269 | 77 | 152 |
| 1987 | 9 | 313 | 60 | 66 |
| 1988 | 28 | 214 | 57 | 28 |
| 1989 | 24 | 209 | 70 | 82 |
| 1990 | | | | |

## *Ambient Air Quality in Bombay Station: Worli-Nak (A3)*

**Units:** µg/m³

January

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 119 | 284 | 49 | |
| 1982 | 92 | 213 | 49 | |
| 1983 | 135 | 365 | 51 | |
| 1984 | 108 | 374 | 55 | |
| 1985 | 109 | 273 | 5 | 241 |
| 1986 | 65 | 418 | 65 | 178 |
| 1987 | 36 | 400 | 77 | 140 |
| 1988 | 40 | 364 | 108 | 113 |
| 1989 | 27 | 400 | 102 | 98 |
| 1990 | 73 | 444 | 119 | |

February

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 77 | 345 | 44 | |
| 1982 | 40 | 250 | 25 | |
| 1983 | 79 | 299 | 31 | |
| 1984 | 132 | 324 | 52 | |
| 1985 | 61 | 245 | 84 | 85 |
| 1986 | 37 | 398 | 52 | 44 |
| 1987 | 19 | 310 | 64 | 170 |
| 1988 | 41 | 334 | 95 | 74 |
| 1989 | 12 | 246 | 67 | 80 |
| 1990 | 45 | 311 | 87 | |

March

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 66 | 264 | 29 | |
| 1982 | 39 | 303 | 32 | |
| 1983 | 36 | 304 | 25 | |
| 1984 | 95 | 305 | 48 | |
| 1985 | 72 | 376 | 76 | 20 |
| 1986 | 22 | 233 | 40 | 50 |
| 1987 | 16 | 278 | 49 | 95 |
| 1988 | 37 | 318 | 58 | 40 |
| 1989 | 10 | 277 | 57 | 23 |
| 1990 | 35 | 247 | 53 | |
| 1991 | | | | |

April

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | | | | |
| 1982 | 55 | 304 | 18 | |
| 1983 | 17 | 211 | 13 | |
| 1984 | 56 | 228 | 18 | |
| 1985 | 41 | 245 | 28 | 102 |
| 1986 | 42 | 236 | 38 | 103 |
| 1987 | 26 | 235 | 28 | 114 |
| 1988 | 8 | 205 | 35 | 50 |
| 1989 | 32 | 278 | 40 | 78 |
| 1990 | 19 | 267 | 66 | |
| 1991 | 10 | 214 | 28 | |

May

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | 180 | 11 | |
| 1981 | 20 | 202 | 8 | |
| 1982 | 12 | 225 | 16 | |
| 1983 | 43 | 190 | 17 | |
| 1984 | 15 | 264 | 9 | |
| 1985 | 21 | 153 | 21 | 37 |
| 1986 | 20 | 239 | 24 | 64 |
| 1987 | 9 | 202 | 28 | 69 |
| 1988 | 40 | 231 | 25 | 63 |
| 1989 | | | | |
| 1990 | 10 | 178 | 24 | |

June

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 22 | 171 | 17 | |
| 1981 | 38 | 247 | 8 | |
| 1982 | 22 | 171 | 10 | |
| 1983 | 80 | 154 | 17 | |
| 1984 | 45 | 162 | 10 | |
| 1985 | 8 | 236 | 16 | 28 |
| 1986 | 11 | 206 | 18 | 73 |
| 1987 | 7 | 216 | 26 | 51 |
| 1988 | 11 | 206 | 34 | 64 |
| 1989 | | | | |
| 1990 | 6 | 215 | 18 | |

***Ambient Air Quality in Bombay Station: Worli-Nak (A3)***

**Units**: µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 179 | 148 | 6 | |
| 1981 | 51 | 163 | 11 | |
| 1982 | 14 | 148 | 9 | |
| 1983 | 40 | 131 | 17 | |
| 1984 | 88 | 130 | 10 | |
| 1985 | 7 | 189 | 11 | 38 |
| 1986 | 7 | 217 | 14 | 61 |
| 1987 | 13 | 186 | 28 | 44 |
| 1988 | 6 | 146 | 23 | 38 |
| 1989 | | | | |
| 1990 | 6 | 160 | 15 | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 21 | 198 | 5 | |
| 1981 | 49 | 163 | 7 | |
| 1982 | 11 | 91 | 10 | |
| 1983 | 39 | 68 | 17 | |
| 1984 | 164 | 167 | 17 | |
| 1985 | 6 | 210 | 13 | 29 |
| 1986 | 28 | 172 | 18 | 79 |
| 1987 | 12 | 143 | 33 | 95 |
| 1988 | 6 | 153 | 24 | 28 |
| 1989 | | | | |
| 1990 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 43 | 143 | 9 | |
| 1981 | 79 | 126 | 23 | |
| 1982 | 17 | 108 | 16 | |
| 1983 | 46 | 115 | 14 | |
| 1984 | 49 | 158 | 17 | |
| 1985 | 41 | 176 | 25 | 45 |
| 1986 | 22 | 193 | 31 | 58 |
| 1987 | 8 | 167 | 31 | 95 |
| 1988 | 13 | 129 | 47 | 30 |
| 1989 | | | | |
| 1990 | | | | |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 74 | 272 | 16 | |
| 1981 | 118 | 150 | 33 | |
| 1982 | 77 | 257 | 56 | |
| 1983 | 92 | | 31 | |
| 1984 | 28 | 201 | 19 | |
| 1985 | 69 | 243 | 42 | 86 |
| 1986 | 40 | 309 | 58 | 128 |
| 1987 | 19 | 221 | 51 | 114 |
| 1988 | 57 | 272 | 82 | 42 |
| 1989 | | | | |
| 1990 | | | | |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 106 | 281 | 48 | |
| 1981 | 141 | 247 | 48 | |
| 1982 | 135 | 159 | 79 | |
| 1983 | 104 | 369 | 77 | |
| 1984 | 73 | 226 | | |
| 1985 | 81 | 370 | 46 | 191 |
| 1986 | 95 | 345 | 70 | 79 |
| 1987 | 51 | 352 | 94 | 109 |
| 1988 | 70 | 300 | 95 | 73 |
| 1989 | | | | |
| 1990 | | | | |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 176 | 341 | 48 | |
| 1981 | 172 | 336 | 48 | |
| 1982 | 92 | 283 | 79 | |
| 1983 | 141 | 372 | 77 | |
| 1984 | | | | |
| 1985 | 47 | 366 | 46 | 139 |
| 1986 | 53 | 376 | 70 | 165 |
| 1987 | 47 | 355 | 94 | 128 |
| 1988 | 53 | 371 | 95 | 98 |
| 1989 | | | | |
| 1990 | | | | |

*Ambient Air Quality in Bombay Station: Dadar (A4)*

Units: µg/m³

**January**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 44 | 294 | 29 | |
| 1981 | 59 | 245 | 46 | |
| 1982 | 45 | 212 | 47 | |
| 1983 | 58 | 333 | 50 | |
| 1984 | 65 | 232 | 73 | |
| 1985 | 56 | 327 | 74 | |
| 1986 | 50 | 323 | 67 | 116 |
| 1987 | 21 | 371 | 69 | 158 |
| 1988 | 22 | 413 | 97 | 63 |
| 1989 | 34 | 355 | 70 | 67 |
| 1990 | 33 | 411 | 88 | |

**February**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 46 | 453 | 30 | |
| 1981 | 40 | 317 | 43 | |
| 1982 | 40 | 227 | 40 | |
| 1983 | 32 | 262 | 38 | |
| 1984 | 55 | 250 | 61 | |
| 1985 | 44 | 290 | 62 | |
| 1986 | 34 | 338 | 68 | 51 |
| 1987 | 14 | 350 | 45 | 108 |
| 1988 | 27 | 347 | 68 | 75 |
| 1989 | 31 | 331 | 64 | 78 |
| 1990 | 39 | 366 | 94 | |

**March**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 51 | 339 | 32 | |
| 1981 | 40 | 217 | 33 | |
| 1982 | 28 | 255 | 41 | |
| 1983 | 12 | 221 | 26 | |
| 1984 | 63 | 220 | 56 | |
| 1985 | 63 | 283 | 47 | 23 |
| 1986 | 36 | 315 | 42 | 72 |
| 1987 | 14 | 294 | 37 | 104 |
| 1988 | 15 | 322 | 41 | 56 |
| 1989 | 13 | 267 | 37 | 46 |
| 1990 | 9 | 202 | 47 | |

**April**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 37 | 241 | 20 | |
| 1980 | 44 | 216 | 18 | |
| 1981 | 27 | 211 | 22 | |
| 1982 | 16 | 145 | 21 | |
| 1983 | 27 | 158 | 28 | |
| 1984 | 21 | 214 | 31 | |
| 1985 | 22 | 200 | 27 | 40 |
| 1986 | 39 | 253 | 43 | 157 |
| 1987 | 8 | 205 | 26 | 720 |
| 1988 | 20 | 285 | 23 | 75 |
| 1989 | 17 | 258 | 31 | 74 |
| 1990 | 9 | 176 | 28 | |

**May**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 26 | 243 | 20 | |
| 1980 | 20 | 104 | 11 | |
| 1981 | 11 | 125 | 14 | |
| 1982 | 17 | 129 | 18 | |
| 1983 | 26 | 112 | 22 | |
| 1984 | 12 | 163 | 21 | |
| 1985 | 38 | 173 | 22 | 178 |
| 1986 | 36 | 373 | 21 | 20 |
| 1987 | 13 | 231 | 22 | 86 |
| 1988 | 20 | 180 | 15 | 62 |
| 1989 | 17 | 238 | 28 | 30 |
| 1990 | 7 | 161 | 19 | |

**June**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 18 | 195 | 15 | |
| 1980 | 21 | 115 | 22 | |
| 1981 | 19 | 137 | 9 | |
| 1982 | 18 | 128 | 12 | |
| 1983 | 35 | 138 | 21 | |
| 1984 | 55 | 121 | 20 | |
| 1985 | 29 | 139 | 18 | 50 |
| 1986 | 60 | 190 | 26 | 48 |
| 1987 | 11 | 190 | 32 | 55 |
| 1988 | 10 | 146 | 22 | 36 |
| 1989 | 22 | 1278 | 22 | 46 |
| 1990 | 7 | 164 | 31 | |

### *Ambient Air Quality in Bombay Station: Dadar (A4)*

Units: µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 33 | 150 | 15 | |
| 1980 | 105 | 176 | 7 | |
| 1981 | 36 | 116 | 14 | |
| 1982 | 12 | 108 | 16 | |
| 1983 | 26 | 223 | 20 | |
| 1984 | 42 | 131 | 16 | |
| 1985 | 44 | 136 | 18 | 60 |
| 1986 | 19 | 162 | 20 | 71 |
| 1987 | 13 | 141 | 21 | 60 |
| 1988 | 9 | 146 | 25 | 28 |
| 1989 | 23 | 116 | 29 | 42 |
| 1990 | 9 | 131 | 21 | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 42 | 154 | 11 | |
| 1981 | 41 | 135 | 8 | |
| 1982 | 36 | 100 | 12 | |
| 1983 | 7 | 93 | 12 | |
| 1984 | 30 | 99 | 28 | |
| 1985 | 66 | 177 | 18 | |
| 1986 | 41 | 165 | 24 | 30 |
| 1987 | 11 | 99 | 25 | 86 |
| 1988 | 8 | 99 | 25 | 73 |
| 1989 | 15 | 141 | 20 | 25 |
| 1990 | 17 | 87 | 21 | 22 |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 52 | 128 | 19 | |
| 1980 | 45 | 70 | 11 | |
| 1981 | 46 | 101 | 21 | |
| 1982 | 19 | 90 | 24 | |
| 1983 | 39 | 121 | 29 | |
| 1984 | 35 | 99 | 32 | |
| 1985 | | | | |
| 1986 | 11 | 125 | 30 | 78 |
| 1987 | 12 | 157 | 36 | 100 |
| 1988 | 22 | 87 | 28 | 26 |
| 1989 | 42 | 97 | 31 | 41 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 58 | 279 | 27 | |
| 1980 | 23 | 191 | 19 | |
| 1981 | 65 | 144 | 33 | |
| 1982 | 48 | 227 | 65 | |
| 1983 | 33 | 184 | 40 | |
| 1984 | 31 | 193 | 45 | |
| 1985 | 44 | 195 | 32 | 100 |
| 1986 | 34 | 300 | 48 | 107 |
| 1987 | 17 | 266 | 52 | 100 |
| 1988 | 26 | 368 | 55 | 34 |
| 1989 | 48 | 195 | 45 | 87 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 62 | 169 | 28 | |
| 1980 | 68 | 256 | 31 | |
| 1981 | 76 | 161 | 43 | |
| 1982 | 34 | 163 | 46 | |
| 1983 | 69 | 229 | 74 | |
| 1984 | 61 | 244 | 65 | |
| 1985 | 51 | 298 | 38 | 161 |
| 1986 | 31 | 298 | 53 | 101 |
| 1987 | 14 | 276 | 57 | 71 |
| 1988 | 39 | 378 | 53 | 29 |
| 1989 | 40 | 291 | 72 | 195 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 51 | 226 | 32 | |
| 1980 | 53 | 297 | 42 | |
| 1981 | 69 | 201 | 43 | |
| 1982 | 63 | 269 | 71 | |
| 1983 | 114 | 317 | 97 | |
| 1984 | 48 | 270 | 58 | |
| 1985 | 31 | 319 | 39 | 113 |
| 1986 | 31 | 361 | 43 | 99 |
| 1987 | 20 | 322 | 78 | 43 |
| 1988 | | | | |
| 1989 | 42 | 351 | 82 | 197 |

*Ambient Air Quality in Bombay Station: Parel (A5)*

**Units:** µg/m³

| January | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 158 | 348 | 42 | |
| 1979 | 100 | 346 | 10 | |
| 1980 | 109 | 291 | 33 | |
| 1981 | 84 | 247 | 49 | |
| 1982 | 75 | 318 | 43 | |
| 1983 | 98 | 330 | 26 | |
| 1984 | 84 | 418 | 101 | |
| 1985 | | | | |
| 1986 | 44 | 463 | 63 | 239 |
| 1987 | 29 | 476 | 90 | 166 |
| 1988 | 33 | 509 | 103 | 108 |
| 1989 | 36 | 426 | 57 | 130 |
| 1990 | 56 | 315 | 123 | |

| February | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 141 | 217 | 34 | |
| 1979 | 122 | 314 | 13 | |
| 1980 | 105 | 349 | 35 | |
| 1981 | 154 | 339 | 53 | |
| 1982 | 75 | 315 | 28 | |
| 1983 | 52 | 322 | 41 | |
| 1984 | 79 | 438 | 80 | |
| 1985 | | | | |
| 1986 | 31 | 507 | 64 | 67 |
| 1987 | 18 | 483 | 83 | 177 |
| 1988 | 57 | 575 | 85 | 47 |
| 1989 | 37 | 487 | 66 | 101 |
| 1990 | 33 | 432 | 92 | |

| March | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 94 | 318 | 32 | |
| 1979 | 99 | 308 | 9 | |
| 1980 | 123 | 353 | 30 | |
| 1981 | 99 | 234 | 39 | |
| 1982 | 57 | 246 | 35 | |
| 1983 | 30 | 278 | 37 | |
| 1984 | 130 | 307 | 73 | |
| 1985 | | | | |
| 1986 | 29 | 413 | 47 | 65 |
| 1987 | 20 | 438 | 52 | 123 |
| 1988 | 42 | 487 | 56 | 73 |
| 1989 | 37 | 420 | 48 | 54 |
| 1990 | 31 | 355 | 63 | |

| April | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 85 | 222 | 12 | |
| 1979 | 76 | 328 | 23 | |
| 1980 | 84 | 249 | 21 | |
| 1981 | 89 | 251 | 22 | |
| 1982 | | | | |
| 1983 | 61 | 173 | 18 | |
| 1984 | 56 | 272 | 37 | |
| 1985 | 72 | 266 | 37 | 83 |
| 1986 | 46 | 318 | 45 | 85 |
| 1987 | 24 | 372 | 48 | 105 |
| 1988 | 42 | 369 | 30 | 71 |
| 1989 | 38 | 277 | 36 | 91 |
| 1990 | 24 | 288 | 38 | |

| May | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 65 | 184 | 5 | |
| 1979 | 126 | 301 | 19 | |
| 1980 | 86 | 158 | 18 | |
| 1981 | 46 | 221 | 17 | |
| 1982 | 31 | 201 | 24 | |
| 1983 | 65 | 132 | 24 | |
| 1984 | 25 | 221 | 21 | |
| 1985 | 74 | 187 | 19 | 36 |
| 1986 | 27 | 322 | 35 | 68 |
| 1987 | 24 | 391 | 34 | 107 |
| 1988 | 50 | 279 | 32 | 52 |
| 1989 | 36 | 317 | 32 | 41 |
| 1990 | 28 | 297 | 33 | |

| June | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 107 | 243 | 11 | |
| 1979 | 89 | 274 | 18 | |
| 1980 | 96 | 123 | 21 | |
| 1981 | 82 | 262 | 11 | |
| 1982 | 61 | 114 | 14 | |
| 1983 | 109 | 140 | 25 | |
| 1984 | 83 | 138 | 15 | |
| 1985 | 45 | 139 | 21 | 38 |
| 1986 | 25 | 148 | 32 | 121 |
| 1987 | 30 | 223 | 37 | 65 |
| 1988 | 21 | 216 | 50 | 69 |
| 1989 | 51 | 263 | 26 | 45 |
| 1990 | 17 | 158 | 30 | |

***Ambient Air Quality in Bombay Station: Parel (A5)***

**Units:** µg/m³

July

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 164 | 211 | 6 | |
| 1979 | 49 | 241 | 15 | |
| 1980 | 64 | 133 | 8 | |
| 1981 | 41 | 156 | 12 | |
| 1982 | 48 | 154 | 16 | |
| 1983 | 56 | 160 | 22 | |
| 1984 | 82 | 160 | 24 | |
| 1985 | 28 | 131 | 14 | 26 |
| 1986 | 30 | 183 | 25 | 68 |
| 1987 | 31 | 147 | 30 | 62 |
| 1988 | 24 | 123 | 24 | 43 |
| 1989 | 27 | 143 | 19 | 52 |
| 1990 | 18 | 143 | 27 | |

August

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 91 | 277 | 5 | |
| 1979 | 41 | 246 | 14 | |
| 1980 | 72 | 107 | 6 | |
| 1981 | 54 | 234 | 15 | |
| 1982 | 18 | 126 | 11 | |
| 1983 | 54 | 169 | 24 | |
| 1984 | 81 | 160 | 23 | |
| 1985 | 63 | 163 | 27 | 52 |
| 1986 | 47 | 152 | 25 | 38 |
| 1987 | 30 | 153 | 29 | 47 |
| 1988 | 20 | 135 | 24 | 30 |
| 1989 | 52 | 128 | 25 | 33 |
| 1990 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 100 | 178 | 8 | |
| 1979 | 84 | 205 | 34 | |
| 1980 | 151 | 129 | 14 | |
| 1981 | 74 | 158 | 20 | |
| 1982 | 51 | 140 | 29 | |
| 1983 | 68 | 174 | 25 | |
| 1984 | 57 | 135 | 37 | |
| 1985 | | | | |
| 1986 | 42 | 216 | 41 | 82 |
| 1987 | 48 | 185 | 35 | 127 |
| 1988 | 36 | 128 | 32 | 30 |
| 1989 | 77 | 145 | 26 | 36 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 97 | 258 | 16 | |
| 1979 | 137 | 236 | 34 | |
| 1980 | 117 | 223 | 30 | |
| 1981 | 154 | 218 | 48 | |
| 1982 | 91 | 230 | 80 | |
| 1983 | 71 | 139 | 44 | |
| 1984 | 62 | 243 | 53 | |
| 1985 | 67 | 225 | 43 | 100 |
| 1986 | 47 | 354 | 70 | 163 |
| 1987 | 41 | 285 | 49 | 117 |
| 1988 | 37 | 302 | 43 | 94 |
| 1989 | 67 | 253 | 47 | 90 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 54 | 260 | 14 | |
| 1979 | 82 | 239 | 35 | |
| 1980 | 125 | 240 | 36 | |
| 1981 | 85 | 246 | 57 | |
| 1982 | 91 | 232 | 81 | |
| 1983 | 75 | 304 | 67 | |
| 1984 | | | | |
| 1985 | 84 | 385 | 50 | 157 |
| 1986 | 49 | 411 | 78 | 99 |
| 1987 | 21 | 479 | 61 | 209 |
| 1988 | 60 | 369 | 65 | 199 |
| 1989 | 46 | 325 | 56 | 217 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 67 | 358 | 12 | |
| 1979 | 79 | 367 | 36 | |
| 1980 | 144 | 290 | 62 | |
| 1981 | 107 | 177 | 55 | |
| 1982 | 84 | 327 | 94 | |
| 1983 | 105 | 368 | 101 | |
| 1984 | | | | |
| 1985 | 74 | 405 | 68 | 318 |
| 1986 | 29 | 426 | 104 | 290 |
| 1987 | 29 | 450 | 90 | 249 |
| 1988 | 47 | 387 | 69 | 186 |
| 1989 | 40 | 441 | 70 | 202 |

*Ambient Air Quality in Bombay Station: Sewree (A6)*

**Units**: µg/m³

**January**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 45 | 280 | 40 | |
| 1982 | 47 | 179 | 41 | |
| 1983 | 83 | 278 | 54 | |
| 1984 | 44 | 255 | 50 | |
| 1985 | 71 | 255 | 42 | 75 |
| 1986 | 52 | 276 | 52 | 162 |
| 1987 | 21 | 258 | 55 | 156 |
| 1988 | 25 | 327 | 84 | 82 |
| 1989 | 36 | 260 | 62 | 57 |
| 1990 | 30 | 326 | 71 | |

**February**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 83 | 429 | 55 | |
| 1982 | 42 | 202 | 23 | |
| 1983 | 46 | 212 | 28 | |
| 1984 | 65 | 296 | 49 | |
| 1985 | 102 | 311 | 56 | 71 |
| 1986 | 58 | 258 | 50 | 124 |
| 1987 | 18 | 296 | 55 | 156 |
| 1988 | 63 | 290 | 84 | 82 |
| 1989 | 29 | 360 | 57 | 57 |
| 1990 | 24 | 260 | 71 | |

**March**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | | | | |
| 1981 | 89 | 226 | 34 | |
| 1982 | 48 | 234 | 35 | |
| 1983 | 33 | 179 | 26 | |
| 1984 | 64 | 254 | 40 | |
| 1985 | 93 | 217 | 32 | 49 |
| 1986 | 63 | 321 | 45 | 149 |
| 1987 | 20 | 253 | 29 | 111 |
| 1988 | 51 | 247 | 43 | 46 |
| 1989 | 21 | 221 | 55 | 51 |
| 1990 | 38 | 240 | 41 | |

**April**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | | | | |
| 1981 | 49 | 244 | 22 | |
| 1982 | 33 | 136 | 11 | |
| 1983 | 50 | 168 | 19 | |
| 1984 | 43 | 223 | 22 | |
| 1985 | 112 | 142 | 24 | 65 |
| 1986 | 60 | 220 | 32 | 120 |
| 1987 | 22 | 356 | 35 | 110 |
| 1988 | 52 | 301 | 36 | 73 |
| 1989 | 33 | 221 | 36 | 69 |
| 1990 | 26 | 217 | 30 | |

**May**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 56 | 140 | 21 | |
| 1981 | 40 | 161 | 13 | |
| 1982 | 36 | 122 | 13 | |
| 1983 | 28 | 127 | 9 | |
| 1984 | 21 | 183 | 12 | |
| 1985 | 106 | 197 | 16 | 30 |
| 1986 | 49 | 216 | 19 | 75 |
| 1987 | 21 | 228 | 22 | 110 |
| 1988 | 48 | 176 | 15 | 58 |
| 1989 | 37 | 251 | 23 | 53 |
| 1990 | 14 | 92 | 15 | |

**June**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 50 | 125 | 11 | |
| 1981 | 56 | 129 | 9 | |
| 1982 | 42 | 85 | 8 | |
| 1983 | 46 | 117 | 13 | |
| 1984 | 22 | 104 | 8 | |
| 1985 | 13 | 133 | 10 | 25 |
| 1986 | 37 | 160 | 26 | 86 |
| 1987 | 18 | 152 | 22 | 69 |
| 1988 | 13 | 117 | 12 | 65 |
| 1989 | 10 | 180 | 11 | 67 |
| 1990 | 22 | 127 | 17 | |

## *Ambient Air Quality in Bombay Station: Sewree (A6)*

**Units:** $\mu g/m^3$

| July | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | | | | |
| 1980 | 110 | 176 | 9 | |
| 1981 | 33 | 115 | 13 | |
| 1982 | 36 | 76 | 8 | |
| 1983 | 13 | 107 | 13 | |
| 1984 | 57 | 101 | 11 | |
| 1985 | 29 | 130 | 13 | 102 |
| 1986 | 49 | 171 | 22 | 89 |
| 1987 | 26 | 123 | 16 | 43 |
| 1988 | 18 | 104 | 19 | 30 |
| 1989 | 27 | 96 | 21 | 62 |
| 1990 | 20 | 126 | 16 | |

| August | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | | | | |
| 1980 | 115 | 255 | 8 | |
| 1981 | 28 | 111 | 11 | |
| 1982 | 24 | 107 | 13 | |
| 1983 | 39 | 125 | 16 | |
| 1984 | 56 | 142 | 10 | |
| 1985 | 39 | 175 | 12 | 45 |
| 1986 | 73 | 133 | 25 | 88 |
| 1987 | 25 | 132 | 22 | 82 |
| 1988 | 25 | 89 | 20 | 32 |
| 1989 | 40 | 98 | 27 | 43 |
| 1990 | | | | |

| September | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | | | | |
| 1980 | 79 | 160 | 10 | |
| 1981 | 28 | 87 | 18 | |
| 1982 | 15 | 94 | 16 | |
| 1983 | 20 | 95 | 13 | |
| 1984 | 42 | 112 | 17 | |
| 1985 | | | | |
| 1986 | 46 | 120 | 33 | 87 |
| 1987 | 24 | 91 | 18 | 100 |
| 1988 | 21 | 83 | 19 | 22 |
| 1989 | 39 | 137 | 22 | 49 |

| October | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | | | | |
| 1980 | 76 | 294 | 20 | |
| 1981 | 47 | 116 | 26 | |
| 1982 | 66 | 93 | 38 | |
| 1983 | 23 | 106 | 20 | |
| 1984 | 36 | 200 | 32 | |
| 1985 | 23 | 130 | 19 | 126 |
| 1986 | 20 | 179 | 38 | 62 |
| 1987 | 25 | 187 | 27 | 117 |
| 1988 | 28 | 174 | 36 | 42 |
| 1989 | 40 | 188 | 50 | 84 |

| November | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | | | | |
| 1980 | 76 | 263 | 26 | |
| 1981 | 59 | 171 | 26 | |
| 1982 | 36 | 110 | 33 | |
| 1983 | 37 | 136 | 42 | |
| 1984 | 41 | 199 | 44 | |
| 1985 | 62 | 257 | 44 | 229 |
| 1986 | 20 | 247 | 47 | 147 |
| 1987 | 14 | 196 | 41 | 155 |
| 1988 | 43 | 174 | 40 | 67 |
| 1989 | 29 | 176 | 38 | 106 |

| December | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | | | | |
| 1980 | 50 | 267 | 36 | |
| 1981 | 60 | 190 | 41 | |
| 1982 | 58 | 161 | 46 | |
| 1983 | 54 | 251 | 51 | |
| 1984 | 58 | 254 | 42 | |
| 1985 | 49 | 285 | 30 | 109 |
| 1986 | 26 | 266 | 64 | 245 |
| 1987 | 16 | 208 | 40 | 81 |
| 1988 | 33 | 259 | 69 | 57 |
| 1989 | 24 | 236 | 59 | 94 |

***Ambient Air Quality in Bombay Station: Sion (A7)***

**Units:** μg/m³

**January**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 49 | 303 | 48 | |
| 1982 | 34 | 354 | 39 | |
| 1983 | 82 | 342 | 51 | |
| 1984 | 48 | 304 | 69 | |
| 1985 | 83 | 374 | 137 | 83 |
| 1986 | 41 | 363 | 65 | 97 |
| 1987 | 33 | 412 | 74 | 123 |
| 1988 | 32 | 428 | 128 | 87 |
| 1989 | | | | |
| 1990 | 43 | 527 | 127 | |

**February**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | | | | |
| 1981 | 71 | 421 | 50 | |
| 1982 | 44 | 236 | 31 | |
| 1983 | 47 | 249 | 43 | |
| 1984 | 49 | 308 | 55 | |
| 1985 | 50 | 365 | 80 | 72 |
| 1986 | 33 | 352 | 63 | 65 |
| 1987 | 18 | 432 | 77 | 100 |
| 1988 | 23 | 360 | 86 | 70 |
| 1989 | | | | |
| 1990 | 26 | 522 | 121 | |

**March**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | | | | |
| 1981 | 50 | 275 | 40 | |
| 1982 | 34 | 331 | 23 | |
| 1983 | 29 | 229 | 38 | |
| 1984 | 63 | 301 | 50 | |
| 1985 | 46 | 267 | 49 | 50 |
| 1986 | 33 | 363 | 40 | 50 |
| 1987 | 10 | 365 | 51 | 89 |
| 1988 | 14 | 417 | 63 | 45 |
| 1989 | | | | |
| 1990 | 12 | 300 | 77 | |

**April**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | | | | |
| 1981 | 32 | 277 | 25 | |
| 1982 | 16 | 189 | 17 | |
| 1983 | 29 | 146 | 22 | |
| 1984 | 21 | 302 | 26 | |
| 1985 | 38 | 234 | 39 | 119 |
| 1986 | 27 | 279 | 34 | 89 |
| 1987 | 9 | 283 | 40 | 73 |
| 1988 | 24 | 349 | 42 | 62 |
| 1989 | | | | |
| 1990 | 11 | 284 | 65 | |

**May**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | | | | |
| 1981 | 11 | 182 | 14 | |
| 1982 | 18 | 193 | 15 | |
| 1983 | 17 | 122 | 14 | |
| 1984 | 9 | 165 | 20 | |
| 1985 | 30 | 273 | 19 | 20 |
| 1986 | 22 | 245 | 26 | 47 |
| 1987 | 14 | 291 | 39 | 49 |
| 1988 | 23 | 249 | 42 | 56 |
| 1989 | | | | |
| 1990 | 11 | 249 | 30 | |

**June**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 26 | 100 | 31 | |
| 1981 | 12 | 310 | 10 | |
| 1982 | 13 | 318 | 10 | |
| 1983 | 31 | 129 | 13 | |
| 1984 | 24 | 134 | 12 | |
| 1985 | 16 | 103 | 25 | 22 |
| 1986 | 22 | 196 | 28 | 64 |
| 1987 | 8 | 151 | 28 | 64 |
| 1988 | 7 | 197 | 29 | 79 |
| 1989 | | | | |
| 1990 | 7 | 201 | 32 | |

***Ambient Air Quality in Bombay Station: Sion (A7)***

**Units:** µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 12 | 171 | 9 | |
| 1981 | 16 | 235 | 15 | |
| 1982 | 13 | 103 | 10 | |
| 1983 | 15 | 89 | 17 | |
| 1984 | 20 | 101 | 14 | |
| 1985 | 10 | 251 | 17 | 20 |
| 1986 | 8 | 206 | 20 | 66 |
| 1987 | 8 | 163 | 30 | 86 |
| 1988 | | | | |
| 1989 | | | | |
| 1990 | 7 | 173 | 25 | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 17 | 127 | 9 | |
| 1981 | 11 | 102 | 11 | |
| 1982 | 8 | 105 | 11 | |
| 1983 | 15 | 107 | 20 | |
| 1984 | 33 | 148 | 20 | |
| 1985 | 48 | 163 | 28 | 20 |
| 1986 | 12 | 145 | 19 | 98 |
| 1987 | 7 | 124 | 25 | 86 |
| 1988 | | | | |
| 1989 | | | | |
| 1990 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 24 | 98 | 10 | |
| 1981 | 31 | 115 | 21 | |
| 1982 | 19 | 135 | 24 | |
| 1983 | 20 | 87 | 20 | |
| 1984 | 24 | 122 | 27 | |
| 1985 | | | | |
| 1986 | 17 | 185 | 39 | 64 |
| 1987 | 7 | 182 | 45 | 92 |
| 1988 | | | | |
| 1989 | | | | |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 50 | 253 | 20 | |
| 1981 | 71 | 178 | 35 | |
| 1982 | 61 | 213 | 53 | |
| 1983 | 41 | 211 | 33 | |
| 1984 | 34 | 214 | 50 | |
| 1985 | 48 | 281 | 41 | 54 |
| 1986 | 31 | 278 | 52 | 102 |
| 1987 | 18 | 299 | 63 | 89 |
| 1988 | | | | |
| 1989 | | | | |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 65 | 283 | 32 | |
| 1981 | 72 | 214 | 44 | |
| 1982 | 66 | 219 | 54 | |
| 1983 | 66 | 198 | 47 | |
| 1984 | 56 | 269 | 61 | |
| 1985 | 76 | 362 | 57 | 230 |
| 1986 | 53 | 324 | 62 | 94 |
| 1987 | 15 | 264 | 83 | 90 |
| 1988 | | | | |
| 1989 | | | | |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 65 | 317 | 52 | |
| 1981 | 73 | 264 | 43 | |
| 1982 | 81 | 262 | 69 | |
| 1983 | 66 | 358 | 66 | |
| 1984 | 41 | | | |
| 1985 | 21 | 489 | 80 | 98 |
| 1986 | | 336 | 62 | 110 |
| 1987 | 30 | 290 | 62 | 53 |
| 1988 | | | | |
| 1989 | | 405 | 81 | 54 |

