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# Urban Air Quality Management Strategy in Asia

# URBAIR

## Kathmandu Valley Report

October 1996

Metropolitan Environmental Improvement Program
A World Bank Initiative

# URBAIR

**URBAN AIR QUALITY MANAGEMENT STRATEGY IN ASIA**

**KATHMANDU VALLEY REPORT**

**Prepared by**:

**Knut Erik Grønskei, Frederick Gram, Leif Otto Hagen, and Steinar Larssen**,
Norwegian Institute for Air Research,
Kjeller, Norway

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

**Anil S. Giri**
Royal Nepal Academy of Science and Technology (RONAST)
Kathmandu, Nepal

**Madan L. Shrestha**
Dpt. of Hydrology and Meteorology,
Min. of Water Resources, Kathmandu, Nepal

**Bimala Shrestha**
Tribhuvan University,
Kathmandu, Nepal

**Edited by**:

**Jitendra Shah and Tanvi Nagpal**
The World Bank,
Washington, DC

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The layout is by Julia Lutz, Environment and Natural Resources Division, Asia Technical Department, The World Bank.

# ENVIRONMENT PROTECTION COUNCIL
## URBAN ENVIRONMENT MANAGEMENT COMMITTEE

## Foreword

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 in numbers of passenger vehicles. The impacts of air pollution are well known: adverse health effects, rising health costs, damage to ecological and cultural properties, deterioration of built environment.

In Kathmandu Valley cities, the main contributor of air pollution comes from 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 an air quality management strategy. A long- run 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.

Kathmandu Valley cities joined the World Bank-executed Metropolitan Environmental Improvement Program (MEIP) in 1993. At the inter-country workshop held in Hawaii in 1990, the cities facing serious air pollution problems sought MEIP intervention to assist in finding solutions. In response to this, URBAIR was conceived and launched in Kathmandu Valley, Nepal in 1993.

URBAIR has assisted His Majesty's Government/Nepal, Environment Protection Council, Urban Environment Management Committee to develop a strategy and time- bound action plan for air quality management in Kathmandu Valley. For the first time, it brought together the different stakeholders -- sectoral agencies, private sector, NGOs, academics, research bodies and media -- to formulate a strategy. From this group was formed the Technical Committee that deliberated for several months with technical support provided by a team of national and international experts. The outcome is the action plan included in this document. The result is truly impressive and His Majesty's Government/Nepal, Environment Protection Council, Urban Environment Management Committee is fully committed to the implementation of the plan. We will need the support of the international community in realizing the goals of the plan.

I wish to acknowledge with gratitude all those who contributed to the development of the strategy and plan, especially to MEIP for facilitating the process.

**Umesh Bahadur Malla**
**Joint Secretary/MHPP**
**Member Secretary**
**Urban Environment Management**
**Committee/EPC**
**Kathmandu, Nepal**

# PARTNERS AND CONTRIBUTORS

Many contributed to the URBAIR process. URBAIR core funds were provided by United Nations Development Programme, the Australian International Development Agency, the Royal Norwegian Ministry of Foreign Affairs, the Norwegian Consultant Trust Funds, and the Netherlands Consultant Trust Funds. Host governments and city administrations provided substantial input.

City studies were conducted by the Norwegian Institute for Air Research (NILU) and the Institute of Environmental Studies (IES) at the Free University in Amsterdam, with assistance from the selected local consultants: Mr. Anil S. Giri and Mr. Rishi Shah, Royal Nepal Academy of Science and Technology; Dr. Madan L. Shrestha, Department of Hydrology and Meteorology, and Dr. Bimala Shrestha, Tribhuvan University. The city-level technical working groups provided operational support, while the steering committee members gave policy direction to the study team. The National Program Coordinator of MEIP-Kathmandu, Mr. Guru Bar Singh Thapa, contributed greatly to the successful outcomes.

At the World Bank, URBAIR was managed by Jitendra Shah and Katsunori Suzuki, and under the advice and guidance of Maritta Koch-Weser and David Williams. Colleagues from the World Bank Country Departments and Resident Mission helped with the program. Tanvi Nagpal was responsible for technical accuracy and editing. Management support was provided by Erika Yanick, Sonia Kapoor and Ronald Waas. Nicole Schofer and Sheldon Lippman provided editorial support.

Many international institutions (World Health Organization, United States Environmental Protection Agency, United States Asia Environment Partnership) provided valuable contribution through their participation at the workshops. Their contribution made at the workshop discussions and follow-up correspondence and discussions has been very valuable for the result of the project. The following is a list of individuals, based in Kathmandu, who contributed to the URBAIR process and its outcome.

- Mr. Murkesh Bhattarai, Ministry of Industry
- Mr. M. Dehal, MEIP/MHPP
- Mr. Surendra R. Devkota, Industrial Pollution Control Project, Ministry of Industry
- Mr. Anil Shankar Giri, URBAIR Project Incharge, RONAST
- Umesh B. Malla, Joint Secretary, MHPP/Member Secretary UEMC/MHPP
- Mrs. Sony Pradhan, Field Expert, URBAIR Project, RONAST
- Mr. Rishi ShahRONAST-Secretary
- Toran Sharma, NESS-Brick Kiln Contribution to Air Quality
- Dr. Madan Lal Shrestha, Department of Hydrology and Meteorology
- Dr. Bimala Shrestha, Teaching Hospital, Maharajgunj
- Rohit Thapa, Vehicle Emission Control Program in the Kathmandu Valley
- Dr. S.P. Sagar Thapaliya, Kathmandu Valley Traffic Police

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **ADT** | average daily traffic |
| **AQG** | air quality guidelines |
| **AQMS** | air quality management system |
| **CO** | carbon monoxide |
| **EIA** | environmental impact assessment |
| **ENPHO** | Environment and Public Health Organization |
| **EPC** | Environmental Protection Council |
| **ERV** | emergency room visits |
| **g/l** | grams per liter |
| **GDP** | gross domestic product |
| **GNP** | gross national product |
| **H** | hypertension |
| **$H_2S$** | hydrogen sulfide |
| **HC** | hydrocarbon |
| **HMG** | His Majesty's Government |
| **IES** | Institute for Environmental Studies, Amsterdam |
| **IPCR** | Industrial Pollution Control Regulation |
| **KVVEPC** | Kathmandu Valley Vehicle Emission Control Project |
| **LDO** | light diesel oil |
| **LPG** | liquefied petroleum gas |
| **µg** | microgram ($10^{-6}$ grams) |
| **mg** | milligrams ($10^{-3}$ grams) |
| **$\mu g/m^3$** | particulate concentration in micrograms per cubic meters |
| **MEIP** | Metropolitan Environmental Improvement Program |
| **MTBE** | methyl-tertial-butyl-ether |
| **NILU** | Norwegian Institute for Air Research, Kjeller, Norway |
| **NGO** | non-governmental organization |
| **$NH_3$** | ammonia |
| **NIEMP** | National Industrial Energy Management Program |
| **$NO_X$** | nitrogen oxide |
| **NPC** | National Planning Commission |
| **PAH** | polycyclic aromatic hydrocarbons |
| **Pb** | lead |
| **$PM_{10}$** | particulate matter of 10 microns or less |
| **ppb** | parts per billion |
| **RAD** | restricted activity days |
| **RHA** | respiratory hospital admission |
| **RHD** | respiratory hospital diseases |
| **RON** | research octane number |
| **RONSAT** | Royal Nepal Academy of Science and Technology |
| **RSD** | respiratory symptom days |
| **SKO** | kerosene |
| **$SO_2$** | sulfur dioxide |
| **$SO_4$** | sulfate |
| **TSP** | total suspended particles |
| **UNDP** | United Nations Development Programme |
| **UNEP** | United Nations Environment Programme |
| **URBAIR** | Urban Air Quality Management Strategy in Asia |
| **USAID** | United States Agency for International Development |
| **VOC** | volatile organic compounds |
| **VSL** | value of statistical life |
| **WHO** | World Health Organization |
| **WTP** | willingness to pay |

**Note**: Except as indicated, "dollars" refers to 1992/93 U.S. dollars.

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# PREFACE

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

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

The preparation of this city-specific report for Kathmandu is based upon the collection of data and specific studies carried out by the local consultants, and upon workshops and fact-finding missions carried out in April and December 1993, June 1994 and March 1995. Norwegian Institute for Air Research (NILU) and the Institute for Environmental Studies (IES) prepared first drafts of the report, before the first workshops. These were based on general and city-specific information available from earlier studies. Later draft reports were prepared before the second workshop, with substantial inputs from the local consultants, and assessment of air quality, damage and control options, and cost analysis carried out by NILU and IES.

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

It is hoped that, based on this preliminary analysis, local institutions will carry out further analysis of data and develop policy plans as well as investment proposals for air quality management in Kathmandu Valley.

# EXECUTIVE SUMMARY

**URBAIR-KATHMANDU VALLEY:** 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 and around cities have resulted in severe air pollution. Emissions from automobiles and factories; and domestic heating, cooking, and refuse burning are threatening the well being of city dwellers, imposing not just a direct cost by impacting 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.

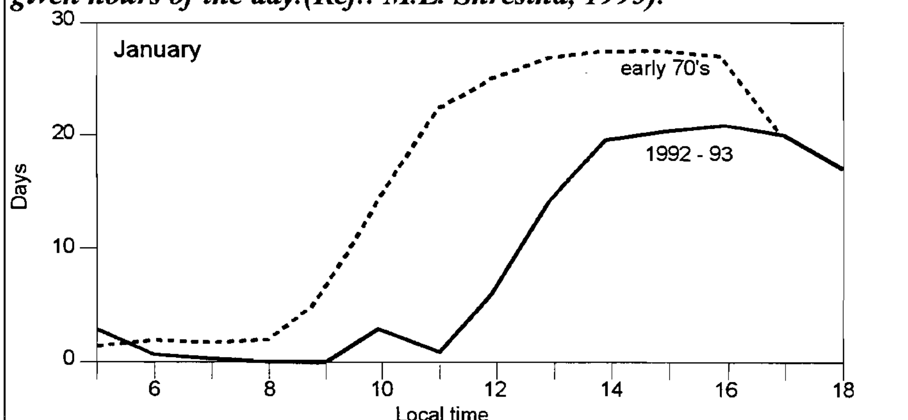
Urban air quality management strategy or URBAIR aims to assist in the design and implementation of policies, monitoring and management tools to restore air quality in major Asian metropolitan areas. At several workshops and working group meetings, government, industry, local researchers, non-government organizations, international and local experts reviewed air quality data and designed actions 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 Kathmandu Valley and the resulting action plan.

### THE DEVELOPMENT OF KATHMANDU VALLEY AND ITS POLLUTION PROBLEM

Kathmandu Valley's population grew by 26 percent from 1970 to 1980, and another 44 percent between 1980 and 1990. In 1992, the population stood at approximately 1,060,000 of which 56 percent was urban. The growth in population has been accompanied by a doubling in the number of vehicles in the past decade. Within the local brick industry, the number of registered kilns has tripled in the last decade. The Himal Cement Plant is one of the major industrial sources of pollution.

With the growth in the number of vehicles and industrial expansion, the consumption of coal and automotive fuel has increased. Over the period 1980-93, the increase has been about 150 percent for gasoline, 175 percent

***Figure ES.1: No. of days in January with good visibility (>8,000 m) at given hours of the day.(Ref.: M.L. Shrestha, 1995).***



for motor diesel, 250 percent for kerosene and 580 percent for fuel oil. The per capita fuel consumption in 1993 was about 27 liters of gasoline, 150 liters of motor diesel, 125 liters of kerosene and 20 liters of fuel oil.

Atmospheric visibility data from Kathmandu's airport analyzed onwards from 1970 show that there has been a very substantial decrease in the visibility in the Valley since about 1980 (Figure ES.1). The number of days with good visibility (greater than 8,000 meters) around noon has decreased in the winter months from more than 25 days per month in the 1970s to about 5 days per month in 1992/93. The loss of tourism could not be exactly calculated, but is significant.

Air pollution measurements show that particulate pollution is the most significant problem in Kathmandu Valley. Total TSP emissions per year amount to 16,500 tons. $PM_{10}$ emissions are 4,700 tons/year. The main sources of particulate pollution are the brick industry (28% $PM_{10}$, 31% TSP); domestic fuel combustion (25% $PM_{10}$, 14% TSP); the Himal Cement Plant (17% $PM_{10}$, 36% TSP); vehicle exhaust (12% $PM_{10}$, 3.5% TSP) and resuspension of the road dust (9% $PM_{10}$, 9% TSP).WHO air quality guidelines (AQG) for TSP and $PM_{10}$ are often substantially exceeded. There have been measured 24-hour TSP concentrations above 800 µg/m³, while the WHO AQG is 150-230 µg/m³.

For practical and methodological reasons only a partial assessment and valuation of the health impacts due to $PM_{10}$ was possible (Table ES.1) In monetary terms the total impact is about NRs200,000 million. Impact of lead pollution due to the use of gasoline which contains lead is not included.

***Table ES.1: Impacts of air pollution ($PM_{10}$) on mortality and health and their valuation in Kathmandu Valley (1990).***

| Type of health impact | Number of cases | Value (NRs) Specific | Value (NRs) Total (1,000) |
|---|---|---|---|
| Excess mortality | 84 | 340,000 | 28,644 |
| Chronic bronchitis | 506 | 83,000* | 41,988 |
| Restricted activity days | 475,298 | 56 | 26,617 |
| Emergency room visits | 1,945 | 470-720** | 1,167 |
| Bronchitis in children | 4,847 | 350 | 1,697 |
| Asthma | 18,863 | 45-4,170** | 11,318 |
| Respiratory symptom days | 1,512,689 | 50 | 75,634 |
| Respiratory hospital admissions | 99 | 4,160 | 415 |
| **Total** | | | **209,051** |

* Shrestha's estimate is about NRs146,000, based on an undiscounted total amount over 27 years. Discounting with 5% leads to an estimate of NRs83,000.

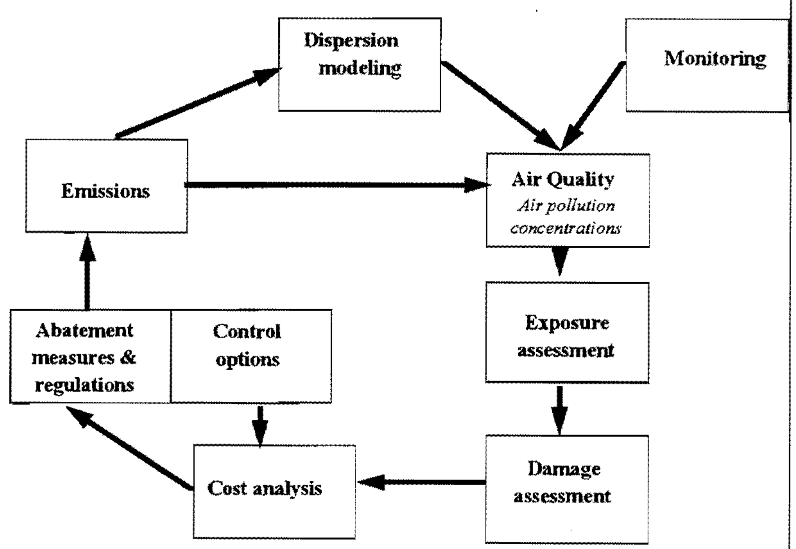
** 600 used as average in calculations.

## CONCEPT OF AIR QUALITY MANAGEMENT SYSTEM

Assessment of pollution and its control form the two prongs of an Air Quality Management System (AQMS). These components are inputs into a cost-benefit analysis. Air Quality Standards or Guidelines, and economic objectives also guide the cost-benefit calculation (See Figure ES.2) An action plan contains the optimum set of abatement and control measures to be enacted in the short, medium, and long term. Successful air quality management 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, materials and urban development; calculation of the effect of abatement and control measures; and establishment and improvement of air pollution regulations.

In order to ensure than an AQMS is having the desired impact, it is also necessary to carry out surveillance and monitoring. This requires the establishment of an Air Quality Information System (AQIS) to inform authorities and the general public about the quality of the air and assess results of abatement. This information system should also provide continuous feedback to the abatememt strategy process.

*Figure ES.2: Air Quality Management System*




### ABATEMENT MEASURES AND ACTION PLANS

Measures to reduce air pollution in Kathmandu Valley focus on one important source--traffic. Traffic emissions contribute about 20 percent of total $PM_{10}$. A reduction in such emissions has a much larger impact in terms of health than a corresponding reduction in emissions from industries or domestic cooking and refuse burning (Table ES.2). While controlling pollution from industries, especially brick kilns and cement plants, has not been discussed at length, it must also be promoted through enforcement and regulation.

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

- **Address gross polluters**. Reinforce the anti-smoke belching program. Existing smoke opacity regulations and overloading of vehicles should be more strictly enforced. The success of this action depends upon the routine maintenance and adjustment of engines.
- **Improved diesel quality**. Domestic refineries could be modified to produce low-sulfur diesel (0.2 percent), or it could be imported. Economic instruments such as taxes and subsidies can

***Table ES.2: Marginal benefits from emissions reduction in different sources.***

| Source | Emissions *(tons)* | % Change in Emission | % Change in Mortality | Change in RSD *(1,000)* | Change in health damage *(NRs thousand)* | Marginal benefits *(NRs/kg)* |
|---|---|---|---|---|---|---|
| Traffic (exhaust) | 440 | -10 | -6 | -108 | -150,374 | 341 |
| Resuspension | 400 | -10 | -2 | - 35 | - 4,903 | 122 |
| Domestic emissions | 1,160 | -10 | -9 | -155 | - 21,360 | 185 |
| Brick (Bull's trench kilns) | 1,250 | -10 | -3 | - 57 | - 7,832 | 62 |

be used to differentiate fuel price according to quality.

- **Inspection and maintenance of vehicles**. Annual or biannual inspections are necessary to enforce clean vehicle standards. These can be carried out by government or private entities.
- **Clean vehicle emissions standard**: State-of-the-art emissions standards should be set for new gasoline cars, diesel vehicles, and motorcycles. Lead-free gasoline, a requirement for this standard, should be cheaper than leaded gasoline.
- **Cleaner fuel oil**: A reduction in the sulfur content of heavy fuel oil, initially to 2 percent.
- **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 emissions 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

It is crucial that a single coordinating institution with a clear mandate and sufficient resources be made responsible for air quality management. Kathmandu Valley presently lacks an ongoing air quality monitoring program. A comprehensive AQMS can only be designed on sound knowledge. In order to improve air quality data, it is recommended that there be continuous, long-term monitoring in two to five general city sites, one to three traffic exposed sites, and one to five industrial or hot spot sites. Further, an on-line data retrieval system directly linked to a laboratory database either via modem or telephone is recommended for modern surveillance.

The determination of population exposure in Kathmandu Valley is based upon a combination of dispersion modeling and pollution measurements. To improve the population exposure calculations beyond what has been developed as part of the first phase of URBAIR for Kathmandu Valley, it is necessary to:

- establish dispersion models for the Valley capable of dealing with the complex topographical/temperature/dispersion conditions, in particular dispersion from roads, and
- improve the input database to such a model, regarding hourly air pollution concentration data, hourly dispersion data, spatial resolution, and hourly emissions data.

Prior to 1994, there were no laws pertaining specifically to pollution. An Environmental Protection Council has now been established, together with an Environmental Protection Division that functions within the National Planning Commission. Laws on vehicle pollution control have been proposed according to the recommendations from the Kathmandu Valley Vehicle Emission Control Project (KVVECP). Standards or guidelines for ambient air quality have not yet been passed. The basis for controlling air pollution in Kathmandu Valley needs to be further developed.

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

# 1. BACKGROUND INFORMATION

## 1.1. SCOPE OF THE STUDY

This report on air quality management for the Kathmandu Valley was produced as part of Urban Air Quality Management Strategy in Asia (URBAIR) program. The major objective of URBAIR is to develop Air Quality Management Strategies (AQMS) and action plans for improving air quality in Asia's cities.

The 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 reduction in the estimated costs of health damage resulting from air pollution. This study emphasizes the damage done to the health of those who are exposed to air pollution. Population exposure is based on measured and calculated concentrations of air pollutants, through emissions inventories and dispersion modeling.

A general strategy for air quality management is described in the *URBAIR Guidebook on Air Quality Management Strategies*, published by the World Bank's Metropolitan Environmental Improvement Program. Reports based on city-specific analysis have been produced for four URBAIR/MEIP cities: Jakarta, Greater Mumbai (Bombay), Metro Manila, and the Kathmandu Valley urban area. These four reports outline action plans for air quality improvement, including estimated costs and benefits. Action plans are based on comprehensive lists of proposed measures and actions developed by local working groups, in consultation with outside experts.

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

## 1.2. GENERAL DESCRIPTION OF KATHMANDU VALLEY AND THE AIR POLLUTION SITUATION

Kathmandu Valley is the administrative, trade and educational center of Nepal, as well as the hub of communications. This densely populated urban area is made up of Kathmandu and Patan. The Bagmati River runs east-west between the two centers. The Tribhuvan International Airport lies just east of this area, which is approximately 7 kilometers in diameter. Villages and housing are scattered outside this area, and the city Bhaktapur is located about 10 kilometers east of Kathmandu City.