***Ambient Air Quality in Bombay Station: Santacruz (A9)***

**Units:** μg/m³

| January | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 34 | 181 | 23 | |
| 1979 | 28 | 261 | 8 | |
| 1980 | 46 | 297 | 27 | |
| 1981 | 44 | 241 | 43 | |
| 1982 | 53 | 233 | 39 | |
| 1983 | 37 | 224 | 26 | |
| 1984 | 48 | 309 | 49 | |
| 1985 | 41 | 267 | 44 | |
| 1986 | 26 | 271 | 36 | 50 |
| 1987 | 32 | 350 | 49 | 92 |
| 1988 | 21 | 424 | 87 | 89 |
| 1989 | 8 | 339 | 58 | 76 |

| February | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 52 | 206 | 23 | |
| 1979 | 28 | 163 | 9 | |
| 1980 | 44 | 348 | 21 | |
| 1981 | 52 | 304 | 34 | |
| 1982 | 33 | 191 | 26 | |
| 1983 | 24 | 270 | 23 | |
| 1984 | 51 | 250 | 35 | |
| 1985 | 26 | 266 | 35 | |
| 1986 | 18 | 278 | 24 | 35 |
| 1987 | 11 | 351 | 53 | 13 |
| 1988 | 14 | 375 | 78 | 77 |
| 1989 | 8 | 267 | 44 | 30 |

| March | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 25 | 226 | 40 | |
| 1979 | 24 | 205 | 14 | |
| 1980 | 29 | 258 | 17 | |
| 1981 | 30 | 189 | 23 | |
| 1982 | 39 | 203 | 26 | |
| 1983 | 9 | 194 | 11 | |
| 1984 | 47 | 237 | 30 | |
| 1985 | 31 | 301 | 53 | 58 |
| 1986 | 18 | 357 | 26 | 136 |
| 1987 | 6 | 326 | 28 | 26 |
| 1988 | 7 | 403 | 22 | 39 |
| 1989 | 7 | 381 | 31 | 53 |

| April | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 29 | 164 | 5 | |
| 1979 | 14 | 173 | 11 | |
| 1980 | 14 | 215 | 9 | |
| 1981 | 20 | 158 | 12 | |
| 1982 | 8 | 144 | 10 | |
| 1983 | 9 | 164 | 10 | |
| 1984 | 16 | 183 | 12 | |
| 1985 | 27 | 241 | 16 | 72 |
| 1986 | 18 | 243 | 24 | 75 |
| 1987 | 6 | 294 | 25 | 128 |
| 1988 | 13 | 334 | 18 | 108 |
| 1989 | 6 | 293 | 24 | 81 |

| May | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 18 | 129 | 5 | |
| 1979 | 16 | 163 | 8 | |
| 1980 | 10 | 12 | 9 | |
| 1981 | 7 | 129 | 6 | |
| 1982 | 7 | 137 | 7 | |
| 1983 | 7 | 91 | 9 | |
| 1984 | 8 | 132 | 7 | |
| 1985 | 12 | 145 | 8 | 44 |
| 1986 | 18 | 172 | 24 | 117 |
| 1987 | 6 | 227 | 17 | 64 |
| 1988 | 18 | 246 | 8 | 88 |

| June | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 35 | 134 | 9 | |
| 1979 | 8 | 456 | 6 | |
| 1980 | 10 | 112 | 9 | |
| 1981 | 7 | 137 | 5 | |
| 1982 | 9 | 94 | 10 | |
| 1983 | 11 | 127 | 11 | |
| 1984 | 10 | 119 | 6 | |
| 1985 | 7 | 128 | 7 | 29 |
| 1986 | 22 | 211 | 24 | 83 |
| 1987 | 6 | 166 | 25 | 68 |
| 1988 | | | | |

***Ambient Air Quality in Bombay Station: Santacruz (A9)***

**Units:** μg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 15 | 135 | 6 | |
| 1979 | 6 | 133 | 6 | |
| 1980 | 6 | 108 | 5 | |
| 1981 | 6 | 113 | 5 | |
| 1982 | 7 | 61 | 7 | |
| 1983 | 10 | 136 | 9 | |
| 1984 | 9 | 119 | 7 | |
| 1985 | 7 | 129 | 8 | 41 |
| 1986 | 6 | 190 | 9 | 20 |
| 1987 | 8 | 160 | 8 | 49 |
| 1988 | 6 | 138 | 6 | 45 |
| 1989 | | | | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 8 | 118 | 6 | |
| 1979 | 7 | 149 | 6 | |
| 1980 | 8 | 168 | 5 | |
| 1981 | 6 | 64 | 5 | |
| 1982 | 7 | 84 | 7 | |
| 1983 | 16 | 101 | 24 | |
| 1984 | 18 | 125 | 5 | |
| 1985 | 8 | 156 | 9 | 29 |
| 1986 | | | | |
| 1987 | 6 | 120 | 11 | 64 |
| 1988 | 6 | 144 | 20 | 20 |
| 1989 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 30 | 88 | 9 | |
| 1979 | 16 | 136 | 8 | |
| 1980 | 18 | 78 | 7 | |
| 1981 | 22 | 82 | 14 | |
| 1982 | 19 | 88 | 20 | |
| 1983 | 15 | 45 | 27 | |
| 1984 | 15 | 105 | 17 | |
| 1985 | | | | |
| 1986 | | | | |
| 1987 | 8 | 151 | 20 | 64 |
| 1988 | 7 | 89 | 11 | 27 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 36 | 189 | 11 | |
| 1979 | 34 | 170 | 15 | |
| 1980 | 44 | 153 | 15 | |
| 1981 | 57 | 124 | 29 | |
| 1982 | 27 | 182 | 42 | |
| 1983 | 39 | 243 | 31 | |
| 1984 | 12 | 196 | 14 | |
| 1985 | 36 | 222 | 31 | 50 |
| 1986 | | | | |
| 1987 | 22 | 270 | 47 | 69 |
| 1988 | 10 | 287 | 49 | 20 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 42 | 235 | 14 | |
| 1979 | 46 | 154 | 24 | |
| 1980 | 48 | 164 | 23 | |
| 1981 | 62 | 140 | 36 | |
| 1982 | 26 | 128 | 42 | |
| 1983 | 51 | 267 | 35 | |
| 1984 | 49 | 226 | 40 | |
| 1985 | 48 | 356 | 38 | 122 |
| 1986 | 36 | 337 | 62 | 64 |
| 1987 | 8 | 254 | 46 | 49 |
| 1988 | 45 | 322 | 66 | 27 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 39 | 265 | 8 | |
| 1979 | 49 | 208 | 23 | |
| 1980 | 49 | 204 | 45 | |
| 1981 | 46 | 228 | 38 | |
| 1982 | 64 | 215 | 60 | |
| 1983 | 89 | 355 | 59 | |
| 1984 | 49 | 280 | 52 | |
| 1985 | 44 | 411 | 51 | 34 |
| 1986 | 40 | 356 | 64 | 234 |
| 1987 | 24 | 352 | 80 | 71 |
| 1988 | 18 | 355 | 60 | 50 |

## *Ambient Air Quality in Bombay Station: Sakinaka (A11)*

**Units:** μg/m³

**January**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 69 | 387 | 22 | |
| 1981 | 61 | 233 | 29 | |
| 1982 | 73 | 233 | 36 | |
| 1983 | 89 | 385 | 41 | |
| 1984 | 118 | 298 | 59 | |
| 1985 | 60 | 314 | 33 | |
| 1986 | | | | |
| 1987 | 25 | 438 | 30 | 156 |
| 1988 | 19 | 380 | 37 | 106 |
| 1989 | 26 | 393 | 63 | 28 |
| 1990 | 33 | 487 | 55 | |

**February**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 41 | 352 | 14 | |
| 1981 | 67 | 358 | 34 | |
| 1982 | 17 | 228 | 44 | |
| 1983 | 58 | 320 | 31 | |
| 1984 | | | | |
| 1985 | 32 | 266 | 19 | |
| 1986 | 32 | 384 | 37 | 55 |
| 1987 | 16 | 341 | 30 | 115 |
| 1988 | 30 | 365 | 43 | 78 |
| 1989 | 22 | 389 | 42 | 29 |
| 1990 | 23 | 353 | 43 | |

**March**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 23 | 285 | 12 | |
| 1981 | 48 | 266 | 21 | |
| 1982 | 58 | 337 | 24 | |
| 1983 | 21 | 311 | 16 | |
| 1984 | | | | |
| 1985 | 25 | 351 | 37 | 41 |
| 1986 | 37 | 384 | 27 | 53 |
| 1987 | 13 | 465 | 28 | 103 |
| 1988 | 20 | 340 | 31 | 46 |
| 1989 | 14 | 366 | 48 | 39 |
| 1990 | 12 | 323 | 28 | |

**April**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 31 | 229 | 20 | |
| 1980 | 43 | 262 | 17 | |
| 1981 | 37 | 325 | 18 | |
| 1982 | 38 | 163 | 22 | |
| 1983 | 46 | 244 | 26 | |
| 1984 | | | | |
| 1985 | 34 | 244 | 16 | 133 |
| 1986 | 43 | 346 | 28 | 91 |
| 1987 | 7 | 308 | 22 | 79 |
| 1988 | 22 | 430 | 32 | 53 |
| 1989 | 15 | 356 | 38 | 72 |
| 1990 | 8 | 328 | 28 | |

**May**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 17 | 251 | 16 | |
| 1980 | 28 | 153 | 11 | |
| 1981 | 17 | 200 | 8 | |
| 1982 | 14 | 230 | 18 | |
| 1983 | 33 | 159 | 17 | |
| 1984 | | | | |
| 1985 | 20 | 229 | 11 | 31 |
| 1986 | 25 | 257 | 18 | 69 |
| 1987 | 20 | 234 | 24 | 31 |
| 1988 | 18 | 241 | 25 | 56 |
| 1989 | 15 | 308 | 26 | 20 |
| 1990 | 9 | 212 | 17 | |

**June**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 14 | 140 | 15 | |
| 1980 | 43 | 119 | 16 | |
| 1981 | 55 | 145 | 8 | |
| 1982 | 28 | 114 | 8 | |
| 1983 | 27 | 182 | 11 | |
| 1984 | | | | |
| 1985 | | | | |
| 1986 | 17 | 147 | 21 | 67 |
| 1987 | 7 | 161 | 25 | 41 |
| 1988 | 9 | 172 | 30 | 62 |
| 1989 | 8 | 208 | 26 | 37 |
| 1990 | 6 | 174 | 21 | |

*Ambient Air Quality in Bombay Station: Sakinaka (A11)*

**Units**: µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 30 | 133 | 15 | |
| 1980 | 6 | 110 | 6 | |
| 1981 | 19 | 134 | 10 | |
| 1982 | 34 | 107 | 17 | |
| 1983 | 12 | 86 | 14 | |
| 1984 | | | | |
| 1985 | | | | |
| 1986 | 8 | 170 | 14 | 58 |
| 1987 | 7 | 148 | 21 | 46 |
| 1988 | 8 | 126 | 28 | 25 |
| 1989 | 6 | 127 | 15 | 58 |
| 1990 | 6 | 152 | 24 | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 25 | 167 | 10 | |
| 1980 | 27 | 121 | 7 | |
| 1981 | 9 | 124 | 7 | |
| 1982 | 12 | 106 | 9 | |
| 1983 | 19 | 151 | 19 | |
| 1984 | 17 | 166 | 12 | |
| 1985 | | | | |
| 1986 | 23 | 129 | 19 | 53 |
| 1987 | 7 | 108 | 29 | 88 |
| 1988 | 6 | 176 | 19 | 29 |
| 1989 | 6 | 128 | 27 | 38 |
| 1990 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 67 | 94 | 20 | |
| 1980 | 52 | 91 | 9 | |
| 1981 | 55 | 105 | 14 | |
| 1982 | 38 | 143 | 24 | |
| 1983 | 27 | 121 | 25 | |
| 1984 | 18 | 125 | 18 | |
| 1985 | | | | |
| 1986 | 43 | 180 | 28 | 52 |
| 1987 | 9 | 154 | 15 | 81 |
| 1988 | 10 | 130 | 28 | 28 |
| 1989 | 27 | 182 | 27 | 55 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 69 | 209 | 18 | |
| 1980 | 73 | 185 | 12 | |
| 1981 | 95 | 146 | 17 | |
| 1982 | 81 | 210 | 62 | |
| 1983 | 39 | 162 | 23 | |
| 1984 | 65 | 41 | 33 | |
| 1985 | | | | |
| 1986 | 49 | 329 | 33 | 104 |
| 1987 | 22 | 266 | 31 | 53 |
| 1988 | 28 | 241 | 43 | 26 |
| 1989 | 31 | 200 | 32 | 57 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 82 | 198 | 18 | |
| 1980 | 67 | 180 | 20 | |
| 1981 | 99 | 173 | 37 | |
| 1982 | 121 | 223 | 41 | |
| 1983 | 67 | 221 | 33 | |
| 1984 | 59 | 262 | 30 | |
| 1985 | | | | |
| 1986 | 30 | 303 | 30 | 71 |
| 1987 | 23 | 280 | 31 | 55 |
| 1988 | 51 | 295 | 53 | 34 |
| 1989 | 24 | 292 | 39 | 44 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 65 | 311 | 23 | |
| 1980 | 91 | 237 | 27 | |
| 1981 | 102 | 230 | 23 | |
| 1982 | 110 | 340 | 51 | |
| 1983 | 76 | 316 | 39 | |
| 1984 | 36 | 267 | 26 | |
| 1985 | 50 | 332 | 18 | 66 |
| 1986 | 38 | 384 | 25 | 92 |
| 1987 | 48 | 447 | 39 | 71 |
| 1988 | 29 | 349 | 48 | 50 |
| 1989 | 29 | 416 | 51 | 51 |

*Ambient Air Quality in Bombay Station: Ghatkopar (A13)*

**Units:** μg/m³

| January | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | 72 | 304 | 11 | |
| 1980 | 100 | 452 | 27 | |
| 1981 | 96 | 246 | 35 | |
| 1982 | 102 | 216 | 30 | |
| 1983 | 140 | 286 | 52 | |
| 1984 | 78 | 400 | 58 | |
| 1985 | 33 | 349 | 53 | |
| 1986 | 75 | 480 | 51 | 66 |
| 1987 | 52 | 438 | 69 | 156 |
| 1988 | 32 | 445 | 63 | 86 |
| 1989 | 40 | 364 | 59 | 57 |
| 1990 | 38 | 498 | 58 | |

| February | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | 71 | 288 | 8 | |
| 1980 | 67 | 327 | 30 | |
| 1981 | 137 | 300 | 49 | |
| 1982 | 46 | 281 | 22 | |
| 1983 | 67 | 253 | 32 | |
| 1984 | 69 | 391 | 41 | |
| 1985 | 57 | 339 | 31 | |
| 1986 | 35 | 433 | 48 | 48 |
| 1987 | 52 | 505 | 47 | 131 |
| 1988 | 34 | 350 | 40 | 86 |
| 1989 | 39 | 471 | 64 | 73 |
| 1990 | 37 | 468 | 70 | |

| March | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | 75 | 355 | 8 | |
| 1980 | 73 | 416 | 28 | |
| 1981 | 54 | 243 | 21 | |
| 1982 | 49 | 269 | 22 | |
| 1983 | 56 | 290 | 39 | |
| 1984 | 46 | 372 | 36 | |
| 1985 | 105 | 311 | 45 | |
| 1986 | 46 | 428 | 45 | 66 |
| 1987 | 21 | 438 | 26 | 135 |
| 1988 | 47 | 225 | 40 | 39 |
| 1989 | 19 | 437 | 37 | 60 |
| 1990 | 10 | 329 | 65 | |

| April | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | 38 | 279 | 12 | |
| 1980 | 60 | 277 | 19 | |
| 1981 | 48 | 365 | 22 | |
| 1982 | 24 | 217 | 15 | |
| 1983 | 31 | 196 | 21 | |
| 1984 | 10 | 280 | 27 | |
| 1985 | | | | |
| 1986 | 44 | 407 | 35 | 136 |
| 1987 | 7 | 312 | 29 | 142 |
| 1988 | 27 | 491 | 23 | 67 |
| 1989 | 19 | 343 | 30 | 84 |
| 1990 | 11 | 339 | 26 | |

| May | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | 15 | 322 | 16 | |
| 1980 | 45 | 183 | 12 | |
| 1981 | 10 | 191 | 14 | |
| 1982 | 19 | 140 | 18 | |
| 1983 | 29 | 181 | 13 | |
| 1984 | 12 | 267 | 23 | |
| 1985 | | | | |
| 1986 | 32 | 343 | 25 | 73 |
| 1987 | 7 | 266 | 20 | 111 |
| 1988 | 21 | 265 | 23 | 59 |
| 1989 | 25 | 312 | 33 | 60 |
| 1990 | 7 | 216 | 19 | |

| June | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1979 | 15 | 140 | 16 | |
| 1980 | 29 | 129 | 14 | |
| 1981 | 9 | 163 | 7 | |
| 1982 | 18 | 101 | 8 | |
| 1983 | 22 | 107 | 14 | |
| 1984 | 12 | 121 | 12 | |
| 1985 | | | | |
| 1986 | 13 | 172 | 17 | 82 |
| 1987 | 6 | 122 | 18 | 134 |
| 1988 | 7 | 223 | 71 | 108 |
| 1989 | 13 | 366 | 17 | 56 |
| 1990 | 6 | 153 | 25 | |

*Ambient Air Quality in Bombay Station: Ghatkopar (A13)*

Units: µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 11 | 143 | 12 | |
| 1980 | 9 | 116 | 6 | |
| 1981 | 9 | 82 | 9 | |
| 1982 | 14 | 105 | 9 | |
| 1983 | 11 | 110 | 18 | |
| 1984 | 7 | 98 | 13 | |
| 1985 | | | | |
| 1986 | 6 | 211 | 14 | 51 |
| 1987 | 6 | 130 | 17 | 50 |
| 1988 | 6 | 104 | 20 | 53 |
| 1989 | 9 | 128 | 21 | 55 |
| 1990 | 6 | 117 | 11 | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 10 | 178 | 10 | |
| 1980 | 32 | 78 | 8 | |
| 1981 | 7 | 88 | 7 | |
| 1982 | 9 | 79 | 18 | |
| 1983 | 17 | 160 | 22 | |
| 1984 | 14 | 112 | 13 | |
| 1985 | | | | |
| 1986 | 26 | 148 | 26 | 63 |
| 1987 | 6 | 98 | 22 | 69 |
| 1988 | 6 | 122 | 14 | 21 |
| 1989 | 7 | 97 | 22 | 32 |
| 1990 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 40 | 325 | 9 | |
| 1979 | 78 | 184 | 16 | |
| 1980 | 60 | 97 | 10 | |
| 1981 | 51 | 101 | 17 | |
| 1982 | 19 | 112 | 17 | |
| 1983 | 16 | 97 | 22 | |
| 1984 | 19 | 141 | 20 | |
| 1985 | | | | |
| 1986 | 37 | 135 | 38 | 57 |
| 1987 | 9 | 167 | 18 | 67 |
| 1988 | 11 | 113 | 28 | 22 |
| 1989 | 28 | 145 | 29 | 33 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 34 | 211 | 10 | |
| 1979 | 100 | 211 | 21 | |
| 1980 | 64 | 209 | 17 | |
| 1981 | 84 | 131 | 22 | |
| 1982 | 83 | 215 | 51 | |
| 1983 | 81 | | 31 | |
| 1984 | 19 | 162 | 24 | |
| 1985 | | | | |
| 1986 | 33 | 308 | 39 | 46 |
| 1987 | 15 | 237 | 34 | 90 |
| 1988 | 64 | 294 | 53 | 25 |
| 1989 | 82 | 255 | 37 | 55 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 35 | 245 | 10 | |
| 1979 | 106 | 154 | 27 | |
| 1980 | 83 | 207 | 22 | |
| 1981 | 81 | 154 | 31 | |
| 1982 | 92 | 218 | 45 | |
| 1983 | 73 | 345 | 51 | |
| 1984 | 48 | 203 | 33 | |
| 1985 | | | | |
| 1986 | | | | |
| 1987 | 27 | 276 | 41 | 45 |
| 1988 | 88 | 334 | 67 | 23 |
| 1989 | 61 | 323 | 59 | 66 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 60 | 295 | 8 | |
| 1979 | 91 | 249 | 32 | |
| 1980 | 99 | 259 | 36 | |
| 1981 | 100 | 218 | 18 | |
| 1982 | 125 | 315 | 55 | |
| 1983 | 102 | 287 | 60 | |
| 1984 | 73 | 311 | 41 | |
| 1985 | 47 | 431 | 48 | 166 |
| 1986 | 66 | 408 | 55 | 177 |
| 1987 | 43 | 337 | 48 | 43 |
| 1988 | 50 | 397 | 64 | 53 |
| 1989 | 51 | 398 | 58 | 61 |

## *Ambient Air Quality in Bombay Station: Mulund (A15)*

Units: μg/m³

**January**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 96 | 267 | 31 | |
| 1982 | 92 | 252 | 26 | |
| 1983 | 136 | 290 | 30 | |
| 1984 | 125 | 387 | 61 | |
| 1985 | 52 | 334 | 25 | |
| 1986 | 41 | 385 | 29 | 80 |
| 1987 | 32 | 405 | 43 | 96 |
| 1988 | 41 | 361 | 31 | 76 |
| 1989 | 58 | 363 | 57 | 85 |
| 1990 | 55 | 432 | 39 | |

**February**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 143 | 399 | 35 | |
| 1982 | 99 | 281 | 23 | |
| 1983 | 94 | 332 | 30 | |
| 1984 | 73 | 319 | 33 | |
| 1985 | 21 | 361 | 16 | |
| 1986 | 27 | 382 | 29 | 50 |
| 1987 | 24 | 362 | 22 | 87 |
| 1988 | 34 | 382 | 31 | 83 |
| 1989 | 47 | 389 | 58 | 83 |
| 1990 | 45 | 357 | 39 | |

**March**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 83 | 248 | 26 | |
| 1982 | 53 | 252 | 18 | |
| 1983 | 44 | 317 | 28 | |
| 1984 | 31 | 320 | 20 | |
| 1985 | 125 | 345 | 30 | 20 |
| 1986 | 36 | 341 | 30 | 93 |
| 1987 | 11 | 345 | 24 | 165 |
| 1988 | 29 | 331 | 20 | 53 |
| 1989 | 15 | 306 | 35 | 35 |
| 1990 | 19 | 309 | 46 | |

**April**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1981 | 47 | 361 | 14 | |
| 1982 | 25 | 175 | 24 | |
| 1983 | 17 | 223 | 14 | |
| 1984 | 14 | 266 | 21 | |
| 1985 | 100 | 231 | 19 | 154 |
| 1986 | 33 | 297 | 20 | 89 |
| 1987 | 23 | 371 | 17 | 118 |
| 1988 | 26 | 339 | 16 | 62 |
| 1989 | 16 | 214 | 20 | 47 |
| 1990 | 11 | 259 | 28 | |

**May**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | | | | |
| 1981 | 20 | 170 | 11 | |
| 1982 | 33 | 178 | 16 | |
| 1983 | 15 | 176 | 10 | |
| 1984 | | | | |
| 1985 | 28 | 202 | 10 | 20 |
| 1986 | 14 | 269 | 16 | 49 |
| 1987 | 16 | 218 | 20 | 138 |
| 1988 | 26 | 209 | 9 | 73 |
| 1989 | 34 | 280 | 21 | 61 |
| 1990 | 8 | 183 | 13 | |

**June**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | | | | |
| 1980 | 27 | 78 | 12 | |
| 1981 | 10 | 140 | 6 | |
| 1982 | 20 | 89 | 6 | |
| 1983 | 10 | 138 | 12 | |
| 1984 | 16 | 122 | 9 | |
| 1985 | 17 | 155 | 9 | 20 |
| 1986 | 22 | 165 | 12 | 56 |
| 1987 | 9 | 122 | 15 | 38 |
| 1988 | 8 | 130 | 16 | 41 |
| 1989 | 6 | 129 | 24 | 20 |
| 1990 | | 134 | 14 | |

***Ambient Air Quality in Bombay Station: Mulund (A15)***

**Units:** µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 7 | 150 | 6 | |
| 1981 | 10 | 83 | 5 | |
| 1982 | | | | |
| 1983 | 8 | 143 | 9 | |
| 1984 | 6 | 10 | 9 | |
| 1985 | 7 | 5 | 7 | 65 |
| 1986 | 8 | 100 | 8 | 54 |
| 1987 | 9 | 166 | 16 | 70 |
| 1988 | 6 | 112 | 8 | 40 |
| 1989 | 10 | 110 | 21 | 52 |
| 1990 | 6 | 105 | 19 | |
| 1991 | | 152 | | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 29 | 102 | 7 | |
| 1981 | 13 | 75 | 6 | |
| 1982 | 8 | 82 | 9 | |
| 1983 | 16 | 105 | 26 | |
| 1984 | 12 | 125 | 9 | |
| 1985 | 9 | 141 | 9 | 39 |
| 1986 | 9 | 135 | 11 | 54 |
| 1987 | 8 | 90 | 16 | 60 |
| 1988 | 9 | 113 | 15 | 28 |
| 1989 | 8 | 112 | 15 | 45 |
| 1990 | | | | |
| 1991 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 62 | 110 | 10 | |
| 1981 | 48 | 96 | 10 | |
| 1982 | 42 | 150 | 19 | |
| 1983 | 9 | 86 | 19 | |
| 1984 | 14 | 133 | 13 | |
| 1985 | | | | |
| 1986 | 11 | 161 | 19 | 51 |
| 1987 | 19 | 195 | 18 | 89 |
| 1988 | 16 | 85 | 19 | 21 |
| 1989 | 22 | 112 | 30 | 29 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 125 | 196 | 16 | |
| 1981 | 116 | 102 | 15 | |
| 1982 | 139 | 225 | 50 | |
| 1983 | 44 | 104 | 31 | |
| 1984 | 20 | 231 | 27 | |
| 1985 | 55 | 198 | 18 | 20 |
| 1986 | 28 | 289 | 21 | 93 |
| 1987 | 29 | 264 | 32 | 70 |
| 1988 | 46 | 190 | 36 | 25 |
| 1989 | 31 | 179 | 32 | 33 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 122 | 216 | 24 | |
| 1981 | 103 | 160 | 30 | |
| 1982 | 181 | 221 | 49 | |
| 1983 | 69 | 270 | 37 | |
| 1984 | 49 | 266 | 24 | |
| 1985 | 69 | 379 | 16 | 34 |
| 1986 | 36 | 347 | 30 | 59 |
| 1987 | 22 | 305 | 29 | 61 |
| 1988 | 70 | 332 | 47 | 21 |
| 1989 | 49 | 232 | 35 | 29 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1980 | 129 | 302 | 38 | |
| 1981 | 112 | 188 | 30 | |
| 1982 | 122 | 259 | 41 | |
| 1983 | 98 | 298 | 52 | |
| 1984 | 49 | 310 | 18 | |
| 1985 | 98 | 442 | 22 | 23 |
| 1986 | 39 | 374 | 33 | 139 |
| 1987 | 32 | 336 | 32 | 41 |
| 1988 | 49 | 339 | 55 | 45 |
| 1989 | 68 | 311 | 41 | 44 |

## *Ambient Air Quality in Bombay Station: Borivali (A16)*

Units: µg/m³

January

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 9 | 214 | 4 | |
| 1980 | 8 | 271 | 21 | |
| 1981 | 7 | 230 | 21 | |
| 1982 | 12 | 205 | 23 | |
| 1983 | 31 | 283 | 24 | |
| 1984 | 18 | 288 | 34 | |
| 1985 | 13 | 341 | 32 | |
| 1986 | 8 | 348 | 23 | 90 |
| 1987 | 8 | 320 | 39 | 103 |
| 1988 | 7 | 440 | 38 | 68 |
| 1989 | 6 | 374 | 61 | 73 |
| 1990 | 10 | 503 | 68 | |
| 1991 | | | | |

February

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 7 | 226 | 5 | |
| 1980 | 7 | 278 | 19 | |
| 1981 | 8 | 285 | 20 | |
| 1982 | 13 | 244 | 20 | |
| 1983 | 13 | 276 | 18 | |
| 1984 | | | | |
| 1985 | 8 | 298 | 27 | |
| 1986 | 8 | 373 | 31 | 57 |
| 1987 | 7 | 352 | 40 | 138 |
| 1988 | 11 | 408 | 42 | 57 |
| 1989 | 9 | 310 | 32 | 42 |
| 1990 | 8 | 381 | 38 | |
| 1991 | 11 | | | |

March

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 8 | 208 | 5 | |
| 1980 | 14 | 283 | 15 | |
| 1981 | 9 | 244 | 18 | |
| 1982 | 10 | 240 | 25 | |
| 1983 | 11 | 180 | 14 | |
| 1984 | 13 | 216 | 19 | |
| 1985 | 13 | 282 | 27 | 46 |
| 1986 | 13 | 431 | 28 | 67 |
| 1987 | 6 | 287 | 15 | 67 |
| 1988 | 11 | 295 | 18 | 45 |
| 1989 | 8 | 256 | 22 | 69 |
| 1990 | 7 | 314 | 27 | |

April

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 6 | 140 | | |
| 1980 | 18 | 257 | 13 | |
| 1981 | 9 | 238 | 9 | |
| 1982 | 9 | 164 | 12 | |
| 1983 | 12 | 182 | 12 | |
| 1984 | 10 | 179 | 11 | |
| 1985 | 10 | 218 | 13 | 136 |
| 1986 | 22 | 331 | 17 | 110 |
| 1987 | 6 | 225 | 13 | 47 |
| 1988 | 14 | 351 | 8 | 67 |
| 1989 | 7 | 224 | 16 | 52 |
| 1990 | 6 | 255 | 25 | |

## *Ambient Air Quality in Bombay Station: Tilaknagar (A17)*

**Units:** µg/m³

**January**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 63 | 271 | 28 | |
| 1979 | 38 | 420 | 9 | |
| 1980 | 56 | 404 | 34 | |
| 1981 | 43 | 356 | 44 | |
| 1982 | 47 | 198 | 35 | |
| 1983 | 63 | 356 | 58 | |
| 1984 | 81 | 417 | 83 | |
| 1985 | 55 | 444 | 60 | |
| 1986 | 49 | 585 | 58 | 125 |
| 1987 | 37 | 533 | 76 | 105 |
| 1988 | 28 | 571 | 82 | 74 |
| 1989 | 34 | 426 | 68 | 104 |
| 1990 | 74 | 440 | 97 | |

**February**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 59 | 254 | 26 | |
| 1979 | 50 | 458 | 9 | |
| 1980 | 53 | 468 | 42 | |
| 1981 | 94 | 539 | 68 | |
| 1982 | 54 | 308 | 49 | |
| 1983 | 64 | 235 | 34 | |
| 1984 | 58 | 367 | 55 | |
| 1985 | 61 | 478 | 65 | 214 |
| 1986 | 37 | 512 | 51 | 124 |
| 1987 | 22 | 608 | 63 | 100 |
| 1988 | 32 | 541 | 76 | 77 |
| 1989 | 32 | 316 | 66 | 99 |
| 1990 | 45 | 362 | 77 | |

**March**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 32 | 238 | 23 | |
| 1979 | 30 | 398 | 11 | |
| 1980 | 35 | 432 | 30 | |
| 1981 | 43 | 325 | 45 | |
| 1982 | 51 | 300 | 46 | |
| 1983 | 41 | 282 | 34 | |
| 1984 | 79 | 348 | 39 | |
| 1985 | | | | |
| 1986 | 51 | 428 | 48 | 160 |
| 1987 | 16 | 529 | 43 | 122 |
| 1988 | 31 | 513 | 49 | 64 |
| 1989 | 17 | 443 | 40 | 66 |
| 1990 | 35 | 295 | 54 | |

**April**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 45 | 273 | 14 | |
| 1979 | 31 | 289 | 22 | |
| 1980 | 37 | 368 | 27 | |
| 1981 | 41 | 292 | 36 | |
| 1982 | | | | |
| 1983 | 32 | 274 | 34 | |
| 1984 | 54 | 283 | 49 | |
| 1985 | 35 | 360 | 36 | 123 |
| 1986 | 40 | 329 | 33 | 98 |
| 1987 | 11 | 389 | 45 | 168 |
| 1988 | 21 | 396 | 24 | 87 |
| 1989 | | | | |
| 1990 | 22 | 250 | 27 | |

**May**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 54 | 265 | 10 | |
| 1979 | 33 | 311 | 28 | |
| 1980 | 15 | 193 | 21 | |
| 1981 | 15 | 220 | 20 | |
| 1982 | 26 | 275 | 23 | |
| 1983 | 36 | 194 | 22 | |
| 1984 | 18 | 309 | 24 | |
| 1985 | 26 | 193 | 26 | 130 |
| 1986 | 27 | 294 | 28 | |
| 1987 | 13 | 416 | 27 | 69 |
| 1988 | 27 | 332 | 20 | 85 |
| 1989 | | | | 62 |
| 1990 | 14 | 193 | 19 | |

**June**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 81 | 184 | 13 | |
| 1979 | 22 | 231 | 12 | |
| 1980 | 52 | 99 | 15 | |
| 1981 | 9 | 156 | 14 | |
| 1982 | 18 | 138 | 9 | |
| 1983 | 19 | 132 | 18 | |
| 1984 | 15 | 128 | 24 | |
| 1985 | 11 | 151 | 22 | 33 |
| 1986 | 26 | 199 | 36 | 131 |
| 1987 | 9 | 232 | 43 | 155 |
| 1988 | 6 | 230 | 37 | 96 |
| 1989 | | | | |
| 1990 | | | | |

## *Ambient Air Quality in Bombay Station: Tilaknagar (A17)*

**Units:** µg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 94 | 207 | 9 | |
| 1979 | 12 | 196 | 14 | |
| 1980 | 11 | 105 | 12 | |
| 1981 | 10 | 74 | 7 | |
| 1982 | 27 | 100 | 13 | |
| 1983 | 16 | 347 | 31 | |
| 1984 | 17 | 67 | 16 | |
| 1985 | 10 | 161 | 17 | 47 |
| 1986 | 10 | 206 | 25 | 89 |
| 1987 | 7 | 167 | 32 | 123 |
| 1988 | 6 | 146 | 45 | 63 |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 25 | 198 | 4 | |
| 1979 | 49 | 201 | 14 | |
| 1980 | 31 | 119 | 11 | |
| 1981 | 6 | 104 | 9 | |
| 1982 | 8 | 109 | 10 | |
| 1983 | 19 | 124 | 23 | |
| 1984 | 44 | 208 | 29 | |
| 1985 | 18 | 146 | 21 | 59 |
| 1986 | 8 | 128 | 22 | 64 |
| 1987 | 7 | 154 | 29 | 171 |
| 1988 | 7 | 151 | 24 | 26 |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 25 | 173 | 12 | |
| 1979 | 55 | 224 | 22 | |
| 1980 | 55 | 134 | 12 | |
| 1981 | 20 | 116 | 19 | |
| 1982 | 20 | 131 | 30 | |
| 1983 | 22 | 87 | 18 | |
| 1984 | 27 | 187 | 30 | |
| 1985 | 51 | | | |
| 1986 | 30 | 265 | 37 | 57 |
| 1987 | 9 | 260 | 33 | 124 |
| 1988 | 13 | 139 | 48 | 51 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 30 | 235 | 12 | |
| 1979 | 48 | 214 | 25 | |
| 1980 | 51 | 259 | 23 | |
| 1981 | 40 | 219 | 33 | |
| 1982 | 61 | 279 | 78 | |
| 1983 | 40 | 348 | 32 | |
| 1984 | 61 | 256 | 65 | |
| 1985 | 51 | 208 | 27 | 66 |
| 1986 | 44 | 467 | 62 | 112 |
| 1987 | 17 | 368 | 48 | 101 |
| 1988 | 36 | 422 | 55 | 30 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 26 | 297 | 12 | |
| 1979 | 29 | 240 | 18 | |
| 1980 | 51 | 306 | 29 | |
| 1981 | 94 | 155 | 34 | |
| 1982 | 45 | 283 | 66 | |
| 1983 | 71 | 263 | 69 | |
| 1984 | 86 | 367 | 61 | |
| 1985 | 58 | 494 | 50 | 177 |
| 1986 | 51 | 425 | 60 | 112 |
| 1987 | 16 | 421 | 58 | 86 |
| 1988 | 50 | 460 | 60 | 27 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 28 | 345 | 5 | |
| 1979 | 29 | 216 | 22 | |
| 1980 | 59 | 302 | 49 | |
| 1981 | 59 | 219 | 28 | |
| 1982 | 33 | 434 | 62 | |
| 1983 | 87 | 412 | 68 | |
| 1984 | 56 | 387 | 49 | |
| 1985 | 52 | 466 | 35 | 93 |
| 1986 | 54 | 457 | 58 | 74 |
| 1987 | 48 | 392 | 57 | 41 |
| 1988 | 40 | 474 | 88 | 52 |

### *Ambient Air Quality in Bombay Station: Chembur Naka (A18)*

**Units**: µg/m³

**January**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 42 | 322 | 52 | |
| 1980 | 71 | 348 | 28 | |
| 1981 | 52 | 274 | 38 | |
| 1982 | 62 | 255 | 48 | |
| 1983 | 71 | 334 | 44 | |
| 1984 | 62 | 324 | 54 | |
| 1985 | 47 | 358 | 50 | 20 |
| 1986 | 22 | 434 | 40 | 95 |
| 1987 | 15 | 388 | 35 | 83 |
| 1988 | 23 | 368 | 65 | 79 |
| 1989 | 28 | 435 | 82 | 64 |
| 1990 | 62 | 504 | 94 | |

**February**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 64 | 277 | 52 | |
| 1980 | 60 | 368 | 28 | |
| 1981 | 92 | 416 | 38 | |
| 1982 | 71 | 230 | 48 | |
| 1983 | 51 | 315 | 44 | |
| 1984 | 48 | 311 | 54 | |
| 1985 | 33 | 328 | 50 | 20 |
| 1986 | 21 | 374 | 40 | 95 |
| 1987 | 16 | 377 | 35 | 83 |
| 1988 | 39 | 389 | 65 | 79 |
| 1989 | 51 | 461 | 82 | 64 |
| 1990 | 29 | 455 | 94 | |

**March**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 43 | 347 | 8 | |
| 1980 | 48 | 237 | 26 | |
| 1981 | 61 | 269 | 43 | |
| 1982 | 27 | 227 | 26 | |
| 1983 | 36 | 281 | 37 | |
| 1984 | 61 | 291 | 41 | |
| 1985 | 41 | 315 | 43 | 90 |
| 1986 | 29 | 406 | 49 | 116 |
| 1987 | 9 | 396 | 27 | 64 |
| 1988 | 23 | 296 | 50 | 50 |
| 1989 | 19 | 370 | 65 | 60 |
| 1990 | 21 | 333 | 69 | |

**April**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 29 | 185 | 23 | |
| 1980 | 37 | 193 | 19 | |
| 1981 | 19 | 241 | 23 | |
| 1982 | 18 | 170 | 25 | |
| 1983 | 26 | 217 | 26 | |
| 1984 | 22 | 242 | 35 | |
| 1985 | 33 | 225 | 34 | 115 |
| 1986 | 22 | 273 | 31 | 118 |
| 1987 | 12 | 358 | 43 | 113 |
| 1988 | 34 | 329 | 49 | 254 |
| 1989 | 22 | 292 | 47 | 95 |
| 1990 | 9 | 300 | 44 | |

**May**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 9 | 190 | 18 | |
| 1980 | 16 | 142 | 12 | |
| 1981 | 9 | 199 | 18 | |
| 1982 | 25 | 166 | 30 | |
| 1983 | 24 | 171 | 26 | |
| 1984 | 12 | 197 | 23 | |
| 1985 | 52 | 200 | 31 | 119 |
| 1986 | 24 | 240 | 38 | 82 |
| 1987 | 17 | 293 | 244 | 113 |
| 1988 | 20 | 214 | 23 | 53 |
| 1989 | 18 | 249 | 34 | 107 |
| 1990 | 9 | 233 | 29 | |

**June**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 13 | 146 | 18 | |
| 1980 | 49 | 114 | 19 | |
| 1981 | 15 | 128 | 11 | |
| 1982 | 27 | 130 | 17 | |
| 1983 | 30 | 178 | 26 | |
| 1984 | 31 | 163 | 27 | |
| 1985 | 11 | 151 | 38 | 71 |
| 1986 | 14 | 147 | 34 | 94 |
| 1987 | 6 | 155 | 25 | 95 |
| 1988 | 15 | 191 | 53 | 227 |
| 1989 | 7 | 264 | 57 | 689 |
| 1990 | 7 | 170 | 42 | |

*Ambient Air Quality in Bombay Station: Chembur Naka (A18)*

**Units**: μg/m³

**July**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 13 | 116 | 18 | |
| 1980 | 14 | 151 | 8 | |
| 1981 | 9 | 98 | 9 | |
| 1982 | 19 | 113 | 26 | |
| 1983 | 20 | 140 | 34 | |
| 1984 | 29 | 149 | 23 | |
| 1985 | 7 | 143 | 31 | 51 |
| 1986 | 7 | 223 | 32 | 85 |
| 1987 | 10 | 125 | 33 | 247 |
| 1988 | 12 | 115 | 32 | 162 |
| 1989 | 8 | 116 | 35 | 134 |
| 1990 | 6 | 185 | 33 | |

**August**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1979 | 29 | 226 | 16 | |
| 1980 | 39 | 126 | 12 | |
| 1981 | 11 | 401 | 12 | |
| 1982 | 7 | 117 | 13 | |
| 1983 | 11 | 203 | 31 | |
| 1984 | 41 | 183 | 26 | |
| 1985 | 9 | 169 | 29 | 55 |
| 1986 | 8 | 144 | 24 | 61 |
| 1987 | 8 | 111 | 19 | 177 |
| 1988 | 13 | 148 | 39 | 34 |
| 1989 | 9 | 134 | 31 | 129 |
| 1990 | | | | |

**September**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 26 | 201 | 8 | |
| 1979 | 53 | 189 | 19 | |
| 1980 | 52 | 96 | 11 | |
| 1981 | 40 | 102 | 19 | |
| 1982 | 27 | 124 | 24 | |
| 1983 | 8 | 198 | 27 | |
| 1984 | 39 | 150 | 32 | |
| 1985 | 24 | 156 | 27 | 54 |
| 1986 | 12 | 163 | 33 | 56 |
| 1987 | 10 | 152 | 27 | 65 |
| 1988 | 9 | 132 | 47 | 128 |
| 1989 | 25 | 134 | 39 | 83 |

**October**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 22 | 212 | 7 | |
| 1979 | 63 | 145 | 23 | |
| 1980 | 66 | 230 | 18 | |
| 1981 | 58 | 123 | 30 | |
| 1982 | 58 | 187 | 49 | |
| 1983 | 26 | 216 | 30 | |
| 1984 | 32 | 184 | 39 | |
| 1985 | 28 | 233 | 31 | 25 |
| 1986 | 22 | 369 | 64 | 154 |
| 1987 | 16 | 259 | 49 | 133 |
| 1988 | 33 | 261 | 62 | 48 |
| 1989 | 45 | 207 | 51 | 46 |

**November**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 21 | | 9 | |
| 1979 | 45 | 95 | 26 | |
| 1980 | 68 | 218 | 24 | |
| 1981 | 43 | 130 | 36 | |
| 1982 | 70 | 210 | 45 | |
| 1983 | 36 | 340 | 42 | |
| 1984 | 40 | 277 | 38 | |
| 1985 | 37 | 361 | 33 | 105 |
| 1986 | 17 | 299 | 37 | 124 |
| 1987 | 23 | 258 | 48 | 77 |
| 1988 | 43 | 261 | 52 | 35 |
| 1989 | 27 | 306 | 61 | 65 |

**December**

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 38 | | 9 | |
| 1979 | 56 | 414 | 27 | |
| 1980 | 81 | 236 | 38 | |
| 1981 | 99 | 232 | 32 | |
| 1982 | 68 | 258 | 51 | |
| 1983 | 76 | 299 | 65 | |
| 1984 | 58 | 336 | 43 | |
| 1985 | 36 | 431 | 31 | 64 |
| 1986 | 23 | 40 | 40 | 199 |
| 1987 | 23 | 4227 | 49 | 82 |
| 1988 | 37 | 369 | 71 | 44 |
| 1989 | 27 | 323 | 60 | 61 |

*Ambient Air Quality in Bombay Station: Aniknagar (A20)*

Units: µg/m³

January

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 65 | 176 | 24 | |
| 1979 | 47 | 206 | 5 | |
| 1980 | 36 | 154 | 16 | |
| 1981 | 25 | 160 | 18 | |
| 1982 | 43 | 135 | 19 | |
| 1983 | | | | |
| 1984 | 26 | 263 | 61 | |
| 1985 | 37 | 332 | 59 | 152 |
| 1986 | 27 | 238 | 59 | 327 |
| 1987 | 19 | 327 | 51 | 192 |
| 1988 | 47 | 360 | 89 | 176 |
| 1989 | | | | |
| 1990 | 27 | 409 | 55 | |

February

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 81 | 237 | 4 | |
| 1979 | 40 | 132 | 9 | |
| 1980 | 53 | 249 | 21 | |
| 1981 | 39 | 308 | 23 | |
| 1982 | 24 | 171 | 11 | |
| 1983 | | | | |
| 1984 | 23 | 391 | 43 | |
| 1985 | 33 | 304 | 55 | |
| 1986 | 30 | 352 | 42 | 156 |
| 1987 | 22 | 318 | 50 | 320 |
| 1988 | 62 | 287 | 61 | 120 |
| 1989 | 39 | 348 | 63 | 205 |
| 1990 | 40 | 3220 | 72 | |

March

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 27 | 190 | 18 | |
| 1979 | 30 | 182 | 5 | |
| 1980 | 30 | 220 | 16 | |
| 1981 | 43 | 164 | 22 | |
| 1982 | 86 | 169 | 18 | |
| 1983 | | | | |
| 1984 | 65 | 261 | 45 | |
| 1985 | | | | |
| 1986 | 41 | 387 | 39 | 200 |
| 1987 | 14 | 290 | 37 | 208 |
| 1988 | 39 | 493 | 37 | 160 |
| 1989 | 18 | 306 | 38 | 274 |
| 1990 | 23 | 231 | 53 | |

April

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 48 | 179 | 10 | |
| 1979 | 27 | 166 | 15 | |
| 1980 | 30 | 223 | 15 | |
| 1981 | 31 | 183 | 11 | |
| 1982 | | | | |
| 1983 | | | | |
| 1984 | 13 | 258 | 25 | |
| 1985 | 46 | 272 | 38 | 141 |
| 1986 | 40 | 297 | 46 | 154 |
| 1987 | 17 | 345 | 23 | 145 |
| 1988 | 32 | 267 | 19 | 140 |
| 1989 | 22 | 236 | 41 | 181 |
| 1990 | 24 | 256 | 32 | |

May

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 43 | 145 | 8 | |
| 1979 | 43 | 205 | 17 | |
| 1980 | 18 | 159 | 18 | |
| 1981 | 28 | 126 | 14 | |
| 1982 | | | | |
| 1983 | | | | |
| 1984 | 14 | 133 | 26 | |
| 1985 | 34 | 193 | 24 | 84 |
| 1986 | 27 | 332 | 28 | 102 |
| 1987 | 9 | 202 | 28 | 265 |
| 1988 | 23 | 194 | 19 | 137 |
| 1989 | 18 | 257 | 27 | 115 |
| 1990 | 9 | 90 | 18 | |

June

| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
|---|---|---|---|---|
| 1978 | 105 | 233 | 11 | |
| 1979 | 42 | 186 | 10 | |
| 1980 | 68 | 156 | 11 | |
| 1981 | | | | |
| 1982 | | | | |
| 1983 | | | | |
| 1984 | 29 | 154 | 17 | |
| 1985 | 19 | 95 | 28 | 95 |
| 1986 | 22 | 144 | 24 | 111 |
| 1987 | 36 | 181 | 21 | 20 |
| 1988 | 52 | 173 | 32 | 113 |
| 1989 | 37 | 229 | 16 | 46 |
| 1990 | 20 | 125 | 21 | |

*Ambient Air Quality in Bombay Station: Aniknagar (A20)*

**Units**: µg/m³

| July | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 92 | 273 | 7 | |
| 1979 | 20 | 324 | 16 | |
| 1980 | 43 | 127 | 15 | |
| 1981 | 14 | 47 | 6 | |
| 1982 | 22 | 122 | 9 | |
| 1983 | | | | |
| 1984 | 38 | 121 | 27 | |
| 1985 | 20 | 126 | 22 | 49 |
| 1986 | 11 | 134 | 22 | 72 |
| 1987 | 15 | 119 | 20 | 90 |
| 1988 | 33 | 97 | 27 | 51 |
| 1989 | 19 | 75 | 20 | 157 |
| 1990 | 27 | 141 | 27 | |

| August | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 29 | 219 | 8 | |
| 1979 | 28 | 320 | 13 | |
| 1980 | 37 | 115 | 13 | |
| 1981 | 12 | 143 | 7 | |
| 1982 | 9 | 100 | 15 | |
| 1983 | 38 | 112 | 23 | |
| 1984 | 34 | 115 | 27 | |
| 1985 | 26 | 112 | 20 | 45 |
| 1986 | 15 | 113 | 19 | 84 |
| 1987 | 26 | 104 | 26 | 82 |
| 1988 | 15 | 136 | 21 | 34 |
| 1989 | 17 | 73 | 24 | 55 |
| 1990 | | | | |

| September | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 34 | 157 | 9 | |
| 1979 | 25 | 127 | 11 | |
| 1980 | 58 | 104 | 10 | |
| 1981 | 23 | 74 | 8 | |
| 1982 | 24 | 121 | 36 | |
| 1983 | 19 | 66 | 26 | |
| 1984 | 41 | 134 | 32 | |
| 1985 | | | | |
| 1986 | 17 | 125 | 26 | 104 |
| 1987 | 16 | 190 | 31 | 199 |
| 1988 | 14 | 93 | 17 | 35 |
| 1989 | 38 | 110 | 26 | 67 |

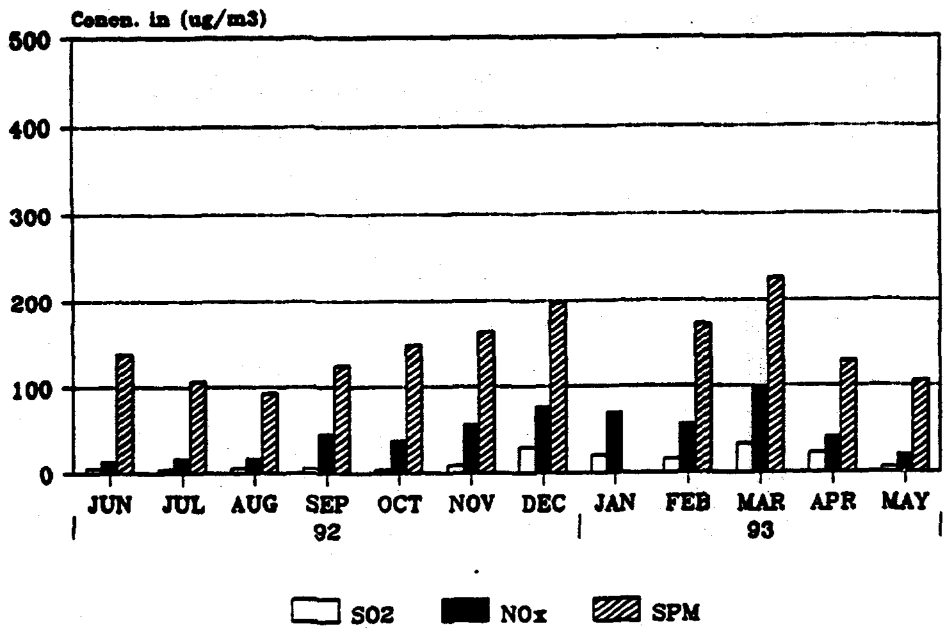
| October | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 32 | 230 | 8 | |
| 1979 | 33 | 141 | 12 | |
| 1980 | 43 | 144 | 12 | |
| 1981 | 16 | 56 | 9 | |
| 1982 | 40 | 162 | 58 | |
| 1983 | 40 | 225 | 48 | |
| 1984 | 35 | 224 | 43 | |
| 1985 | 38 | 284 | 35 | 54 |
| 1986 | 36 | 245 | 53 | 175 |
| 1987 | 67 | 171 | 20 | 119 |
| 1988 | 28 | 171 | 35 | 42 |
| 1989 | 60 | 206 | 46 | 145 |

| November | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 25 | 173 | 9 | |
| 1979 | 29 | 101 | 9 | |
| 1980 | 32 | 129 | 14 | |
| 1981 | 12 | 83 | 9 | |
| 1982 | | | | |
| 1983 | 35 | | 50 | |
| 1984 | 25 | 213 | 34 | |
| 1985 | 31 | 290 | 30 | 131 |
| 1986 | 23 | 249 | 34 | 154 |
| 1987 | 22 | 229 | 44 | 103 |
| 1988 | 51 | 270 | 54 | 23 |
| 1989 | 31 | 233 | 45 | 128 |

| December | | | | |
|---|---|---|---|---|
| Year | $SO_2$ | SPM | $NO_x$ | $NH_3$ |
| 1978 | 30 | 181 | 7 | |
| 1979 | 34 | 128 | 14 | |
| 1980 | 66 | 155 | 24 | |
| 1981 | 19 | 115 | 13 | |
| 1982 | | | | |
| 1983 | 58 | 277 | 64 | |
| 1984 | 75 | 253 | 46 | |
| 1985 | 46 | 333 | 39 | 123 |
| 1986 | 29 | 266 | 53 | 196 |
| 1987 | 29 | 240 | 36 | 92 |
| 1988 | 34 | 256 | 49 | 33 |
| 1989 | 26 | 315 | 54 | 34 |

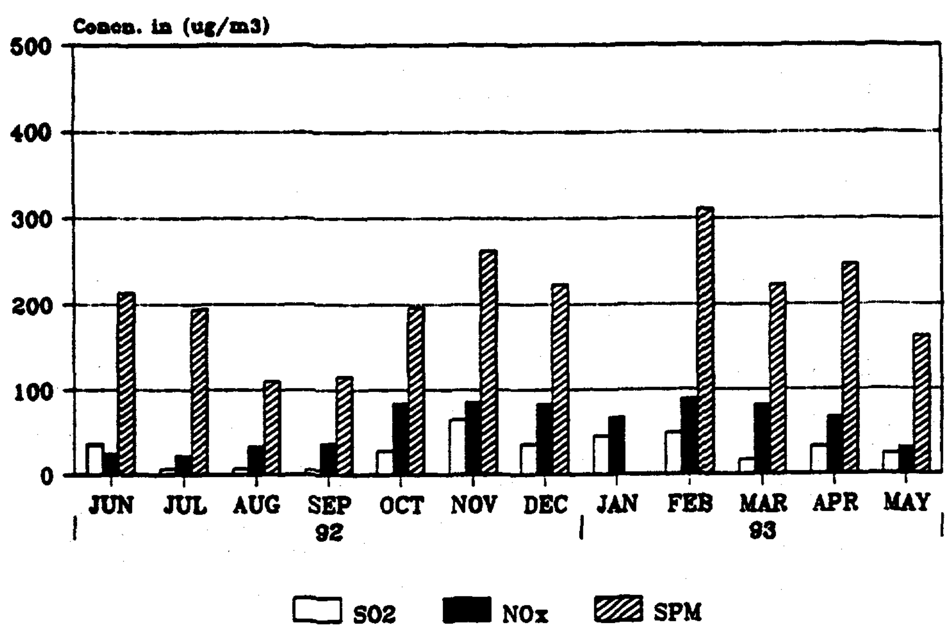
# ANNEX III
# MONTHLY AVERAGE $SO_2$, $NO_X$ AND TSP AT MCGB AND GEMS (NEERI) STATIONS, FOR THE URBAIR PERIOD JUNE 1992–MAY 1993

**AMBIENT AIR QUALITY DATA – COLABA**
**MONITORING AGENCY: M.C.G.B.**

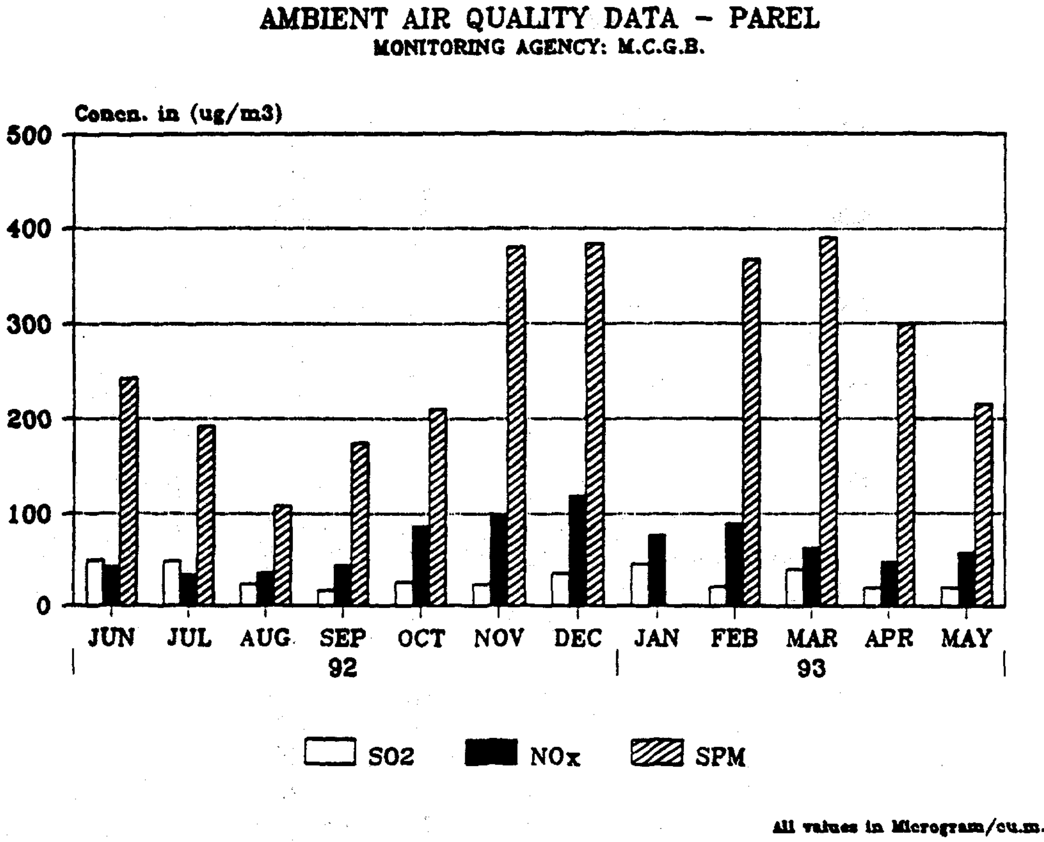


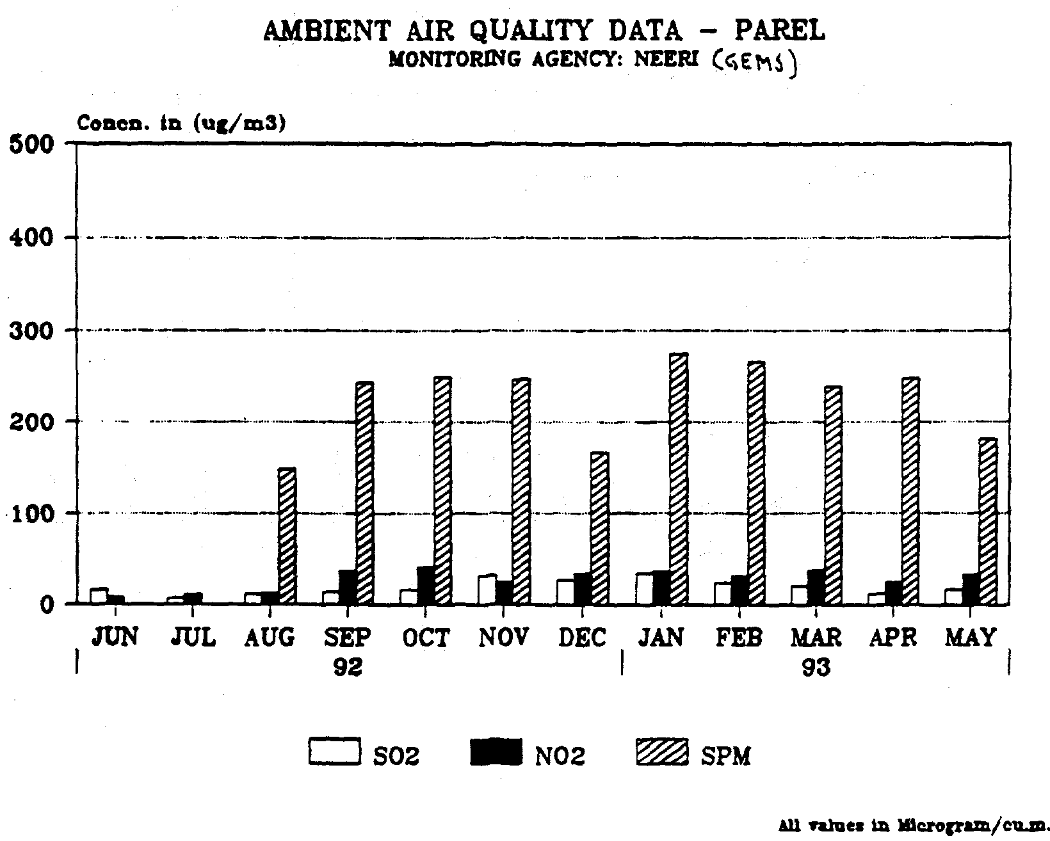

All values in Microgram/cu.m.

**AMBIENT AIR QUALITY DATA – WORLI NAKA**
**MONITORING AGENCY: M.C.G.B.**

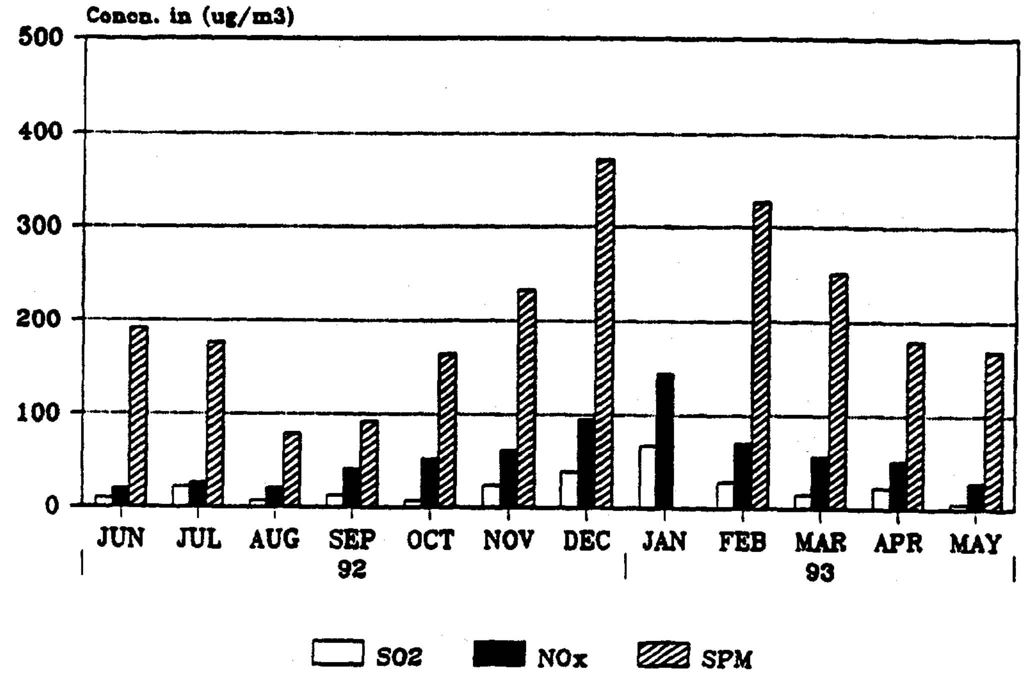



All values in Microgram/cu.m.


AMBIENT AIR QUALITY DATA - PAREL
MONITORING AGENCY: M.C.G.B.
Concn. in (ug/m3)
500
400
300
200
100
0
JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
92
93
SO2 NOx SPM
All values in Microgram/cu.m.