Figure 1.1 shows the locations of various cities and industrial zones in Kathmandu Valley. Dispersion modeling and population exposure studies were conducted for the area demarcated in this figure. As can be seen, it covers most of the Valley.

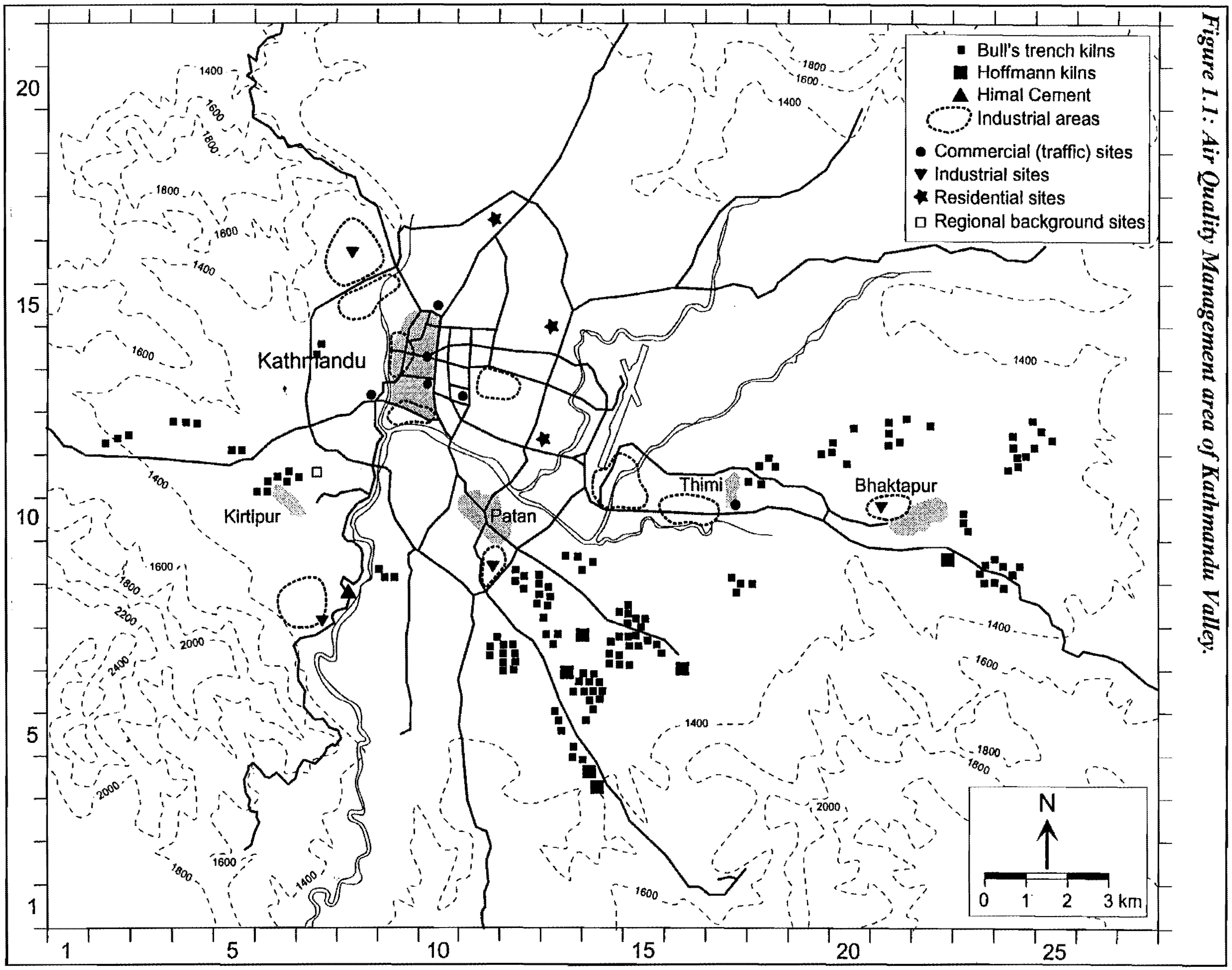



*Figure 1.1: Air Quality Management area of Kathmandu Valley.*

While agricultural activities dominate, substantial parts of the flat valley floor are used for brick production. There are more than a hundred brick production facilities in the Valley, many of them situated in areas immediately south and east of Kathmandu City, within 5 to 10 kilometers of the city's center. Coal and other energy sources are used to fire bricks in these industries, creating significant air polluting emissions.

Road traffic is also an important source of air pollution because of exhaust emissions, and the resuspension of particles from dust and refuse on the roads. A substantial portion of the vehicle fleet is in poor condition, overloaded and produces large amounts of visible emissions. Road traffic is quite dense from the city center to the ring road, about 3 kilometers from the center.

A cement plant is situated on the banks of the Bagmati river, about 6 kilometers south of the city center. The emissions from this plant affect the air quality in its neighborhood and may contribute to overall air pollution in the city, especially when there are southerly winds during the monsoon season. Domestic emissions from cooking, heating, and refuse burning also contribute to the pollution. In Kathmandu, kerosene and wood are the primary sources of cooking fuel.

Kathmandu Valley forms a basin that is approximately 30 by 30 kilometers. It is surrounded by hills that rise 500 to 1,000 meters above the valley floor (approximately 1,300 meters above sea level). Hills completely surround the valley, with the exception of one narrow outlet in the southwest where the Bagmati river flows out of the valley. This bowl-like topography, and generally low wind speeds during the dry (winter) season create poor dispersion conditions, predisposing Kathmandu Valley to serious air pollution problems. Growing populations and an accompanying increase in pollution-generating activities have resulted in a substantial rise in air pollution concentrations in the valley, particularly in the last decade (see Appendix 1 and 2 for details).

## 1.3. DATA SOURCES

### *1.3.1. Previous studies*

There have been no comprehensive studies that describe air quality, pollution sources, emissions and population exposure in Kathmandu Valley. The following publications provided important background information for this report.

- Surendra Raj Devkota (1992) Energy Utilization and Air Pollution in Kathmandu Valley, MS Thesis.
- Study of Kathmandu Valley Urban Road Development by Japan International Cooperation Agency (JICA, 1992).
- Ram M. Shrestha and Sunil Malla (1993) Energy Use and Emission of Air Pollutants: Case of Kathmandu Valley, Asian Institute of Technology, Bangkok.
- H.B. Mathur (1993) Final Report on the Kathmandu Valley Vehicular Emission Control Project (KVVECP), HMG/UNDP.
- Nepal Environmental and Scientific Services (1995) Assessment of the Applicability of Indian Cleaner Technology for Small Scale Brick Kiln Industries of Kathmandu Valley, Thapathali, Kathmandu.

Presentations at the first URBAIR workshop in Kathmandu also provided review data on the meteorological conditions (M.L. Shrestha), as well as on industrial and traffic pollution sources in the Valley (M.D. Bhattarai, S. Thapa et al.).

United States Agency for International Development (USAID) funded a study on vehicle emission measurements in Asia, using a remote sensing (FEAT) technique. Such measurements were also made in Kathmandu, providing useful data (Steadman and Ellis, 1993). A joint UNDP/World Bank Energy Efficiency and Fuel Substitution Study (World Bank, 1993) evaluated options for rationalizing energy use in Nepal, with the aim of developing a coherent strategy for the National Industrial Energy Management Program (NIEMP).

### *1.3.2. URBAIR data collection*

The following local consultants provided additional data.

- RONAST provided data on population, pollution sources, fuel use, vehicle and traffic statistics, air quality measurements, air quality laws and regulations, and institutions dealing with air pollution. RONAST also generated new traffic data by counting rush hour traffic at 33 locations.
- Dr. Madan L. Shrestha collected meteorological and visibility data, and evaluated the dispersion and visibility conditions of the Valley .
- Dr. Bimala Shrestha conducted an assessment of the health effects of air pollution, and estimated the costs related to health damage.

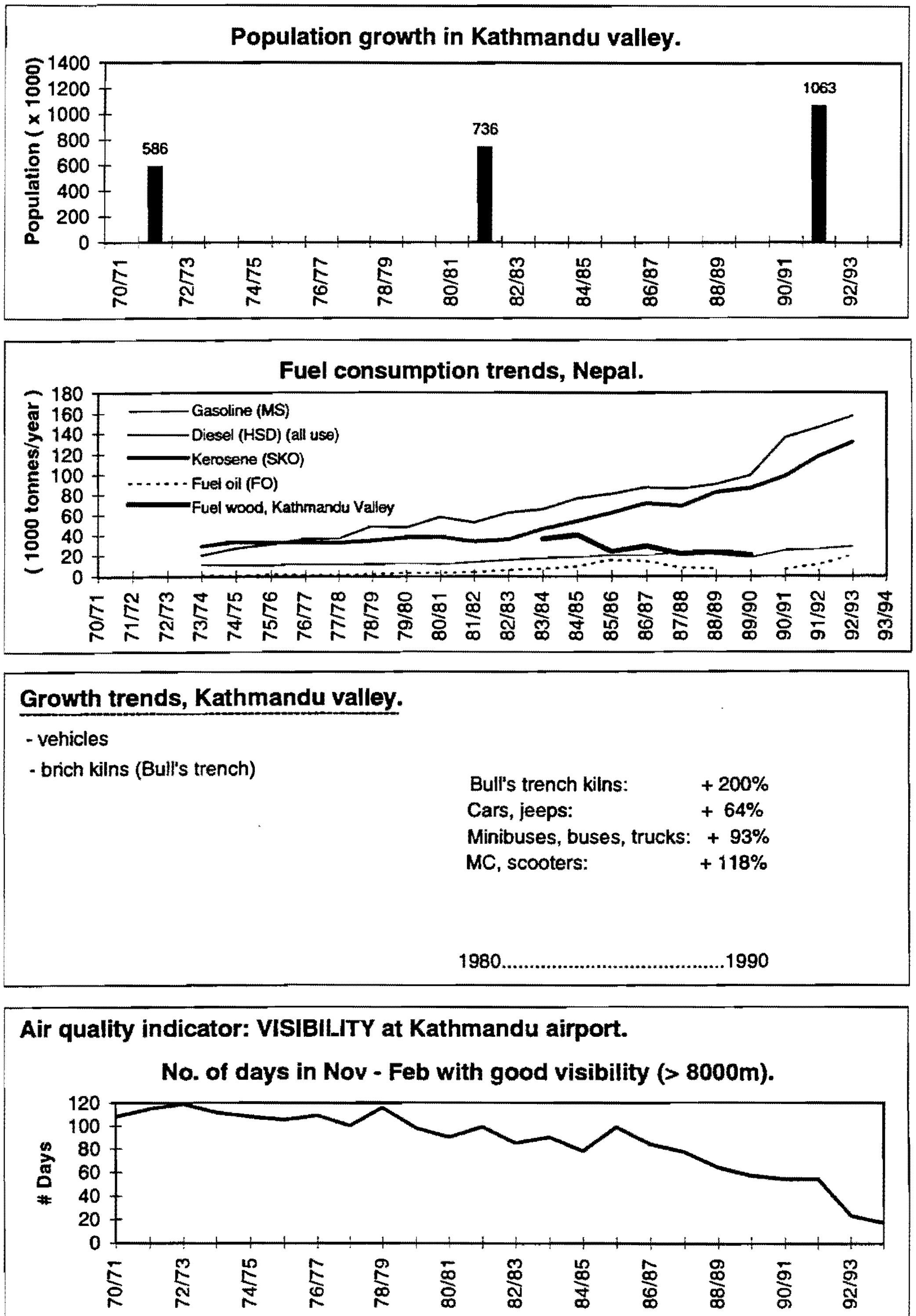
## 1.4. SUMMARY OF DEVELOPMENT IN THE KATHMANDU VALLEY

Figure 1.2 provides a summary of population, fuel consumption, vehicles, brick kiln development, and visibility data in Kathmandu Valley (and Nepal) over the past 20 years. Kathmandu Valley's population grew by 81 percent from 1971 to 1991. In 1991, 56 percent of the population was urban. There has been an average annual increase of 0.5 percent in gross domestic product (GDP) per capita between 1965 and 1990. However, the GDP/capita was very low--US$170 in 1990. This has not impacted the development of transport in the region; the number of registered road vehicles has almost doubled in the last decade. Registered brick kilns have grown by 200 percent over this period.

Liquid fuel consumption, for Nepal as a whole, has increased dramatically since 1980. The consumption of gasoline and motor diesel (HSD) has increased 150 percent. Kerosene use is 250 percent higher, and fuel oil use is 580 percent higher. Fuel wood consumption appears to be declining by 20 percent from 1984 to 1987 (Devkota, 1992), having been replaced by kerosene (SKO) to a large extent.

These growth trends have caused an acute air pollution problem in the Valley, as exemplified by the observed deterioration in visibility conditions. In the four-month period between November and February, the months with lowest visibility, the number of days with fairly good visibility (greater than 8,000 meters at 11:45 local time) has decreased from 115 days in early 1970s to only about 20 days in 1992/93.

*Figure 1.2: Development and growth trends over the last two decades, Kathmandu Valley.*



## 1.5. POPULATION

Available population data for 1971, 1981 and 1991 are shown in Table 1.1 (JICA, 1992). In the Valley as a whole, the growth rate has been 3.7 percent per annum.

***Table 1.1: Population data (thousands), Kathmandu Valley (JICA, 1992).***

| | Kathmandu district | Lalitpur district | Bhaktapur district | Total Population |
|---|---|---|---|---|
| 1971 | 354 | 122 | 110 | 586 |
| 1981 | 427 | 165 | 144 | 736 |
| 1991 | 668 | 222 | 736 | 1,063 |
| | (62% urban) | (53% urban) | (35% urban) | (56% urban) |
| | | Growth rate % | | |
| 1971-81 | 1.9 | 3.1 | 2.7 | 2.3 |
| 1981-91 | 4.6 | 3.0 | 1.8 | 3.7 |

## 1.6. FUEL CONSUMPTION

Data are not available for every category of fuel consumed in the Kathmandu Valley. Motor diesel (HSD) and kerosene (SKO) by volume are the most used liquid fuels in Nepal, followed by gasoline (MS) and fuel oil (FO). Liquid fuel consumption totals are given in Table 1.2.

***Table 1.2: Liquid fuel consumption ($10^3$ kl/yr), Nepal (Gautam, 1994).***

| Years | Gasoline MS | Motor diesel HSD | Kerosene SKO | Light diesel oil LDO | Aviation fuel | Fuel oil FO | LPG |
|---|---|---|---|---|---|---|---|
| 1975/76 | 10.5 | 30.8 | 32.2 | 9.4 | 11.2 | 1.8 | 0.6 |
| 1980/81 | 11.5 | 57.3 | 37.8 | 10.3 | 16.8 | 3.0 | 0.7 |
| 1985/86 | 20.4 | 80.4 | 62.2 | 8.3 | 23.2 | 15.8 | 2.6 |
| 1990/91 | 24.6 | 135.6 | 97.7 | 3.0 | 19.0 | 6.3 | 7.4 |
| 1992/93 | 28.3 | 156.9 | 131.1 | 0.3 | 28.1 | 20.3 | ? |
| Change (%) 1980-93 | +146 | +174 | +247 | ~-100 | +67.3 | +576 | » |

The quality of liquid fuel is governed by established specifications. Maximum allowed sulfur contents are: 4 percent in fuel oil, 1 percent in motor diesel, and 0.2 percent in 93-octane gasoline. Maximum lead content is 0.56 g/l in 83-octane gasoline, and 0.80 g/l in 93-octane gasoline. The actual contents of sulfur and lead are not known, and may be considerably less than the maximum allowed.

Fuelwood consumption data for Kathmandu Valley is given in Table 1.3. Because of diminishing resources, fuelwood consumption has declined by close to a factor of 2 between 1983 and 1990. Increased use of kerosene and agricultural waste has replaced fuelwood as the major domestic fuel.

Coal has replaced fuelwood in the brick industry. In the early 1980s, fuelwood and coal were almost equally used in the local brick industry, now the ratio between

***Table 1.3: Fuelwood consumption, Kathmandu Valley (Devkota, 1992).***

| Year | $10^3$ t/yr | Year | $10^3$ t/yr |
|---|---|---|---|
| 1983/84 | 35.9 | 1987/1888 | 21.2 |
| 1984/85 | 40.0 | 1988/1989 | 23.7 |
| 1985/86 | 23.7 | 1989/1990 | 20.0 |
| 1986/87 | 29.0 | | |

coal and fuelwood consumption is about 7 to 1 (NESS, 1995).

Brick and cement industries use mainly coal. Table 1.4 shows the available data on coal consumption. In the Hoffman kilns, coal consumption is somewhat lower than it was in 1970. In the Himal Cement Factory, coal consumption has increased dramatically from 1990/91 to 1992/93. The dominant coal consumer in the Valley is the Bull's trench kiln industry. Shrestha and Malla's estimate for 1992/93 appears to underestimate consumption. Although data for past coal consumption in the Bull's trench kilns are not available, coal consumption has most likely increased substantially, especially since it has almost completely replaced fuelwood.

***Table 1.4: Coal consumption in the brick and cement industries, Kathmandu Valley (tons/yr).***

| | Bull's trench* kilns | Chinese** (Hoffman) kilns | Himal Cement** factory | Total# |
|---|---|---|---|---|
| 1970/71 | | 3,300 | | |
| 1975/76 | | 2,950 | | |
| 1980/81 | | 1,690 | 6,400 | |
| 1985/86 | | 2,200 | 5,860 | |
| 1990/91 | | 2,440 | 7,980 | |
| 1992/93 | 21,000 | 4,100 | 17,100 | 47000 |
| 1993 | 43,800 | | | |
| 1994 | 54,800 | | | |

Sources: * NESS, 1995
** Devkota, 1992 # Shrestha and Malla, 1993

## 1.7. INDUSTRIAL DEVELOPMENT

Industrial growth has been very strong in Kathmandu Valley, especially in the last decade. In 1991/92, there were approximately 2,200 industrial establishments with more than 10 employees as compared with 1,504 industries in 1986/87.

Brick and cement industries are the main industrial polluters. The number of registered Bull's trench kilns has increased markedly from 102 in 1984 to 305 in 1993. The rise in the number of smaller industries represents an increase in the combustion of such fuels as fuel oil, HSD and agricultural refuse, as well as some process emissions. The exact amount of increase in such industrial combustion and process emissions is not known. It is believed to have less significance for general air pollution than the brick and cement industries, but it has led to increased pollution exposure.

## 1.8. ROAD VEHICLE FLEET

In 1993, there were an estimated 67,000 registered vehicles in Kathmandu Valley (see Appendix 3 for more details). These included:

- 22,000 cars/jeeps (21 per 1,000 inhabitants);
- 36,000 motorcycles (34 per 1,000 inhabitants);
- 5,000 trucks/buses.

Specific vehicle fleet data are not presented for previous years. The KVVECP study reported a 64 percent increase in registered car/jeeps from 1980 to 1990; 118 percent increase for motorcycles, and 93 percent increase for buses and trucks.

# 2. AIR QUALITY ASSESSMENT

This chapter provides estimates of the population's exposure to area air pollutants, and quantifies the contributions of different pollution sources to this exposure. Population exposure is estimated by:

- describing existing air pollution concentration measurements, and their variation in time and space;
- making an inventory of air pollution sources, and their relative contributions;
- calculating concentration distributions in the area, using dispersion modeling; and
- calculating population exposure by combining spatial distributions of population and concentrations, and incorporating the exposure on and near roads, and in industrial areas.

National air quality standards or guidelines have not yet been proposed for Nepal. In this study the World Health Organization air quality guidelines (WHO AQG) are used to evaluate the air quality in Kathmandu.

## 2.1. AIR POLLUTION CONCENTRATIONS

**Overview of air pollution measurements, and observations.** Non-scientific observations, especially in the dry season, indicate the following significant air pollution problems:

- very high roadside air pollution, especially particles and odor, due to high emission vehicles of all types, and resuspension of street dust and litter;
- black smoke plumes from brick kilns;
- generally low visibility, especially before noon, and
- one large point source, the cement factory, has highly visible particle emissions

The air pollution concentrations have only recently been directly measured. The shortness of measurement periods at each site limits the accuracy of the measurements. The study, however, does provide a picture of the variation in space and time. In 1993, measurements were taken in the Environment and Public Health Organization (ENPHO) study (Karmacharya et al., 1993), the KVVECP study (Devkota, 1993), by the Hydrological and Meteorological Services (HMS) (Shrestha, 1994), and by NESS (1994).