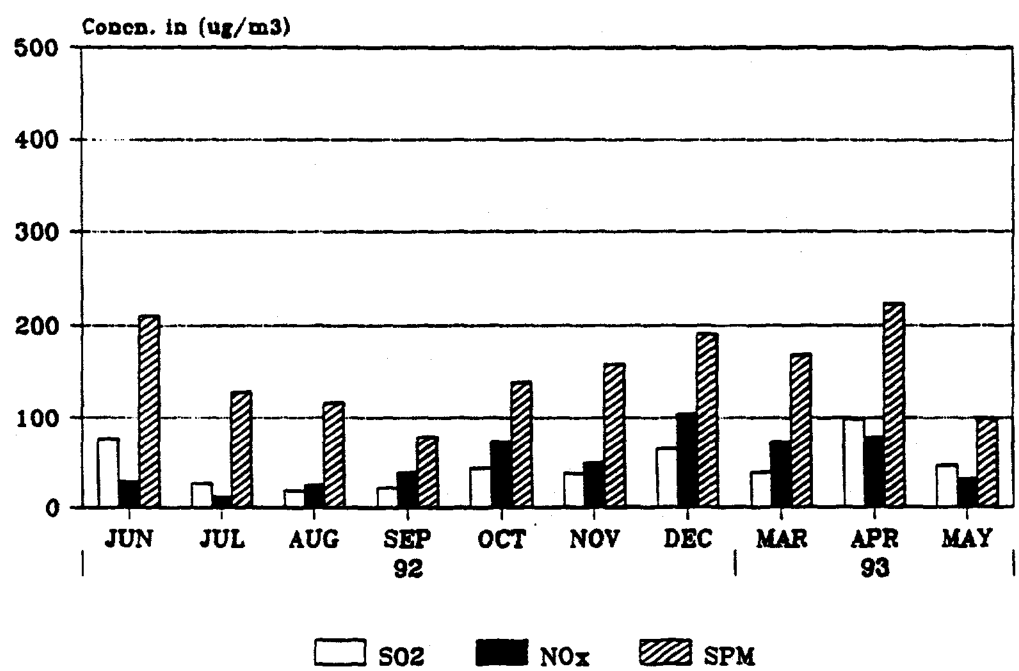

AMBIENT AIR QUALITY DATA - PAREL
MONITORING AGENCY: NEERI (GEMS)
Concn. in (ug/m3)
500
400
300
200
100
0
JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
92
93
SO2 NO2 SPM
All values in Microgram/cu.m.

**AMBIENT AIR QUALITY DATA - DADAR**
**MONITORING AGENCY: M.C.G.B.**




All values in Microgram/cu.m.

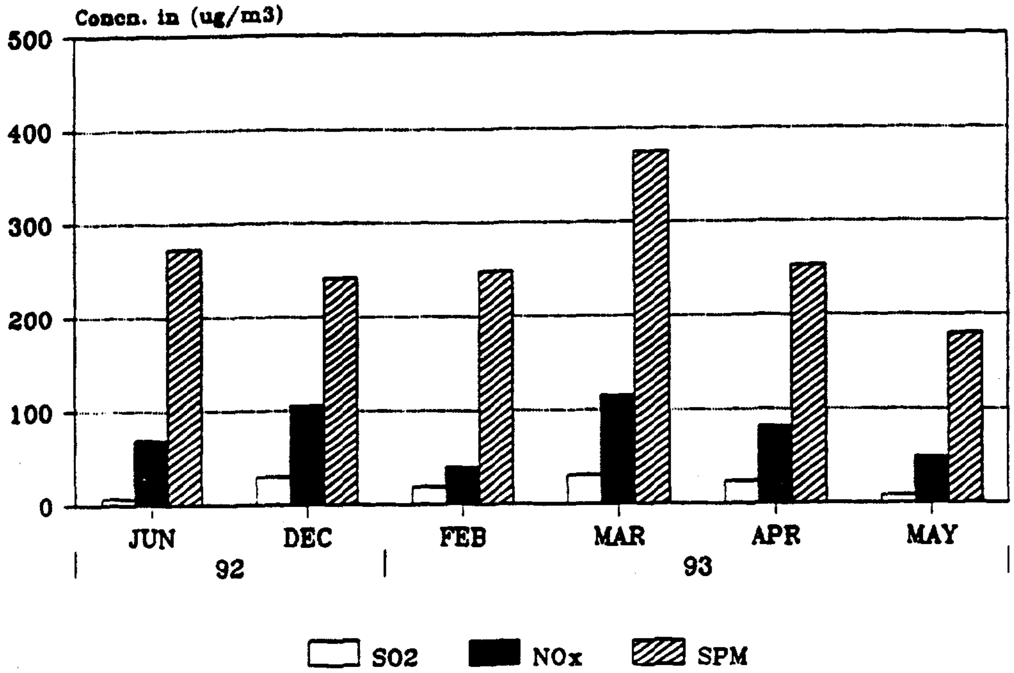
**AMBIENT AIR QUALITY DATA - SEWREE**
**MONITORING AGENCY: M.C.G.B.**




All values in Microgram/cu.m.

## AMBIENT AIR QUALITY DATA – SION

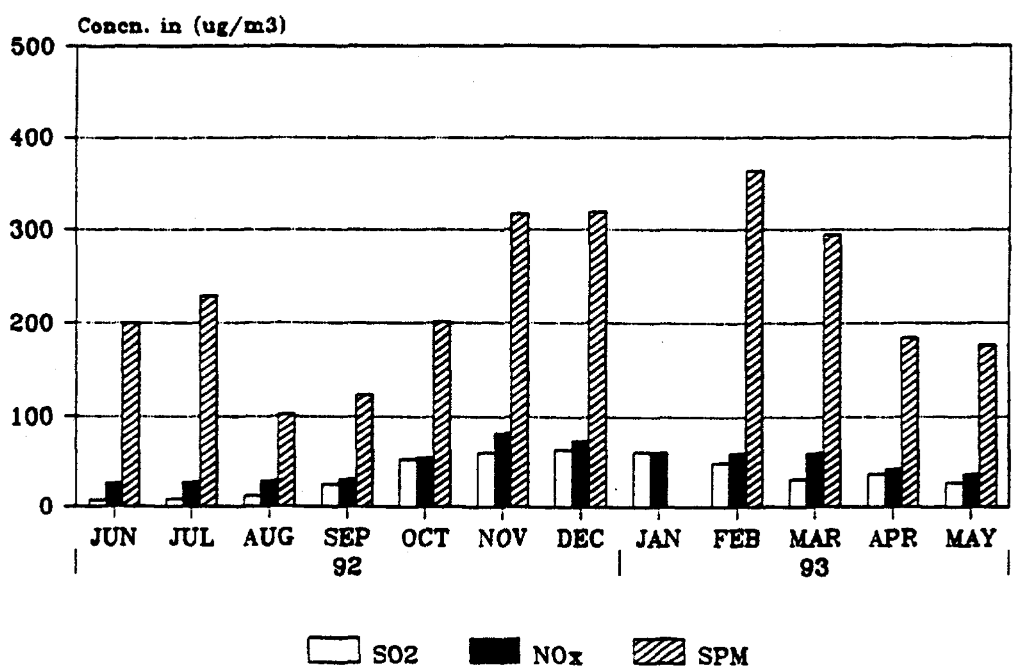
MONITORING AGENCY: M.C.G.B.




All values in Microgram/cu.m.

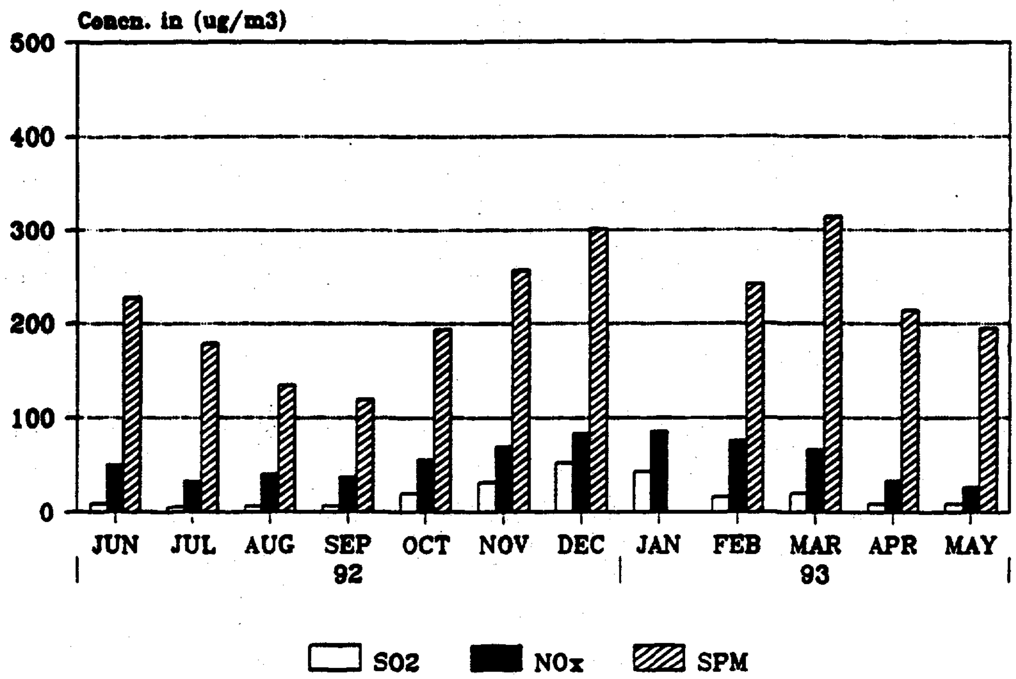
## AMBIENT AIR QUALITY DATA – ANDHERI

MONITORING AGENCY: M.C.G.B.



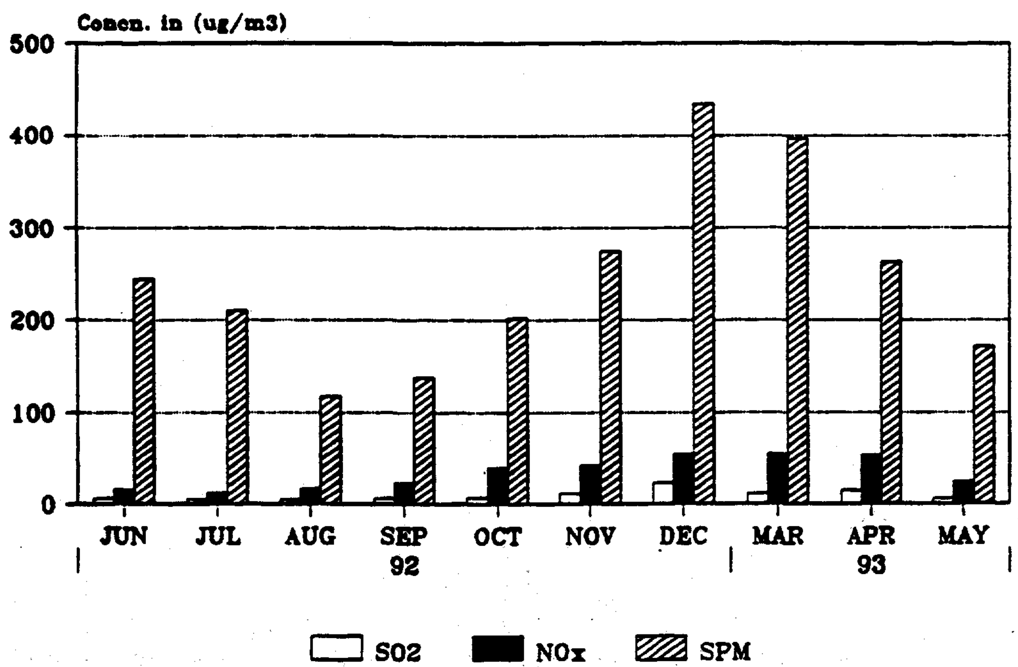

All values in Microgram/cu.m.

AMBIENT AIR QUALITY DATA - SAKI NAKA
MONITORING AGENCY: M.C.G.B.




All values in Microgram/cu.m.

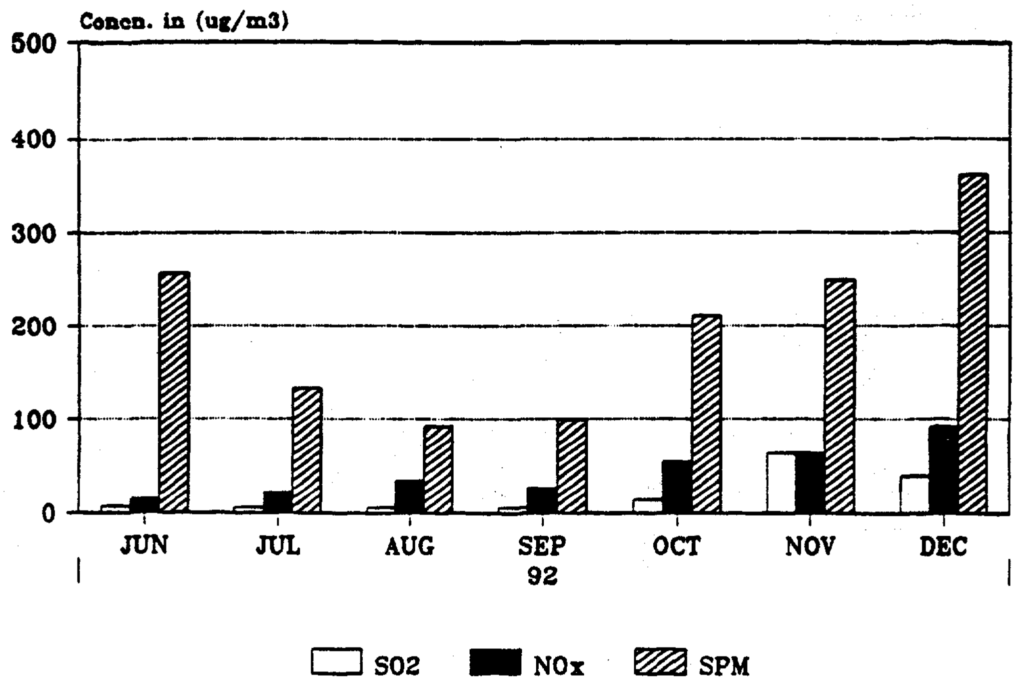
AMBIENT AIR QUALITY DATA - JOGESHWARI
MONITORING AGENCY: M.C.G.B.




All values in Microgram/cu.m.

AMBIENT AIR QUALITY DATA - GHATKOPAR

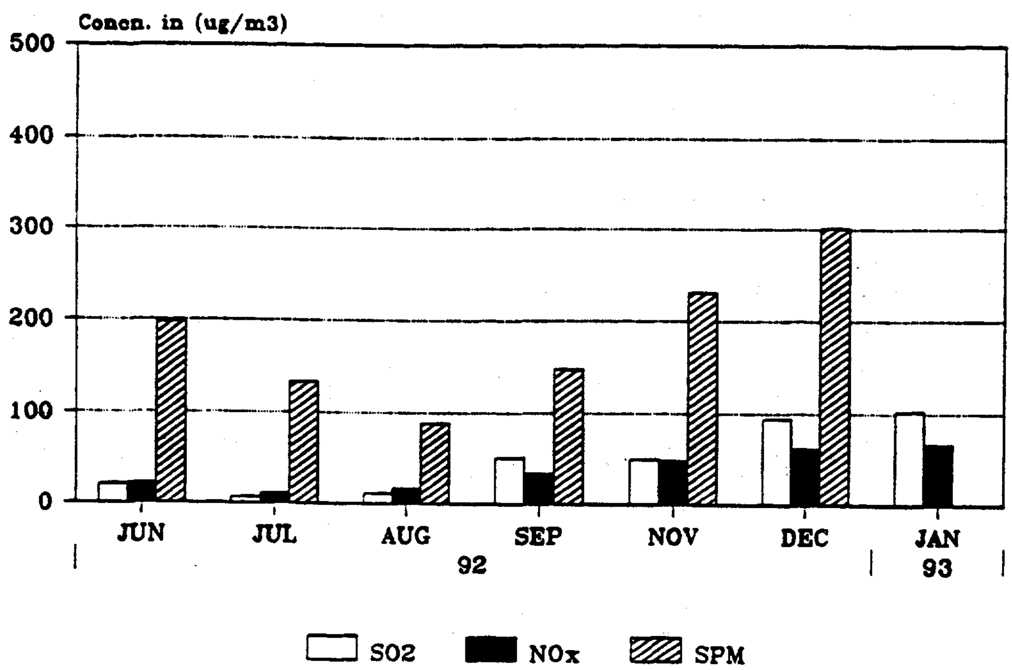
MONITORING AGENCY: M.C.G.B.




All values in Microgram/cu.m.

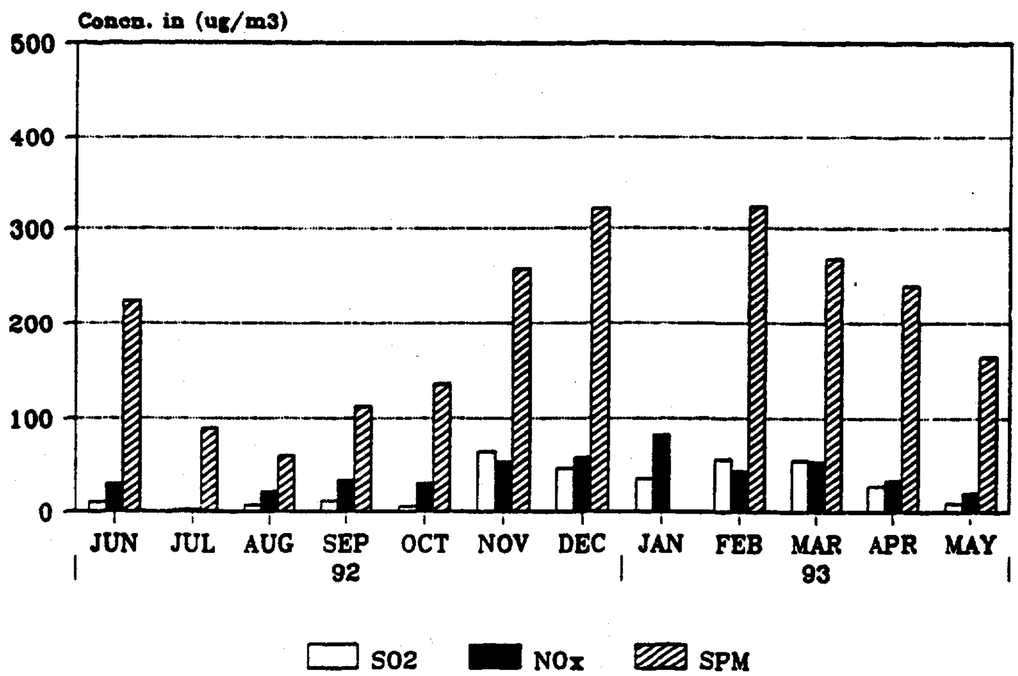
AMBIENT AIR QUALITY DATA - BHANDUP

MONITORING AGENCY: M.C.G.B.



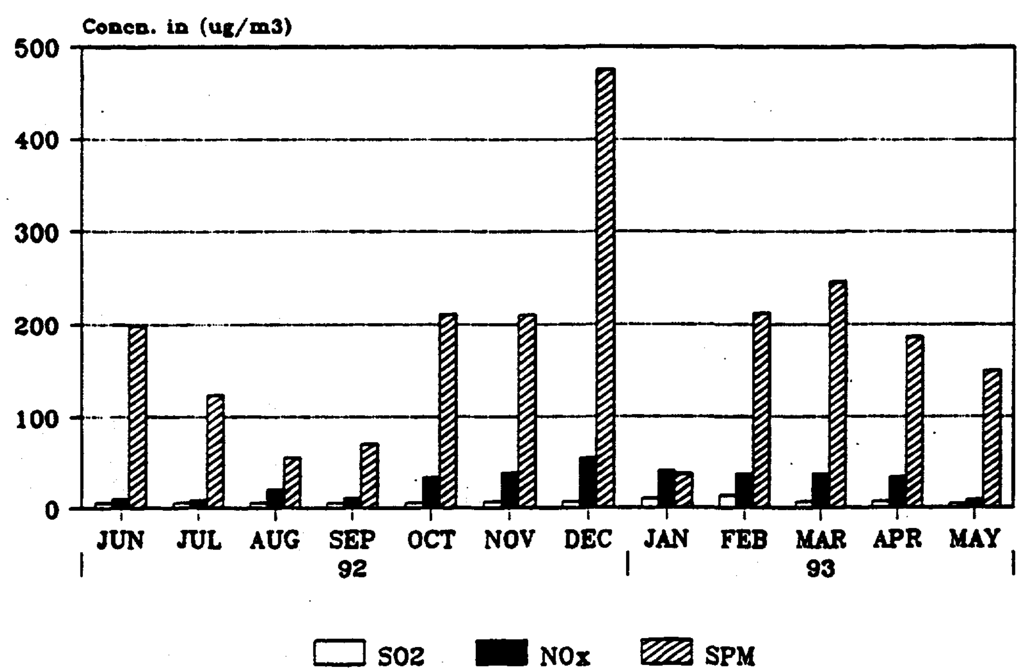

All values in Microgram/cu.m.

## AMBIENT AIR QUALITY DATA - MULUND
MONITORING AGENCY: M.C.G.B.



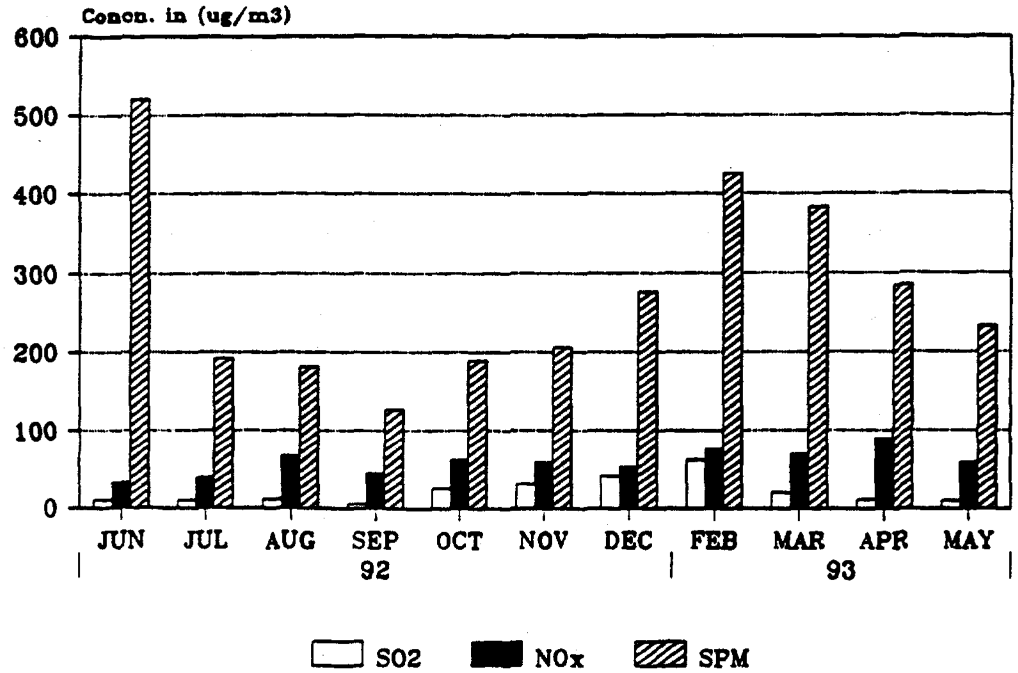

All values in Microgram/cu.m.

## AMBIENT AIR QUALITY DATA - BORIVALI
MONITORING AGENCY: M.C.G.B.



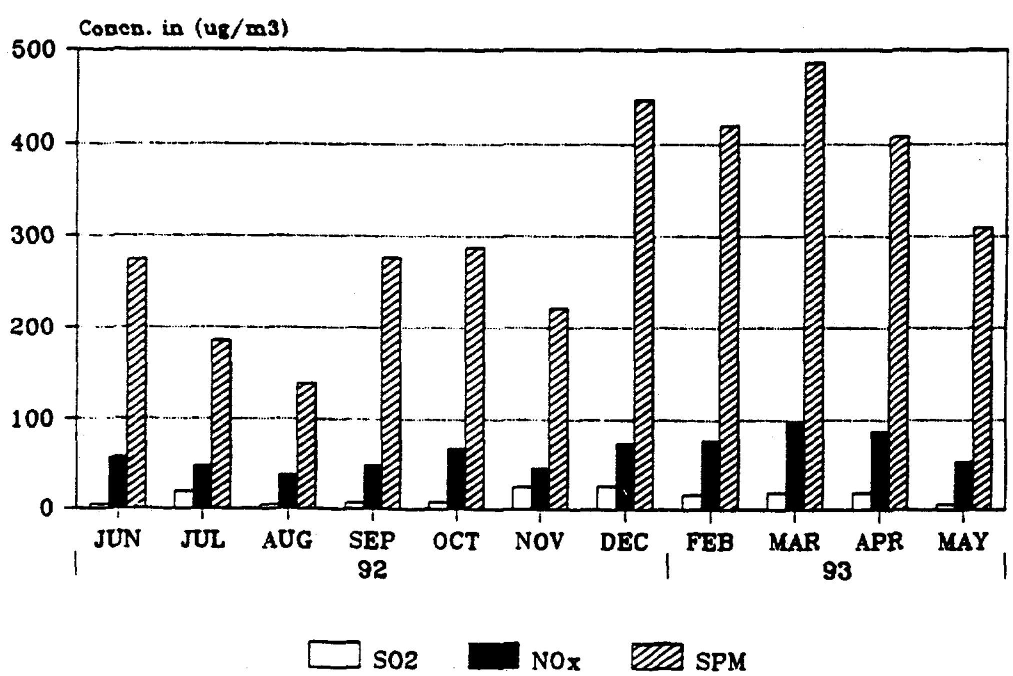

All values in Microgram/cu.m.

AMBIENT AIR QUALITY DATA – CHEMBUR NAKA
MONITORING AGENCY: M.C.G.B.




All values in Microgram/cu.m.

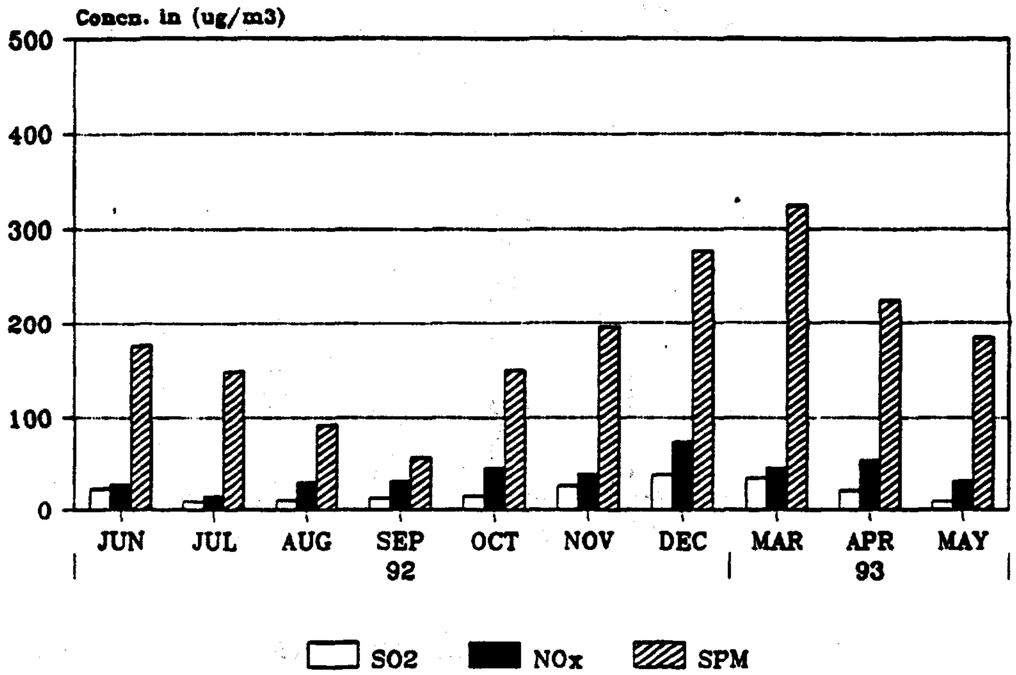
AMBIENT AIR QUALITY DATA – MARAVALI
MONITORING AGENCY: M.C.G.B.




All values in Microgram/cu.m.

## AMBIENT AIR QUALITY DATA – ANIKNAGAR

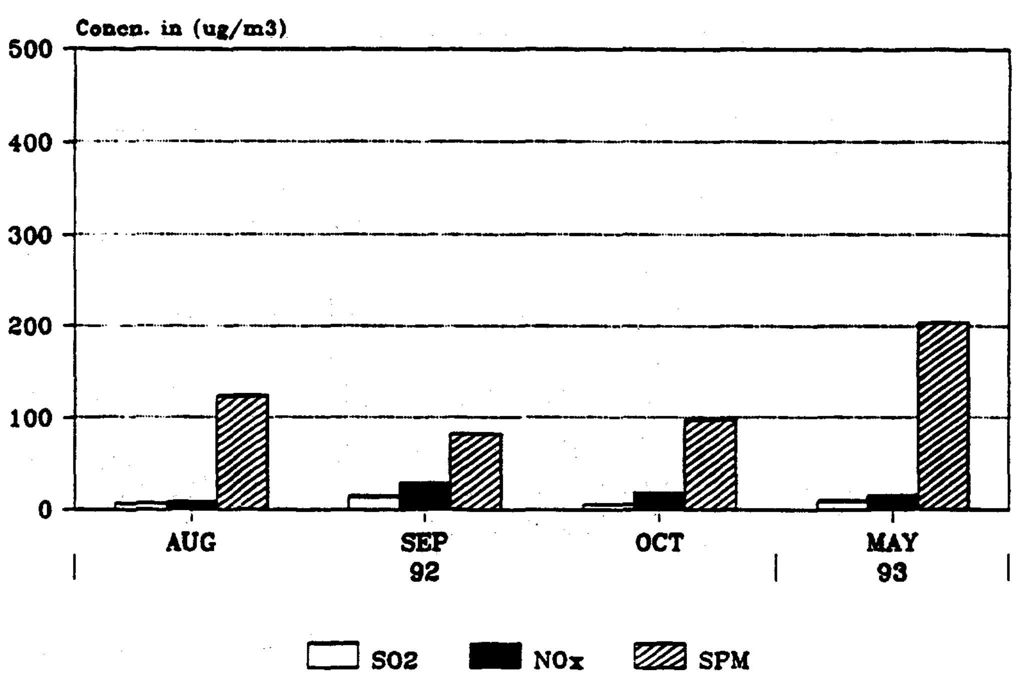
**MONITORING AGENCY: M.C.G.B.**




All values in Microgram/cu.m.

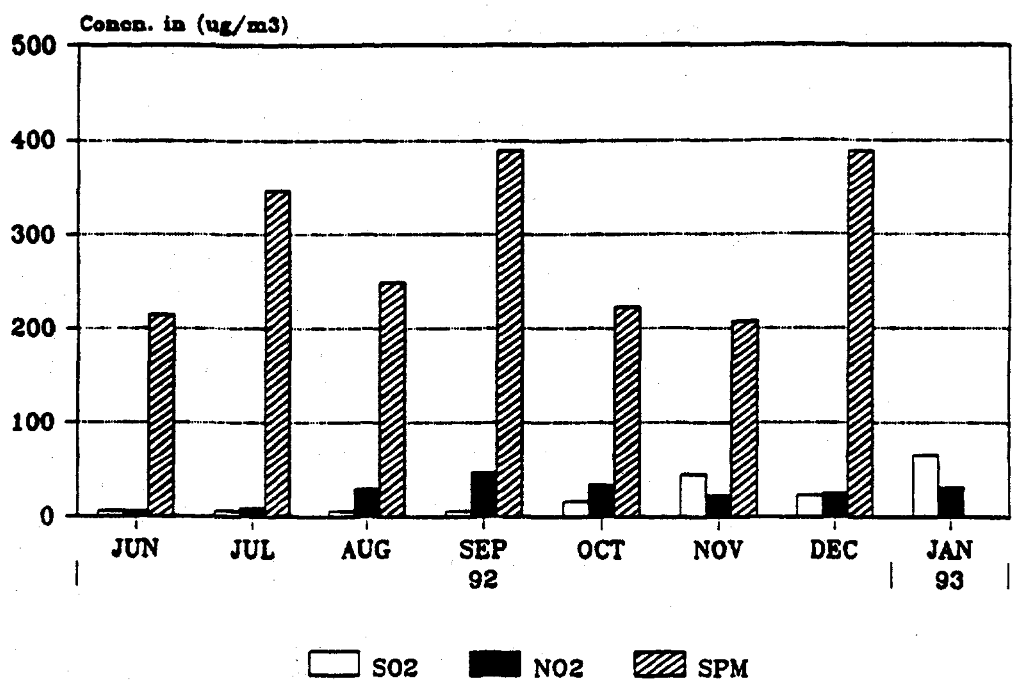
## AMBIENT AIR QUALITY DATA – MAHUL

**MONITORING AGENCY: M.C.G.B.**



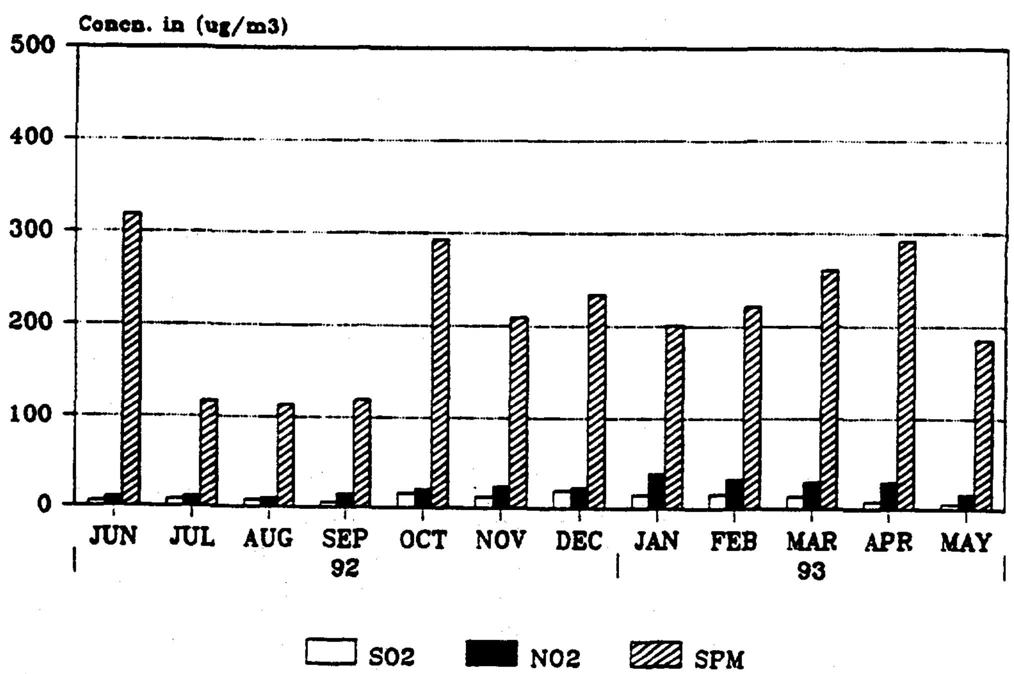

All values in Microgram/cu.m.

AMBIENT AIR QUALITY DATA – BANDRA
MONITORING AGENCY: NEERI




All values in Microgram/cu.m.

AMBIENT AIR QUALITY DATA – KALBADEVI
MONITORING AGENCY: NEERI




All values in Microgram/cu.m.

# APPENDIX 2
# AIR QUALITY GUIDELINES

## AIR QUALITY GUIDELINES

*National ambient air quality standards in India.* These were established in 1994 and are given in Table 1 below. The Indian Standards differentiate between Industrial, Residential and Sensitive areas. Bombay is considered an Industrial area. The Indian Standards for industrial areas are less restrictive than the WHO guidelines (Table 2) for $SO_2$ annual average, and especially for TSP and $PM_{10}$ (the WHO recommended guideline for $PM_{10}$ is 70 µg/m³, as 24 hour average). For $NO_2$, the Indian standards are stricter than WHO.

***Table 1: National Ambient Air Quality Standards***

| Pollutants | Time weighted average | Concentration in ambient air | | | Method of measurements |
|---|---|---|---|---|---|
| | | Industrial area | Residential, Rural and other areas | Sensitive of Area | |
| Sulfur Dioxide $SO_2$ | Annual average* | 80 µg/ m³ | 60 µg/m³ | 15 µg/m³ | 1. Improved West and Geake method |
| | 24 hours** | 120 µg/ m³ | 80 µg/m³ | 30 µg/m³ | 2. Ultraviolet fluorescence |
| Oxides of Nitrogen as $NO_2$ | Annual average* | 80 µg/ m³ | 60 µg/m³ | 15 µg/m³ | 1. Jacob & Hochheiser modified (Na-Arsenite) Method |
| | 24 hours* | 120 µg/m³ | 80 µg/m³ | 30 µg/m³ | 2. Gas Phase Chemiluminescence |
| Suspended Particulate Matter (SPM) | Annual average*<br>24 hours** | 360 µg/m³<br>500 µg/m³ | 140 µg/m³<br>200 µg/m³ | 70 µg/m³<br>100 µg/m³ | High Volume sampling, (Average flow rate not less than 1.1 m³/minute) |
| Respirable matter (size less than 10 µm) ($PM_{10}$) | Annual average*<br>24 hours** | 120 µg/m³<br>150 µg/m³ | 60 µg/m³<br>100 µg/m³ | 50 µg/m³<br>75 µg/m³ | Respirable particulate matter sampler |
| Lead (Pb) | Annual average*<br>24 hours** | 1.0 µg/m³<br>1.5 µg/m³ | 0.75 µg/m³<br>1.00 µg/m³ | 0.50 µg/m³<br>0.75 µg/m³ | ASS method after sampling using PM 2000 or equivalent Filter paper |
| Carbon Monoxide (CO) | 8 hours**<br>1 hour | 5.0 mg/m³<br>10.0 mg m³ | 2.0 mg/m³<br>4.0 mg/m³ | 1.0 mg/m³<br>2.0 mg/ m³ | Non dispersive infrared spectroscopy |

* Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval.

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

**NOTE:**

1. National Ambient Air Quality Standard: The levels of air quality with an adequate margin of safety, to protect the public health, vegetation and property.
2. Whenever two consecutive values exceed the limit specified above for the respective category, it would be considered adequate reason to institute regular/continuous monitoring and further investigations.
3. The State Government/State Board shall notify the sensitive and other areas in the respective states within a period of six months from the date of Notification of National Ambient Standards.

***Table 2: WHO Air Quality Guidelines (WHO, 1977a, 1977b, 1978, 1979, 1987)***

| Parameter | | 10 minutes | 15 minutes | 30 minutes | 1 hour | 8 hours | 24 hours | 1 year | Year of standard |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | $\mu g/m^3$ | 500 | | | 350 | | 125 [a] | 50 [a] | 1987 |
| $SO_2$ | $\mu g/m^3$ | | | | | | 100–150 | 40–60 | 1979 |
| BS [b] | $\mu g/m^3$ | | | | | | 125 [a] | 50 [a] | 1987 |
| BS [b] | $\mu g/m^3$ | | | | | | 100–150 | 40–60 | 1979 |
| TSP | $\mu g/m^3$ | | | | | | 120 [a] | | 1987 |
| TSP | $\mu g/m^3$ | | | | | | 150–230 | 60–90 | 1979 |
| $PM_{10}$ | $\mu g/m^3$ | | | | | | 70 [a] | | 1987 |
| Lead | $\mu g/m^3$ | | | | | | | 0.5–1 | 1987, 1977 [b] |
| CO | $mg/m^3$ | | 100 | 60 | 30 | 10 | | | 1987 |
| $NO_2$ | $\mu g/m^3$ | | | | 400 | | 150 | | 1987 |
| $NO_2$ | $\mu g/m^3$ | | | | 190-320 [C] | | | | 1977 [b] |
| $O_3$ | $\mu g/m^3$ | | | | 150–200 | 100–120 | | | 1987 |
| $O_3$ | $\mu g/m^3$ | | | | 100–200 | | | | 1978 |

**Notes:**

a) Guideline values for combined exposure to sulfur dioxide and suspended particulate matter (they may not apply to situations where only one of the components is present).

b) Application of the black smoke value is recommended only in areas where coal smoke from domestic fires is the dominant component of the particulates. It does not necessarily apply where diesel smoke is an important contributor.

c Not to be exceeded more than once per month.

**Suspended particulate matter measurement methods**

BS = Black smoke; a concentration of a standard smoke with an equivalent reflectance reduction to that of the atmospheric particles as collected on a filter paper.

TSP = Total suspended particulate matter; the mass of collected particulate matter by gravimetric analysis divided by total volume sampled.

$PM_{10}$ = Particulate matter less than 10 $\mu m$ in aerodynamic diameter; the mass of particulate matter collected by a sampler having an inlet with 50 per cent penetration at 10 $\mu m$ aerodynamic diameter determined gravimetrically divided by the total volume sampled.

TP = Thoracic particles (as $PM_{10}$).

IP = Inhalable particles (as $PM_{10}$).

**Source:** (WHO/UNEP 1992)

# APPENDIX 3
# AIR POLLUTION LAWS AND REGULATIONS FOR INDIA AND BOMBAY

CONTENTS

## LEGAL ASPECTS OF POLLUTION CONTROL—OPERATIONAL REQUIREMENTS

The Government of India has promulgated 3 important Acts in the field of pollution control:

i. The Water Pollution (Prevention & Control) Act, 1974.
ii. The Air Pollution (Prevention & Control) Act, 1981.
iii. The Environment Protection Act, 1986.

According to these Acts, industry-specific discharge/emission standards called MINAS (Minimum National Standards) have been prescribed. A few general standards as applicable to SSI units for air pollution are given in Annexure. All industries including SSI units are to comply with these standards and meet other stipulation laid down in these Acts. The responsibility of enforcing the provisions of these Acts rests with the Central/State Pollution Control Boards. Depending on the location of unit, the concerned State Boards expect that the units in their jurisdiction will obtain their permission to discharge the pollutants, or their 'CONSENT.'

The legal position, is that all the existing units are to obtain the CONSENT of their respective Boards. New units, even before they start putting up the industry, have to obtain a NOC (No Objection Certificate) from the Board. In fact, now, financial institutions and banks, too, demand production of NOCs before disbursement of loans even though the loans may have been sanctioned on the basis of the techno-economic feasibility of the project.

In order to obtain the NOC from a Pollution Control Board (PCB), application is to be made with a complete project-report, including the proposed measures of controlling pollution. Since, pollution control is site-specific, the PCBs also have to be apprised of proposed project site and, sometimes, depending on the need, Board may even ask for EIA (Environment Impact Assessment) reports for site clearance.

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

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

## SALIENT FEATURES OF POLLUTION RELATED ACTS

## *The Air (Prevention and Control of Pollution) Act, 1981*

An Act to provide for the prevention, control and abatement of air pollution, given assent by the President of India on March 29, 1981.

The Act has the following chapters:

I. Preliminary
II. Central and State Boards for the Prevention and Control of Air Pollution
III. Powers and Functions of Boards
IV. Prevention and Control of Air Pollution
V. Fund, Accounts and Audit
VI. Penalties and procedure
VII. Miscellaneous

## *Salient features*

This Act is applicable to the whole of India.

## *Central and State Boards for the prevention and control of air pollution*

*Constitution of State Board*:

a. The State Government will appoint a Chairman, member representing institutions, industries, government departments and social bodies etc. and a member secretary as executive head.
b. In union territory Central Board is to act as State Boards.
c. The Board may appoint officers and other employees as it may fit for efficient functioning of the Board.

*Functions of Central Board*:

a. Advise the Central Government on any matter concerning the improvement of the quality of air and the prevention and control of abatement of air pollution,
b. Plan the nation-wide programme for air pollution abatement,
c. Coordinate the activities of State Boards,
d. Provide guidance and technical assistance to the State Boards,
e. Plan and organize training of persons engaged in air pollution abatement programmes,
f. Organize through media abatement plans,
g. Collect, compile, and publish technical and statistical data relating to air pollution,
h. Lay down standards for the quality of air,
i. To establish and recognize a laboratory to enable it to perform its function under this Act.

*Functions of State Boards*:

a. to plan comprehensive programmes for air pollution abatement,
b. to advise the State Government on any matter concerning the air pollution abatement,
c. to collaborate with Central Board,
d. to collect and disseminate information relating to air pollution,
e. to inspect industrial plants at intervals as it may consider necessary and to give directions to related persons for air pollution abatement,
f. to lay down, in consultation with the Central Board, standards for the quality of air, standards for emissions of air pollutants into the atmosphere for industrial plants, automobiles, and other sources excluding ships and air crafts.
g. to establish or recognize a laboratory/laboratories to enable it to perform its functions efficiently.

*Powers to give directions*:

a. Central Board shall be bound by written direction issued by Central Government; and
b. State Board shall be bound by written direction issued by Central Board or the State Government.

## *Prevention and control of air pollution*

The State Government may, after consultation with the State Board by official Gazette notification declare:

a. any area or areas within the State as "Air Pollution control Area or Areas" for the purposes of this act,
b. alter any air pollution control area,
c. prohibition of usage of any fuel other than the approved fuel in air pollution control area,
d. prohibition of burning of any material (other than fuel) in any air pollution control area or part of it.

*Restriction or use of certain industrial plants*:

a. No person shall without the prior consent of the State Board, operate any industrial plant for the purpose of any industry specified in the schedule in an air pollution control area;
b. An application for the consent of the Board shall be accompanied by prescribed fee and shall be made in the prescribed form and shall contain the particulars of the industrial plant and other prescribed particulars;
c. The State Board may make such inquiries at it may deem fit in respect of the application for consent and shall follow the prescribed procedures;
d. Within a period of 4 months after the receipt of consent application the State Board shall by order in writing either grant or refuse it, for reasons recorded in the order;
e. Every person to whom consent has been granted by the State Board shall comply with the following conditions;

i. The prescribed control systems shall be installed and operated in existing/proposed industry.
ii. The existing control equipment if any shall be altered/replaced in accordance with the directions of State Board.
iii. The control system as per clause (i) or (ii) will be kept under good conditions.
iv. Chimney wherever necessary of prescribed specifications, shall be erected or re-erected in the premises.
v. And the condition prescribed from (i) or (iv) complete within the prescribed period.

f. If due to technological improvement, State Board may alter as a whole or part, of the conditions mentioned above;
h. In case of the transfer of the unit from one person to the other person the consent will deemed to be transferred with conditions.

Persons carrying on industry etc. not to allow emission of air pollutants in excess of the standards laid down by State Board. No person carrying on any industry specified in the schedule or industrial, plants in any air pollution control area shall discharge or cause or permit to be discharged, the emission of any air pollutants in excess of the standard laid down by the State Board.

## *Power of entry and inspection*

Any person empowered by a State Board shall have a right to enter, at all reasonable times with necessary assistance, any place:

a. for the purpose of performing any of the function entrusted to him,
b. for the purpose of examination of control system, inspection of related documents, to conduct search and to check whether all directions/ instructions, issued time to time are being followed,
c. all persons carrying on any industry specified activities in the schedule are bound to render all assistance to the persons empowered by the Board and delay or non-cooperation shall be an offense under this Act.

## *Power to obtain information*

The State Board or its empowered person may ask for any information like the type of pollutants and the level of emission from the occupier or the person carrying on any industry and can inspect the premises/control equipment for verifying purposes.

The State board or any officer empowered by it shall have power to take, for analysis purpose sample of air or emission from any chimney, flue, duct or any other outlet in prescribed manner.

Where a sample of emissions has been sent for analysis by Board to the laboratory established or recognized by the State Board the Board's analyst shall analyze the sample and submit a report in the prescribed form.

### *State Air Laboratory*

State Government may, by official notification, establish or specify one or more laboratory or institutions as state laboratory.

### *Analyst*

The State Government may by official Gazette notification appoint a Government Analyst.

### *Report of Analysts*

The report of a Government Analyst may be used as evidence in the court of the law.

### *Appeals*

Any person aggrieved by an order made by the State Board may appeal to an appropriate Appellate Authority within 30 days of the action.

### *Fund, accounts, and audit*

a. The Central Board and every State Board shall have its own fund funded by Central Government/State Government.
b. The Central Board and every State Board shall prepare annual budget and annual report duly audited by a competent authority.

### *Penalties and Procedures*

Failure to comply with the orders or directions of the Board issued under the Act:

a. Whoever fails to comply with the provisions mentioned above is punishable with imprisonment up to 3 months or fines up to Rs 10,000 or both. And in case the failure continues, with an additional fine up to Rs 10/- day during which the failure continues after the conviction for the first such failure.
b. If the failure continues beyond 1 year after the date of conviction, the offender shall be punishable with imprisonment up to 6 months.

## *Penalties for certain acts*

Whoever damages the Board's property, fails to furnish information asked for, obstructs any Board's officer from performing his duty or makes false statements etc., shall be punished with imprisonment up to 3 months or fine up to Rs 500/ or both.

## *Penalty for contravention of certain provisions of the Act*

For any contravention of any the provisions of the act for which no penalty has been else where provided in this Act shall be punishable with a fine of up to Rs 5000/- and with continuation of contravention a fine Rs 100/day after conviction for first contravention.

## *Offenses by Companies and Government Departments*

Where an offense under this act has been committed by a company/ government department, every person who was at that time directly in charge of the company/department shall be deemed to be guilty of the offense and shall be liable to be prosecuted and punished accordingly unless he proves that the offense was made without his knowledge.

## *Miscellaneous*

a. State Central Government/State Government may supersede Central Board/State Board respectively.
b. The Central Government may amend the schedule of industries.

### THE SCHEDULE

1. Asbestos and asbestos product industries,
2. Cement and cement products industries,
3. Ceramic and ceramic product industries,
4. Chemical,
5. Coal and lignite based chemical industries,
6. Engineering industries,
7. Ferrous metallurgical industries,
8. Fertilizer industries,
9. Foundries,
10. Food and agricultural product industries,
11. Mining industries,
12. Non-ferrous metallurgical industries,
13. Ores/mineral processing industries including benefaction, pelletization etc.,
14. Power (coal, petroleum and their products) generating plants and boiler plants,

15. Paper and pulp (including paper products) industries,
16. Textile processing industries (made wholly or in part of cotton),
17. Petroleum refineries,
18. Petroleum products and petrochemical industries,
19. Plants for recovery from and disposal of wastes,
20. Incinerators.

# CENTRAL POLLUTION CONTROL BOARD

(MINISTRY OF ENVIRONMENT & FORESTS, GOVERNMENT OF INDIA)

No-B-31012/2/91/PCI -II/ September 17, 1992

DIRECTIONS FROM THE CENTRAL POLLUTION CONTROL BOARD
UNDER CLAUSE (b) OF SUB-SECTION 1 OF SECTION 18 OF
THE AIR (PREVENTION & CONTROL OF POLLUTION) ACT, 1981

Whereas Clause (g) of Sub-section 1 of Section 17 of the Air (Prevention and Control of Pollution) Act, 1981 establishes standards by a State Pollution Control consultation with Central Pollution Control Board for emission of air pollutants into the atmosphere from industrial plants and automobiles.

And whereas the mass emission standards for petrol, and diesel driven vehicles as given in Annexure I & II respectively, have been evolved and proposed to be made effective from the first day of April, 1995.

As where it is further proposed to strive to attain the indicative standards by all the petrol and diesel driven vehicles as given in Annexure III & IV respectively for the year 2000.

Now, therefore, in exercise of the power vested with the Central Pollution Control Board under Clause (b) of sub-section I of Section 18 of the Air (Prevention and Control of Pollution) Act, 1981, the following directions are issued herewith:-

> "State Council Board shall ensure that on and from the 1st day of April 1995 all petrol and diesel driven vehicles shall be so manufactured that they comply with the mass emission standards as specified in Annexure I and II respectively given herein above;
>
> "The State Pollution Control Board shall also ensure to strive to attain the indicative standards by the petrol and diesel driven vehicles for the year 2000 as given in Annexure III and IV respectively."

(A. BHATTACHARIYA)
Chairman

Annexure I

## MASS EMISSION STANDARD FOR PETROL DRIVEN VEHICLES EFFECTIVE FROM 1/4/1995

## *Type approval tests*

1. *Passenger cars*

| Reference mass R(Kg) | CO g/km | HC + NOx g/km |
|---|---|---|
| R < 1020 | 5.0 | 2.0 |
| 1020 < R < 1250 | 5.7 | 2.2 |
| 1250 < R < 1470 | 6.4 | 2.5 |
| 1470 < R < 1700 | 7.0 | 2.7 |
| 1700 < R < 1930 | 7.7 | 2.9 |
| 1930 < R < 2150 | 8.2 | 3.5 |
| R > 2150 | 9.0 | 4.0 |

Note:
1. The test will be as per Indian driving cycle with cold start.
2. There should be no crankcase emission. (To be implemented from 1/1/1994)
3. Evaporative emission should not be more than 2.0 g/test. (To be implemented from 1/1/1994)

2. *Two-wheelers* (for all categories). The test will be as per Indian driving cycle with cold start.

- CO - 3.75 g/km
- HC - 2.40 g/km

3. *Three-wheelers* (for all categories). The test will be as per Indian driving cycle with cold start.

- CO - 5.6 9/km
- HC - 3.6 g/km

## *Conformity of production tests*

*Passenger Cars* (For all categories).

- A relaxation of 20% for CO & 25% for combined HC+$NO_x$ for the corresponding values of Type Approval Test given above would be permitted.

*Two & Three Wheelers* (For all categories).

- A relaxation of 20% for CO and 25% for HC for the values of Type Approval Test given above would be permitted.

**Annexure II**

## MASS EMISSION STANDARD FOR DIESEL VEHICLES EFFECTIVE FROM 1/4/1995

### *Type approval tests*

| Vehicle category | HC* (g/kWh) | CO* (g/kWh) | $NO_x$ (g/kWh) | Smoke |
|---|---|---|---|---|
| Medium & Heavy over 3.5-Ton/GVW | 2.4 | 11.2 | 14.4 | *** *** |
| Light diesel up to 3.5 Ton GVW | 2.4 | 11.2 | 24.4 | *** |

or

| Reference mass *R(Kg)* | CO** *g/km* | HC + $NO_x$ *g/km* |
|---|---|---|
| R < 1020 | 5.0 | 2.0 |
| 1020 < R < 1250 | 5.7 | 2.2 |
| 1250 < R < 1470 | 6.4 | 2.5 |
| 1470 < R < 1700 | 7.0 | 2.7 |
| 1700 < R < 1930 | 7.7 | 2.9 |
| 1930 < R < 2150 | 8.2 | 3.5 |
| R > 2150 | 9.0 | 4.0 |

**Note:**

* The test cycle is as per 13 mode cycle on dynamometer.

** The test should be as per Indian driving cycle with cold start.

*** The emissions of visible pollutants (smoke) shall not exceed the limit values to smoke density, when expressed as light absorption coefficient given at Page 2 of Annexure II for various nominal flows when tested at constant speeds over full load.

### *Conformity of production tests*

A relaxation of 10% for the values of Type Approval Test given above would be permitted.

## *Nominal flows tested at constant speeds over full load*

| Nominal Flow G (1/s) | Light Absorption Coefficient (K (m-1) |
|---|---|
| ------------ | ------------ |
| 42 | 2.00 |
| 45 | 1. 91 |
| 50 | 1. 82 |
| 55 | 1. 75 |
| 60 | 1. 68 |
| 65 | 1. 61 |
| 70 | 1.56 |
| 75 | 1.50 |
| 80 | 1. 46 |
| 85 | 1. 41 |
| 90 | 1.3 8 |
| 95 | 1.34 |
| 100 | 1.31 |
| 105 | 1.27 |
| 110 | 1.25 |
| 115 | 1.22 |
| 120 | 1.20 |
| 125 | 1.17 |
| 130 | 1.15 |
| 135 | 1.13 |
| 140 | 1.11 |
| 145 | 1. 09 |
| 150 | 1. 07 |
| 155 | 1. 05 |
| 160 | 1. 04 |
| 165 | 1. 02 |
| 170 | 1. 01 |
| 175 | 1. 00 |
| 180 | 0. 99 |
| 185 | 0. 97 |
| 190 | 0. 96 |
| 195 | 0. 95 |
| 200 | 0. 93 |

**Annexure III**

## MASS EMISSION STANDARD FOR PETROL DRIVEN VEHICLES EFFECTIVE FROM 1/4/2000

### *Type approval test*

1. *Passenger cars* (for all categories). The test-should be as per Indian start.

- CO - 2.72 g/km
- HC + NOx - 0.97 g/km

2. *Two-wheelers* (for all categories). The test start should be as per Indian driving cycle with cold start.

- CO - 2. 0 g/km
- HC - 1. 5 g/km

3. *Three-wheelers* (for all categories). The test start should be as per Indian driving cycle with cold start.

- CO - 4.0 g/km
- HC - 1.5 g/km

### *Conformity of production tests*

1. *Passenger Cars* (For all categories)
- A relaxation of 16% for CO & combined HC + NOx for corresponding values of Type Approval Test would be permitted.

2. *Two- & Three-Wheelers* (For all categories)
- A relaxation of 20% for CO as well as HC for the values of Type Approval Test given above would be permitted.

**Annexure IV**

# MASS EMISSION STANDARD FOR DIESEL VEHICLES EFFECTIVE FROM 1/4/2000

## *Type approval tests*

| Vehicle category | HC* | CO* (g/kWh) | NOx * | FM* | Smoke |
|---|---|---|---|---|---|
| Medium & Heavy over 3.5 ton GVW | 1.1 | 4.5 | 8.0 | 0.36 | *** |
| Light diesel up to 3.5 ton GVW | 1.1 | 4.5 | 8.0 | 0.61 | *** |

or

| CO** g/km | HC + $NO_x$** g/km | PM** |
|---|---|---|
| 2.72 | 0.97 | 0.14 |

**Note:**

* The test should be as per 13 mode cycle.

** The test should be as per Indian driving cycle with cold start.

*** The emission of visible pollutants (smoke) shall not exceed the limit values of smoke density, when expressed and light absorption coefficient given at Page 2 of Annexure IV for various nominal flows when listed at constant speed over full load.

## *Conformity of production tests*

A relaxation of 10% for the values of Type Approval Test given above would be permitted for Conformity Of Production Test for all vehicles.

***Various nominal flows listed at constant speed over full load***

| Nominal Flow G (1/s) | Light Absorption Coefficient K($m^{-1}$) |
|---|---|
| ---------- | ---------- |
| 42 | 2.00 |
| 45 | 1. 91 |
| 50 | 1.82 |
| 55 | 1.75 |
| 60 | 1.68 |
| 65 | 1.61 |
| 70 | 1.56 |
| 75 | 1.50 |
| 80 | 1.46 |
| 85 | 1. 41 |
| 90 | 1.38 |
| 95 | 1. 34 |
| 100 | 1.31 |
| 105 | 1.27 |
| 110 | 1.25 |
| 115 | 1.22 |
| 120 | 1.20 |
| 125 | 1.17 |
| 130 | 1.15 |
| 135 | 1.13 |
| 140 | 1.11 |
| 145 | 1.09 |
| 150 | 1.07 |
| 155 | 1.05 |
| 160 | 1.04 |
| 165 | 1.02 |
| 170 | 1.01 |
| 175 | 1.00 |
| 180 | 0.99 |
| 185 | 0.97 |
| 190 | 0.96 |
| 195 | 0.95 |
| 200 | 0.93 |

## *Requirements of liquefied petroleum gases*

| Sr. No | Characteristics | Requirements Commercial Butane | Commercial Butane Propane Mixture | Commercial Propane | Method of Test Ref. To (P) of IS-1448 |
|---|---|---|---|---|---|
| i. | Vapour Pressure @ 65°C, kgf/cm2 (see note 1) | 10 max. | 16.87 max (see note 2) | 26 max. | P:71 |
| ii. | Volatility evaporate temperature in °C, for 95% vol. @ 760 mm. pressure, max. | 2 | 2 | -38 | P:72 |
| iii. | Total volatile sulphur, % by mass, max. | 0.02 | 0.02 | 0.02 | P:34 |
| iv. | Copper strip corrosion @ 38°C for one hour. | ------------ Not worse than no. 1 ---------- | | | P:15 |
| v. | Hydrogen Sulfide | absent | absent | absent | P:73 |
| vi. | Dryness | No free entrained water | No free entrained water | shall pass the test | P:74 (see note 3) |
| vii. | Odour (See note 4) | Level 2 | Level 2 | Level 2 | P:75 |

**NOTE 1:** Vapour pressure may be determined at any temperature and convened to 65'C by means of suitable vapour pressure temperature graph. The same can also be determined by analyzing the gas by means of gas chromatograph and then using the composition. The vapour pressure can be calculated @ 65°C from the standard value of vapour pressures at various temperatures.

**NOTE 2:** Each consignment of commercial butane - propane mixture shall be designated by its maximum vapour pressure in kgf/cm @ 65°C. Further, if desired by the purchaser and subject to prior agreement between the purchaser and the supplier, the minimum vapour pressure of that mixture shall not be lower than 2 kgf/c m$^2$ gauge compared to the designated maximum vapour pressure and in any case the minimum for the mixture shall not be lower than 10 kgf/cm$^2$ @ 65°C.

**NOTE 3:** The presence or absence of free entrained water in commercial butane or commercial butane - propane mixture shall be determined by visual inspection of the sample.

**NOTE 4:** Subject to agreement between the purchaser and the supplier, odour requirements of LPG may be changed for certain *applications where unodourised* LPG is required.

CONFORMS TO IS:4576-1978 FOR LPG.

## *Specification of motor gasoline*

| Sr. No. | Characteristics | Test Method IS:1448 | Requirements | |
|---|---|---|---|---|
| | | | 87 OCTANE | 93 OCTANE |
| i. | Colour, Visual | - | Orange | Red |
| ii. | Copper Strip Corrosion for 3 hours at 50°C | P:15 | Not worse than No. 1 | Not worse than No. 1 |
| iii. | Density at 15°C, g/mi | P:16 | | |
| iv. | Distillation | P:18 | | |
| | Initial Boiling point °C | | To be reported | To be reported |
| | Recovery upto 70°C, % v, min. | | 10 | 10 |
| | Recovery upto 125°C, % v, min. | | 50 | 50 |
| | Recovery upto 180°C, % v, min. | | 90 | 90 |
| | Final boiling point °C, max. | | 215 | 215 |
| | residue, %v, max. | | 2 | 2 |
| v. | Octane number (Research Method) min. | P:27 | 87 | 93 |
| vi. | Oxidation Stability in Minutes, min. | P:28 | 360 | 360 |
| vii. | Residue on Evaporation, mg/100 ml, max. | P:29 (Air-Jet, Solvent Washed) | 4.0 | 4.0 |
| viii. | Sulphur, % wt. max. | P:34 | 0.25 | 0.20 |
| ix. | Lead content (as Pb), g/l max. | P:38 | 0.56 | 0.80 |
| x. | Reid Vapour Pressure at 36°C, $kgf/cm^2$. max. | P:39 | 0.70 | 0.70 |

CONFORMS TO IS:2796-1971 SPECIFICATIONS FOR MOTOR GASOLINES

## *Specification of diesel fuels*

| Sr. No. | Characteristics | Test Method IS:448 | HSD | LDO |
|---|---|---|---|---|
| 1. | Acidity, inorganic | P:2 | Nil | Nil |
| 2. | Acidity, total, mg KOH/g, max. | P:2 | 0.50 | - |
| 3. | Ash. % wt., max. | P:4 | 0.01 | 0.02 |
| 4. | Carbon residue (Ramsbottom), % wt.. max. | P:8 | 0.20 | 1.50 |
| 5.* | Cetane number, min. | P:9 | 42 | - |
| 6.** | Pour Point, °C, max. | P:10 | 6 | Winter 12*** Summer 18 |
| 7. | Copper strip Corrosion for 3 hrs. at 100°C | P:15 | Not worse than No. 1 | Not worse than No. 2 |
| 8. | Distillation, percentage recovery at 366°C. min. | P:18 | 90 | - |
| 9.**** | Flash Point | | | |
| | a) Abel °C. min. | P:20 | 32 | - |
| | b) PMCC °C. min. | P:21 | - | 66 |
| 10. | Kinematic Viscosity cSt at 38°C | P:25 | 2.0 to 7.5 | 2.5 to 15.7 |
| 11. | Sediment, % wt., max. | P:30 | 0.05 | 0.10 |
| 12. | Total Sulphur, % wt., max. | P:33 or P:35 | 1.0 | 1.8 |
| 13. | Water Content, % V. max. | P:40 | 0.05 | 0.25 |
| 14. | Cold Filler Plugging Point (CFPP) °C, max. | IP 309/76 | To be reported | - |
| 15.***** | Total Sediments, mg/100 ml. max. | Appendix A of Specification | 1.0 | - |

**Notes**:

* *Cetane Number:* Diesel Fuel for Naval applications shall have a cetane number of 45, min. When an engine for determination of celane number is not available, diesel index determined by IS:1448-1960. Methods of test for petroleum and its products P:17. Diesel Index may be used as a rough indication of ignition quality. A diesel index of 45 is normally considered sufficient to ensure a minimum cetane number of 42. This approximate correlation holds good only in case of fuels which are of petroleum origin and contain no additives. For arbitration purposes, the direct determination of cetane number by means of the standardized engine test shall be used unless the buyer and the seller agree otherwise.

** *Pour Point:* Subject to agreement between purchaser and supplier, a lower or higher maximum pour point may be accepted. The Ministry of Petroleum & Natural Gas issues instructions periodically to the refineries to reduce/increase pour point of HSD according to ambient temperature conditions.

*** Winter shall be the period from November to February (both months inclusive) and rest of the months of the year shall be called as summer.

**** *Flash Point:* Diesel Fuel for Naval applications and for Merchant Navy shall have a flash point of 66°C, min. when tested by the method prescribed in IS:1448 (P:21)-1970. Methods of test for petroleum and its products P:21 Flash Point (Closed) by Pensky-Manens apparatus (first revision).