- ENPHO study measured TSP, $PM_{10}$, $SO_2$, $NO_x$, CO and Pb in November 1992 and February 1993, at 20 sites.
- KVVECP study measured TSP, $PM_{10}$, $SO_2$, $NO_2$ from September to December 1993; a total of 14 sites (traffic, industrial, residential, background) were involved with 4 to 22 days of measurements at each site. Some CO measurements were also made. Locations of the various monitoring stations in the KVVECP study are shown in Table 2.1.
- HMS measured TSP at the HMS Building, Babar Mahal, from January-August 1993, for 10-31 days of measurement each month.

*Table 2.1: Ambient Air Quality Monitoring Stations in the KVVECP study.*

| Category | Locations | Distance from main road *(m)* | Height of the station *(m)* |
|---|---|---|---|
| 1. Commercial Areas: | | | |
| i. Heavy traffic (30,000-40,000 ADT) | Singha Durbar, | 2 | 3 |
| | GPO | 3 | 3 |
| ii. Medium traffic (20,000-30,000 ADT) | Ratnapark, | 4 | 3 |
| | Lainchaur, | 2 | 2.5 |
| | Kalimati | 3 | 3 |
| iii. Low traffic (<7,000 ADT) | Thimi (NTC) | 2 | 2.5 |
| 2. Residential Areas | Maharajgunj (TUTH), | 30 | 3 |
| | Naya Baneswor, | 20 | 7 |
| | Jaya Bageshwori | 15 | 8 |
| 3. Industrial Areas | Balaju, | 15 | 4 |
| | Bhaktapur, | 50 | 3 |
| | Patan Industrialized districts, | 5 | 5 |
| | Himal Cement Factory surrounding | 100 | 10 |
| 4. Regional background/control site | Tribhuvan University Kirtipur | 50 | 3 |

ADT: Average Daily Traffic

- NESS (Pvt) Ltd measured $PM_{10}$ and Pb in air, and Pb in road dust; samples were taken at a total of 19 sites from September to November, 1993.
- Visibility observations have been made at the Kathmandu Airport since 1969, through hourly observations of meteorological visibility.

These observations and measurements indicate that suspended particles are the primary air pollution problem in the Valley, leading both to potential health risks, and to visibility deterioration. According to the measurements of $SO_2$ and $NO_2$, these compounds seem to represent little risk at present. The CO concentrations can be fairly high at rush hours along the roads with the heaviest traffic.

In Appendix 1, the analysis and evaluation of the results of these air quality measurements and observations have been summarized. An extract of that summary follows.

### 2.1.1. *Air pollution concentrations.*

The following WHO AQG for TSP, $PM_{10}$, and $SO_2$ are used in Nepal (Table 2.2).

**TSP concentrations**. TSP concentrations measured by ENPHO, KVVECP, and HMS show that the WHO AQG for daily averages (150-230 μg/m³) are substantially exceeded both in heavily traveled and residential areas. In addition, the guideline for the annual average (60-90 μg/m³) is also exceeded. Results of TSP measurements, both average and maximum, are shown in Figures 2.1 and

*Table 2.2: Applicable WHO AQG for TSP, $PM_{10}$, and $SO_2$ in Kathmandu*

| | TSP (μg/m³) | $PM_{10}$ (μg/m³) | SO2 (μg/m³) |
|---|---|---|---|
| Long-term (annual average): | 60 - 90 | - | - |
| Short-term (24-hour average): | 150 - 230 | 70 | 100-150 |

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

**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.

2.2 (average and maximum concentrations).

The maximum 24-hour concentrations of TSP measured, 467 μg/m³ at the Babar Mahal building, and 319-876 μg/m³ at traffic exposed sites in the KVVECP study, were more than twice the upper level of the 24-hour WHO AQG. In addition, daily TSP guidelines were exceeded on the majority of days at Babar Mahal. TSP ranged between the following values for the different sites of the KVVECP study (near ground level):

- Traffic sites: 319-876 μg/m³
- Residential sites: 273-350 μg/m³
- Industrial sites: 102-290 μg/m³
- Near Himal Cement Factory: 560 μg/m³
- Tribhuvan University (reg. background): 155 μg/m³

The KVVECP measurements were made from September to December of 1993. Had they been taken in the winter, measurements would have shown higher maximum concentrations.

The ENPHO measurements showed a maximum of 555 μg/m³ and an average of 308 μg/m³ at 9 sites representing Central Kathmandu City air. At the 11 roadside sites, the measurements showed TSP maximum of 2,258 μg/m³ and average of 1,397 μg/m³. These values are based on a 9-hour average and only one sample was taken at each site. The 2,258 μg/m³ maximum in the ENPHO measurements represents an estimated 24-hour average value of about 1,100 μg/m³.

HMS measurements indicate an annual average concentration around 180 μg/m³ at Babar Mahal, 15 meters above ground level. This is more than twice the WHO AQG. At more exposed sites, such as heavily trafficked areas and around the Himal Cement Factory, the annual average would be much higher. At KVVECP stations, the WHO AQG values of 150-230 μg/m³ are exceeded by 70 percent for the lower limit, and by 50 percent for the higher limit. No measurements have been taken in the brick kiln areas. However, the high concentrations at Thimi may be partly the result of contributions from the brick kiln emissions.

These measurements point to a severe TSP pollution problem in the Kathmandu Valley, and in Kathmandu City in particular.

***Figure 2.1: Summary of TSP measurements, Babar Mahal Building. (Ref.: Shrestha, 1995.)***

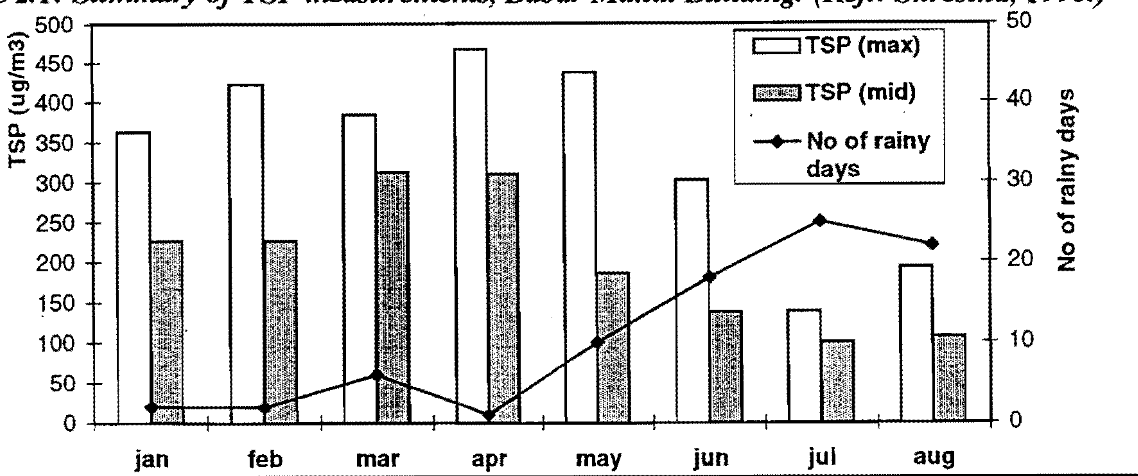
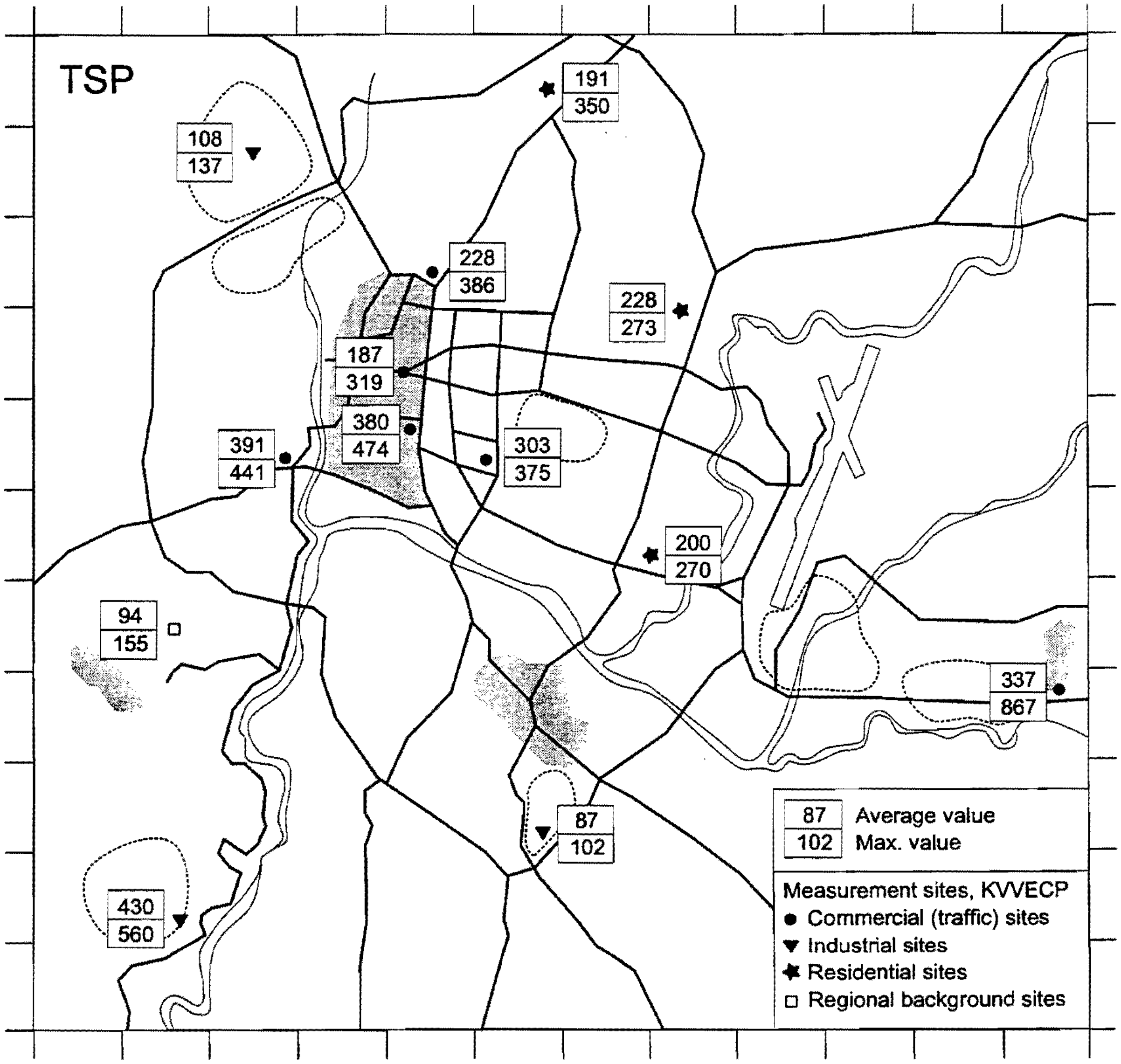
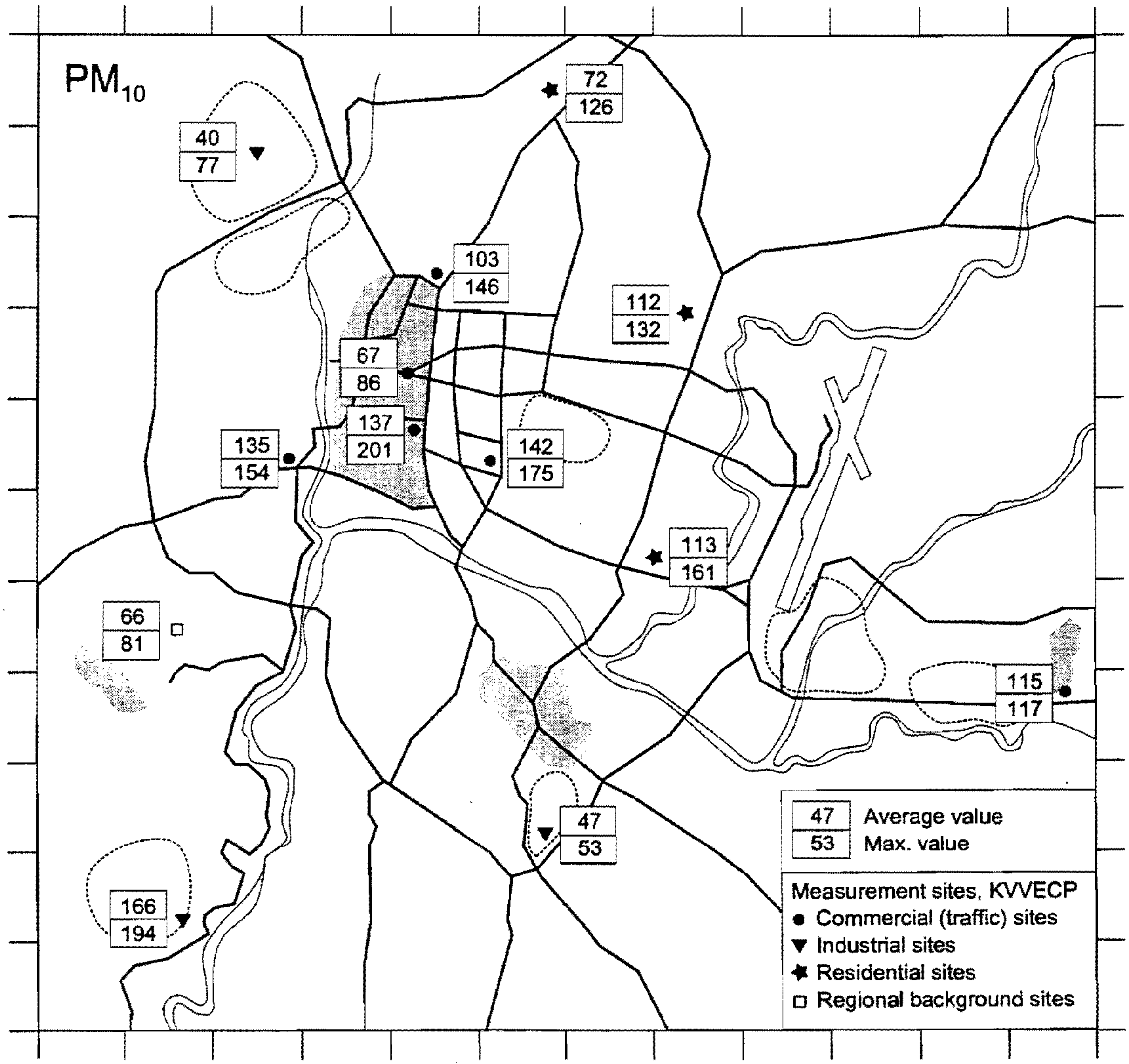


*Figure 2.2: Results of TSP measurements, KVVECP study September-December, 1993. (Relatively short measurement periods at each site.) (Ref.: Devkota, 1993.)*




**$PM_{10}$ concentrations.** $PM_{10}$ has been measured by ENPHO, KVVECP, and NESS. The results of the KVVECP measurements are shown in Figure 2.3. $PM_{10}$ concentrations were above the recommended WHO AQG (70 μg/m³) on all the days on which concentrations were measured. The exception were the Balaju and Patan industrial sites, which had the lowest TSP and $PM_{10}$ levels, Ratnapark traffic site and at Tribhuvan University. At the University site, $PM_{10}$ was above the AQG on about half the days. The low values at Balaju and Patan are not representative, since measurements were made only for a few days in September.

*Figure 2.3: Results of $PM_{10}$ measurements, KVVECP study September-December, 1993. (Relatively short measurement periods at each site.) (Ref.: Devkota, 1993.)*




The highest $PM_{10}$ concentrations were 201 µg/m³ in November at the General Post Office, which is the site of heavy traffic and 194 µg/m³ at the Himal Cement Plant site in December. About 50 percent of all the measurements in the KVVECP study were above the recommended guideline.

The ENPHO measurements of $PM_{10}$ in Kathmandu City gave an average concentration of 89 µg/m³, and a maximum concentration of 127 µg/m³ at the general sites. The roadside sites were higher with an average concentration of 296 µg/m³, and a maximum of 498 µg/m³ (9-hour average values). ENHPO results support the results of the KVVECP study.

$PM_{10}$ measurements taken by NESS, representing one 1-hour average samples during daytime at 9 sites, gave values up to 2,100 µg/m³ with an average of 800 µg/m³. These are much higher than both ENHPO and KVVECP measurements. Reasons for the apparent discrepancies between these results and those from the ENPHO and KVVECP studies may be found when comparing the different samplers and laboratories used.

The ratios between measured $PM_{10}$ and TSP are given in Table 2.3. The ratio 0.70 is in the range typically found at sites that are not exposed to a high degree of resuspension. The low $PM_{10}$ ratio for the sites (0.4-0.5) indicates that the resuspension pollution is high. In the case of the Himal Cement site, the size distribution of cement factory emissions dominates the low ratio found there.

***Table 2.3: Ratios between $PM_{10}$ and TSP, from KVVECP and ENPHO measurements.***

| | Based on | |
|---|---|---|
| | **Average concentration** | **Max. concentration** |
| KVVECP | | |
| Traffic sites | 0.39 | 0.34 |
| Residential sites | 0.48 | 0.48 |
| Industrial sites | 0.47 | 0.51 |
| Himal Cement site | 0.39 | 0.35 |
| Tribhuvan Univ. (Background site) | 0.70 | 0.52 |
| ENPHO | | |
| Traffic sites | 0.21 | 0.18-0.25 |
| General sites | 0.29 | 0.23 |

**$SO_2$ concentrations.** Results from the KVVECP measurements in Figure 2.4 indicate that $SO_2$ concentrations from September-December 1993 were low. Kalimati (traffic site) and Jaya Bageshwori (residential) are the exception. At these sites $SO_2$ concentrations were above the guideline (100-150 µg/m³) on several days, and the maximum concentration was 225 µg/m³. KVVECP measurements indicate that although $SO_2$ concentrations are not generally a problem in Kathmandu, area and point sources may create high local concentrations. No measurements have been made in areas exposed to brick kiln emissions.

**$NO_2$ concentrations.** KVVECP measurements shown in Figure 2.5 indicate that $NO_2$ concentrations were generally low, and well below the 24-hour WHO AQG (150 µg/m³). The Jaya Bageshwori site had elevated $NO_2$ and $SO_2$ concentrations, pointing to a local source.

*Figure 2.4: Results of $SO_2$ measurements, KVVECP study September-December, 1993. (Relatively short measurement periods at each site.) (Ref.: Devkota, 1993.)*

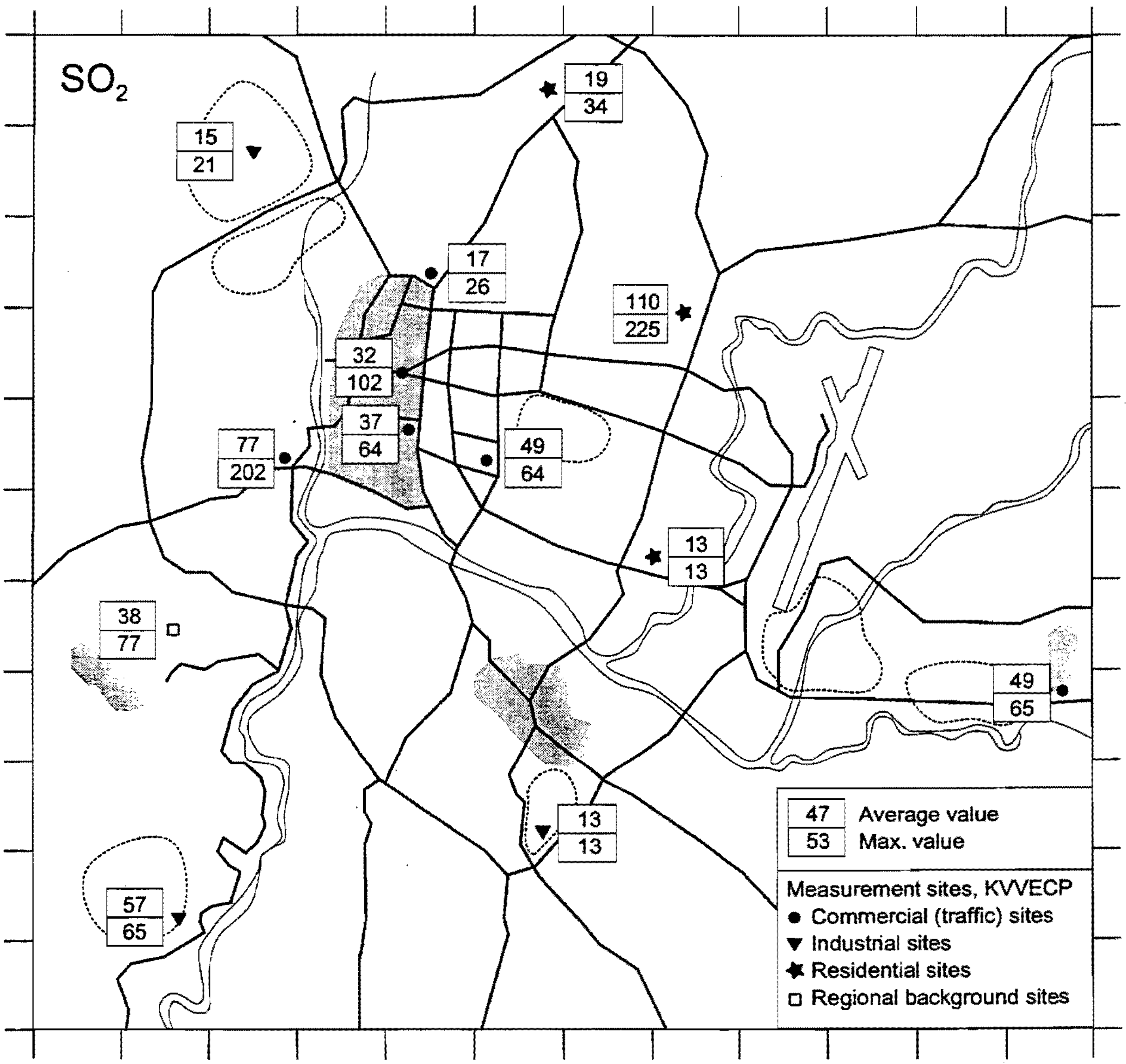


*Figure 2.5: Results of $NO_2$ measurements, KVVECP study September-December, 1993. (Relatively short measurement periods at each site.) (Ref.: Devkota, 1993.)*

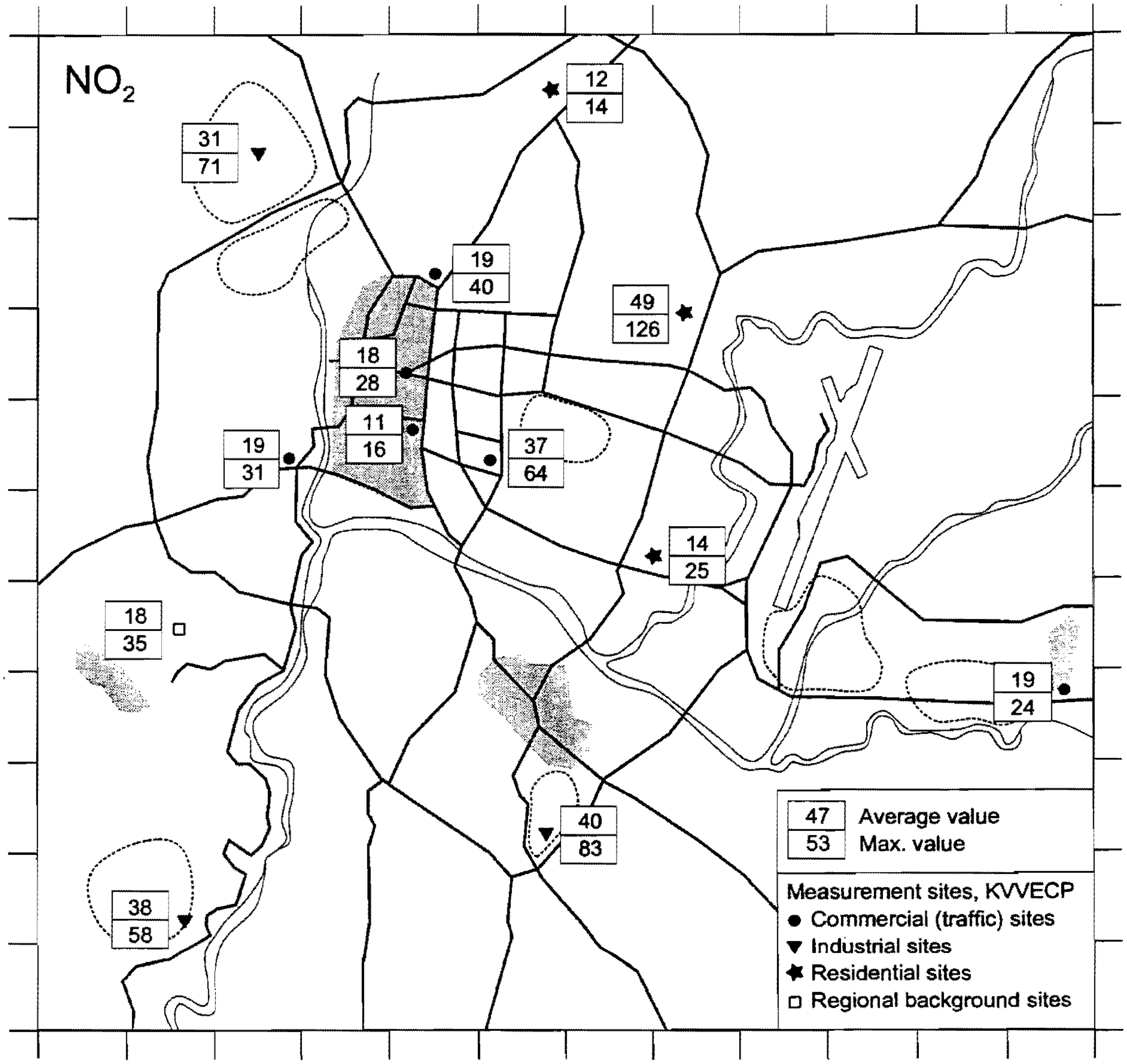
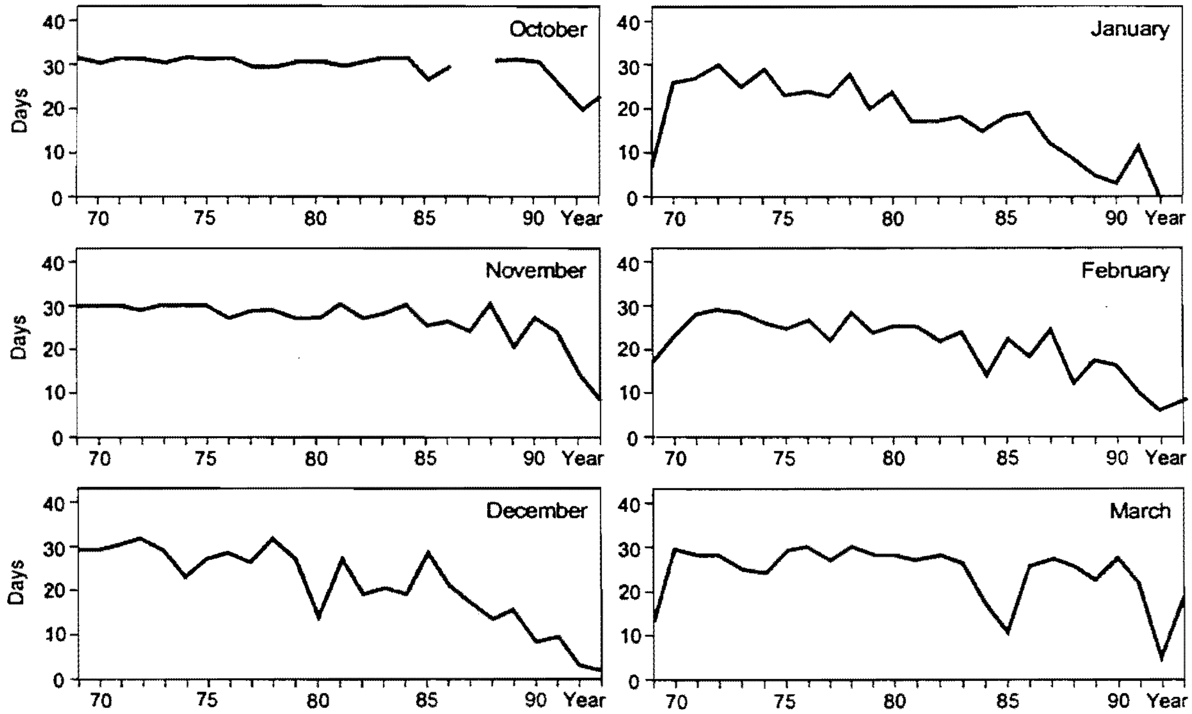


*Figure 2.6: No. of days in Kathmandu Valley with fair-to-good visibility (>8,000 m) in the winter months. (Ref. M.L. Shrestha, 1995).*




**Visibility**[1]**.** Observations point to a clear decline in visibility in Kathmandu Valley in the dry season (November-March), especially beginning in 1980. In the monsoon season, visibility appears to be unaffected. Figure 2.6 shows the number of days in the winter months with fair-to-good visibility of greater than 8,000 meters at noon. Before 1980, this was the case on most days. Presently, there are very few days that have good visibility at noon.Figure 2.7 shows the number of foggy mornings (around 9:00 a.m.). This has increased from 35-40 days around 1970, to more than 60 in 1993.

The nature of the "lifting" of the morning fog is visualized in Figure 2.8. In the relatively unpolluted air of the early 1970s this normally took place before 10 a.m. Fog dispersal is now typically delayed for 3 hours, and on hazy days, good visibility only occurs after 1:00 p.m. or 2:00 p.m. On some days the haze never lifts.

[1] Madan L. Shrestha (1994) analysis of visibility data from the Kathmandu Airport for 1963-1993 is summarized in Appendix 1.

Visibility reduction is mainly caused by particles (aerosol) of the size range comparable to the wavelength of light, e.g. 0.2-0.5 μm diameter. These are combustion aerosols from sources such as cars (diesel and gasoline), coal, fuelwood, and agricultural residue combustion. This aerosol contains hygroscopic particles, such as particles containing sulfate ($SO_4$), condensed organic compounds, etc. Thus, the morning fog is caused by water vapor absorbed in the hygroscopic aerosol. As the temperature rises, the water vapor evaporates. In the afternoon, the still-reduced visibility is caused by the dry aerosol which remains in the air.

***Figure 2.7: No. of foggy days at 9 a.m., Kathmandu Valley, 1969-93. (Ref.: M.L. Shrestha, 1995).***

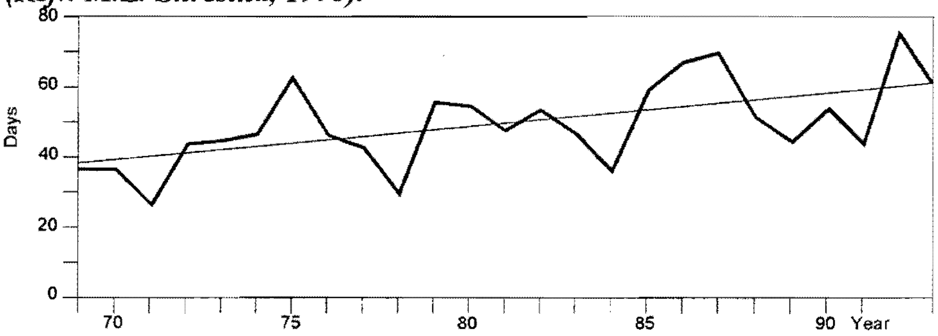
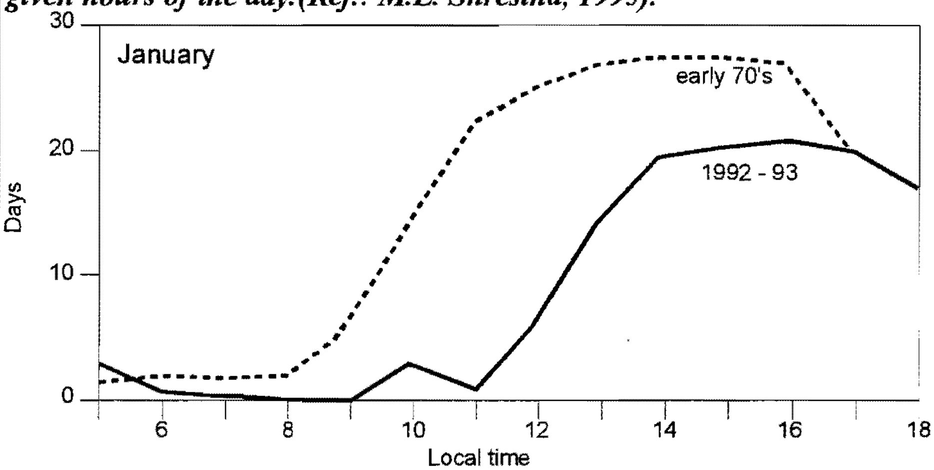



***Figure 2.8: No. of days in January with good visibility (>8,000 m) at given hours of the day.(Ref.: M.L. Shrestha, 1995).***




The relative humidity in Kathmandu Valley is on average over 70 percent throughout the day in the monsoon period (June-September). Even so, day-time visibility is not reduced in these months, indicating that the concentration of hygroscopic aerosol is rather low in the monsoon season.

In the winter months, the relative humidity falls below 70 percent between 9:00 to 10:00 a.m.. However, visibility is reduced throughout the morning. It improves gradually until 12:00 to 1.00 p.m. at which time the relative humidity has declined to about 50 percent. This corresponds to the situation in which a typical urban aerosol absorbs water vapor gradually from a relative humidity of 30-40 percent. Sulfate particles have a deliquescence point of 72 percent, which means that the relative humidity must approach 72 percent before such particles grow substantially and cause visibility reduction. Therefore sulfate particles may be a part of the visibility-reducing aerosol, but other types of aerosol, e.g. organic aerosol, make important contributions.

## 2.2. AIR POLLUTANT EMISSIONS IN KATHMANDU VALLEY

**Total emissions.** An emissions inventory covering all source categories has been compiled for the Kathmandu Valley. It contains emission data for TSP, $PM_{10}$ and $SO_2$. Details of the emissions inventory development are described in Appendix 4. Calculated and estimated total emissions are presented in Table 2.4. They are based on the emission factor data in Table 2.5, and the fuel consumption and traffic activity data in Table 2.6.

The inventory covers main source categories. The emissions from road vehicles are relatively reliable and are based on fuel consumption, traffic activity and emission factors. Emissions from industrial and commercial activities, other than brick combustion, are based on figures and emission factors provided by Shrestha and Malla (1993). Emissions from Bull's trench brick kilns have been estimated by NESS (1995). Chinese kiln emissions are based on coal consumption and on estimated emission factors. Himal Cement factory has provided numbers on emissions from the factory (Bhattarai, 1993).

***Table 2.4: Total annual emissions in Kathmandu Valley, 1993 (tons/yr).***

| | | | TSP | $PM_{10}$ | $SO_2$ |
|---|---|---|---|---|---|
| **Transport sector** | | | | | |
| ***Vehicles exhaust*** | | | | | |
| Gasoline | Cars/taxis | | 38.4 | - | |
| | TC | | 67.5 | - | 4.2-105[1] |
| | MC | | 107.5 | - | |
| Diesel | Jeeps | | 68.4 | - | |
| | Minibuses | | 22.5 | - | |
| | Buses | | 45.0 | - | 78-390[1] |
| | Trucks | | 114 | - | |
| | Tractors | | 21.6 | - | |
| | TC | | 85.8 | - | |
| Sum vehicle exhaust | | | 570 | 570 | 82-495[1] |
| ***Sum Resuspension from roads*** | | | 1,530 | ~400 | 0 |
| **Energy/industry sector** | | | | | |
| ***Fuel combustion*** | | | | | |
| Industrial/commercial (excl. brick/cement) | | | | | |
| | Fuelwood | | 61.9 | 31 | |
| | Coal | | 48.0 | 24 | 172 |
| | Charcoal | | 20.0 | 10 | |
| | HSD | | 1.8 | 2 | |
| | LDO/FO? | | | | |
| | Kerosene/LPG | | 0.1 | | |
| | Agri. residue | | 4,50.0 | 225 | |
| **Sum industrial/commercial** | | | **5,82.0** | **292** | |
| Domestic | Fuelwood | | 18,32.0 | 916 | |
| | Agri. residue | | 4,54.0 | 227 | |
| | Anim. waste | | 30.0 | 15 | |
| | Kerosene/LPG | | 2.3 | 2.3 | |
| | Charcoal | | 10.0 | 5 | |
| **Sum domestic** | | | **2328.0** | **1,165** | |
| ***Industrial processes*** | | | | | |
| ***Brick industry*** | | | | | |
| Bull's Trench | | | 5000 | 1,250 | 4.8-4465[2] |
| Chinese | | | 180 | 45 | |
| **Sum brick** | | | **5180** | **1,295** | |
| ***Himal Cement*** | | *Sum Stack* | **~2000** | **~400** | **615** |
| | | *Sum Diffuse dust* | **~4000** | **~400** | |
| **Other** | | | | | |
| **Sum Refuse burning** | | | **385** | **190** | |
| **Sum Construction** | | | **-** | **-** | |
| **Total** | | | **16,565** | **4,712** | |

1 High value: Based on max. allowable S content
Low value: Based on actual S content, according to IOC Ltd. certificate

2 NESS (1995): Estimates based on different methodologies.

*Table 2.5: Emission factors used for URBAIR study, Kathmandu Valley.*

| | TSP | | $PM_{10}$/ TSP | $SO_2$ | $NO_x$ | %S max. |
|---|---|---|---|---|---|---|
| **Fuel combustion (kg/t)** | | | | | | |
| Residual oil (FO) ind./comm. | 1.25S+0.38 | | 0.85 | 20-S[1] | 7 | 4 |
| Distillate oil (ind./comm.) | 0.28 | | 0.5 | 20-S | 2.84 | HSD: 1[4] |
| (HSD, LDO) (residential) | 0.36 → 1.6[2] | | 0.5 | 20-S | 2.6 | LDO: 1.8[5] |
| LPG (ind./dom.) | 0.06 | | 1.0 | 0.007 | 2.9 | 0.02 |
| Kerosene (dom.) | 0.06 | | 1.0 | 17-S | 2.5 | 0.25 |
| Natural gas (utility) | 0.061 | | 1.0 | 20-S | 11.3 · f | |
| (ind./dom) | 0.061 | | | 20-S | 2.5 | |
| Wood (dom.) | 15 | | 0.5 | 0.2-A | 1.4 | |
| Fuelwood (ind.) | 3.6 | | 0.5 | | | |
| Coal (dom./comm.) | 10 | | 0.5 | | | |
| Charcoal dom./comm. | 20 | | 0.5 | | | |
| Agri. residue | 10 | | 0.5 | | | |
| Anim. waste | 10 | | 0.5 | | | |
| Refuse burning, open | 37 | | 0.1 | 0.5-A | 3 | |
| **Road vehicles (g/km)** | **(A)** | **(B)** | | | | |
| Gasoline (Cars) | 0.2 | | 1 | | 2.7 | 83 Octane (RON) 0.25[3] |
| (MC/TC) | 0.5 | | 1 | | 0.07 | 93 Octane (RON) 0.20 |
| Diesel (Cars, jeeps, tractors) | 0.6 | 0.9 | 1 | | 1.4 | 1[4] |
| (Minibuses, tempos) | 0.9 | 1.5 | 1 | | 13 | |
| (Buses, trucks) | 2.0 | 3.0 | | | 13 | |

1) A: Ash content, in %; S: sulfur content, in %
2) Well → poorly maintained furnaces
3) Actual S content in 87 RON gasoline, according to IOC Ltd quality certificate: 0.009%
4) Actual S content, according to IOC Ltd quality certificate: 0.20%
5) Actual S content, according to IOC Ltd quality certificate: <1%
**(A)** Used for Manila, Jakarta, Bombay
**(B)** Proposed and used for Kathmandu Valley.

*Table 2.6: Fuel consumption and traffic activity data for Kathmandu Valley.*

| Emission source/ fuel type | Category | Fuel consumption | Traffic activity $10^6$ veh. km/yr | |
|---|---|---|---|---|
| **Vehicles** | | **kl/yr** | | |
| Cars | Gasoline | 28.015 | 192 | |
| Tempos (TC) | " | | 135 | |
| Motorcycles (MC) | " | | 215 | 542 subtotal |
| Jeeps | Diesel | 22.955 | 76 | |
| Minibuses/buses | " | | 30 | |
| Trucks | " | | 15 | |
| Tractors | " | | 38 | |
| Tempos | " | | 24 | 183 subtotal |
| | | | | 725 total |
| **Industry** | | **$10^3$ tons/yr** | | |
| Himal Cement | | | | |
| Bull's trench kilns | Coal/fuelwood/rice husk | 42/5.7/15.8 | | |
| Chinese kilns | Coal | 20 | | |
| **Other industry/commercial** | HSD/LDO | ?/? | | |
| | Coal/charcoal | 4.8/1.0 | | |
| | Wood/agricultural residue | 17.2/45 | | |
| | SKO/LPG | 1.0/? | | |
| **Domestic** | Wood/charcoal | 122/0.5 | | |
| | Agric. res./anim. waste | 45.4/3.0 | | |
| | SKO/LPG | 35/4 | | |
| **Refuse burning** | Refuse | 10 | | |

For resuspension from roads, a TSP emission factor of 2 g/km is used (the same as was used for Greater Mumbai and Manila). This emission factor is based upon USEPA data.

Data on fuel consumption and emission factors are often uncertain. The amount of open refuse burning, not for cooking purposes, is unknown. For Kathmandu the same estimate has been used as was used for Bombay: 1 kg of refuse burned per week, per household (some 200,000 households in Kathmandu Valley), with an emission factor of 37 g/kg (Economopoulos, 1993; Semb, 1985).