***** *Total Sediments:* This test shall be carried out only at the refinery or manufacturer's end.

CONFORMS TO IS:1460-1974 SPECIFICATIONS FOR DIESEL FUELS

## *Specification of diesel high pour point-a*

| Sr. No. | Characteristics | Requirements |
|---|---|---|
| 1. | Colour, ASTM, max. | 3.5 |
| 2. | Flash Point. min. | 55°C<br>(Navy - min. 65°C) |
| 3. | Cetane No., min. | 45 |
| 4. | Diesel index, min. | 48 |
| 5. | Distillation: | |
| | % recovered upto 357°C. min. | 90% |
| | F.B.P., max. | 385°C |
| | Residue. % vol., max. | 2.0 |
| 6. | Total Sulphur. % wt., max. | 0.5 |
| 7. | Olefins, % vol., max. | 5.0 |
| 8. | Aromatics, % vol., max. | 20.0 |
| 9. | Carbon (Ramsbottom on 10% residue), max. | 0.2 |

OTHER REQUIREMENTS AS PER IS:1460-1974 SPECIFICATIONS FOR HSD

## Specification of furnace oil

| Sr. No. | Characteristics | Test Method IS:1448 | Requirements | | | |
|---|---|---|---|---|---|---|
| | | | Grade LV | Grade MV1 | Grade MV 2 | Grade HV |
| 1. | Acidity, inorganic | P:2 | Nil | Nil | Nil | Nil |
| 2. | Ash, % wt., max. | P:4 (Method A) | 0.1 | 0.1 | 0.1 | 0.1 |
| 3. | Gross. calorific value, cal/g. | P:6 or 7 | Not limited, but to be reported (typical -1.0260) | | | |
| 4. | *Relative density at 15/15°C. | P:32 | Not limited, but to be reported (typical -1.950) | | | |
| 5. | Flash point, (PMCC) C, min. | P:21 | 66 | 66 | 66 | 66 |
| 6. | Kinematic viscosity in centistokes at 50°C. | P:25 | 80 Max. | 80-125 | 125 - 180 | 180-370 |
| 7. | Sediment, % wt., max. | P:30 | 0.25 | 0.25 | 0.25 | 0.25 |
| 8. | **Sulphur, total, % by wt., max. | P:33 or P:35 | 3.5 | 4.0 | 4.0 | 4.5 |
| 9. | Water content, % by vol., max. | P:40 | 1.0 | 1.0 | 1.0 | 1.0 |

**Note:**

* Furnace oil for marine uses in diesel engines shall not exceed a limit of 0.99

** *Sulphur Content:* Recognizing the necessity for low-sulphur fuel oils in some specialized use, a lower limit may be specified by mutual agreement between the purchaser and the supplier.

CONFORMS TO IS:1593-1988 SPECIFICATIONS FOR FUEL OIL

# APPENDIX 4
# EMISSION INVENTORY

## INTRODUCTION

Several attempts have been made to establish a comprehensive survey of air pollution emissions for the Bombay area (refs). The most recent survey was worked out by Coopers & Lybrand and AIC, as part of their Study on Environmental Strategy and Action Plan for Bombay Metropolitan Region (Government of Maharashtra, 1993).

For the URBAIR project for Bombay, a more through procedure was conducted to work out the best

Most of the data collection and emission calculations was performed by Aditya Environmental Services of Bombay. The production of gridded emission files (emissions distributed in a $km^2$ grid net) was done using the supporting software programs for the KILDER dispersion modeling program system developed by NILU.

The road traffic activity and emissions distribution was calculated by NILU, based on traffic and road data provided by W.S. Atkins 1993, produced in connection with their Comprehensive Transportation Study for Bombay Metropolitan Region.

The area selected for air quality modeling, and thus for emission inventorying, is shown in Figure 1. It consists of 42x20 $km^2$ grid squares, covering the area from the tip of Colaba in the South to Bassein Creek in the North, and from the ocean in the West to Thane Creek in the East. It includes the Chembur-Thane industrial area.

In the following, the data sources and methods for distributing the consumption and emissions is described, and then the calculated emissions are presented.

An evaluation of data gaps and short-comings is presented at the end of this Appendix.

## POPULATION DISTRIBUTION

The spatial distribution of the population within the grid system is important information when the fuel consumption, especially domestic fuel consumption, is to be distributed within the grid system.

The fuel consumption practices differ for the non-slum and slum populations. For Bombay, separate spatial distributions has thus been worked out for the two populations.

The total population for the URBAIR modeling area for Bombay, for the year 1991, is given in Table 1.

Details of the procedure for distribution of the population is given in Annex 1.

The distribution of the total population is given in Figure 2.

***Table 1: Total population of Bombay URBAIR modeling area***

| | |
|---|---|
| Non slum population | 7,056,760 |
| Slum population | 2,806,260 |
| Total population | 9,863,020 |

*Figure 1: Greater Bombay air quality modeling area*

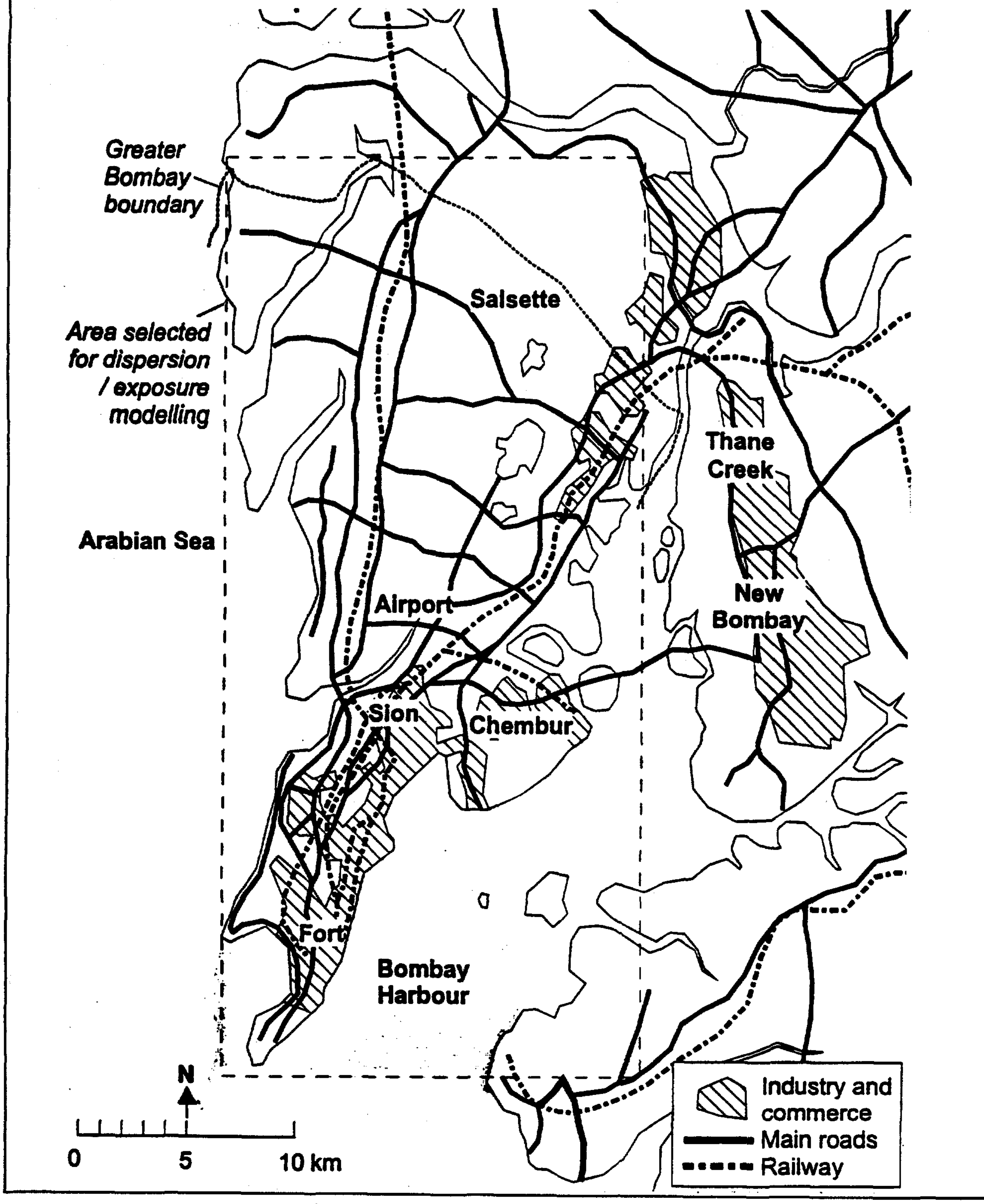


*Figure 2: Distribution of total Bombay population within $km^2$ grid modeling area, 1990*

MALESTOKK: 1 RUTE ER 1000 METER

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J=42 | 2. | 5. | 5. | . | | . | . | 32. | 248. | 271. | 300. | 34. | . | | | . | | | | |
| J=41 | 2. | 6. | 4. | . | . | . | . | 152. | 264. | 156. | 106. | 106. | . | 98. | 40. | . | | . | . | |
| J=40 | 2. | 3. | 2. | . | . | . | 102. | 237. | 261. | 149. | 106. | 106. | 106. | | . | . | . | . | . | . |
| J=39 | 4. | 1. | 1. | 2. | . | . | 257. | 317. | 324. | 160. | 106. | 106. | 106. | . | . | . | . | . | | . |
| J=38 | 9. | 4. | . | . | . | . | 134. | 346. | 376. | 248. | 106. | 106. | 106. | . | . | . | . | . | . | . |
| J=37 | 9. | 16. | 2. | . | 38. | 99. | 190. | 318. | 274. | 222. | 134. | 133. | 44. | 2. | 1. | 17. | . | . | . | . |
| J=36 | 4 | 2. | 45. | 128. | 209. | 264. | 303. | 161. | 146. | 146. | 146. | 146. | 44. | 12. | 30. | 28. | . | . | | |
| J=35 | 5. | 8. | 67. | 137. | 183. | | 241 | 456. | 304. | 144 | 153 | 145. | 146. | 113. | 18. | 23. | 30. | . | . | |
| J=34 | . | . | 136. | 201. | 95. | 91. | 366. | 571 | 375. | 139. | 139. | 139. | 139. | 82. | 21. | 19. | 30. | 71. | 105. | 26. |
| J=33 | | . | 79. | 150. | | . | 335. | 465. | 364. | 139. | 139. | 139. | 43. | 30. | 30. | 46. | 210. | 259. | 242. | . |
| J=32 | 1. | 6. | 19. | 32. | . | . | 278. | 427. | 342. | 123. | 124. | 124. | 75. | 30. | 30. | 30. | 101. | 258. | 265. | 267. |
| J=31 | | . | 14. | . | . | . | 414. | 381. | 154. | 43. | 43. | 43. | 33. | 20. | 2. | 15. | 165. | 249. | 268. | 325. |
| J=30 | 1 | 5. | 3. | . | . | . | 305. | 383. | 99. | 43. | 43. | 43. | 38. | 14. | . | 29. | 234. | 249. | 186. | |
| J=29 | . | 30. | 10. | 378. | 27. | . | 315. | 371 | 313. | 179. | 53. | 43. | 71. | 73. | 91. | 184. | 249. | 233. | 95. | . |
| J=28 | | 35. | 2. | 149. | 197. | 31. | 408. | 428. | 507. | 503. | 295. | 168. | 199. | 171 | 199. | 249. | 252. | 229. | | |
| J=27 | | . | . | . | 69. | 219. | 500. | 406. | 335. | 354. | 231. | 295. | 258. | 238. | 194. | 269. | 149. | 72. | | |
| J=26 | | | | . | 14. | 265. | 495. | 367. | 291. | 291. | 291. | 295. | 305. | 302. | 276. | 272. | 272. | 85. | | |
| J=25 | | | . | . | . | 127. | 168. | 220. | 238. | 266. | 288. | 297. | 305. | 330. | 400. | 287. | 269. | 20. | . | . |
| J=24 | . | . | . | . | . | 89. | 161. | 220. | 237. | 224. | 220. | 284. | 305. | 421. | 444. | 323. | 204. | | . | |
| J=23 | | | . | . | . | 53. | 291. | 315. | 346. | 222. | 218. | 298. | 371. | 423. | 371. | 290. | 32. | | . | . |
| J=22 | | . | . | . | 38. | 308. | 568. | 344. | 349. | 340. | 348. | 422. | 329. | 355. | 351. | 136. | | . | . | . |
| J=21 | | | . | . | 34. | 341. | 668. | 485. | 224. | 224. | 330. | 648. | 243. | 403. | 383. | 219. | | . | . | . |
| J=20 | | | | | 28. | 265. | 542. | 803. | 113. | 40. | 499. | 303. | 428. | 223. | 24. | 291. | 188. | | | |
| J=19 | | | . | | 57. | 239. | 510. | 344. | 98. | 287. | 608. | 359. | 421. | 421. | 403. | 260. | 166. | | . | . |
| J=18 | | | . | . | 98. | 39. | 171. | 627. | 836. | 632. | 353. | 149. | 286. | 322. | 320. | 260. | 260. | 195. | | |
| J=17 | | | . | | . | . | 210. | 846. | 694. | 550. | 134. | . | 260. | . | . | . | . | 195. | . | . |
| J=16 | | | . | . | 87. | 15. | 431. | 791. | 388. | 554. | 389. | 260. | 260. | 260. | . | . | 130. | 97. | . | . |
| J=15 | | | . | . | 312. | 430. | 546. | 477. | 438. | 343. | 249. | . | 260. | 260. | | | | . | . | . |
| J=14 | | . | | 34. | 507. | 544. | 572. | 550. | 390. | 140. | | 260. | 260. | 260. | . | | | . | | . |
| J=13 | | | . | 84. | 454. | 542. | 574. | 412. | 211. | . | . | . | . | . | . | | | . | . | |
| J=12 | | | | 51. | 339. | 554. | 531. | 280. | 186. | . | | . | | | . | | | . | | . |
| J=11 | | | . | 44. | 344. | 589. | 437. | 304. | 189. | . | | . | . | . | . | | . | | . | . |
| J=10 | | | 94. | 469. | 560. | 746. | 392. | 518. | . | | . | . | . | . | . | | | . | . | . |
| J= 9 | . | . | 138. | 405. | 864. | 1238. | 590. | 266. | . | | . | . | . | . | . | . | . | . | . | . |
| J= 8 | | 36. | 281. | 135. | 543. | 971. | 406. | 232. | . | | . | . | . | . | . | . | . | . | | . |
| J= 7 | | 79. | 59. | 138. | 541. | 144. | 81. | . | . | . | . | . | . | . | . | . | . | . | . | . |
| J= 6 | . | . | . | . | 6. | 133. | 159. | 42. | . | . | . | . | . | . | . | . | . | . | . | . |
| J= 5 | . | . | . | . | 5. | 86. | 102. | 16. | | . | . | . | . | . | . | . | . | . | . | . |
| J= 4 | | . | . | | 115. | 227. | 26. | 2. | . | | . | . | | . | | | | | | |
| J= 3 | | . | 9. | 109. | 93. | 48. | . | . | . | . | . | . | | | | . | | | . | |
| J= 2 | | . | 15. | 132. | 24. | . | | | | . | | . | . | | . | | | | . | |
| J= 1 | . | . | 17. | | . | . | . | . | . | . | . | . | . | | . | . | | | . | . |

## FUEL CONSUMPTION

The consumption of various petroleum fuels by industries is available from four Petroleum Refineries selling their products in Bombay.

Data for LPG and SKO (Kerosene) consumption for domestic purposes is available from the Rationing Office of Bombay.

Consumption of wood was considered for the slum population, and for bakeries and crematoria, according to information and evaluation from various agencies.

The evaluation and considerations made by Aditya E.S. Inc. regarding the calculation and distribution of the fuel consumption for domestic purposes and for industries, are given in Annexes II and V of this Appendix.

The resulting fuel consumption data are given in Table 2. (Fuel consumption for road traffic is considered in Chapter 4 of this Appendix).

***Table 2: Fuel consumption data for Greater Bombay for 1992-93***

| Category | Fuel type | $10^3$ Metric tons/yr | |
|---|---|---|---|
| Tata Power Plant | LSHS | 927 | |
| | Coal | 298 | |
| | Gas | 496 | |
| Industrial | LSHS | 499 | 279 in Petrochem. ind.<br>164 in large/medium ind.<br>56 in small scale ind. |
| | FO | 306 | 183 in large/medium ind.<br>123 in small scale ind. |
| | 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 | |

**Note:** Data for industry, domestic purposes, and by ships in Bombay port/bay area.

## COMMENTS

*Domestic*:

- LPG: was distributed grid-wise in the non-slum population. Combustion takes place during 10 hours of the day.
- SKO: was distributed gridwise in the total population. Combustion takes place during 10 hours of the day.

*Wood consumption*:

- Bakeries: a total of 440 tons/day, in 1100 bakeries, distributed in the total population, 12 hours per day.
- Crematoria: a total of 87.5 tons/day in 76 crematoria, distributed in the total population, 24 hours per day.
- Combustion in slums: a total of 276 tons/day, distributed in the total population, 10 hours per day.

*Industrial*:

- There are some 40,000 commercial establishments and industries in Bombay of which 400-500 use fuel for combustion.
- A total of 280 large- and medium-scale industries were identified and located, based on the following criteria:

- LSHS consumption greater than 500 tons/year
- FO consumption greater than 200 tons/year

The industries were mainly in the categories engineering (10-15 large industries), chemical, pharmaceutical and textile.

For these industries, emission data were given based on reported measurement data, and, where not available, emissions were calculated based on emission factors. Stack data were also given.

This list of industries included the Tata Power Plant, three chemical/ petrochemical plants and a fertilizer plant, all in the Chembur area.

The gridwise distribution of the fuel consumption was done in the following manner:

- The fuel consumed by the identified large/medium sources was assigned to the grids where the industries were located.
- The remainder (balance) fuel was distributed in the grids according to the number of medium/small industries in the grid for which data was not available.

## TRAFFIC ACTIVITY, FUEL CONSUMPTION AND EMISSIONS

The basis for the calculation of vehicle exhaust emissions, and their spatial distribution, is the file with traffic and road data provided by Atkins Inc., produced within their Comprehensive Transportation Study for Metropolitan Bombay Region. This file basically contained:

- the main road network, separated into links (a total of 275 links), with the link endpoint co-ordinates (nodes) fixed in an arbitrary co-ordinate system
- traffic data for each link, for morning rush hour (10-11 A.M.):
  - light duty traffic (cars + MC/TC), in passenger car units (PCU);
  - truck traffic, in PCU (1 truck = 2.4 PCU);
  - bus traffic, in PCU (1 bus = 3.4 PCU); and
  - traffic speed.

It was considered that the morning rush hour (10-11 A.M.) accounted for 6 percent of the annual average daily traffic.

The traffic activity, for each vehicle class, has been calculated separately for the "Island" Area and "Suburb" area (see Figure 1), and distributed in the km$^2$ grid.

Additional data from the Atkins' report, and from Aditya were used to estimate the overall distribution of traffic activity between the vehicle classes, and the gasoline/diesel mix (Table 3):

The total fuel consumption for road traffic in Greater Bombay used in this analysis, is, as provided by Aditya:

- Gasoline: 248,578 tons/year.
- Motor diesel: 243,444 tons/year.

The calculated traffic activity for separate classes/road systems is given in Table 4.

***Table 3: Vehicle classes and gasoline and diesel consumption***

| Vehicle classes | Gasoline/diesel | Fuel cons. (l/km) |
|---|---|---|
| Passenger cars | 80% gasoline/20% diesel | 0.1 |
| Motorcycles/tricycles | 100% gasoline | 0.067* |
| Trucks | 100% diesel | 0.3 |
| Buses | 100% diesel | 0.3 |

* Based on: Motorcycles: 40% 0.05 l/km
Tricycles: 50% 0.075 l/km

The methodology used was as follows:

1. The traffic activity on the main road (Atkins') network, and the associated fuel consumption was calculated.
2. The traffic activity was distributed in the km2 grids, according to the location of the road links.
3. The fuel consumption not accounted for by this main road traffic, was calculated by difference (total minus main road fuel consumption).
4. This balance fuel consumption was used to distribute the balance traffic activity, assuming:
   - the same vehicle composition in the traffic as on the main road system.
   - the spatial distribution of this balance traffic activity within the km2 grid system is as the distribution of the non-slum population.

Using the following emission factors, the calculated emissions of TSP (e.g. exhaust particles) and $NO_x$ from traffic is as given in Table 5.

***Table 4: Traffic activity ($10^3$ vehicle km/day), Greater Bombay 1992***

| | Cars | MC/TC | Trucks | Buses | Total |
|---|---|---|---|---|---|
| **Traffic activity** | | | | | |
| Main roads (Atkins' data) | | | | | |
| "Island" | 1 827 | 457 | 306 | 177 | 2 767 |
| "Suburbs" | 1 353 | 1 793 | 833 | 234 | 4 213 |
| Sub-total | 3 180 | 2 250 | 1 139 | 411 | 6 980 |
| Additional ("small") roads | | | | | |
| "Island" | 2 097 | 480 | 148 | 86 | 2 811 |
| "Suburbs" | 1 771 | 2 160 | 177 | 113 | 4 221 |
| Sub-total | 3 868 | 2 640 | 325 | 199 | 7 032 |
| **Total** | **7 048** | **4 890** | **1 464** | **610** | **14 012** |

***Table 5: Exhaust Particles and $NO_x$***

| Emission factors (g/km) | Exhaust particles | $NO_x$ |
|---|---|---|
| Cars, gasoline | 0.2 | 2.7 |
| Cars, diesel | 0.6 | 1.4 |
| MC/TC, gasoline | 0.5 | 0.1 |
| Trucks, diesel | 2.0 | 13.0 |
| Buses, diesel | 2.0 | 13.0 |

***Table 6: Exhaust emissions from road traffic, Greater Bombay, 1992 (kg/h, averaged over the year, all hours)***

| | TSP | | $NO_x$ | |
|---|---|---|---|---|
| | main roads | "small" roads | main roads | "small" roads |
| **Gasoline** | | | | |
| Cars | 26.5 | 29.7 | 358 | 401 |
| MC/TC | 29.1 | 55.0 | 9 | 11 |
| **Diesel** | | | | |
| Cars | 79.5 | 7.7 | 186 | 18 |
| Trucks | 94.9 | 46.0 | 617 | 299 |
| Buses | 34.2 | 16.6 | 222 | 108 |
| **Total** | **264.2** | **155.0** | **1,392** | **826** |

*Table 7: Total annual emission in Greater Bombay, 1992 (metric tons/year)*

| Vehicles | TSP | $PM_{10}$ | $SO_2$ | $NO_X$ | Hours of operation |
|---|---|---|---|---|---|
| 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 |
| **Power plant** | ~1 500 | ~1 500 | ~26 000 | ~11 200 | 24 |
| **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** 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 | |
| **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 | |
| **Industrial processes[2]** | | | | | |
| Refuse burning Domestic | 3 700 | 3 700 | | | |
| Dumps | 408 | 408 | 26 | 153 | 12 (3 PM-3 AM) |
| Construction | | | | | |
| Stone crushers | 6 053 | | | | 12 (day) |

1 Uncontrolled
2 Emissions from processes in Bombay is considered less important than to the fuel combustion emissions.

## EMISSION FACTORS

The emission factors used in this URBAIR calculation for Bombay were selected based on the following sources of data:

- USEPA emission factors of AP42 publication.
- Emission factors of the WHO publication: "Assessment of Sources of Air, Water and Land Pollution", Part I: Rapid inventory techniques in Environmental Pollution (Geneva, 1993).
- Emission factors worked out by the Bombay Urbair Working Group I (on Air Quality Assessment), shown in Table 8.
- Emission factors for road vehicles described in Appendix 5.
- Emission factors from Indian vehicles (IIP, 1985; Luhar and Patil, 1986).
  The selected emission factors for fuel combustion and road vehicles are shown in Table 7.

***Table 8: Emission factors used for URBAIR, Bombay, 1992***

| | TSP | $PM_{10}$/TSP | $SO_2$ | $NO_x$ | %S max. |
|---|---|---|---|---|---|
| **Fuel combustion (kg/t)** | | | | | |
| Coal, bituminous, power plant | | | | | |
| - uncontrolled | 5A1) | | 19.5Sa) | 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 → 1.6b) | 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 | 0.061 | 1.0 | 20S | 11.3 · f | |
| ind./dom. | 0.061 | | 20S | 2.5 | |
| Wood dom. | 15 | 0.5 | 0.2 | 1.4 | |
| Refuse burning, open | 37 | 1 | 0.5 | 3 | |
| **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 | | 13 | |
| Buses and trucks, heavy duty | 2.0 | | | " | |

a) A: Ash content, in %; S: sulfur content, in %
b) Well → poorly maintained furnaces

***Table 9: Emission factors as worked out by the Bombay URBAIR Working Group I on air quality assessment***

| Type of Source | Fuel Burned | Unit | Particulates (kg/unit) | $SO_2$ (kg/unit) | $NO_x$ (kg/unit) |
|---|---|---|---|---|---|
| Power plants | Coal | t | 8(A) | 19(S) | 9 |
| | Fuel Oil | t | 1.04 (controlled) | 19.9(S) | 13.2 |
| | Natural Gas | $10^3m^3$ | 0.24 | 16.6(S) | 9.6 |
| | | t | 0.29 | 19.9(S) | 11.5 |
| Industrial & Commercial Furnaces | Coal | t | 6.5(A) | 19(S) | 7.5 |
| | Fuel Oil | t | 2.87 | 19(S) | 7.5 |
| | Oil, distillate | t | 2.13 | 20.1(S) | 7.5 |
| | LPG | $m^3$ | 0.21 | 0.01(S) | 1.43 |
| | | t | 0.38 | 0.02(S) | 2.6 |
| | Natural Gas | $10^3 m^3$ | 0.29 | 6.6(S) | 3 |
| | | t | 0.34 | 20(S) | 3.6 |
| Domestic Furnaces | Coal (hand fired) | t | 10 | 19(S) | 1.5 |
| | Wood | t | 13.7 | 0.5 | 5 |
| | Kerosene | t | 3 | 17(S) | 2.3 |
| | LPG | $m^3$ | 0.23 | 0.01(S) | 1 |
| | | t | 0.42 | 0.02(S) | 1.8 |
| Solid Waste Dumps | Refuse | t | 8 | 0.5 | 3 |
| | Wood | t | 13 | 0.1 | 4 |
| | Rubber Tires | t | 138 | - | - |
| | Municipal Refuse | t | 37 | 2.5 | - |

**Note:** A is % ash content (combustible by wt.); S is % sulfur content (combustible by wt.); Coal used in Bombay by Industries and for Domestic purposes is of Bituminous type.

The selected factors for fuel combustion is in some cases somewhat different from those worked out by the Bombay Working Group I. The factors in Table 7 (from EPA AP42) were used because factors from the AP42 reference were used also in the other URBAIR cities (Manila, Jakarta), and because the Bombay factors were worked out a bit late in the process, after dispersion calculations were well under way. The Bombay factors would modify the emission inventory and calculated concentrations somewhat, but would not change the main results from the calculations.

The emission factors for Indian vehicles referenced, include:

For $NO_x$, these are in fair agreement with the selected factors in Table 7. For "TSP" (presumably exhaust particles) from buses and trucks, they are considerably lower, and seem quite a bit too low compared to all other references.

***Table 10: Emission factors for Indian vehicles***

| | | |
|---|---|---|
| Light duty, gasoline | 2.1 g/km at 30 km/h | |
| MC/3-wheelers | 0.06 g/km at 30 km/h. | |
| | $NO_x$ | TSP |
| Buses, suburban | 11.1 | 0.37 |
| urban | 8.52 | 0.28 |
| Trucks | 6.65 | 0.22 |
| Light commercial vehicles | 2.5 | 0.1 |

*Total emissions.* Table 10 gives the total annual emissions of TSP, $PM_{10}$, $SO_2$ and $NO_x$ associated with the various source categories, fuels and vehicle types. Those emission figures were calculated by multiplying the fuel consumption with the emission factor. The table also gives the operation hours of the various sources.

Comments to Table:

- There is no specific file of data available regarding industrial process emissions. Based on their survey work in Bombay, Aditya is of the opinion that the process emissions are not significant totally in Bombay, compared to emissions from fuel combustion. Still, process emissions will in many cases give significant exposure in areas near industrial process plants.
- There is a large discrepancy between the calculated emissions of $SO_2$ and $NO_x$ in Table 11, and those from the emission data file produced by AES Inc. for the input to the KILDER model (see below), regarding industrial emissions. The discrepancy is as follows:

***Table 11: Discrepancies between emissions***

| | Emissions in Table 6 | Emissions from the AES Point source file |
|---|---|---|
| $SO_2$ (t/yr) | 66,710 | 18,290 |
| $NO_x$ (t/yr) | 15,285 | 5,590 |

- Part of the discrepancy may be explained as follows:
  – In the AES point source file, results from actual emission measurements were used, where available. Where not available, a calculation of the emissions was based on fuel consumption and emission factors.
  – Table 5 is based on the maximum S contents of oil, while the average actual S contents may be considerably lower.
- Refuse burning, open burning on dumps.

AES has estimated the total emissions from the Dumps Deonar, Chincholi + Gorai, and Mulund. The estimation was based on TSP, $SO_2$ and $NO_x$ measurements carried out by MCGB near Deonar, by means of box model. The details are described in Annex IV to this Appendix.

NEERI has also estimated total emissions of the same compounds from open burning on dumps in Bombay, based on some measurements of their own.

Table 12 below summarized the results.

There is a fair agreement between these estimates, considering that the burning mainly takes place during 10-15 hour periods evening-nights.

The AES estimates have been used in Table 6.

***Table 12: Summary of estimates of emissions from open burning on dumps in Bombay***

| | | TSP | $SO_2$ | $NO_x$ |
|---|---|---|---|---|
| AES | kg/hr | 54.3 | 3.4 | 20.4 |
| NEERI | kg/day | 950 | 71 | 175 |

*Refuse burning, domestic*. Several discussions within the URBAIR groups have not led to a conclusion regarding the amount of refuse burnt domestically (street sweepings, vegetation debris, domestic refuse) in Bombay.

It might be estimated that a total of 2 mill households in Bombay each burn 1 kg of refuse per week. Using a SPM emission factor of 37 g/kg, this produces annually some 3 700 tons of SPM.

*Stone crushers*. The SPM emissions from 47 registered stone crushers in Greater Bombay has been estimated by AES, as described in Annex V to this Appendix.

## *Spatial emission distribution*

The total emissions from each source category has been distributed within the km2 grid system based on

- the actual location of point sources
- the population distribution, separate for non-slum and slum populations
- the traffic activity distribution.

AES and NILU has produced the spatial emission distributions listed below. For each distribution, an average emission rate was calculated for each grid square, in kg/hr, representing the average emission during the operating hours of the source.

For some further details, see Annex VII of this Appendix.

***Table 13: Spatial emission distribution***

| Fuel consumption | Operating time (hrs/day) | Distribution |
|---|---|---|
| Road traffic, gasoline | 12 | According to traffic activity on roads, and non-slum population |
| Road traffic, diesel | 12 | According to traffic activity on roads, and non-slum population |
| LPG, domestic | 10 (day) | Non-slum population |
| SKO, domestic | 10 (day) | Total population |
| Wood, domestic | 10 (day) | Slum population |
| Wood, bakeries | 12 (day) | Total population |
| Wood, crematoria | 24 | Total population |
| Refuse burning, dumps | 12 (evening-night) | 3 dumps |
| Stone crushers | 12 | 47 units |
| Balance fuel | 24 | Non-slum population |
| Point sources | 24 | Actual locations |

## *References*

Luhar, A.K. and R. S. Patil. (1986). "Estimation of Emission Factors for Indian Vehicles." *Indian Journal of Air Pollution Control.* 1 7 (4). New Dehli.

Tata Energy Research Institute (1992*). Environmental Effects of Energy Production, Transportation and Consumption in National Capital Region, 1992*. TERI: New Delhi.

**Annexure I**

## DATA ON POPULATION DISTRIBUTION—GRID-WISE

### *Total population*

*Data available*:

- Total population and area of each Census District obtained from BMRDA. (There are a total of 88 Census Districts in Bombay).
- Map of Bombay.

*Distribution of population*:

- Population Density per sq. km. area was calculated using data obtained from BMRDA. However, it was noticed that area with no possible human habitation (like waterbodies/marshy lands/airport/ industrial area etc.) was also included in many of the census districts. Hence, new population densities were derived after deducting such areas.
- Actual habitable area of each of the census districts in a grid was measured and multiplied by population density to arrive at population per grid.

*Data Constraints*:

- Non-availability of Specific Zoning Maps showing clearly the land use pattern.

### *Slum population*

*Data Available*:

- Wardwise list of slums in Bombay on Private land/Central Govt. lands/State Govt. lands/BHADA (Bombay Housing and Area Development Authority) and M.C.G.B. land giving number of tenements in each slum pocket. List obtained from Slum Improvement Dept., M.C.G.B. and is for the year 1985. (No updated list was available from the Dept.).
- Map of Bombay from MHADA (Maharashtra Housing & Area Development Authority) showing positions of these slums.

*Slum population distribution*:

- No figures were available on actual population in the slums. Also distribution of slums in each Census District was not available.

- Available data on total population and number of households obtained from BMRDA and discussions with faculty of Tata Institute of Social Sciences, Deonar indicates average number of persons per tenement as 5. Hence total slum population was derived as:

| | |
|---|---|
| Number of Tenements | 561,252 |
| Average no. of persons per tenement | x 5 |
| Total Slum Population | 2,806,260 |

The slum population was then distributed in the grids based on number of tenements in each grid.

Data gaps:

- Conflicting reports exist on total population of Bombay residing in slums. Estimates indicate upto 40-45% (of total population) as total slum population.
- The Book "Slums Squatter Settlements & Organised Sector Worker Housing in India some Affordable Myths" authored by R.M. Kapoor and M.S. Mitra published by the Times Research Foundation (1987) puts Task Force Estimates on slum population for million plus cities for 1981 (based on 1981 population) as varying from a low of 40% to a high of 45% of total population.
- *It is suspected that data given by Slum Improvement Dept. gives number of registered slums only and hence total slum population as worked out for URBAIR is only 28.5% of total population. This is a major data gap as this will affect the consumption pattern of SKO/Wood in the grids.*

## *Non-slum population*

The slum population in each grid was substracted from total population in that grid to arrive at non-slum population in that grid.