The source contributions in Table 2.7 are derived from estimated emissions given in Table 2.4.

The contributions to population exposure may differ substantially from the contributions to total emissions. This difference depends on the height of the emissions (ground level or high stack), the distance from the source to populated areas, and the dominating wind directions.

**TSP.** It is estimated that the total emissions are approximately 16,500 tons/year. The brick industry, domestic fuel combustion, and resuspension from roads are estimated to be the dominant sources for the Valley as a whole. Emissions from construction activities have not been estimated.

*Table 2.7: Source Contributions of TSP and $PM_{10}$.*

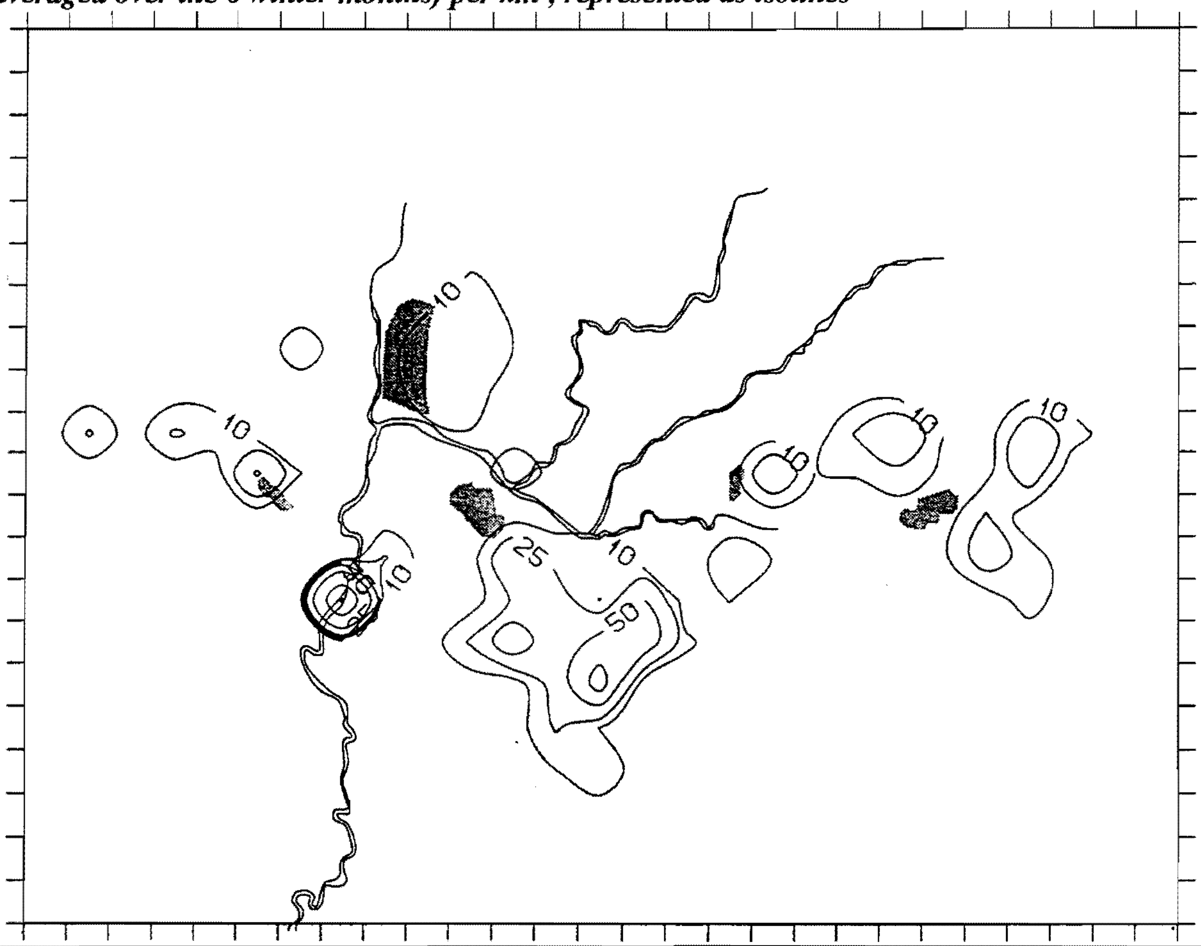
| Source category | Contribution % TSP | Contribution % $PM_{10}$ |
|---|---|---|
| Road vehicles | | |
| gasoline | 1.3 | 4.5 |
| diesel | 2.2 | 7.6 |
| Resuspension from roads | 9.3 | 8.5 |
| Domestic fuel combustion | 14.1 | 24.7 |
| Brick industry | 31.3 | 27.5 |
| Himal Cement | 36.2 | 17.0 |
| Other industry/commercial | 3.5 | 6.2 |
| Refuse burning | 3.2 | 4.0 |

**$PM_{10}$.** Total estimated emissions are some 4,700 tons/year. For $PM_{10}$, the main sources are the brick industry and domestic fuel combustion, followed by vehicles and road resuspension. Himal Cement Factory and other industrial/commercial activities are fairly equal contributors.

**Spatial distribution of emissions.** Total emissions have been distributed within the grid system based on the actual location of point sources, industrial areas, and road links, and the population distribution (as described in Appendix 4). The resulting emissions distribution, summed for all source categories, is shown in Figure 2.9, in the form of isolines. This distribution forms the input of the dispersion calculations.

The figure shows high emissions densities, particularly in Kathmandu City, due to a combination of vehicle exhaust, road resuspension, and domestic fuel combustion. High densities are also present in areas that have a concentration of brick kilns, west of Kathmandu and Southeast of Patan. The Himal Cement factory shows the maximum level in the distribution.

***Figure 2.9 Spatial emissions distribution in Kathmandu Valley, 1993. Total emissions (kg/h, averaged over the 6 winter months) per km$^2$, represented as isolines***



## 2.3. DISPERSION MODEL CALCULATIONS

### *2.3.1. General description of topography and climate*

Kathmandu Valley is located between the Himalayas in the North and the Mahabharat mountains in the South. Kathmandu City is located on a plain, about 1,325 meters above sea level and is surrounded by hills and mountains.

The Siwalik Mountains form the border between the Terai and Nepal's central region, and the valleys that run east-west of which Kathmandu Valley is the most important. The Bagmati river runs through the valley, and the river plain is covered with fertile river deposition. The Himalayan range rises north of the central valley, with Mount Everest peaking at 8,846 meters and several others above 8,000 meters. There are large height differences between the valleys and the mountains that surround them. The monsoon circulation determines the climate. In the lowest parts of the country, the climate is subtropical; at higher elevations one finds a cooler temperate climate; and in the high mountain ranges there are tundra and glacial climates.

The mean annual temperature in Kathmandu is 18° C. The coldest month is January with a mean temperature of 10° C. The warmest months are July and August, with an average temperature of 24° C.

Kathmandu has an annual rainfall of 1,400 mm. The wettest month is July with an average rainfall of about 370 mm. November and December are the driest months; the average rainfall is less than 6 mm.

High altitudes, combined with extreme diurnal radiation variations, lead to substantial differences between the day and night temperatures. The days are warm and there is rapid cooling at night. In the dry season, the cooling at night may cause the formation of deep inversion layers, with the air temperature increasing with height. When such an inversion layer is deep enough, it takes time for the insulation to break it up. The atmosphere then acts as a lid over the city, and pollution concentrations can build up considerably

### *2.3.2. Dispersion Conditions*

During the winter there is a build-up of a strong high pressure center over central Asia. In the northern parts towards the Himalayas, the prevailing winds come from northwest. In the spring the Asian high pressure weakens, and the northwest monsoon disappears. The summer monsoon is a continuation of the southeast monsoon from the southern hemisphere. After crossing the equator, the airmass turns towards the east, causing the southwest summer monsoon. This monsoon is driven by a low-pressure area located over central Asia. This airflow becomes southeast upon reaching Nepal, due to physical and dynamic reasons.

Local wind conditions in the Kathmandu Valley have been measured at Tribhuvan Airport for many years. A wind/stability matrix has been constructed from these data, the distribution of stability classes, and observations of diurnal wind pattern. Such a matrix, representing the statistics of dispersion climatology, can be used as an input to dispersion models for calculation of long-term average concentrations of pollutants. Figure 2.10 shows selected monthly wind roses for the period 1971-75 and 1993 (Shrestha, 1994). In the summer and early autumn, the prevailing wind regime in Kathmandu Valley is the southwest monsoon. In the winter, the prevailing winds are more westerly. High mountains in the north prevent the entry of cold Siberian winds from the northeast. The pattern is dominated by weak winds. The high occurrence of calm and low wind speeds causes poor dispersion conditions in the Valley. The combined matrix is given in Table 2.8.

***Table 2.8: Wind/stability frequency matrix for the winter months (Jan-March, Oct-Dec) 1993, Tribhuvan Airport.***

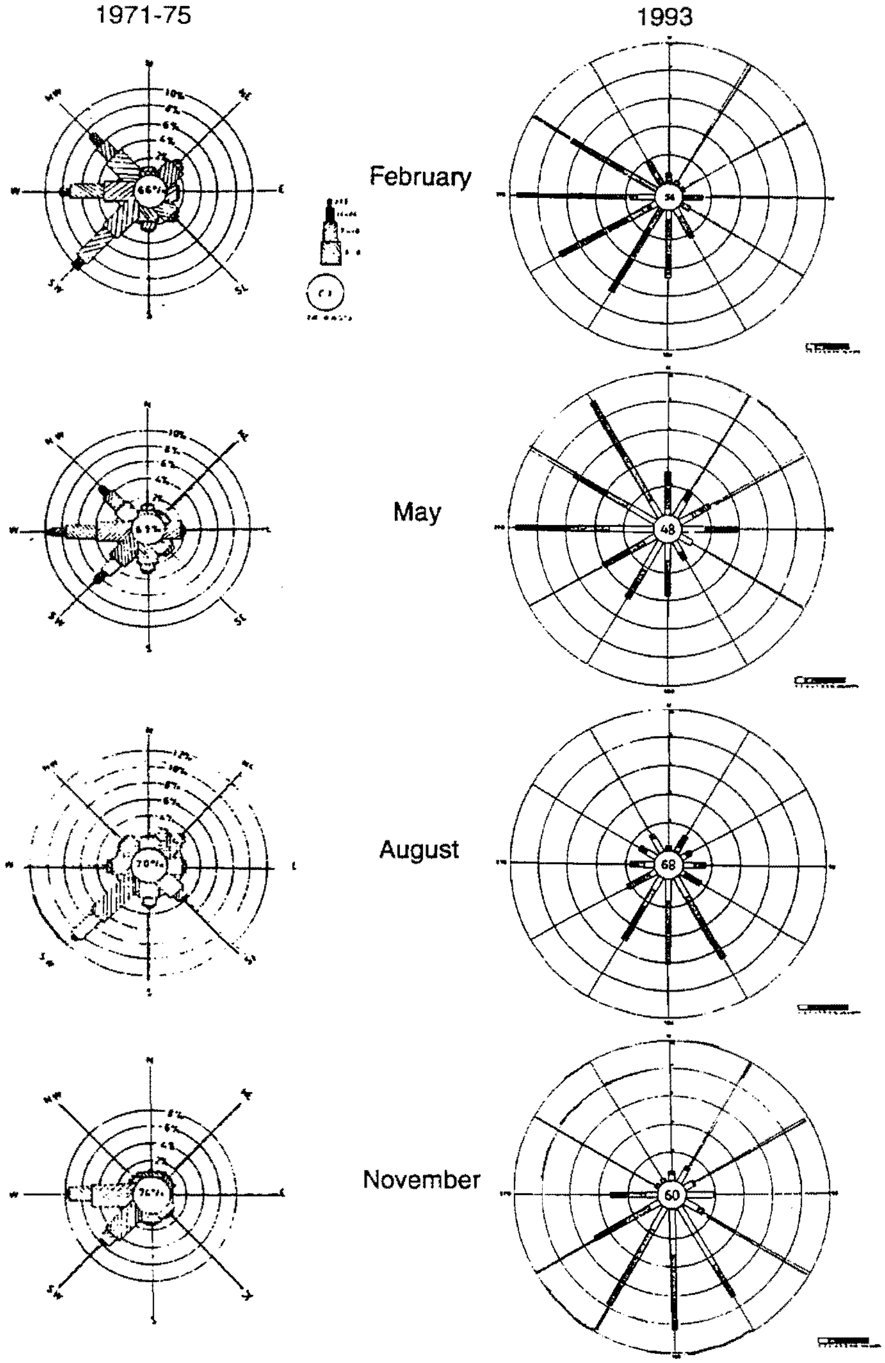
| | .8 m/s | | | | 1.8 m/s | | | | 3.3 m/s | | | | 6.3 m/s | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** |
| 30 | .6 | .1 | 1.0 | .6 | .1 | .0 | .1 | .1 | .0 | .0 | .0 | .0 | .0 | .0 |
| 60 | .5 | .1 | 1.0 | .5 | .1 | .0 | .2 | .1 | .0 | .1 | .0 | .0 | .0 | .0 |
| 90 | 1.6 | .3 | 2.8 | 1.6 | .1 | .0 | .2 | .1 | .0 | .1 | .1 | .0 | .0 | .1 |
| 120 | .8 | .3 | 2.6 | 1.6 | .0 | .0 | .3 | .2 | .0 | .0 | .0 | .0 | .0 | .0 |
| 150 | 1.9 | .6 | 6.3 | 3.8 | .2 | .1 | .6 | .4 | .0 | .2 | .1 | .0 | .0 | .0 |
| 180 | 1.6 | .5 | 5.4 | 3.2 | .3 | .1 | 1.0 | .6 | .1 | .8 | .3 | .1 | .0 | .3 |
| 210 | 4.7 | 1.0 | 3.1 | 1.6 | .9 | .2 | .6 | .3 | .4 | 1.4 | .2 | .2 | .0 | .6 |
| 240 | 3.5 | .8 | 2.3 | 1.1 | .9 | .2 | .6 | .3 | .5 | 1.6 | .3 | .3 | .0 | .3 |
| 270 | 1.8 | .4 | 3.2 | 1.8 | .5 | .1 | .8 | .5 | .4 | 1.4 | .6 | .4 | .0 | .8 |
| 300 | .7 | .1 | 1.3 | .7 | .3 | .1 | .5 | .3 | .2 | .6 | .2 | .2 | .0 | .5 |
| 330 | .8 | .2 | 1.5 | .8 | .2 | .0 | .3 | .2 | .1 | .2 | .1 | .1 | .0 | .1 |
| 360 | .7 | .1 | 1.1 | .5 | .1 | .0 | .1 | .1 | .0 | .0 | .0 | .0 | .0 | .1 |

| | | | | |
|---|---|---|---|---|
| Stability | 1 | 2 | 3 | 4 |
| Windprof. exponent | .20 | .28 | .36 | .42 |
| Mixing height | 1,200. | 1,000. | 400. | 200. |

| Stability classes | Velocity classes (m/s) |
|---|---|
| I: Unstable | 0.3-1.5 (0,8 m/s average) |
| N: Neutral | 1.5-2.0 (1.8 m/s average) |
| SS: Weakly stable | 2.5-4 (3.3 m/s average) |
| S: Stable | >4 (6.3 m/s average) |

The frequencies of calm are distributed in the direction sectors within each of the stability classes of the 0.3-1.5 m/s velocity class, proportional to the joint occurrence of wind and stability.

*Figure 2.10: Wind roses for 1971-75 and 1993, Tribhuvan Airport (Shrestha, 1995).*




| % calm | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1971/75 | 71 | 66 | 69 | 68 | 69 | 63 | 70 | 70 | 77 | 74 | 74 | 79 |
| 1993 | 62 | 56 | 47 | 41 | 48 | 62 | 67 | 68 | 65 | 62 | 60 | 65 |

*Figure 2.11a: TSP concentrations in Kathmandu Valley. Calculated winter average concentrations (km² averages), 1993. Total distribution and contributions from various source categories.*

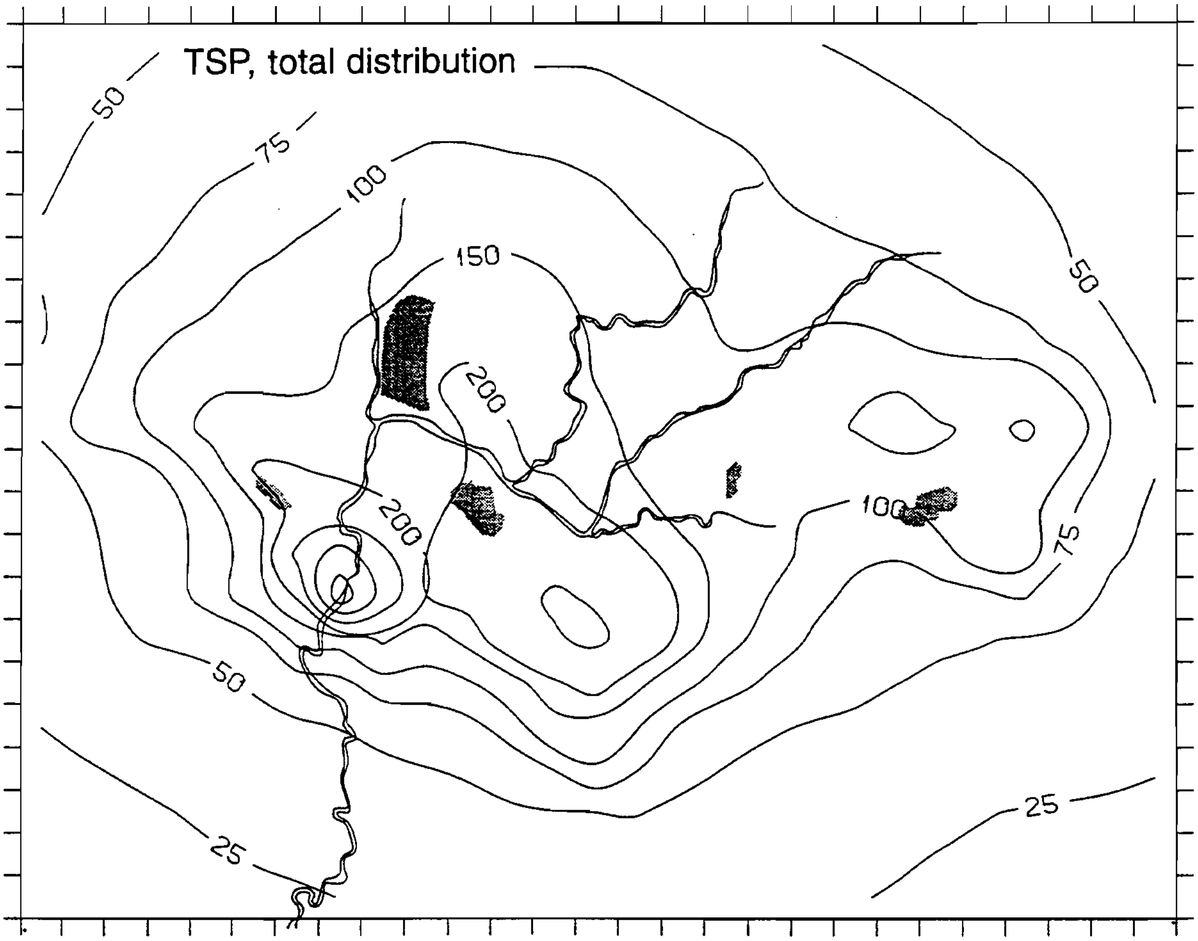


*Figure 2.11b TSP Concentrations in Kathmandu Valley*

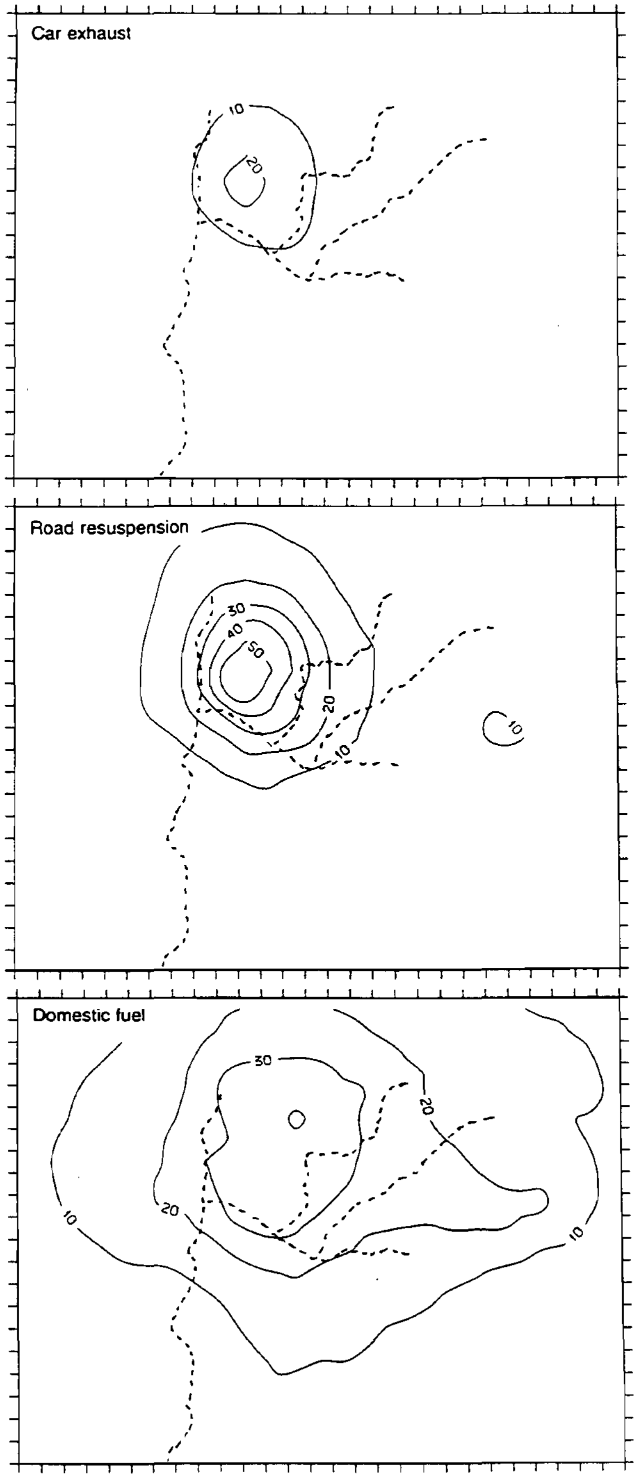
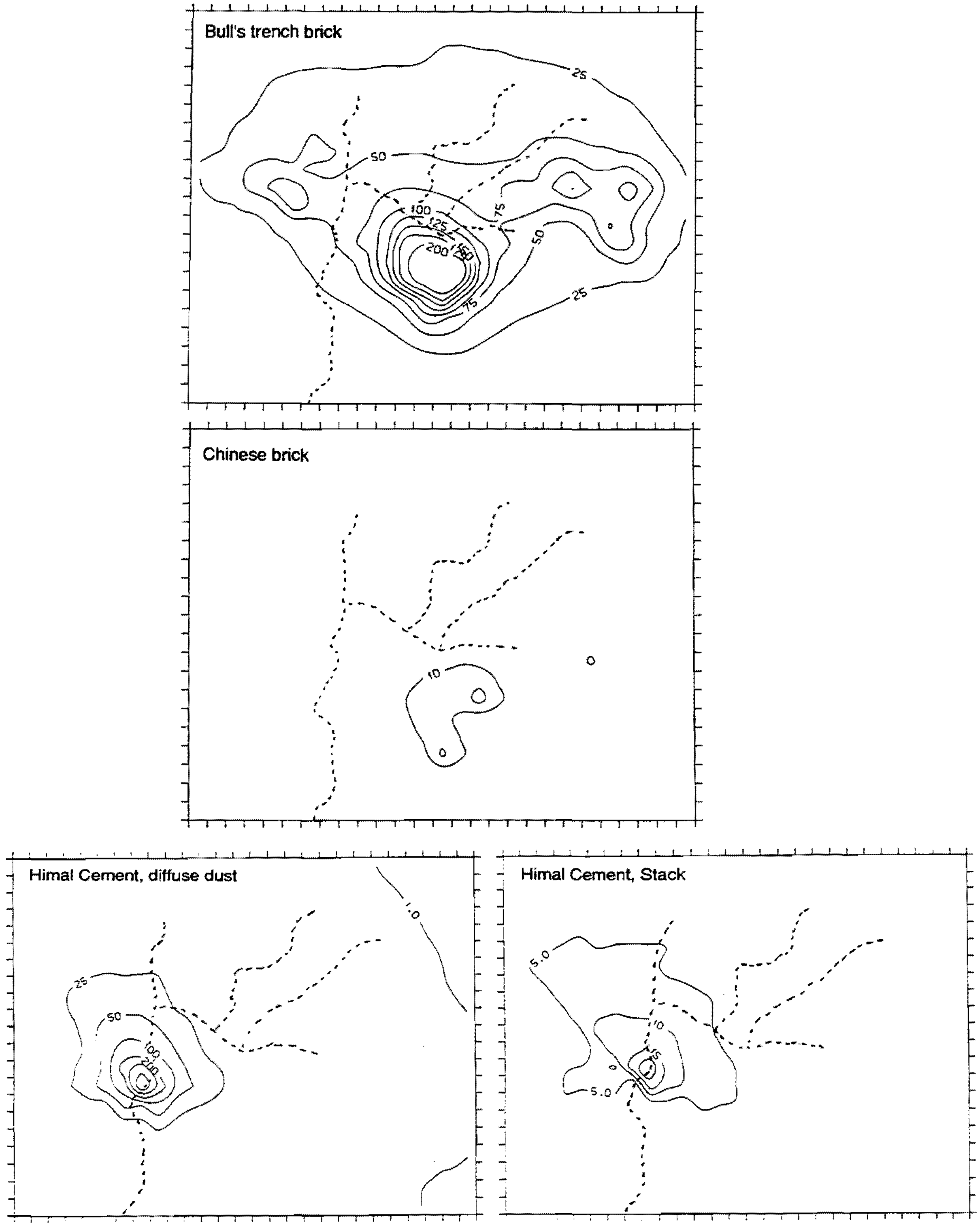


*Figure 2.11c TSP Concentrations in Kathmandu Valley*



### *2.3.3. Dispersion model calculations, city background*

**Model description.** In the first phase of URBAIR, dispersion models concentrate on the calculation of long-term (winter) average concentrations, representing the average within $km^2$ grids ("city background" concentrations). Contributions from local sources, in specific receptor points such as industrial hot spots, is evaluated separately.

The dispersion model used here is a multisource, Gaussian model, which treats area, point and volume sources separately. Such a model is sufficient for calculating a first approximation of the contribution from various source groups to long-term average air pollution concentrations.

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

For point sources, plume rise (Brigg's equations), the effects of building turbulence, and plume downwash are taken into account. For area sources, total emissions in a $km^2$ grid is simulated by 100 ground level point sources, equi-spaced over the $km^2$ grid, using the actual height of the emissions. For example, for a traffic source, a 2 meters emission height is used.

**Total suspended particles (TSP).** Calculated, average TSP concentration distributions in the winter months, are shown in Figures 2.11a, b and c. A regional background value of 10 $\mu g/m^3$ has been added. Emissions from refuse burning and other commercial/industrial fuel combustion can be estimated. The following sources are covered:

- Road vehicle exhaust (gasoline and diesel).
- Resuspension from roads.
- Domestic fuel combustion (including estimated emissions from cottage-scale pottery).
- Bull's trench brick kilns.
- Chinese (Hoffmann-Bhatta) brick kilns.
- Himal Cement Factory.

**TSP, total distribution.** Calculated TSP source contribution for Kathmandu City and the brick kiln area given in Table 2.9. There are distinct peaks in the distributions from the various sources:

- due to road traffic (vehicle exhaust and resuspension) and domestic fuel combustion in Kathmandu City;

***Table 2.9: TSP contributions ($\mu g/m^3$, winter average) calculated for certain grids and maximum grid contribution.***

| Source | Kathmandu City maxima (grid 11,14) | Brick area maxima (grid 14,7) | Maximum | |
|---|---|---|---|---|
| | | | From each source | in grid no. |
| Vehicle exhaust | 22 | 2.5 | 22 | (11,14) |
| Resuspension from roads | 57 | 5.0 | 57 | (11,14) |
| Domestic fuel combustion | 35 | 17.0 | 41 | (13,16) |
| Bull's trench kilns | 47 | 238.0 | 238 | (14,7) |
| Chinese kilns | 2 | 19.0 | 24 | (16,7) |
| Himal Cement | 1 | 0.5 | 23 | (9,9) |
| Regional background | 10 | 10.0 | | |
| TOTAL | 174 | 292 | | |

*Figure 2.12a: $PM_{10}$ concentrations in Kathmandu Valley. Calculated winter average concentrations (km² averages) 1993. Total distribution and contributions from various source categories.*

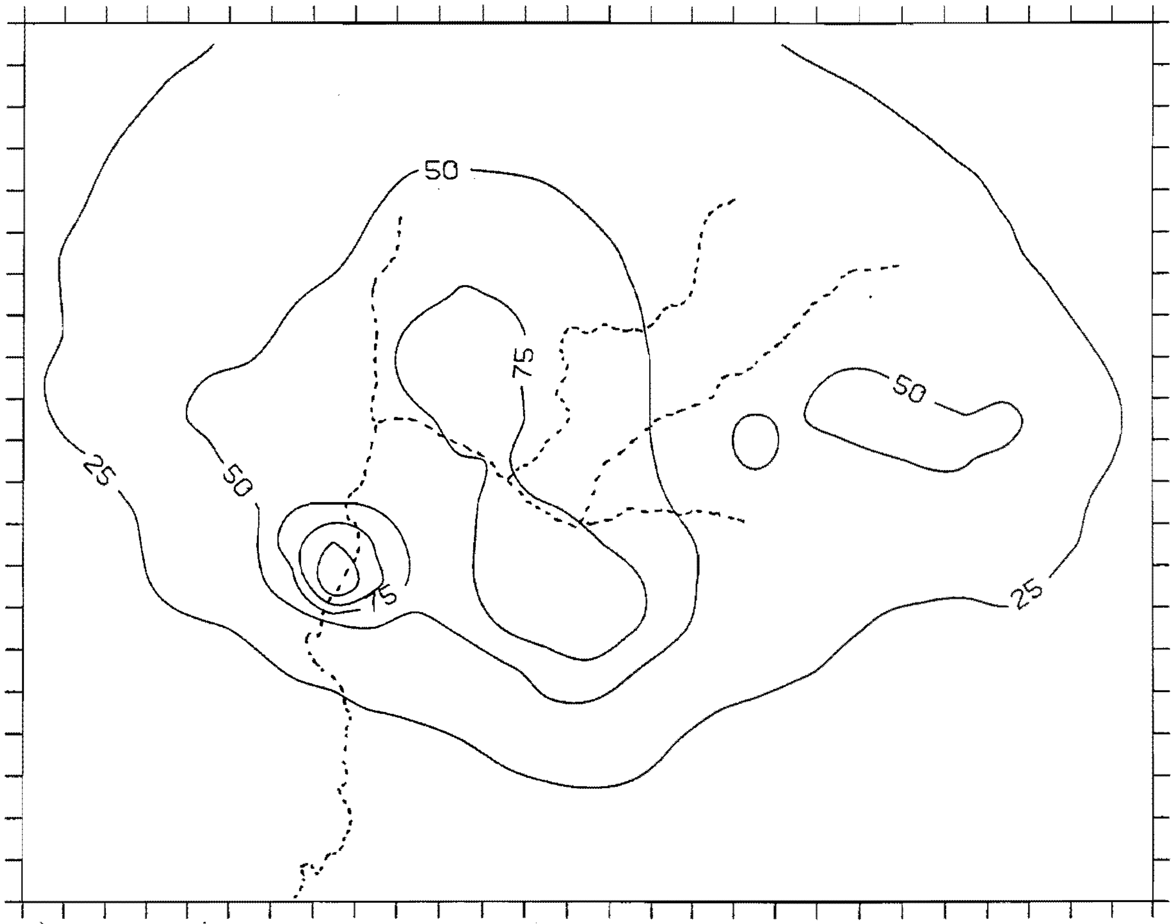


***Figure 2.12b PM$_{10}$ concentrations in Kathmandu Valley***

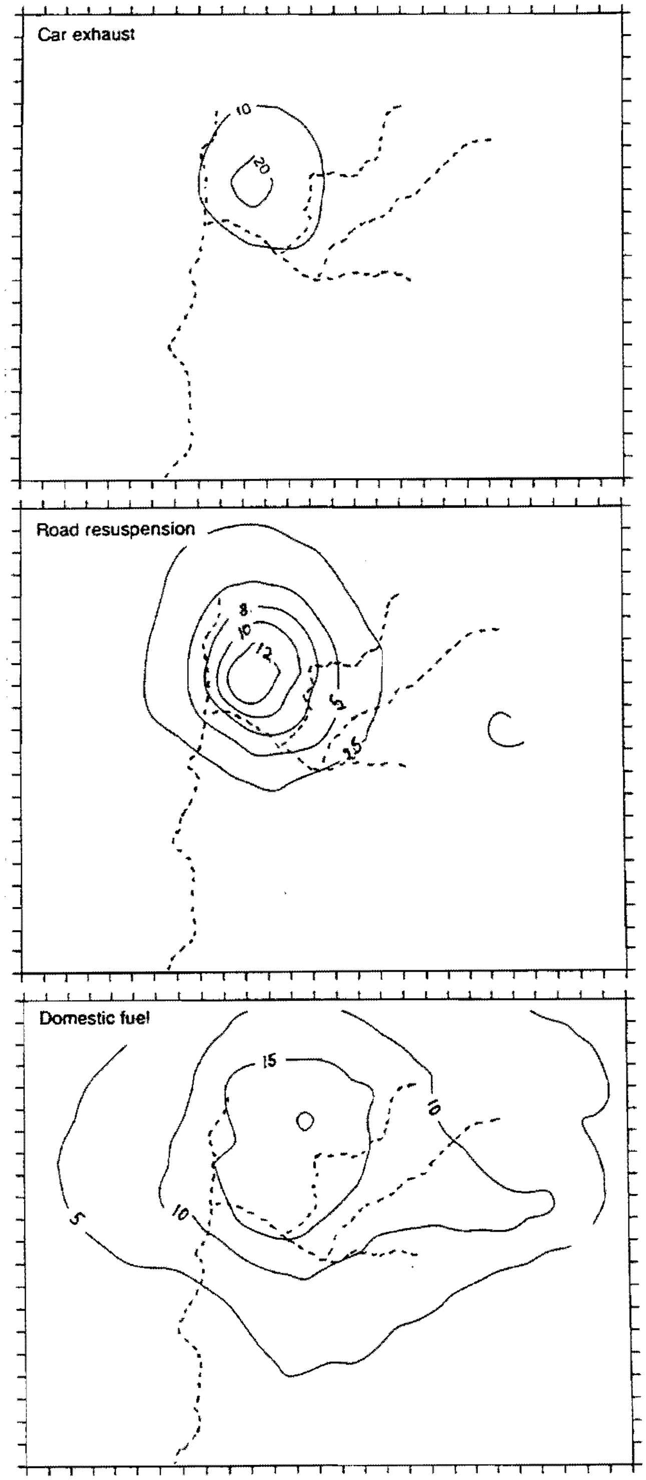
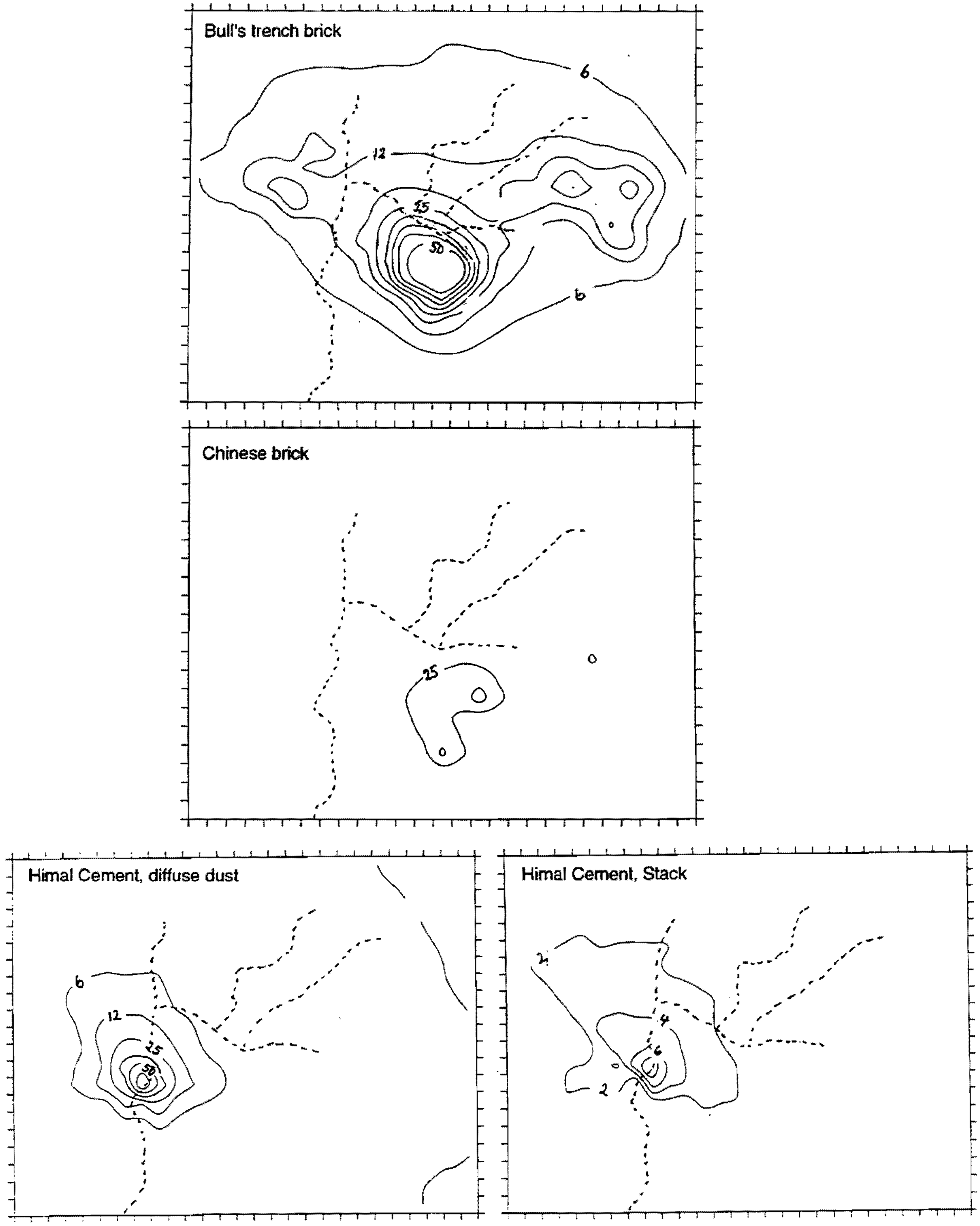


*Figure 2.12c $PM_{10}$ concentrations in Kathmandu Valley*



- in the brick kiln areas, especially southeast of Patan, and
- near Himal Cement factory.

The Himal Cement Factory, despite its large emission, makes a small overall contribution to the total TSP levels in Kathmandu City and population exposure because of its tall stack, and the sparse population close to the factory.

Estimated additional contribution from refuse burning is 5 μg/m3 at the Kathmandu City maximum, with a spatial distribution similar to domestic fuel combustion (comments on source contributions). The contribution from commercial/industrial fuel combustion (in addition to brick kilns) is about the same as the refuse burning.

These calculated concentrations can be compared with Shrestha's measurements at Babar Mahal Building (in grids 11,12 and 12,12):

- **Calculated** winter average: 160-170 μg/m3
- **Measured** average, Jan-March, 1993: 255 μg/m3

It can be seen that the calculated value is lower than that measured. The calculated value represents the km2 grid average, while the Babar Mahal Building (at which the actual measurements were taken) is affected by heavy traffic. This site is situated approximately 100 meters downwind from the Arniko Rajmarg Road which carries close to 31,000 vehicles each day. The measurement site thus experiences emissions from vehicles on the road, and thus actual measurements are higher than the calculations. Nevertheless, the dispersion calculations may underestimate the actual TSP concentration in Kathmandu City to a small degree.

Comparison with KVVECP measurements can only be indicative, since the measurements were taken only in short autumn periods. As expected, however, measurements close to roads (2-30 meters from roads), give much higher concentrations than those calculated as $km^2$ grid square averages.

**$PM_{10}$.** Calculated $PM_{10}$ distributions, and the source contributions, are shown in Figures 2.12a,b and c. The $PM_{10}$ calculations are based on TSP calculations, using the $PM_{10}$/TSP ratios given in Tables 8 and 9 in Appendix 3. As was the case for TSP, the $PM_{10}$ measurements from the KVVECP sites close to roads show considerably higher concentrations than those calculated. Calculated $PM_{10}$ contributions in selected grids are given in Table 2.10.