**Annexure II**

## DATA ON DOMESTIC FUEL CONSUMPTION

### *Data available*

- LPG Consumption for Domestic purposes as indicated by Rationing Office
- SKO Consumption for Domestic purposes as indicated by Rationing Office.

(Data on LPG/SKO consumption for domestic purposes was not separately available for one of the Petroleum Companies and hence data from Rationing Inspectorate was used).

- Total Population/Slum Population/Non-slum population gridwise from POPDIST1.WK1 files.

### *Basis for distribution of data*

*LPG consumption*: Total LPG consumption per day for domestic purposes as indicated by Rationing Inspectorate is 639 MT/d. As this is predominantly used in well-to-do households, the entire LPG consumption was distributed gridwise in the non-slum population. Daily use of LPG is for cooking purposes and hence restricted to 10 hours/day; LPG consumption in Kg/hr was calculated for this period.

*SKO consumption:* The total SKO consumption for domestic purposes and by establishments is 1,236 KL/d or 1062.96 T/d. This was distributed in the grids according to total population in that grid. Daily use of SKO is mainly for cooking and to some extent water heating. Total daily period of such use is restricted to 10 hours. Hence, SKO consumption in Kg/hr was calculated for this period.

*Wood consumption:* Major wood consumers in Bombay were identifid as bakeries, other small establishments, domestic households (slums/pavement dwellers) and crematories.

## WOOD CONSUMPTION IN BAKERIES/SMALL ESTABLISHMENTS

### *Data available*

No figures were available on wood consumption by small establishments. The Indian Bakers Association indicated that there are about 1,100 bakeries in the city which are using wood for their fuel needs. The average wood consumption in each bakery was estimated by them as @ 400 kg/day. (Large bakeries in the city are not using wood, but are using HSD or electricity). Based on these figures the total wood consumption by bakeries works out to be 440 T/day.

## *Basis for distribution*

The bakeries are more or less evenly spread out in the city and hence wood consumption was distributed based on % of total population in a particular grid.

### WOOD CONSUMPTION IN CREMETORIA

## *Data available*

- Wardwise list of Hindu cremetoria.
- Death figures for 1991 from Health Dept., M.C.G.B.
- Wood consumption per dead body 500 Kg (obtained from a visit to cremetoria).

## *Data derived*

- Deaths in Bombay: 80,000 (1991).
- Hindu Deaths (approx. 80%): 64,000.
- Deaths/day (approx.): 175.

| | |
|---|---|
| Deaths per day: | 175 |
| Wood required per body: | 500 Kg/day |
| Total wood consumption : | 87,500 kg/day or 87.5 T/day |

- No. of cremetoria (Pvt. & Municipal): 76

Hence, the total wood consumption was distributed in the wards based on location of cremetoria in the wards. Daily use of wood in cremetoria is for purpose of burning dead bodies. Such use covered whole 24 hours period. Hence use of wood in Kg/hr was based on 24-hours usage period.

### WOOD CONSUMPTION IN SLUMS

## *Data available*

Discussions with faculty members of Tata Institute of Social Sciences, Deonar showed that wood and not charcoal (as shown by the E.M.S. study) was used as fuel in slums. However, no figures were available to substantiate the total slum population using wood or the per capita wood consumption.

## *Data derived*

A study on "Energy Consumption in Pune City" conducted by S.P. College, Pune (1989) indicates that 20% of slum dwellers use firewood and average consumption is 180-200 Kg/capita/year. Since Pune city has a colder climate compared to Bombay, the lower figures of 180 kg/capita/year was assumed for Bombay city. Based on the above, the total wood consumption by this source per day works out as given below :

| | |
|---|---|
| Total Slum Population: | 28 lakhs |
| 20% population assumed using wood: | 5.6 lakhs |
| | 560,000 (persons) |
| | x 180 (kf/capita/day) |
| Total wood consumption per year | 100,800 T/year |
| Total wood consumption per day | 276 T/day |

This was distributed in the grids based on slum population in the grid. Daily use of wood in slum is extended over 10-hours period. Hence, to calculate the load in kg/hr this period was considered.

## *Total wood consumption*

Since, bakeries and crematoria are situated in predominantly domestic areas the total wood consumption by these sources was added to wood consumption by slum population for estimating total wood consumption for Bombay city.

| | |
|---|---|
| Wood consumption (T/day) | |
| for cemetaries: | 87.5 |
| for bakeries: | 440.0 |
| for slums: | 276.0 |
| Total wood consumption (T/day): | 803.5 |

Gridwise distribution of wood was added to arrive at total wood consumption per grid.

## *Data gaps*

From the available data no energy consumption pattern could be derived for the urban population of Bombay. Attempts to derive energy consumption pattern gave rise to very conflicting results.

The S.P. College, Pune, showed the fuel consumption pattern in slums is as below:

Energy requirements in slums :

| | |
|---|---|
| SKO | 70% |
| Wood | 20% |
| LPG/others | 10% |

The per capita consumption of SKO is indicated by the study as 50 L/capacity/year. This works out to a average figure of 135 ML/capita/day. Assuming a higher value of 150 ML/capita/day, the consumption pattern of SKO works out as follows:

| | |
|---|---|
| Slum population: | 28 lakhs |
| Population using SKO (@70%): | 20 lakhs |
| SKO used in slums @ 150 ML/capita/day: | 300 KL/day |

Available data indicates total domestic consumption for SKO as 1,198 KL/day. Balance SKO of 898 KL/day when distributed on the basis of 150 ML/capita/day shows a total of 59.86 lakhs people using SKO. This means about 85% of non-slum population uses SKO which is a unreasonably high figure.

Even assuming 45% of total population as slum population (i.e. including the non-registered slums) the total SKO consumed by slums works out as below:

| | |
|---|---|
| Total population: | 98 lakhs |
| Slum population: | 44.1 lakhs |
| SKO users: | 30 lakhs |
| SKO consumed: (based on 150 ML/cap/day) | 463 KL/day |

The balance 735 KL/day when distributed @ 150 ML/cap/day shows 49 lakh non-slum population using SKO which also works out to a high figure of 70%.

The LPG consumption for domestic purposes has been indicated by Rationing Inspectorate as 233,235 MT/year (16,425,000 cylinders/year). Assuming requirement of each household as 1 cylinder/month or 12 cylinders/year.

No. of households using LPG works out to 16,425,000 divided by 12 cylinders/year equals 13.69 1akhs.

Assuming average size of each household as 5; total population using LPG works out to @ 68 lakhs which is @ 70% of Bombay's total population which is a very high figure.

The SKO consumption by establishments (Hotels/Restaurants) has been shown as 38 MT/day which is a very low figure considering numerous such establishments in the city.

Available data for Pune indicates that charcoal is used in slums by a very small amount of population (<5%). However, no quantification exists for Bombay.

*Considering the above, it is very much apparent that data on fuel distribution by domestic sector is very much rudimentary and there is an urgent need to study the pattern of usage in these sectors and consider cost effective alternatives to reduce pollution from this sector.*

**Annexure III**

## EMISSION FROM DOMESTIC SOURCES

### *Data available*

Fuel consumption by Domestic Sources for Total SKO/LPG and Wood consumption (inclusive of usage by establishments).

Emission Factors used:

| Type of Source | Fuel burned | Unit | Particulates *(Kg/unit)* | $SO_2$ *(Kg/unit)* | $NO_x$ *(Kg/unit)* |
|---|---|---|---|---|---|
| Domestic | Wood | t | 13.7 | 0.5 | 5.0 |
| | Kerosene | t | 3.0 | 17.0 (s) | 2.3 |
| Furnaces | LPG | t | 0.42 | 0.02 (s) | 1.8 |

**SOURCE:** Rapid Assessment of sources of Air/Water and Land Pollution, WHO Offset Publication No. 62.

Annexure IV

## EMISSIONS FROM REFUSE BURNING

### *Data available*

Total quantity disposed: 4,000 T/day.

| Site | Quantity (T/day) | Available Area |
|---|---|---|
| Deonar | 2526.5 | 200 acres |
| Mulund (Checknaka) | 631.5 | 50 acres |
| Chincholi | 421.0 | 60 acres |
| Gorai Rd. (Borivali) | 421.0 | 20 acres |
| Total quantity disposed | 4,000.0 | |

**Source:** Mr. D.K. Dhokale (Asst. Engineer), Solid Waste Management, M.C.G.B.

The Bombay Solid Waste has the following composition :

| | |
|---|---|
| Moisture: | 40% (by wt) |
| Combustible: | 22% (by wt) |
| Ash content: | 38% (by wt) |
| Total | 100% |

Physical Composition:

| | |
|---|---|
| Paper: | 10% (by wt.) |
| Glass: | 0.2% (by wt.) |
| Metal: | 0.2% (by wt.) |
| Plastics: | 2% (by wt.) |
| Textile: | 3.6% (by wt.) |
| Wood/Grass: | 20% (by wt.) |
| Ash/Soil: | 38% (by wt.) |
| Others: | 26% (by wt.) |
| TOTAL | 100% |

Although municipal officials claim that no refuse burning takes place (or is very negligible), a number of complaints are received and the fact that refuse burning does take place is definitely established.

The Air Quality Monitoring laboratory of the M.C.G.B. (Environmental Sanitation & Projects Dept.) has carried out air monitoring near the solid waste dump site at the time of refuse burning. The reports are as given as follows:

| Parameters | | Concentration | Sampling Period |
|---|---|---|---|
| TSP | 2011 | µg/m$^3$ | 16:30 to 22:15 hrs. |
| $SO_2$ | 702 | µg/m$^3$ | 19:00 to 22:15 hrs. |
| $NO_2$ | 164 | µg/m$^3$ | 19:00 to 22:15 hrs. |
| $NH_3$ | 1014 | µg/m$^3$ | 19:00 to 22:15 hrs. |

**Source:** MCGB (Environmental Sanitation & Projects Dept.

There is no documented data on rate of burning; area of dump which is burnt or the emission factors.

To find out the rate of burning of the Solid Wastes it was decided to develop a Box Model and back calculate from the ambient monitoring data.

To find out total emissions from refuse burning discussions were held with residents in the neighbourhood, NGOs and factory owners near the Deonar dump. The findings from this discussions are as follows:

1. Refuse burning is an unauthorised activity of rag pickers operating at the dumps. Objective is to recover metallic scrap, glass and other valuables.
2. Fresh refuse is high in moisture content and is left to dry for 10-15 days. Generally the dry refuse is lighted at 4-5 p.m. and burns till late night 2-3 a.m.
3. The nuisance of the smoke is felt upto 3rd/4th floors and, hence, height of smoke plume can be guessed as 10-15 m. Nuisance is felt upto a downwind distance of 3-4 km.

## BOX MODEL CALCULATIONS

From the above, the emissions *(Qj)* from refuse burning (from Deonar site) were back calculated as below :

$$Cj = Qj / uWD$$

It is assumed in the development of the box model that:

1. Air is transported through the volume with a face velocity of *u* and
2. The pollutants are assumed to be instantaneously and uniformly mixed throughout the volume of the box.

From the available data the following values were assigned to various variables:

*u = Avg. wind velocity = 1 m/sec.* (Observed for night time from Santacruz data)

*W = Width of box normal to wind direction = 500 m.*

*D = Depth of box normal to wind direction = 15 m* (Elevation of 4 storeyed building)

*Cj = Concentration recorded* = $2{,}011\ \mu g/m^3 = 2{,}011 \times 10^{-6}\ gm/m^3$

*Therefore:* $2{,}011 \times 10^{-6} = Qj / (1 \times 500 \times 15)$

$Qj = 15.0825$ *gm/sec. or 54.297 Kg/hr.*

Assuming WHO emission factor 8 Kg/T for SPM from Refuse burning, Quantity of Refuse burnt was calculated:

*Quantity burnt/hour = 54.297 / 8 = 6.787 T/hr.*

Further calculations were carried out by applying WHO Emission Factors for $SO_2/NO_x$ (by assuming above rate of burning). Thus emissions at Deonar for $SO_2$ and $NO_x$ are estimated as :

$SO_2 = 3.393$ *Kg/hr.*

$NO_x = 20.361$ *Kg/hr.*

As no details regarding other sites are available, it is assumed that refuse burning is proportional to daily quantity of waste dumped. Applying WHO emission factors the emission from these dumps are calculated as below :

| Grid No. | Site | Wastes dumped/day | SPM | $SO_2$ (kg/hour) | $NO_x$ |
|---|---|---|---|---|---|
| 16-17 | Deonar | 2056.0 | 54.29 | 3.39 | 20.36 |
| 6-36 | Chincholi + Gorai | 842.0 | 22.22 | 1.39 | 8.34 |
| 17-30 | Mulund | 631.5 | 16.66 | 1.04 | 6.25 |

## *Data gaps*

No specific studies have been carried out as burning of refuse and the air pollution impact of these.

NEERI is currently carrying out a study under MEIP on this aspect. Results of this study will be shortly available.

**Annexure V**

## STONE CRUSHER EMISSION

### *Data available*

Data on capacity of stone crushers was obtained from M.P.C.B. records.

The data collected shows that there are 19 registered stone crushers in Kandivali (Ward 'R'/North); 21 registered crushers in Dahisar (Ward R/North) and 7 in Andheri (Ward K/W) area.

No data is available of any air monitoring carried out close to these sites.

### *Emissions from crushers*

Emissions from stone crushers were calculated by using EPA emission factors as outlined below:

| Type of Process<br>Dry Crushing Operation | Suspended Dust Emission<br>(Kg/MT) |
|---|---|
| Primary Crushing | 0.05 |
| Secondary Crushing/Screening | 0.30 |
| Tertiory Crushing/Screening | 1.80 |
| Recrushing & Screening | 1.25 |
| Fines Mill | 2.25 |

**Source**: EPA.

The capacity of each crusher and the emission from them work out to very high loads as indicated in enclosed sheets. Hence, seperate box file has been prepared for this source.

### *Preparation of box file*

While preparing box files, the following assumption were made:

1. The exact locations of the crushers on map were not known, but as it is well known that these crushers are very close to each other, they have been clubbed together and total emission has been shown from one particular grid only.
2. Micro-level details of each crusher like the types of control measures existing, the method of transfer of rock, the moisture content of rock, etc. are not known and it is assumed in preparation of the box file that all crushers have no installed control systems.
3. *It has been assumed that crusher operates for 24 hours and suspended particulate emissions reported as Kg/hour accordingly. However, normal period of operation of crushers is between 8:00 hrs. and 19:30 hrs. and emissions should be corrected for further accuracy in the box file.*

Annexure VI

## BALANCE FUEL EMISSION FILE

### *Data available*

The consumption of various Petroleum fuels by industries in Bombay is available from four Petroleum Refineries selling their products in Bombay. The data on fuel consumption obtained from emission inventory carried out for URBAIR was compiled and used to prepare box file (area files) for industries for which adequate data was not available and for small scale industries.

### *Emission inventory*

Data available thus far from emission inventory indicates the following:

1. There are about 40,000 odd commercial establishments and industries in Bombay. About 500-600 of these use fuel for combustion. (Very small scale and tiny units are not considered in preparing this estimate).
2. The data indicates the following pattern of fuel use:

| Industry Type | Estimated Nos./Area Where Present | Fuel |
|---|---|---|
| Large scale (Chemical/Petrochemical) | 3 (Chembur) | LSHS/Gas |
| Large (Engineering) | 10-15 (Western/Central Suburbs) | LDO/LPG& small quantity LSHS. |
| Medium scale (Chemical/Pharmaceutical/ Textile) | 250-275 (Western/central Suburbs) (Textile Industires:Bombay Island) | FO/LSHS small quantity LDO. |
| Medium scale (Dyeing/Printing/Bleaching works) | 50-75 ( Western/Central Suburbs) | FO |
| Small scale | 100-150 (Western/Central Suburbs) | FO/LDO |

In general, usage of LPG and SKO is restricted to Engineering industries. Usage of HSD is generally in diesel generators/compressors and in large bakeries.

### *Fuel usage*

*Furnace Oil:* About 839 T/d of Furnace Oil was sold in Bombay city in 1992-93. F.O. is used by industries in boilers for steam generation; of this 500 T/day was accounted for in the emissions inventory data gathered for preparation of POISOURC.DAT file. The balance 339 T/d was distributed in the grids based on number of industries in each grid for which adequate data is not available.

*LSHS:* The two Petroleum Refineries, Fertilizer Plant and the Power Plant together account for more that three-quarters of the LSHS consumption in the city.

These units are not allowed to burn Furnace Oil and use Associated Gas (available through pipeline from GAIL/ONGC) alongwith LSHS. For some part of the year, the Associated Gas supply from ONGC was affected and, consequently, LSHS consumption in the city has increased considerably.

*LSHS consumption by Tata Themal:* Tata Thermal has 6 units for power generation at Chembur. Unit Nos. 1,2, and 4 are normally on stand-by and used for peaking the supply. Unit 3 has been decommissioned and is not in use. Units 5 & 6 are of 500 MW capacity each. All units have multi-fuel capabilities. Unit 5 can fire LSHS/Coal/Gas, whereas Unit 6 can fire LSHS and Gas. The total daily heat requirement at Tata Thermal is estimated at 5.25 x $10^{10}$ Kcal/d and the fuels burnt for this consumption for 1992-93 work out as an average daily basis as (please refer enclosed sheets):

| **Consumption based on annual sales figures of product** | |
|---|---|
| Oil (LSHS) | 2710 T |
| Gas | 1448 T |
| Coal | 870 T |

The higher LSHS requirement may be due to reduced supply of gas during the year form ONGC.

*LSHS Consumotion by refineries:* The Refineries (BPCL & HPCL) have daily usage of LSHS as 230 T and 534 T, respectively, (based on MPCB Consent figures).

*Fertilizer Factorv (RCF):* RCF uses associated gas for steam generation and as feedstock for their plants. They have no consented LSHS usage.

*Emission Inventory for URBAIR:* The emission inventory could account for additional 450 T of LSHS usage by other Large/Medium Industries.

*LSHS Consumption from Refinery Sales Figures:* The total average per day sale for LSHS is put at 3,312 T/day. The difference between the consumption figures (indicated above) and average sale per day comes out as follows:

| **Difference between consumption and average sale per day** | |
|---|---|
| Estimated average supply LSHS | 3,312 T/day |
| - Tata Thermal | - 2,710 |
| - Emission inventory | - 450 |
| | 152 T/day |

| Average daily usage of LSHS | |
|---|---|
| Estimated average supply LSHS | 3,312 T/day |
| Consumption by refineries | + 534 |
| | + 230 |
| | 4,076 T/day |

*Comments*: LSHS consumption in Bombay is highly variable, the daily consumption being governed by the four large factories in Chembur.

The availability of Associated Gas changes the entire consumption pattern of all these four units. This makes it very difficuilt to arrive at the average daily consumption figure based on yearly consumption/sales dates. Considering the above, the balance LSHS of 152 T/d has not been distributed in the grids while preparing Balance fuel distribution files (*FUE.DAT).

*LDO Consumption*: About 135 T of LDO was supplied per day in 1992-93. Of this about 67 T/d could be accounted for in the Emission Inventory. The balance 69 T was distributed in the grids based on number of industries in each grid (for which adequate data is not available).

*HSD Consumption*: About 127 T/d of HSD was supplied on an average basis in 1992-93. Of this about 30 T could be accounted for in the Emission Inventory. The balance 97 T was distributed in grids based on number of industries in each grid for which adequate data is not available.

## CALCULATION FOR TATA THERMAL

2 units, 500 MW each

Each 500 MW requires 5,000 T/d Coal, or 2,500 T/d 0il.

Therefore, total requirement of fuels works out as 10,000 T Coal or 5,000 T 0il; total heat requirement works out as follows:

| | |
|---|---|
| Quantity in tons | 5,000 |
| x Kcal/kg | x 10,500 |
| x Conversion factor to Kg | x 1,000 |
| Total Heat Requirement (Kcal/day) | $5.25 \times 10^{10}$ |

Tata have reported annual purchase of fuels as follows:

| | |
|---|---|
| LSHS: | 926,886 T |
| Gas: | 495,082 T |
| Coal: | 297,556 T |

Corresponding Heat load/year works out as:

| | |
|---|---|
| LSHS | 9.73 x $10^{12}$ Kcal/yr. |
| Gas | 6.67 x $10^{12}$ Kcal/yr. |
| Coal | 1.56 x $10^{10}$ Kcal/yr. |
| TOTAL | 1.796 x $10^{13}$ Kcal/yr |

For a total of 342 working days this gives a heat load/day as 5.25 x $10^{10}$.

Therefore:

| | |
|---|---|
| Total Oil required/day: | 2710 T/d |
| Total Gas supply/day: | 1448 T/d. |
| Total Coal supply/day: | 870 T/d. |

## *Comments*

This has been worked out considering that total fuel purchased by the plant in the year has been utilized. Quantities in stock have not been considered and daily average consumption may vary to that extent.

Annexure VII

## BASIS OF PREPARATION OF POISOURC.DAT

### *Data available*

Data on emissions from industries was gathered from the applications made by them to obtain MPCB consents. Data was gathered for about 210 industries belonging primarily to large and medium sector. Data was collected on the basis of following criteria :

*F.O. consumption > 200 T/year;*
*LSHS consumption > 500 T/year.*

Data collected included physical details of stacks and data on type of emisions, velocity, flow rate and monitoring data wherever available.

### *Preparation of poisourc.dat file*

This is on following basis:

1. Wherever possible monitoring data (as submitted by Industries) has been used to calculate emission load. Only where monitoring data was entirely absent, emissions were calculated from fuel quantity.
2. No data is required to be submitted by Industries on total $NO_x$ emission and hence this data was entirely computed from emission factors.
3. Emission Factors used for calculations are as given below, where A = % Ash, S = % Sulphur by wt.

| Type Of Fuel | Unit | Particulates | $SO_2$ | $NO_x$ |
|---|---|---|---|---|
| Bituminous Coal | t | 6.5 (A) | 19 (S) | 7.5 |
| Fuel 0i1 | t | 2.87 | 19 (S) | 7.5 |
| LPG | t | 0.38 | 0.02 (S) | 2.6 |
| Natural Gas | t | 0.34 | 20 (S) | 3.6 |

There is only one power plant in Bombay and emissions were directly taken from actual monitored levels at the plant.

Process emissions in Bombay are unimportant compared to the large number of stacks connected to fuel sources. Wherever available data from such sources is collected and complied in Poisour.dat file.

4. Building heights and widths were not available for buildings nearest to the chimney and, hence, default width and heights of 30 m and 10 m were given in the file.

### *Data gaps*

A wide variation is observed in the monitored data and data calculated from emission factors. This may be because of any of the following reasons:

1. Low amount of sulphur in fuels compared to those available in standard specifications. For example: BPCL specifications for FO shows Sulphur content between 3.5-4% whereas actual observed level is between 2.5–3%. Similarly for LSHS actual % observed is between 0.5–0.7% whereas specifications shows sulphur content of 1%.
2. Greater amount of excess air used by the industries.
3. Inaccurate monitoring practices adopted.

The type of data in MPCB files is not up-to-date and should be improved.

$NO_x$ monitoring is not required by MPCB, even when there is a ambient air standard prescribed for the same.

**Annexure VIII**

## BASIS FOR DATA FILES

| Sr. No. | File Name | Basis | Source | Additional details |
|---|---|---|---|---|
| **WORKSHEET FILES** | | | | |
| 1. | popdist1.wk1 | Census districtwise population distribution for year 1991. Distribution into grids based on actual area of census districts in each grid. | BMRDA | Annexure 1 |
| 2. | fuelcond.wk1 | | | Annexure II |
| | LPG (Domestic) | Total Usage: 639 TPD. Period of use: 10 hrs/day. User: Non-slum population. | Rationing office | - |
| | SKO (Domestic) | Total usage: 1,236 KL/day. Period of Use: 10hrs/day. User: Slum/non-slum population. | Rationing office | - |
| | Wood (Domestic) | Total usage: 276 TPD. Period of Use: 12 hrs/day. User: 20% slum population. | S.P.College Pune study | - |
| | Wood (Bakeries) | Total usage: 440 TPD. Period of Use: 12 hrs/day. User: Bakeries. | Bakeries association | - |
| | Wood (Crematoria) | Total usage: 87.5 TPD. Period of Use: 24 hrs/day. User: Crematoria. | Health Dept./BMC & visits to crematoria | - |
| | Total Wood | Gridwise addition of wood consumption by domestic source + bakeries + crematoria. | - | - |
| 3. | emisndom.wk1 | Emissions from Domestic fuel usage.<br><br>Emission factors - WHO | Fuel data from FUELCOND.WK.1 | Annexure III |
| | **BOX FILES** | | | |
| 4. | popdist.dat | Population distribution in box. | Data from POPDISTI.WK1 | Annexure I |

| Sr. No. | File Name | Basis | Source | Additional details |
|---|---|---|---|---|
| 5. | slumdist.dat | Slum population distribution in box | Data from POPDISTI. WK1 | Annexure I |
| 6. | bldg-ht.dat | Average building height in grid | Own observation | - |
| 7. | **DOMESTIC DATA FILES** | | | |
| 7.1 | spmardom.dat | Area source SPM from LPG/SKO/total wood | Data from FUELCON D.WK1 & EMISNDO M.WKI | - |
| 7.2 | so2ardom.dat | Area source $SO_2$ from LPG/SKO/Total wood | Data from FUELCON D.WK1 & EMISNDO M.WKI | - |
| 7.3 | noxardom.dat | Area source $No_x$ from LPG/SKO/Total wood | Data from FUELCON D.WK1 & EMISNDO M.WKI | - |
| 8. | **REFUSE BURNING** | | | |
| 8.1 | spmarsw.dat | Area source SPM from Solid Waste (refuse burning). E.F. - WHO & monitoring data from MCGB. | Box model calculations | Annexure IV |
| 8.2 | so2arsw.dat | Area source $SO_2$ from Solid Waste (refuse buring). E.F. - WHO | Box model calculations | Annexure IV |
| 8.3 | noxarsw.dat | Area source $NO_x$ from Solid Waste (refuse buring). E.F. - WHO | Box model calculations | Annexure IV |
| 9. | **STONE CRUSHERS** | | | |
| 9.0 | spmarcru.dat | Area source SPM from stone crushers | E.F. - EPA capacity of crushers MPCB files | Annexure V |
| 10. | **BALANCE FUEL DISTRIBUTION** | | | |

| Sr. No. | File Name | Basis | Source | Additional details |
|---|---|---|---|---|
| 10.1 | smparfue.dat | Area source SPM from Balance fuel consumption | Total fuel consumption from POISOURC .DAT and sale figures from petroleum companies | Annexure VI |
| 10.2 | so2arfue.dat | Area source $SO_2$ from Balance fuel consumption | Total fuel consumption from POISOURC .DAT and sale figures from petroleum companies | Annexure VI |
| 10.3 | noxarfue.dat | Area source $NO_x$ from Balance fuel consumption | Total fuel consumption from POISOURC .DAT and sale figures from petroleum companies | Annexure VI |
| 11. | **POINT SOURCE DATA FILES** | | | |
| 11.0 | poiscourc.dat | Emission from industries | MPCB files (monitoring data submitted by industries) + E.F. - WHO | Annexure VII |

# APPENDIX 5
# EMISSION FACTORS, PARTICLES

## INTRODUCTION

Emission factors (emitted amount of pollutant per quantity of combusted fuel, or per kilometers driven, or per produced unit of product) are important input data to emission inventories, which again are essential input to dispersion modeling.

The knowledge of emission factors representative for the present technology level of Asian cities is limited. For the purpose of selecting emission factors for the URBAIR study, references on emission factors were collected from the open literature and from studies and reports from cities in Asia.

This appendix gives a brief background for the selection of emission factors for particles used in the air quality assessment part of URBAIR.

### *Motor vehicles*

The selection of emission factors for motor vehicles for use in the URBAIR project to produce emission inventories for South-East Asian cities, was based on the following references:

- WHO (1993)
- USEPA (EPA AP42 report series) (1985)
- Vehicles Emission Control Project (VECP), Manila (Baker, 1993)
- Indonesia (Bosch, 1991)
- Williams et al. (1989)
- Motorcycle emission standard and emission control technology (Weaver and Chan, 1993)

Table 1 gives a summary of emission factors from these references for various vehicle classes. From these, the emission factors given in Table 2 were selected, for use as a basis for URBAIR cities.

Taking account of the typical vehicle/traffic activity composition, the following vehicle classes give the largest contributions to the total exhaust particle emissions from traffic:

- Heavy duty diesel trucks
- Diesel buses
- Utility trucks, diesel
- 2-stroke 2- and 3-wheelers.

Thus, the emission factors for these vehicle classes are the most important ones.

**COMMENTS**

It is clear that there is not a very solid basis in actual measurements on which to estimate particle emission factors for vehicles in South-East Asian cities. The given references represent the best available basis. Comments are given below for each of the vehicle classes.

***Table 1: Emission factors (g/km) for particle emissions from motor vehicles***

| Fuel and Vehicle | Particles (g/km) | Reference |
|---|---|---|
| **Gasoline** | | |
| Passenger cars | 0.33 | USEPA/WHO |
| | 0.10 | VECP, Manila |
| | 0.16 | Indonesia (Bosch) |
| | 0.07 | Williams |
| Trucks, utility | 0.12 | VECP, Manila |
| | 0.33 | USEPA |
| | | USEPA |
| Trucks, heavy duty | 0.33 | USEPA |
| 3-wheelers, 2-stroke | 0.21 | USEPA/WHO |
| MC 2/4 stroke | 0.21/ | USEPA/WHO |
| | 2.00/ | VECP, Manila |
| | 0.21/0.029 | Indonesia VWS |
| | 0.28/0.08 | Weaver and Chan |
| **Diesel** | | |
| Car, taxi | 0.6 | VECP, Manila |
| | 0.45 | USEPA/WHO |
| | 0.37 | Williams |
| Trucks, utility | 0.9 | VECP, Manila |
| | 0.93 | EPA |
| Trucks, heavy/bus | 0.75 | WHO |
| | 1.5 | VECP, Manila |
| | 0.93 | USEPA |
| | 1.2 | Bosch |
| | 2.1 | Williams |

**Note:** Relevant as a basis for selection of factors to be used in South-East Asian cities.

*Gasoline*:

- Passenger cars: Fairly new, normally well maintained cars, engine size less than 2.5 l, without 3-way catalyst, running on leaded gasoline (0.2-0.3 g Pb/l), have an emission factor of the order of 0.1 g/km. Older, poorly maintained vehicles may have much larger emissions. The USEPA/WHO factor of 0.33 g/km can be used as an estimate for such vehicles.
- Utility trucks: Although the VECP study (Manila) uses 0.12 g/km, we select the EPA factor of 0.33 g/km was selected for such vehicles, taking account of generally poor maintenance in South-East Asian cities.
- Heavy duty trucks: Only the USEPA have given an estimate for such vehicles, 0.33 g/km, the same as for passenger cars and utility trucks.
- 3-wheelers, 2-stroke: The USEPA and WHO suggest 0.2 g/km for such vehicles.
- Motorcycles, 2-stroke: The Weaver report supports the 0.21 g/km emission factor suggested by USEPA/WHO. In the VECP Manila study a factor of 2 g/km is suggested. This is the same factor as for heavy duty diesel trucks, which seems much too high.
  Visible smoke emissions from 2-stroke 2- and 3-wheelers is normal in South-East Asian cities. Low-quality oil as well as worn and poorly maintained engines probably both contribute to the large emissions. The data base for selecting a representative emission factor is small. In the data of Weaver and Chan (1993), the highest emissions factor is about 0.55 g/km.
  For URBAIR, we choose a factor of 0.5 g/km. Realizing that this is considerably higher than the factor suggested by USEPA, we also have a view to the factor 2 g/km used in the VECP study in Manila, which indicates evidence for very large emissions from such vehicles.

***Table 2: Selected emission factors (g/km) for particles from road vehicles used in URBAIR study***

| Vehicles class | Gasoline | Diesel |
|---|---|---|
| Passenger cars/taxies | 0.20 | 0.6 |
| Utility vehicles/light trucks | 0.33 | 0.9 |
| Motorcycles/tricycles | 0.50 | |
| Trucks/buses | | 2.0 |

- Motorcycles, 4-stroke: The emission factor is much less than for 2-stroke engines. The Weaver report gives 0.08 g/km, while 0.029 g/km is given by the VWS study in Indonesia (Bosch, 1991).