***Table 2.10: $PM_{10}$ contributions (μ/m³, winter average), calculated for certain grids, and maximum grid contribution.***

| | Kathmandu City (grid 11,14) | Brick area maxima (grid 14,7) | From each source | In grid no. |
|---|---|---|---|---|
| Vehicle exhaust | 22 | 2,5 | 22 | (11,14) |
| Resuspension from roads | 15 | 1 | 15 | (11,14) |
| Domestic fuel combustion | 18 | 8 | 21 | (13,16) |
| Bull's trench kilns | 12 | 60 | 60 | (14,7) |
| Chinese kilns | 0,5 | 5 | 6 | (16,7) |
| Himal Cement | ~0 | ~0 | 10 | (9,9) |
| Reg. background | **10** | **10** | | |
| TOTAL | **78** | **87** | | |

**$SO_2$ and $NO_2$.** Dispersion calculations have not been carried out for $SO_2$ and $NO_x$ (or $NO_2$). In general, actual measurements indicate fairly low values.

The emissions inventory indicates that the ratio between $SO_2$ and $PM_{10}$ for road traffic (vehicle exhaust plus resuspension) is within the range 0.1-0.6 μg/m³. The numbers differ depending on whether the maximum sulfur content in fuel or the IOC certificate value sulfur content is used. For total $SO_2$ emission, the corresponding range is 0.2-1.4 μg/m³. The measurements give an $SO_2/PM_{10}$ ratio of 0.3-0.6 μg/m³ near road sites, indicating that the actual sulfur content in HSD is close to the maximum value of 1 percent sulfur.

### *2.3.4. Pollution hot spots*

Significant pollution sources contribute to large concentrations in their neighborhoods, adding to the general city background. Such pollution hot spots are generally located along the main road system, and near industrial areas with significant emissions through low stacks.

Industrial pollution hot spots in Kathmandu Valley include the areas near Himal Cement Factory that are exposed to the diffuse dust source associated with quarrying, transport, and other handling of materials. The brick kiln areas are also pollution hot spots. Emissions from each low chimney (10 meters), expose nearby areas with very high short-term concentrations, depending upon the wind and dispersion conditions. In the dispersion calculations of long-term averages, however, the kilns are represented as area sources, and the calculated concentrations represent the average of each square kilometer.

The KVVECP measurements of $SO_2$ and $NO_2$, such as at the Jaya Bageshwori site, indicate that other sources in the Valley may also create pollution hot spots. Undoubtedly, the entire main road system which has a daily traffic higher than 15-20,000 vehicles, represents pollution hot spots. Such hot spot areas contribute significantly to the health damage caused by air pollution.

### *2.3.5. Population exposure to air pollution*

Population exposure is defined as the number of people experiencing pollution compound concentrations within established concentration ranges. The cumulative population exposure distribution gives the percentage of the total population exposed to concentrations above standard accepted values. People are exposed to air pollutants at home, in transit, at work and other places. More often than not, complete data are not available to make population exposure calculations. The methodology used must be adapted to the data available in each country. In order to correctly map population exposure, data are needed on:

- concentration distributions and their variation with time, in homes (general city air pollution or "city background"), along main road network and near other hot spots, such as industrial areas; and
- population distribution (residences and workplace), the number of commuters, and time-dependent travel habits.

**Exposure to TSP and $PM_{10}$.** Population exposure calculations have been carried out for winter concentrations of TSP and $PM_{10}$, which are the major air pollution problems in Kathmandu Valley. These calculations used to assess the costs of health damage.

Although exposure to high, short-term concentrations of particles or hot spot exposure to other pollutants is very important, these calculations have not been made because of the lack of data for Kathmandu Valley. In addition, comprehensive dose-effect relationships regarding health have not yet been developed for short-term exposure, although there are established air quality guidelines for such exposure.

The calculation of population exposure is based on the calculated $km^2$ -grid average concentrations. All the people who live within a grid square are assumed to be exposed to the same concentration, whether they live close to a hot spot, such as a road, or near a park. The exposure of drivers and commuters while they are on the road is also not taken into consideration. Thus, the calculation underestimates actual exposure. Calculations for Manila and Greater Mumbai reveal that approximately 5 percent of the population, residing near roads, and taxi, bus, or tempo drivers, are exposed to 25-50 μg TSP/$m^3$ more than is calculated by the $km^2$ average method.

The results of the population exposure calculations for winter average TSP and $PM_{10}$ are shown in Figure 2.13. An annual average exposure is estimated, based on the ratio between annual average and winter average TSP of 0.75, measured at the Babar Mahal Building (Figure 2.1). The same ratio is used for $PM_{10}$.

The exposure situation in Kathmandu Valley can be summarized as follows:

- Approximately 50 percent of the population is exposed to a TSP concentration above the WHO AQG--90 μg/$m^3$, annual average.
- 3 to 4 percent of the population is exposed to TSP greater than twice the WHO AQG (180 μg/$m^3$). These are residents in the brick kiln areas, drivers, and those who live near the most heavily traveled roads.

**Indoor air pollution** exposure is not taken into account in these calculations. Undoubtedly, such pollution is a very important source of exposure and greatly impacts human health, especially that of women and children who are most directly exposed. During cooking, the indoor exposure may significantly exceed the outdoor concentrations, increasing total exposure considerably. This drawback must be corrected in future analyses.

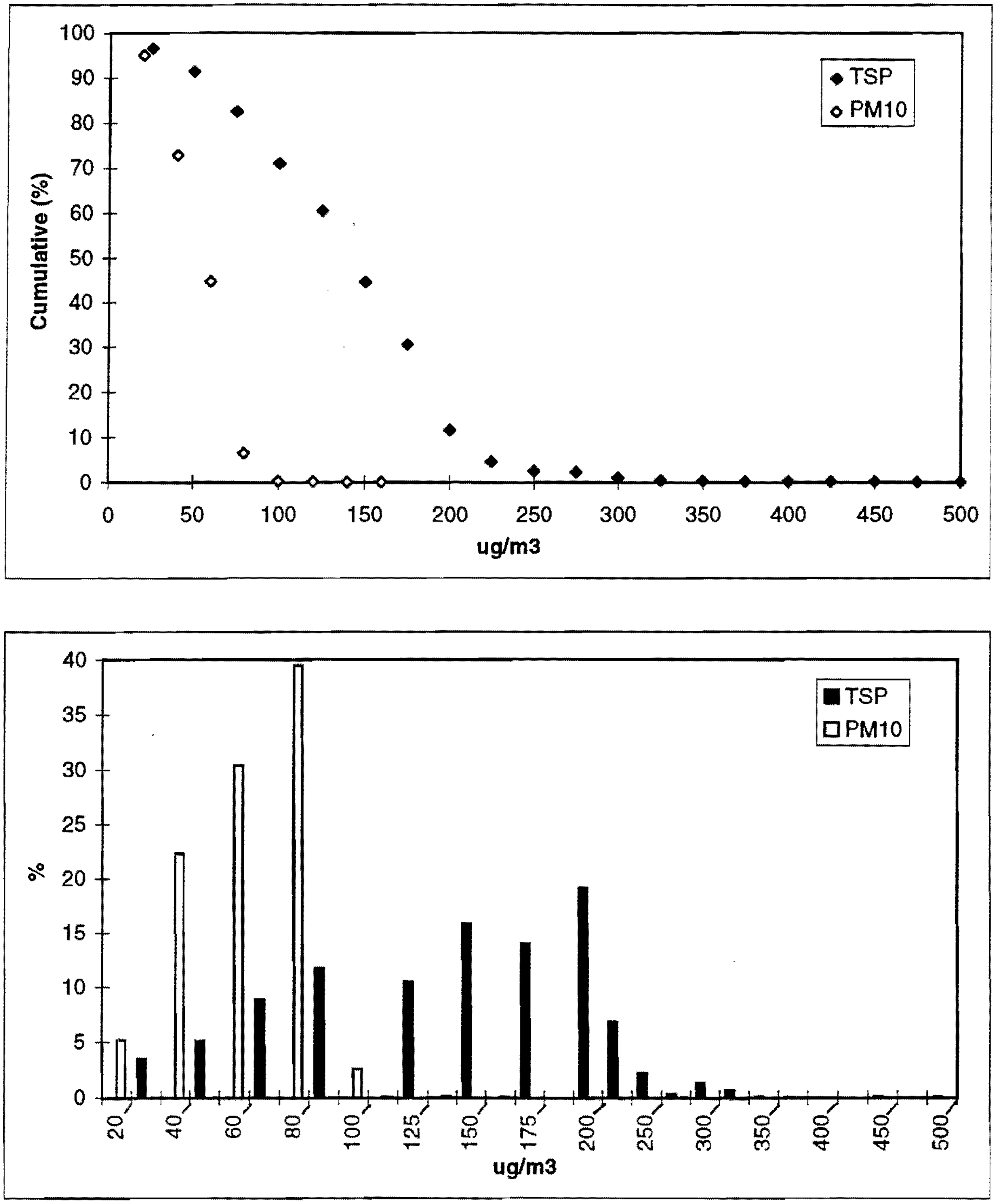
General exposure at residences is mainly caused by the following (in approximate order of importance):

- For TSP: Resuspension from roads, brick kilns, domestic fuel combustion, diesel vehicles, gasoline vehicles (See Table 2.9.)
- For $PM_{10}$: Diesel vehicles, gasoline vehicles, resuspension, domestic fuel, brick kilns. (See Table 2.10.)

Additional exposure because of proximity to roads is significant for part of the population. This additional roadside exposure is accounted for in the following way.

1. Considering the high TSP and $PM_{10}$ measurements at roadside sites, average roadside TSP exposure concentration is estimated to be 500 μg/$m^3$ (winter average).
2. Half the population, 200,000 people, living in the most highly exposed areas in Kathmandu City within the 75 μg/$m^3$ $PM_{10}$ isoline on Figure 2.13, are assumed to be subjected to additional roadside exposure.
3. These 100,000 people are assumed to spend half their time at the roadside and the other half at home. The total exposure resulting from this calculation is 350 μg/$m^3$ TSP, corresponding to about 130 μg/$m^3$ $PM_{10}$ in Kathmandu.

***Figure 2.13: Population exposure distributions for TSP and $PM_{10}$ (winter average concentrations, $\mu g/m^3$), Kathmandu Valley, 1993, based on calculated average $km^2$ concentrations.***



4. Thus, these 100,000 people are moved from the 60-80 $\mu g/m^3$ exposure level (see Figure 2.13, $PM_{10}$) to 130 $\mu g/m^3$.

The effect of increased and reduced emissions from each source category has been calculated. These calculations reveal that in order to reduce TSP and $PM_{10}$ exposures, reductions in the brick kiln emissions are crucial, followed by reductions in domestic fuel combustion, road resuspension and vehicle exhaust. The results are shown in Figures 2.14 and 2.15 for TSP and $PM_{10}$, respectively. Calculations were made for ± 25 percent change in emissions from each source, on the number of people experiencing exceedance of the following pollution levels:

- TSP: Exceedance of 100 $\mu g/m^3$ as winter average, corresponding to approximately 75 $\mu g/m^3$ as annual average in Kathmandu Valley (which is within the WHO AQG range 60-90 $\mu g/m^3$). Exceedance of 175 $\mu g/m^3$ as winter average, corresponding to an annual average of 130 $\mu g/m^3$.
- $PM_{10}$: Exceedance of 60 $\mu g/m^3$ as winter average, corresponding to about 45 $\mu g/m^3$ as annual average in Kathmandu Valley. Exceedance of 100 $\mu g/m^3$ as winter average, corresponding to about 75 $\mu g/m,^3$ as annual average.

*Figure 2.14: Change in population exposure to TSP as a result of ±25 percent change in the total emissions from each source category.*

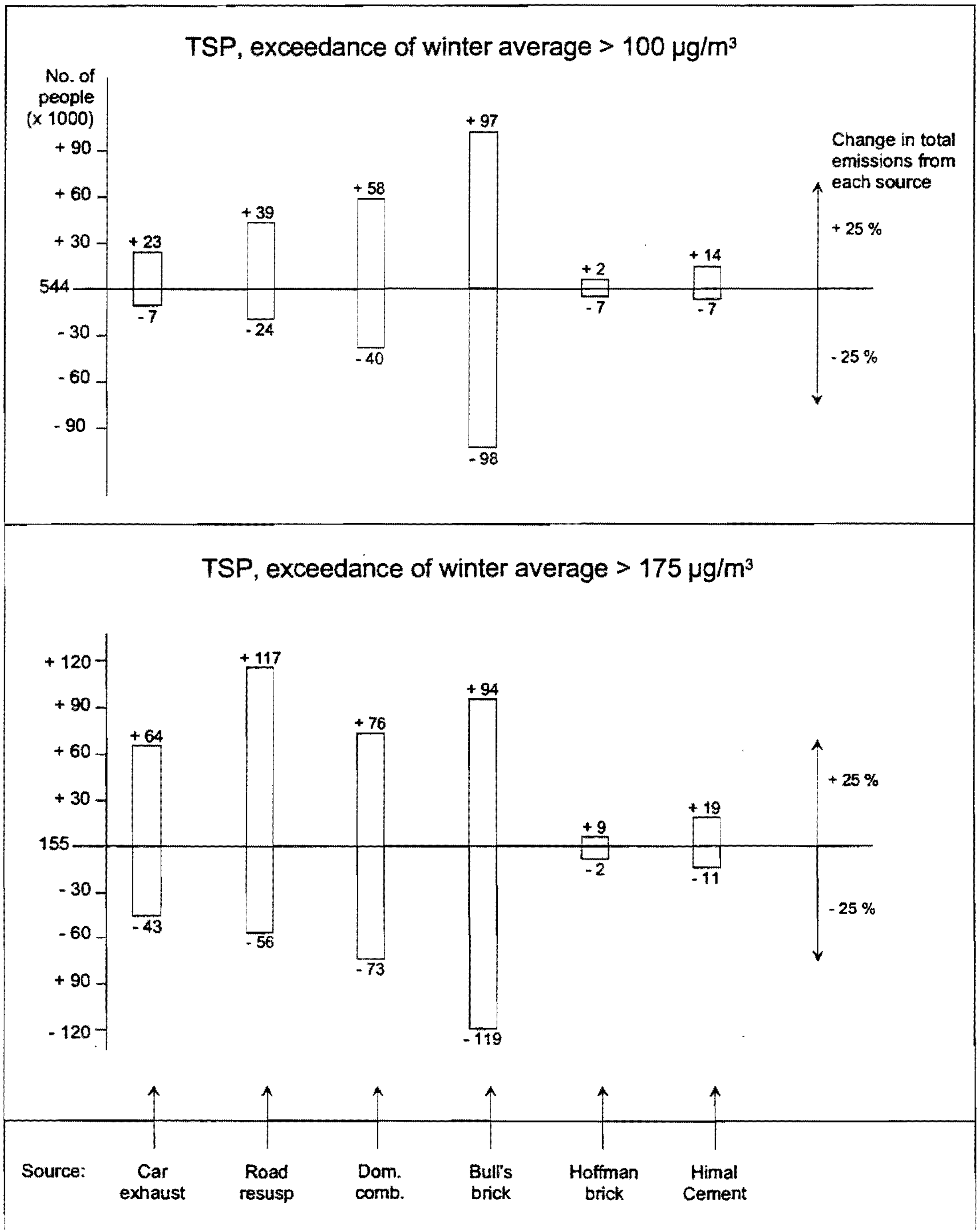
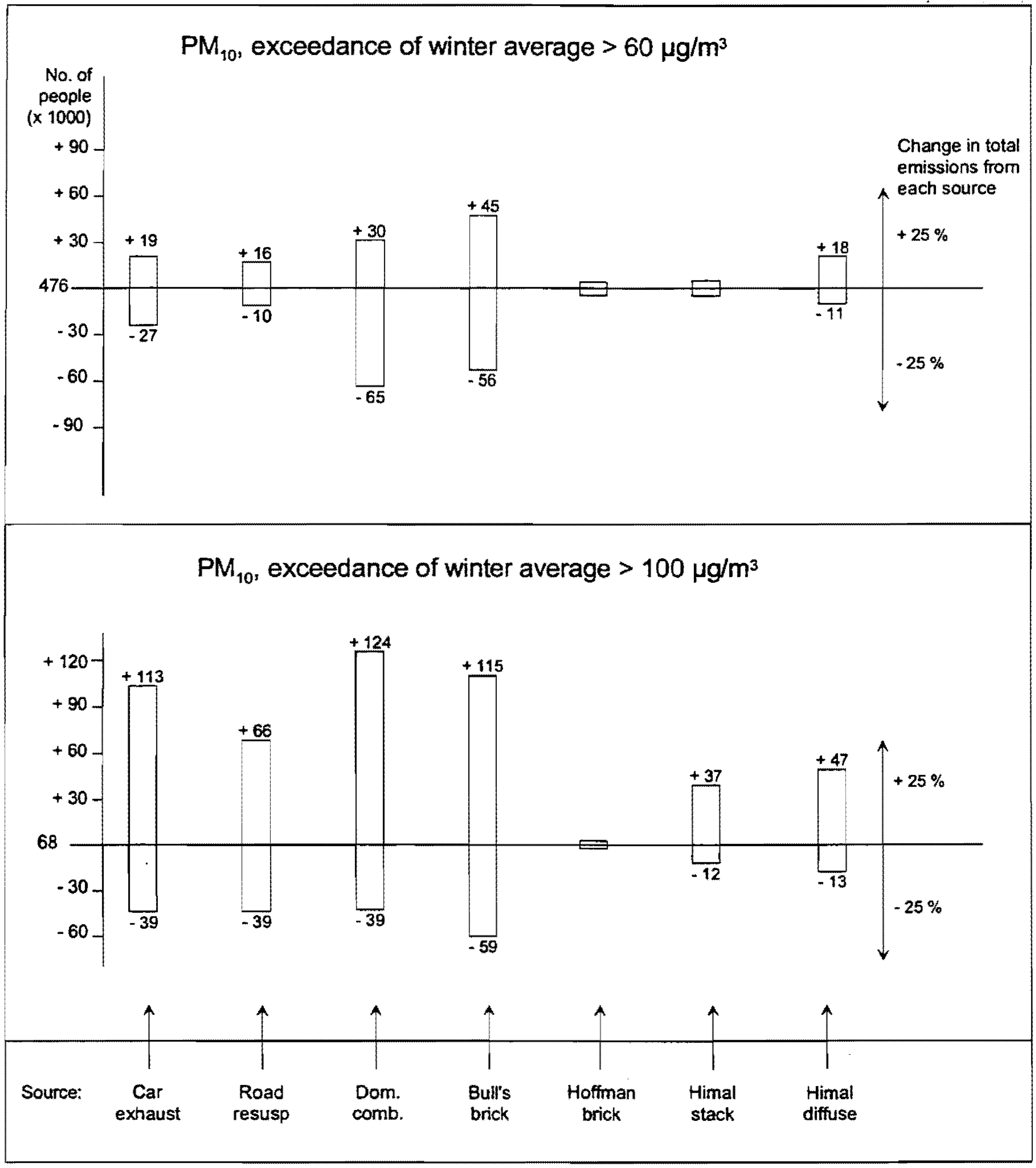


*Figure 2.15: Change in population exposure to $PM_{10}$ as a result of ±25 percent change in the total emissions from each source category.*



## 2.4. SUMMARY OF AIR QUALITY ASSESSMENT, KATHMANDU VALLEY

### *2.4.1. Air pollution concentrations*

Air pollution concentrations have not been fully measured. At KVVECP's 14 sites, TSP, $PM_{10}$, $SO_2$ and $NO_2$ were been measured for 5 to 30 days during the autumn of 1993. One fairly long series of TSP measurements, from Babar Mahal Building, was taken from January to August 1994. These measurements, as well as subjective observations, reveal that the main air pollution problem in the Valley is associated with suspended particles, such as TSP, $PM_{10}$ and combustion particles. Concentrations exceed WHO AQG on more than 50 percent of the days.

The highest 24-hour concentrations, compared with the WHO AQG are given in Table 2.11. The 8-month average TSP at Babar Mahal was 201 µg/m³, compared to the WHO AQG of 60-90 µg/m³. The highest concentrations occurred in the most heavily trafficked sites and at the site near the Himal Cement factory. No measurements were made in the areas most exposed to brick industry emissions. High levels measured at the Thimi site may partly be due to such emissions.

***Table 2.11: Highest 24-Hour Concentrations in Kathmandu***

| | Max. concentration | WHO Guidelines |
|---|---|---|
| TSP, KVVECP (traffic exposed) | 867 µg/m³ | 150-230 µg/m³ |
| TSP, Babar Mahal (residential) | 467 µg/m³ | 150-230 µg/m³ |
| $PM_{10}$, KVVECP (traffic exposed) | 201 µg/m³ | 70 µg/m³ |

### *2.4.2. Air pollutant emissions inventory*

The main particle emission sources are smoking vehicles (diesel and gasoline), brick kilns, and the Himal Cement Factory. Based on available emissions data and estimates, a first approximation of an emissions inventory for suspended particles has been worked out.

In terms of total emissions in 1993, the main sources are given in Table 2.12. Diesel vehicles contributed about 60 percent of the particles and gasoline vehicles about 40 percent. The actual impact of these emissions on human health depends on the emission conditions such as the height of emissions, and their position relative to population centers. There are significant uncertainties in the emission figures for the sources. This may be especially important for road resuspension and Bull's trench kilns, which are the predominant polluters in the brick industry. The $PM_{10}$/TSP ratios used for various source categories are also uncertain.