*Diesel*:

- Passenger cars, taxis: The factor of 0,6 g/km given by the VECP Manila is chosen, since it is based on measurements of smoke emission from vehicles in traffic in Manila. The 0,45 g/km of USEPA/WHO was taken to represent typically maintained vehicles in Western Europe and the United States, as also measured by Larssen and Heintzenberg (1983) on Norwegian vehicles. This is supported by the Williams' factor of 0.37 g/km for Australian vehicles.
- Utility trucks: The USEPA and the VECP Manila study give similar emission factors, about 0.9 g/km.
- Heavy duty trucks/buses: The factors given range from 0.75 g/km to 2.1 g/km.
  It is clear that "smoking" diesel trucks and buses may have emission factors even much larger than 2 g/km. In the COPERT emission data base of the European Union ( ), factors as large as 3-5 g/km are used for "dirty" city buses. Likewise, based on relationships between smoke meter reading (e.g. Hartridge smoke units, HSU) and mass emissions, it can be estimated that a diesel truck with a smoke meter reading of 85 HSU, as measured typically on Kathmandu trucks and buses (Rajbahak and Joshi, 1993), corresponds to an emission factor of roughly 8 g/km!
  As opposed to this, well maintained heavy duty diesel trucks and buses have an emission factor of 0.7-1 g/km.
  As a basis for emission calculations for South-East Asian cities we choose an emission factor of 2 g/km. This corresponds to some 20 percent of the diesel trucks and buses being "smoke belchers". A larger fraction of "smoke belchers", such as in Kathmandu, will result in a larger emission factor.

## FUEL COMBUSTION

*Oil*. The particle emission factors suggested by USEPA (AP 42) is taken as a basis for calculating emissions from combustion of oil in South-East Asian cities. The factors are given in Table 3.

***Table 3: Emission factors for oil combustion (kg/m³)***

| | Emission factor | |
|---|---|---|
| | Uncontrolled | Controlled |
| Utility boilers: | | |
| Residual oil[a)] | | |
| Grade 6 | 1.25(S)+0.38 | ×0.008 (ESP) |
| Grade 5 | 1.25 | ×0.06 (scrubber) |
| Grade 4 | 0,88 | ×0.2 (multicyclone) |
| Industrial/commercial boilers: | | |
| Residual oil | (as above) | ×0.2 (multicyclone) |
| Distillate oil | 0.24 | |
| Residential furnaces: | | |
| Distillate oil | 0.3 | |

**Note:** S: Sulfur content in % by weight

a): Another algorithm for calculating the emission factors is as follows: 7,3xA kg/m³, where A is the ash content of the oil.

**Source:** USEPA (1985).

## *References*


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

Bosch, J. (1991) Air quality assessment in Medan. Extract from Medan urban transportation study. Final Report. Washington D.C., World Bank.

Larssen, S. and Heintzenberg, J. (1983) Measurements of emissions of soot and other particles from light duty vehicles. Lillestrøm (NILU OR 50/83). (In Norwegian).

Rajbahak, H.L. and Joshi, K.M. (1993) Kathmandu Valley vehicular transportation and emission problems. *Metropolitan Environment Improvement Program. Urban Air Quality Management Workshop (URBAIR),* December 2, 1993.

U.S. Environmental Protection Agency (1985) Compilation of air pollutant emission factors, 4th ed. Supplement A. Research Triangle Park, NC, EPA (Environmental Protection Agency ; AP-42).

Weaver, C.S. and Chan, L.-M. (1993) Motorcycle emission standards and emission control technology. Draft report. Sacramento, CA., Engine, Fuel, and Emissions Engineering, Inc.

Williams, D.J., J. W. Milne, D. B. Roberts, and M. C. Kimberlee. (1989). Particulate emissions from 'in-use' motor vehicles - I. Spark ignition vehicles. *Atmos. Environ., 23,* 2639-2645.

Williams, D.J., S. M. Quigley, J. W. Milne, D. B. Roberts, and M. C. Kimberlee. (1989). Particulate emissions from 'in-use' motor vehicles - II. Diesel vehicles. *Atmos. Environ., 23,* 2647-2662.

World Health Organization (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).

# APPENDIX 6
# POPULATION EXPOSURE CALCULATIONS

The basis for the calculations of the exposure of the Bombay population to TSP is the following:

1. The population distribution, calculated per $km^2$ as described in Appendix 2, Chapter 2, and shown in Figure 2 in that appendix.
2. The TSP distribution in Bombay, calculated by dispersion modeling as annual average concentration in $km^2$ grids (city background) described in the main report.

These two distributions are combined, and give an estimate of the residential exposure frequency distribution shown in Table 1 of this Appendix, Columns 1. and 2.

This residential exposure is modified to account for additional roadside exposure experienced by drivers, commuters and roadside workers. This modification is done in the following way --

- 300,000 drivers are given fairly high annual exposures,
  - 100,000 at 195 $\mu g/m^3$
  - 100,000 at 205 $\mu g/m^3$
  - 100,000 at 215 $\mu g/m^3$
- 1,500,000 commuters are given a moderately high annual exposure (see 3rd column, Table 1),
  - 500,000 at 125 $\mu g/m^3$
  - 500,000 at 155 $\mu g/m^3$
  - 500,000 at 175 $\mu g/m^3$

--which is thought to correspond to commuting on intermediate, high and very high traffic density roads.

These 1.8 million people are then subtracted from the residence distribution, somewhat arbitrarily at equal rate from exposure classes between 95 $\mu g/m^3$ and 185 $\mu g/m^3$ (see 4th column, Table 1), i.e. the residents of the commuters and drivers are thought to be in moderately-to-fairly highly exposed areas.

This modification gives the total exposure frequency distribution of Table 2, column 5.

Columns 6 and 7 of Table 1 give the resulting cumulative distributions.

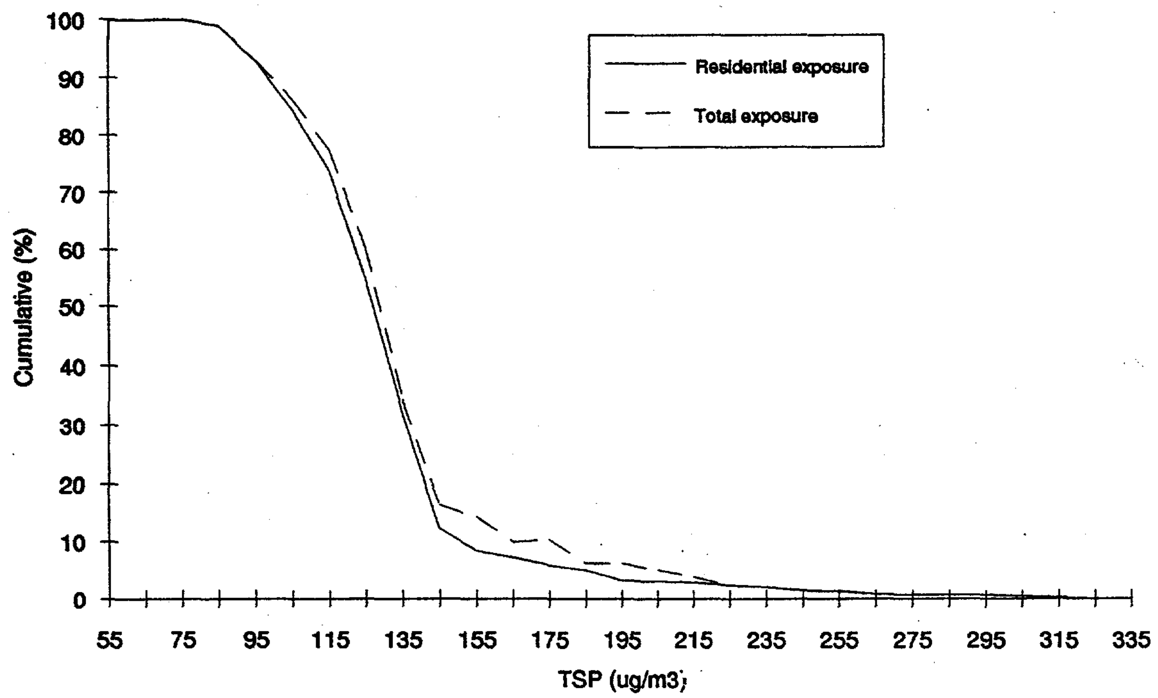
Figure 1 shows the calculated exposure distributions.

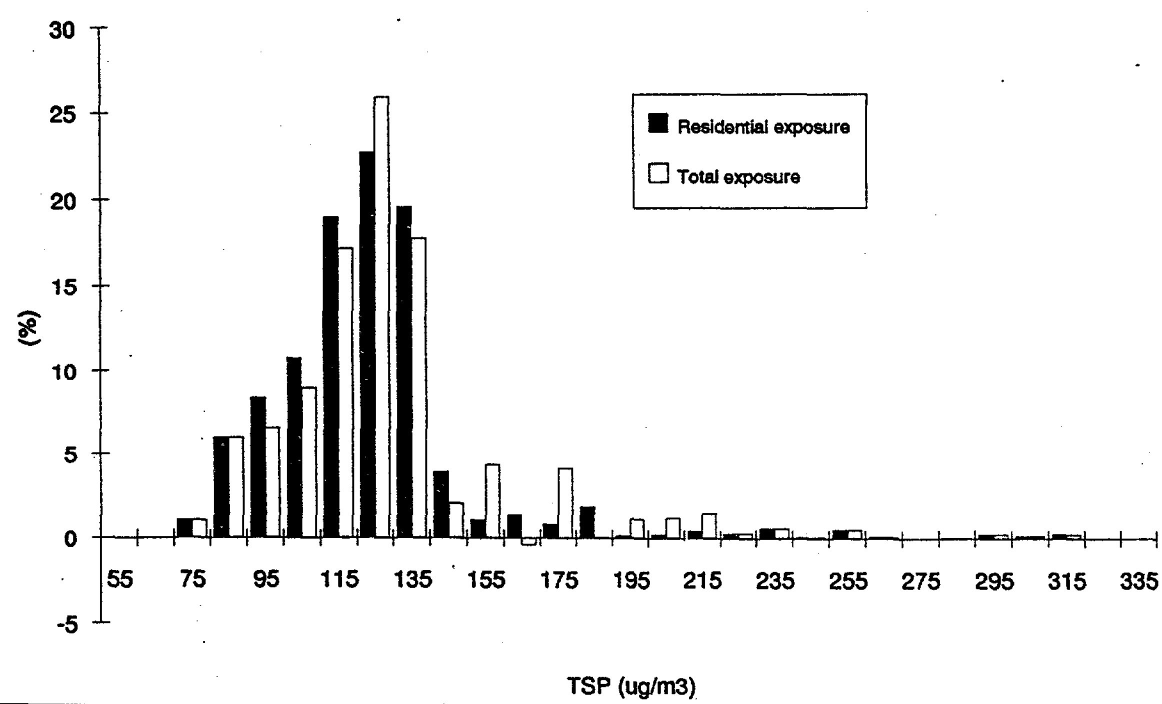
The residential distribution show that most people are exposed to annual concentrations between 110-140 $\mu g/m^3$ (annual average TSP). Small fractions of the population are exposed to higher concentrations near specific particle sources, which are stone quarries. The roadside exposure causes a considerably increased exposure for a considerable part of the population.

***Table 1: Calculated distributions of population exposure to TSP in Bombay, 1993 (annual average, µg/m³)***

| Exposure class (TSP, µg/m³) | Residential exposure, freq. distr. | Traffic exposure modification | | Total exposure freq.distr. | Cumulative distr. | |
|---|---|---|---|---|---|---|
| | | Add. | Subtr. | | Residential | Total |
| 55 | 0.0 | | | 0.0 | 99.843 | 99.873 |
| 65 | 0.0 | | | 0.0 | 99.843 | 99.873 |
| 75 | 1.085 | | | 1.085 | 99.843 | 99.873 |
| 85 | 6.007 | | | 6.007 | 98.758 | 98.788 |
| 95 | 8.405 | | 1.83 | 6.575 | 92.751 | 92.781 |
| 105 | 10.800 | | 1.83 | 8.970 | 84.346 | 86.206 |
| 115 | 19.008 | | 1.83 | 17.178 | 73.546 | 77.236 |
| 125 | 22.662 | 5.09 | 1.83 | 25.922 | 54.538 | 60.058 |
| 135 | 19.600 | | 1.83 | 17.770 | 31.876 | 34.136 |
| 145 | 3.900 | | 1.83 | 2.070 | 12.276 | 16.366 |
| 155 | 1.100 | 5.09 | 1.83 | 4.360 | 8.376 | 14.296 |
| 165 | 1.400 | | 1.83 | -0.430 | 7.276 | 9.936 |
| 175 | 0.846 | 5.09 | 1.83 | 4.106 | 5.876 | 10.366 |
| 185 | 1.868 | | 1.83 | 0.038 | 5.03 | 6.260 |
| 195 | 0.143 | 1.02 | | 1.163 | 3.162 | 6.222 |
| 205 | 0.218 | 1.02 | | 1.238 | 3.019 | 5.059 |
| 215 | 0.466 | 1.02 | | 1.486 | 2.801 | 3.821 |
| 225 | 0.302 | | | 0.302 | 2.335 | 2.335 |
| 235 | 0.606 | | | 0.606 | 2.033 | 2.033 |
| 245 | 0.093 | | | 0.093 | 1.427 | 1.427 |
| 255 | 0.518 | | | 0.518 | 1.334 | 1.334 |
| 265 | 0.108 | | | 0.108 | 0.816 | 0.816 |
| 275 | 0.0 | | | 0.0 | 0.708 | 0.708 |
| 285 | 0.020 | | | 0.020 | 0.708 | 0.708 |
| 295 | 0.270 | | | 0.270 | 0.688 | 0.688 |
| 305 | 0.152 | | | 0.152 | 0.418 | 0.418 |
| 315 | 0.266 | | | 0.266 | 0.266 | 0.266 |
| 325 | 0.0 | | | 0.0 | 0.0 | 0.0 |
| 335 | 0.0 | | | 0.0 | 0.0 | 0.0 |

*Figure 1: Calculated distributions of population exposure to TSP in Bombay, 1993 (annual average)*



# APPENDIX 7
# SPREADSHEET FOR CALCULATING EFFECTS OF CONTROL MEASURES ON EMISSIONS

# SPREADSHEET FOR CALCULATING EFFECTS OF CONTROL MEASURES ON EMISSIONS

## *Emissions spreadsheet*

The spreadsheet is shown in Figure 1. (Example: TSP emissions, Greater Bombay, Base Case Scenario, 1992.) Figure 2 shows emission contributions in absolute and relative terms.

The purpose of the spreadsheet is to calculate modified emission contributions, due to control measures, such as:

- new vehicle technology
- improved emission characteristics, through measures on existing technology
- reduced traffic activity/fuel consumption
- other.

The emissions are calculated separately for large point sources (with tall stacks) and for area sources and smaller distributed point sources. The reason is that air pollution concentrations and population exposures are calculated differently for these two types of source categories.

The columns and rows of the worksheet are as follows:

*Columns*:

a) q: Emission factor, g/km for vehicles, kg/$m^3$ or kg/ton for fuel combustion and process emissions. For vehicles, emission factors are given for "existing" and "new" technology.
b) F,T: Amount of "activity"
   - T (vehicle km) for traffic activity
   - F ($m^3$ or ton) for fuel consumption in industrial production.
c) qT,qF: Base case emissions, tons, calculated as product of columns a) and b).
d) fq, fF, fT, f-: Control measures. Relative reduction of emission factor (fq), amount (fF, fT) or other (f-) resulting from control measures.
e) qFfqfFf-: Modified emissions, due to control measures.
f) d(qFfqfFf-): Relative emission contributions from each source, per source category:
   - vehicles
   - fuel combustion
   - industrial processes
   - miscellaneous
g) d(qFfqfFf): Relative emissions contributions, all categories summed.

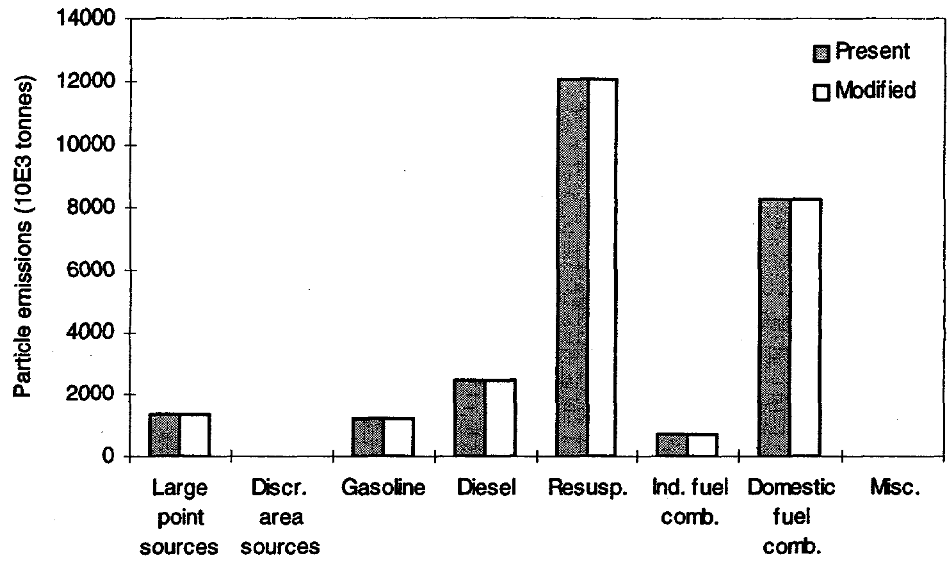
*Rows*:

a) Separate rows for each source type and category, "existing" and "new" technology.
b) "Background": Fictitions emissions, corresponding to an extra-urban background concentration.
c) Modified emission/emissions: Ratio between modified and base case emissions.

*Figure 1: URBAIR spreadsheet for emissions calculations, Greater Bombay, TSP base case, 1992*

| | | Emission factor | Amount | Base-case Emissions | Control measures | | | Modified emissions | Relative emissions per category | Relative emissions total |
|---|---|---|---|---|---|---|---|---|---|---|
| **LARGE POINT SOURCES** | | | | | | | | | | |
| | | q (kg/t) | F (10E3 t/a) | qF (tonnes) | fq | fF | f- | qF fq fF f (10E3 tonnes) | (dqF fq fFf) (percent) | (dqF fq fFf)tot (percent) |
| Power plant | LSHS | 0.10 | 927 | 93 | 1.00 | 1.00 | 1.00 | 93 | | 6.7 |
| | Coal | 0.50 | 298 | 149 | 1.00 | 1.00 | 1.00 | 149 | | 10.8 |
| | Gas | 0.06 | 496 | 30 | 1.00 | 1.00 | 1.00 | 30 | | 2.2 |
| Petrochem. ind. | LSHS | 0.28 | 279 | 78 | 1.00 | 1.00 | 1.00 | 78 | | 5.6 |
| Large/med. ind. | LSHS | 0.28 | 164 | 46 | 1.00 | 1.00 | 1.00 | 46 | | 3.3 |
| | FO | 5.40 | 183 | 988 | 1.00 | 1.00 | 1.00 | 988 | | 71.4 |
| **Sum large point sources** | | | | 1384 | | | | 1384 | | 100.0 |
| **Modified emissions/emissions, point sourc.** | | | | | | | | 1 | | |
| **DISCRETE AREA SOURCES** | | | | | | | | | | |
| Waste dumps | | | | | 1.00 | 1.00 | 1.00 | | | |
| Stone crushers | | | | | 1.00 | 1.00 | 1.00 | | | |
| **Sum discrete area sources** | | | | 0.00 | | | | 0 | | |
| **Modified emissions/emissions, discr. area sourc.** | | | | | | | | | | |
| **DISTRIBUTED AREA SOURCES** | | | | | | | | | | |
| **Vehicles** | | q (g/km) | T (10E9 vehkm/a) | qT (tonnes) | fq | fT | f- | qT fq fTf (10E3 tonnes) | (dqT fq fTf) (percent) | (dqT fq fTf) (percent) |
| **Gasoline exhaust** | | | | | | | | | | |
| Cars, taxis | | 0.20 | 2.46 | 492 | 1 | 1 | 1 | 492 | 13.4 | 2.0 |
| MC/TC | | 0.50 | 1.47 | 735 | 1 | 1 | 1 | 735 | 20.0 | 3.0 |
| Sum gasoline | | | | 1227 | | | | 1227 | | 5.0 |
| Modified emissions/emissions, gasoline | | | | | | | | 1 | | |
| **Diesel exhaust** | | | | | | | | | | |
| Cars, taxis | | 0.6 | 1.27 | 762 | 1 | 1 | 1 | 762 | 20.8 | 3.1 |
| Trucks | | 2.0 | 0.62 | 1240 | 1 | 1 | 1 | 1240 | 33.8 | 5.0 |
| Buses | | 2.0 | 0.22 | 440 | 1 | 1 | 1 | 440 | 12.0 | 1.8 |
| Sum diesel | | | | 2442 | | | | 2442 | 100.0 | 9.9 |
| Modified emissions/emissions, diesel | | | | | | | | 1 | | |
| Sum total vehicle exhaust | | | | 3669 | | | | 3669 | | 14.8 |
| Modified emissions/emissions, total vehicle exhaust | | | | | | | | 1.00 | | |
| **Resuspension** | | 2.0 | 6.04 | 12080 | 1 | 1 | 1 | 12080 | | 48.8 |
| **Sum total vehicles (exh.+resusp.)** | | | | 15749 | | | | 15749 | | 63.7 |
| **Modified emissions/emissions, total vehicles (exh.+resusp.)** | | | | | | | | 1.00 | | |
| **Fuel combustion** | | q (kg/t) | F (10E3 t/a) | qF (tonnes) | fq | fF | f- | qF fq fF f (10E3 t/a) | (dqF fq fFf)fuel (percent) | (dqF fq fFf)tot (percent) |
| **Industrial** | | | | | | | | | | |
| LHSH | | 0.28 | 56 | 15.68 | 1.00 | 1.00 | 1.00 | 15.68 | 0.2 | 0.1 |
| FO | | 5.40 | 123 | 664.20 | 1.00 | 1.00 | 1.00 | 664.20 | 7.4 | 2.7 |
| LDO | | 0.28 | 42 | 11.76 | 1.00 | 1.00 | 1.00 | 11.76 | 0.1 | 0.0 |
| Diesel (HSD) | | 0.28 | 40 | 11.20 | 1.00 | 1.00 | 1.00 | 11.20 | 0.1 | 0.0 |
| LPG | | 0.06 | 7 | 0.42 | 1.00 | 1.00 | 1.00 | 0.42 | 0.0 | 0.0 |
| Sum industrial | | | | 703.26 | | | | 703.26 | | 2.8 |
| Modified emissions/emissions, industrial | | | | | | | | 1.00 | | |
| **Domestic** | | | | | | | | | | |
| Wood | | 15.00 | 293 | 4395.00 | 1.00 | 1.00 | 1.00 | 4395.00 | 48.9 | 17.8 |
| SKO | | 0.06 | 480 | 28.80 | 1.00 | 1.00 | 1.00 | 28.80 | 0.3 | 0.1 |
| LPG | | 0.06 | 233 | 13.98 | 1.00 | 1.00 | 1.00 | 13.98 | 0.2 | 0.1 |
| Coal | | 10.00 | | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| Dung | | 10.00 | | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| Refuse | | 37.00 | 104 | 3848.00 | 1.00 | 1.00 | 1.00 | 3848.00 | 42.8 | 15.6 |
| Sum domestic | | | | 8285.78 | | | | 8285.78 | | 33.5 |
| Modified emissions/emissions, domestic | | | | | | | | 1.00 | | |
| **Sum fuel combustion** | | | | 8989.04 | | | | 8989.04 | 100.0 | 36.3 |
| **Modified emissions/emissions, fuel** | | | | | | | | 1.00 | | |
| **Miscellaneous** | | q | M | qM | fq | fM | f- | qM fq fM f | (dqM fq fMf)misc (percent) | (dqM fq fMf)tot (percent) |
| **Construction** | | | | | | | | | | |
| **Sum miscellaneous** | | | | 0 | 1 | 1 | 1 | 0 | 0.0 | 0.0 |
| **Modified emissions/emissions, misc.** | | | | | | | | #DIV/0! | | |
| **Sum total distributed area sources** | | | | 24738.04 | | | | 24738.04 | | 100.00 |
| **Modified emissions/emissions, distr. area sources** | | | | | | | | 1.00 | | |

*Figure 2: Emissions contributions from various source categories*



# APPENDIX 8: PROJECT DESCRIPTIONS, LOCAL CONSULTANTS

## PROJECT DESCRIPTION REGARDING AIR QUALITY ASSESSMENT

Information should be collected regarding the items described below. The information to be collected *shall go beyond* the information contained in the material referenced in the Draft Report from NILU and Institute of Environmental Studies (IES) of the Free University of Amsterdam prepared for the Workshop, and summarized in that report.

Available information shall be collected regarding the following items, and other items of interest for Air Quality Management System Development in Bombay:

- Meteorological measurements in and near the city.
- Activities/population data for Bombay:
  - — Fuel Consumption data:
    Total fuel consumption (1) per type (high/low sulfur oil, coal, gas, firewood and other biomass fuels, other) and (2) per sector (industry, commercial, domestic)
  - — Industrial plants:
    Location (on map), type/process, emissions, stack data (height, diameter, effluent velocity and temperature)
  - — Vehicle statistics:
    1. number of vehicles in each class (passenger cars, small/medium/large trucks, buses, motorcycles (2- and 3-wheels, 2- and 4-stroke);
    2. Age distribution;
    3. Average annual driving distance per vehicle class.
  - — Traffic data:
    Definition of the main road network marked on map.
    Traffic data for the main roads:
    1. annual average daily traffic (vehicles/day)
    2. traffic speed (average, and during rush hours)
    3. vehicle composition (passenger cars, motorcycles, trucks/buses).
  - — Population data:
    Per city district (as small districts as possible)
    1. total population;
    2. age distribution.

- Air pollution emissions
  — Emission inventory data (annual emissions)
    1. per compound ($SO_2$, $NO_x$, particles in size fractions: <2 µg, 2-10 µg, >10 µg, VOC, lead);
    2. emissions per sector (industry, transport, domestic, etc.).

- Air pollution data:
  — concentration statistics per monitoring station:
    1. annual average, 98 percentile, maximum concentrations (24-hour, 1 hour);
    2. trend information;
    3. methods description, and quality control information on methods.

- Dispersion modeling: Reports describing studies and results.

- Air pollution laws and regulations: Summary of existing laws and regulations.

- Institutions:
  — Description of existing institutions working in and with responsibilities within the air pollution sector, regarding:
    1. monitoring,
    2. emission inventories,
    3. law making,
    4. enforcement.
  — The information shall include:
    1. responsibilities and tasks of the institution,
    2. authority,
    3. manpower,
    4. expertise,
    5. equipment (monitoring, analysis, data, hard/software),
    6. funds.

It is important that the gathering of information is *as complete as possible* regarding each of the items, so that we have a basis of data which is as updated and complete as possible. Remember that this updated completed information database is to form the basis for an action plan regarding Air Quality Management in Bombay. Such an action plan will also include the need to collect more data. In that respect, it is very important that the gathering of existing data is *complete*.

## PROJECT DESCRIPTION REGARDING DAMAGE ASSESSMENT AND ECONOMIC VALUATION

## *URBAIR: topics for research*

*Physical impacts*

1. Describe available studies on relations between air pollution and health.
2. Decide on the acceptability of dose-effect relationships from U.S.A.
   a) Mortality: 10 $\mu g/m^3$ TSP leads to 0.682 (range: 0.48-0.89) percentage change in mortality.
   b) Work loss days (WLD): 1 $\mu g/m^3$ TSP leads to 0.00145 percentage change in WLD.
   c) Restricted activity days (RAD): 1 $\mu g/m^3$ TSP leads to 0.0028 percentage change in RAD per year.
   d) Respiratory hospital diseases (RHD): 1 $\mu g/m^3$ TSP leads to 5.59 (range: 3.44-7.71) cases of RHD per 100,000 persons per year.
   e) Emergency room visits (ERV): 1 $\mu g/m^3$ TSP leads to 12.95 (range: 7.1-18.8) cases of ERV per 100,000 persons per year.
   f) Bronchitis (children): 1 $\mu g/m^3$ TSP leads to 0.00086 (range: 0.00043-0.00129) change in bronchitis.
   g) Asthma attacks: 1 $\mu g/m^3$ TSP leads to 0.0053 (range: 0.0027-0.0079) change in daily asthma attacks per asthmatic persons.
   h) Respiratory symptoms days (RSD): 1 $\mu g/m^3$ TSP leads to 1.13 (range:0.90-1.41) RSD per person per year.
   i) Diastolic blood pressure (DBP): change in DBP = 2.74 ([Pb in blood]$_{old}$ -[Pb in blood]$_{new}$) with [Pb in blood] is blood lead level (μg/dl).
   j) Coronary heart disease (CHD): change in probability of a CHD event in the following ten years is --

   $$[1 + exp - \{-4.996 + 0.030365(DBP)\}]^{-1} - [1 + exp - \{-4.996 + 0.030365(DBP_2)\}]^{-1}$$

   i) Decrement IQ points: IQ decrement = 0.975 x change in air lead ($\mu g/m^3$)

Calculation example:

- Let population be 10 million people.
- Let threshold value of TSP be 75 $\mu g/m^3$ (the WHO guideline).
- Let the concentration TSP be 317 $\mu g/m^3$.
  ⇒ Concentration - threshold = 317 - 75 = 242 = 24.2 (10 $\mu g/m^3$).
  ⇒ Change in mortality = 24.2 x 0.682 = 16.5%.
- Let crude mortality be 1% per year.
  ⇒ Crude mortality = 100,000 people per year.
  ⇒ Change in mortality due to TSP = 16.5% of 100,000 people = 16,500 people per year.

3. For those dose-effect relationships that are acceptable, base value must be gathered, e.g.:
   a) crude mortality
   b) present work days lost

*Valuation*

1. Mortality.

   a) *Willingness to Pay.* In the United States, research has been carried out on the relation between risks of jobs and wages. It appeared that 1 promille of change in risk of mortality leads to a wage difference of ca. US$1,000. If this figure is applicable to all persons of a large population (10 million), the whole population values 1 promille change in risk of mortality at US$1,000 x 10 x $10^6$ = $10 billion. An increase in risk of 1 promille will lead to ca. 10,000 death cases, so per death case the valuation is US$1 million. It should be decided if in other countries, c.q. cities, this valuation should be corrected for wage differences (e.g. if the average wage is 40 times lower than in the United States the valuation of 1 death case is US$25,000). If this approach is acceptable, the only information needed is average wage.

   b) *Production loss.* If the approach of willingness to pay is not acceptable, the alternative is valuing human life through production loss, i.e. foregone income of the deceased. Again. the information needed is average wage. Moreover, information is needed on the average number of years that people have a job. However, those without a job should also be assigned a value. An estimate of the income from informal activities can be an indication. Otherwise a value derived from the wages (e.g. half the average wage) can be a (somewhat arbitrary) estimation.
2. *Morbidity.* Estimates are needed for all cases of morbidity of the duration of the illness, so as to derive an estimation of foregone production due to illness. Just as in the case of mortality (B.1.b) wages can be used for valuation of a lost working day. Moreover, the hospital costs and other medical costs are to be estimated. These costs still do not yet include the subjective costs of illness, which can be estimated using the willingness-to-pay approach to pay to prevent a day of illness.
3. *Willingness to pay to prevent a day of illness.* Valuation in the United States, based on surveys among respondents, indicate that the willingness to pay to prevent a day of illness is ca. US$15. This amount could, just like the amount of willingness to pay for risk to human health, be corrected for wage differences. The acceptability of such a procedure is, perhaps, somewhat lower.
4. *IQ points.* Loss of IQ of children may lead to a lower earning capacity. A U.S. estimate is ca. US$4,600 per child, per IQ point, summed over the child's lifetime. If this is acceptable, the figure could be corrected for wage differences between the United States and the city.

*Other impacts*

1. *Buildings.* An estimate by Jackson et al is that prevented cleaning costs per household per year are US$42 for a reduction in TSP concentration, from 235 µg/m3 to 115 µg/m3. This would imply a benefit of US$0.35 per household per µg/m3 reduction. This figure could be corrected for wage differences between the United States and the city. If that is acceptable, the information needed is the number of households in the city.
2. *Monuments.* It is difficult to say which value is attached to monuments, as they are often unique and their value is of a subjective character. Nevertheless, the restoration and cleaning costs of monuments could be an indication of the order of magnitude of damage to monuments. Revenue of tourism might also give a certain indication of valuation of future damage to monuments.

*Remark*

- In most cases, the valuation of damage is not very precise, and certainly not more than an indication of the order of magnitude.

*Technological reduction options.* To give a reliable estimate of the costs of technological reduction options, one needs a reliable emission inventory in which is included the currently used technologies and the age and replacement period of the installed equipment. In the absence of this, the study by the city team might wish to concentrate on a case study (e.g. traffic, fertilizer industry, large combustion sources.)

- The first step is to identify options. Cooperation with IES is possible, once a case study is identified.
- The second step is to estimate the costs, i.e. investment costs and O&M (operation and maintenance) costs. Based on the economic lifetime of the invested equipment, the investment costs can be transformed to annual costs, using writing-of procedures. Costs will often depend to a large extent on local conditions.
- The third step is to estimate the emission reductions of the various reduction options.
- The fourth step is to rank the options according to cost-effectiveness. For this purpose the various types of pollution have to be brought under a common denominator. A suggestion could be to calculate a weighed sum of the pollutants, using as weights the amount by which ambient standards are exceeded on average.

The calculation of the cost-effectiveness consists then of the calculation of the ratio of reduction over annual cost (R/C). The options with the highest ration R/C are the most cost-effective ones.

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