***Table 2.12 Main Emissions Sources in Kathmandu (1993)***

| TSP | | $PM_{10}$ | |
|---|---|---|---|
| Himal Cement | 36% | Brick industry | 28% |
| Brick industry | 31% | Domestic fuel | 25% |
| Domestic fuel combustion | 14% | Himal Cement | 17% |
| Road resuspension | 9% | Vehicle exhaust | 12% |
| Vehicle exhaust | 3.5% | Road resuspension | 9% |

### *2.4.3. Population exposure to air pollutants*

A first approximation of the population exposure is based on the emissions inventory, a multisource Gaussian dispersion model for long-term averages, and meteorological statistics from Tribhuvan Airport. The calculated contributions to the winter average concentrations in Kathmandu City are given in Table 2.13.

***Table 2.13: Average Winter Concentrations in Kathmandu City***

| | TSP µg/m$^3$ | $PM_{10}$ µg/m$^3$ |
|---|---|---|
| Vehicle exhaust | 22 | 22 |
| Road resuspension | 57 | 15 |
| Domestic fuel combustion | 35 | 18 |
| Bull's trench kilns | 47 | 12 |
| Background | ? | ? |
| Total | ? | ? |

The calculated winter average TSP concentrations underestimate the actual concentrations in Kathmandu City (Babar Mahal Building). The indoor air pollution, which is very significant in rural areas, has not been taken into account in these calculations The present TSP exposure situation to the population in Kathmandu Valley is as follows:

- about 50 percent is exposed above the upper limit of the WHO AQG (90 µg/m$^3$), and
- approximately 3 to 4 percent is exposed to concentrations that are more than twice this level (180 µg/m$^3$ ), which include residents in the brick kiln areas, drivers and roadside residents.

### *2.4.4. Visibility reduction*

Visibility in the Valley has been very significantly reduced in the dry season since early 1980s. Visibility is mainly affected by sub-micrometer particles, mainly from fuel combustion. Hygroscopic particles like sulfate, nitrate and organic aerosols, cause strong visibility reduction at relative humidities above 70 percent. Combustion aerosols absorb water, which causes reduced visibility, at 30 to 40 percent relative humidity. Location and height of the emission source is of little importance for visibility reduction.

The main sources of combustion particles in Kathmandu Valley cannot be ranked because the emissions and, consequently, exposure estimates are not very accurate. The main sources are:

- Domestic fuel combustion
- Road vehicles
- Brick industry
- Himal Cement Factory

## 2.5. IMPROVING AIR QUALITY ASSESSMENT

### *2.5.1. Main shortcomings and data gaps*

**Air pollution concentrations.** There is a need for a comprehensive air pollution monitoring program in Kathmandu Valley. Such a program should encompass the following items:

- Compounds
  *1st priority* -- TSP, $PM_{10}$, submicron particles, black smoke, chemical composition, CO.
  *2nd priority* -- $SO_2$, $NO_2$, PAH, benzene, lead.
- Air quality sites -- roadside, background, brick kiln area, rural, valley outskirts (hilltop).
- Meteorological data -- 3 to 5 measurement sites, wind, relative humidity, stability, visibility.

- Measurement methods -- continuous monitors for $PM_{10}$ , combustion aerosol, CO, meteorological data, visibility.

**Emissions**. It is important to improve the emissions inventory. Special attention must be given to the following:
- comprehensive fuel statistics,
- emission factors for vehicles,
- measurement of emissions from Bull's trench kilns,
- emission factors for domestic fuel combustion,
- determination of resuspension emission factors, and
- particle size distribution for different source emissions.

**Population exposure**. The determination of population exposure in Kathmandu Valley is based on a combination of dispersion modeling and pollution measurements. A reliable population exposure estimate is crucial for estimating health damage, and assessing the beneficial health impacts of measures to reduce the exposure, as part of a cost-benefit analysis. In order to improve the population exposure calculations, it is necessary to:
- establish dispersion models that are capable of dealing with complex topographical, temperature, dispersion conditions, and also for dispersion from roads; and
- improve the input database especially hourly air pollution concentration data, hourly dispersion, emissions and spatial resolution data.

A list of proposed actions to improve the air quality assessment in Kathmandu are given in Table 2.14

*Table 2.14: Proposed actions to improve the Air Quality Assessment*

| Actions | Time Schedule |
|---|---|
| *Air Quality Monitoring* | |
| Design and establish a modified, improved, and extended ambient air, meteorological, and dispersion monitoring system<br>• evaluate sites (at least 10 locations);<br>• select parameters, recommended ones are CO, $NO_X$, $O_3$, HC, TSP and $PM_{10}$<br>• select methods/monitors/operation schedule; and<br>• upgrade laboratory facilities, and manpower capacities. | This activity should start immediately, and a proposed schedule is as follows:<br>• By 31 June 1996: Finalize plan for an upgraded air quality monitoring system, including plans for laboratory upgrading.<br>• During 1996:<br>- Establish of 1 to 2 modem monitoring stations; and<br>- Carry out first phase of laboratory upgrading. |
| Design and establish a Quality Control/Quality Assurance System | This activity should 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<br>• public. | |
| ***Emissions*** | |
| Improve emissions inventory for Kathmandu Valley, including<br>• industrial emissions inventory (location, process, emissions, stack data);<br>• road and traffic data inventory;<br>• domestic emissions inventory.<br>Study resuspension from roads and surfaces | First priority:<br>• industrial emissions inventory;<br>• study of resuspension from roads,<br>• start developing an emissions inventory procedure |
| Estimate contribution from construction and refuse buming.<br>Establish emission factors for Nepal conditions. | |
| Develop an integrated and comprehensive emissions 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 Kathmandu Valley. | This activity should be started without delay. |

# 3. AIR POLLUTION IMPACTS

### 3.1. INTRODUCTION

This chapter presents an overview of the major impacts of air pollution in Kathmandu Valley and estimates of the monetary value of these damages. Concern about air pollution focuses on the high concentrations of suspended particles, especially $PM_{10}$, which regularly exceed the WHO AQG (See Chapter 2). Figure 3.1 summarizes the information presented in Chapter 2 in a frequency distribution of population exposure to $PM_{10}$. The WHO AQG for $PM_{10}$ (41 $\mu g/m^3$) is derived by multiplying the WHO AQG for TSP (70 $\mu g/m^3$) with a factor 0.55 which expresses the typical fraction of $PM_{10}$ in TSP.

Health impact estimates are based on air pollution dose-response research conducted in the United States (Ostro, 1994). The methodology for deriving these estimates is described in the *URBAIR Guidebook*. The dose response equations used here are based on Ostro's work. Guidelines for acceptable pollution concentrations, also known as "no-damage benchmarks," have been proposed by WHO.

Although damage to human health is not the only adverse impact of air pollution, the lack of appropriate data prevents the quantification of other impacts, such as a reduction in tourism, a particularly important source of earnings for Nepal.

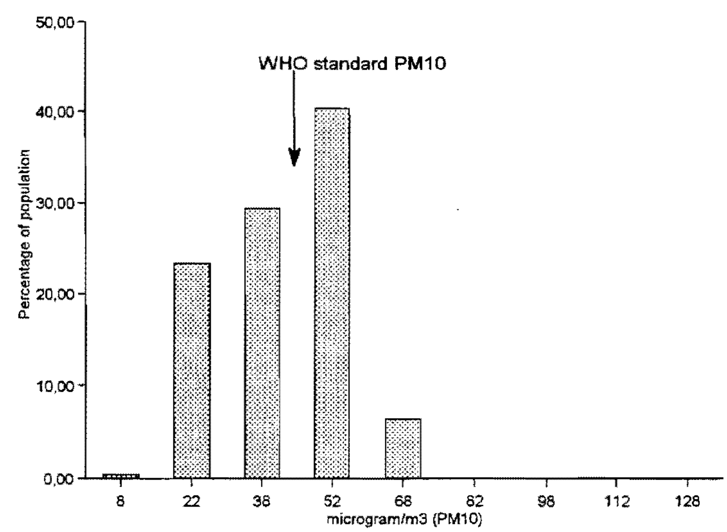
### 3.2. IMPORTANT IMPACTS IN KATHMANDU VALLEY

**Health**. Although U.S. research relates to TSP concentrations, in this study it has been adapted and applied to $PM_{10}$, since these particles are considered a more serious threat to health in Kathmandu Valley.

The conversion from TSP to $PM_{10}$ was done as follows:

- $PM_{10}$ concentrations are calculated from dispersion models using

***Figure 3.1: Frequency distribution of $PM_{10}$ exposure (annual average). Kathmandu Valley, situation 1992/1993.***



actual $PM_{10}$ emissions, and measurements of $PM_{10}$ as control.

- TSP dose-response relationship is converted to $PM_{10}$, using a ratio of 0.55 between $PM_{10}$ and TSP concentrations.
- WHO AQG, which is used as a "no-damage benchmark," is converted from TSP to $PM_{10}$, using the same ratio, 0.55.

**Tourism.** An October 1993 article in *Newsweek* painted a pessimistic, but accurate image of the air pollution situation in Kathmandu Valley. Such negative publicity could have an adverse impact on tourism. In the early 1990s, foreign currency revenues amounted to approximately US$60 million a year. Although no "dose-effect" relationships of air pollution and tourism are available, it can be assumed that an approximate 10 percent decrease in tourism could lead to a loss of close to US$6 million for Nepal. This is a very significant amount of foreign exchange for a country that has a negative balance of trade. Moreover, indirect effects may have the same impact. This leads us to a tentative estimate of US$10 million, or NRs0.5 billion per year, in tourism losses due to pollution. The following sections deal with the impacts on death rates and illness, and their economic valuation in Kathmandu Valley.

### *3.2.1. Mortality*

Health impacts are divided into mortality (excess deaths) and morbidity (excess cases of illness). Mortality and morbidity rates are derived from air quality data using dose-effect relationships. In principle such relationships are derived by statistical comparison of death rates and morbidity in (urban) areas with different air quality. Dose-effect relationships for different pollutants for cities in the United States, have been compiled by Ostro (1994). Although the use of these relationships for Kathmandu may be speculative, until specific dose-effect relations are derived for Valley-like conditions, Ostro's dose-effect relations are the best available. While indoor air pollution such as that caused by cooking also damages health, this analysis is limited to outdoor concentrations.

**Mortality due to $PM_{10}$.** The following relation between air quality and mortality is used:

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

where $P$ equals the number of people exposed to a specific concentration; $c$ equals crude rate mortality = 0.0091 in Kathmandu (Shrestha, 1995); $PM_{10}$ is its annual average concentration ($\mu g/m^3$). A $PM_{10}$ benchmark of *41* is used. It is assumed that mortality increases when concentrations exceed this number. From this relationship and the data presented in Chapter 2 , it can be concluded that excess mortality due to $PM_{10}$ was about 85[2] cases, in a population of approximately 1 million.

### *3.2.2. Illness (morbidity)*

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

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2 Results of calculations are detailed for reasons of consistency and not accuracy.

The following dose-effect relationships are used:

- Chronic Bronchitis--Change in yearly cases of chronic bronchitis per 100,000 persons is estimated at 6.12 per mg/m$^3$ $PM_{10}$. The total number of yearly cases of chronic bronchitis per 100,000 persons is 6.12 x ([$PM_{10}$] - 41).
- RAD--Change in restricted activity days per person per year per mg/m$^3$ $PM_{10}$ is estimated at 0.0575. If we use the WHO standard, the change is 0.0575 x ([$PM_{10}$] - 41).
- RHD--The change in respiratory hospital diseases per 100,000 persons is estimated at 1.2 per mg/m$^3$ $PM_{10}$. Using the WHO standard, the respiratory diseases requiring hospital treatment per 100,000 persons are estimated at 1.2 x ([$PM_{10}$] - 41).
- ERV--The change in the number of emergency room visits per 100,000 persons is estimated at 23.54 per mg/m$^3$ $PM_{10}$, and the total number per 100,000 persons at 23.54 x ([$PM_{10}$] - 41).
- Bronchitis--Change in the annual risk of bronchitis in children below 18 years is estimated at 0.00169 x ([$PM_{10}$] - 41). It is estimated that 46 percent of the population is composed of children under 18 years of age. (estimate based on communication with Professor Bimala Shrestha).
- Asthma--Change in daily asthma attacks, per asthmatic person, is estimated at 0.0326 x ([$PM_{10}$] - 41). It is estimated that 20 percent of the population suffers from asthma (estimate based on communication with Professor Bimala Shrestha).
- RSD--The number of respiratory symptoms days, per person, per year, is estimated at 0.183 x ([$PM_{10}$] - 41).

Table 3.1 combines dose-response relationships with the frequency distribution of $PM_{10}$ exposure (given in Figure 3.1) to derive total numbers of people impacted by various types of pollution and the economic valuation of these impacts.

### 3.3. VALUATION OF HEALTH IMPACTS

**Mortality.** Attaching a monetary value to mortality is often the subject of ethical debate. However, the damage caused by air pollution would be grossly underestimated if mortality was omitted from the calculations. Two approaches can be used to estimate a monetary value for

***Table 3.1: Impact on mortality and health and their valuation (NRs) of health impact in Kathmandu Valley.***

| Type of health impact | Number of cases | Value (NRs) Specific | Value (NRs) Total ($10^3$) |
|---|---|---|---|
| Excess mortality | 84 | 340,000 | 28,644 |
| Chronic bronchitis | 506 | 83,000* | 41,988 |
| Restricted activity days | 475,298 | 56 | 26,617 |
| Emergency room visits | 1,945 | 470-720 (600 in calculations) | 1,167 |
| Bronchitis in children | 4,847 | 350 | 1,697 |
| Asthma | 18,863 | 450-4,170 (600 average in calculations) | 11,318 |
| Respiratory symptom days | 1,512,689 | 50 | 75,634 |
| Respiratory hospital admissions | 99 | 4,160 | 415 |
| Total | | | 209,051 |

* Shrestha's (1995) estimate is approx. NRs146,000, but this is not based on a discounted sum over 27 years. Discounting at a 5% rate leads to an estimate of NRs83,000.

mortality. The first approach is based on willingness to pay (WTP). The WTP approach is described in detail in the *URBAIR Guidebook*. In the United States, a value of approximately 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 the purchasing power parity in Nepal, divided by the purchasing power in the United States. This factor is 930/21,900 = 0.0425 (Dichanov, 1994). At an exchange rate of 1NR = US$0.02, the value of a statistical (VSL) life in Nepal is estimated at NR6.4 million (US$0.1275 million).

The second approach is based on income lost due to mortality. VSL is estimated as the discounted value of expected future income, at the average age. If the average age of population is 23 years, and the life expectancy at birth is 60 years, VSL is:

$$VSL = \sum_{t=0}^{36} w/(1+d)^t$$

where, *w* equals average annual income (Shin et al., 1992) and *d* equals discount rate. In this method, the value of those persons who do not earn a salary, for example women who work in their homes, is taken to be the same as the value of those with a salary. With a yearly wage of NRs20,000 and a discount rate of 5 percent, the VSL is NRs340,000. Considering both approaches to the valuation of premature death, the cost figure associated with increased mortality due to $PM_{10}$ air pollution in 1990 (84 cases) ranges from NRs28.3 million to NRs540 million.

**Morbidity.** The valuation of illnesses should be interpreted with care as it is based on dose-response relations derived in other parts of the world. More research is needed to derive relations that are specific for Kathmandu Valley.

### 3.4. HEALTH IMPACT AND ECONOMIC DAMAGE BY SOURCE CATEGORY

In targeting and prioritizing actions, it is useful to know which pollution sources are the most harmful and the extent to which they have contributed to health damage. Given the present data, it is impossible to identify the relative contributions of all the source categories; however, we do gain some insight into the relative importance of each by estimating their marginal contributions to total particulate pollution. Table 3.2 presents the results of these calculations. The first two columns summarize emissions data as presented in the emissions inventory (see Appendix 3). The third column indicates the assumed changes in emissions which were evaluated in the air quality model (see chapter 2). The fourth, fifth and sixth columns summarize the additional damages caused by pollution, for example change in respiratory symptom days, and the estimated costs associated with these changes. The last column presents the estimated marginal "damage costs" and "benefits" of changes in emissions (change in health damage costs divided by the change in emissions).

*Table 3.2: Marginal impacts from different sources.*

| Source | Emissions *(ton)* | Change in Emissions *(%)* | Change in Mortality | Change in *RSD (1,000)* | Change in health damage *(NRs thousand)* | Marginal costs/benefits *(NRs/kg)* |
|---|---|---|---|---|---|---|
| Traffic (exhaust) | 440 | 25 | 20 | 354 | 48,952 | |
| | | 10 | 10 | 180 | 25,351 | 576 |
| | | -10 | -6 | -108 | -15,037 | 341 |
| | | -25 | -9 | -160 | -22,118 | |
| Resuspension | 400 | 25 | 12 | 219 | 30,273 | |
| | | 10 | 9 | 165 | 22,842 | 571 |
| | | -10 | -2 | -35 | -4,903 | 122 |
| | | -25 | -7 | -125 | -17,382 | |
| Domestic | 1160 | 25 | 23 | 407 | 56,238 | |
| | | 10 | 13 | 227 | 31,367 | 270 |
| | | -10 | -9 | -155 | -21,360 | 185 |
| | | -25 | -13 | -239 | -33,056 | |
| Brick (Bull's trench kilns) | 1250 | 25 | 25 | 443 | 61,199 | |
| | | 10 | 13 | 229 | 31,688 | 253 |
| | | -10 | -3 | -57 | -7,832 | 62 |
| | | -25 | -15 | -274 | -37,921 | |
| Hoffman brick kilns | 45 | 25 | 0 | -3 | 446 | |
| | | -25 | 0 | -6 | -765 | |

* These calculations are based on an earlier version of an air quality damage model in which roadside air exposure is not taken into account. Therefore, this model tends to under estimate the impacts or the air pollution, e.g. mortality is estimated at 65 instead of 84, as mentioned in the section above.

It can be seen from the data in the last column of the above table that changes in traffic sources (exhaust emissions and resuspension) may have the largest impact on health. An increase in emission of 1 kg increases health damage by NRs570. This is followed by domestic sources and Bull's trench brick kilns (NRs270 and NRs250, respectively). These results are generally reflected in the ranking of marginal benefits of emissions reduction. Reduction of vehicle exhaust emissions is the most effective in terms of reduced health damage (NRs341 per kg emission reduction). Next in order of importance is "reduction of domestic emissions" (NRs185 per reduced kg of $PM_{10}$ emission). In absolute terms, however, the reduction in domestic emissions yields the greatest benefits. Preliminary calculations (not shown here) indicate that a reduction of the diffuse (non-stack) emissions of the Himal cement plant will have marginal benefits of similar magnitude to domestic emissions, up to NRs300 per kilogram emission reduction..

## 3.5. CONCLUSIONS

Damage caused by air pollution has many components: human and ecosystem health, physical materials, vegetation and crops, buildings and monuments, visibility reduction and tourism. In theory, all this damage can be assessed. In practice, however, the absence of empirical dose-effect relations makes this assessment difficult.

Health damage consists of mortality and morbidity. If the human capital approach (i.e. lost earnings due to premature death) is used, the value of a statistical life amounts to approximately NRs340,000. The total excess mortality is then valued at NRs28.3 million.

The willingness-to-pay approach yields a "damage value" of NRs540 million. Health impacts are assessed using dose-response relations derived in the United States, and the air quality model developed for Kathmandu Valley (Chapter . Key data are excess mortality totaling 85 cases, and the number of respiratory symptom days at about 1.5 million.

Cost estimates of morbidity are more reliable than the estimates for mortality. These consist of foregone wages and costs of medical treatment. The costs of morbidity resulting from $PM_{10}$ were assessed specifically for Kathmandu Valley. Morbidity costs are valued at about NRs180 million, and total health damage at NRs210 million (with lost salary as the value of statistical life). This valuation of damage approach to human health tends to be underestimated, as suffering due to illness or premature death is not included.

An analysis of the marginal impacts of emissions increase and reduction by source categories showed that the health impacts are mostly affected by developments in the transport sector, while domestic sources and brick manufacturing rank second in this respect.

It is difficult to value the damage to Kathmandu's cultural assets such as its temples and monuments. However, there is a good reason to believe that tourism has ben negatively affected by pollution. The yearly revenue from tourism is US$60 million. If we assume a reduction of 10 percent, and if the indirect economy-wide impact of a reduction in tourism is of the same magnitude, the total economic loss related to pollution can be estimated at roughly NRs0.5 billion.

# 4. ABATEMENT MEASURES: EFFECTIVENESS AND COSTS

## 4.1. INTRODUCTION

This chapter outlines measures that are appropriate for reducing air pollution in Kathmandu Valley. They are chosen based on their effectiveness in controlling emissions, the benefits associated with the reduction in emissions, and the cost of implementing the measure. The same criteria may be used in drafting an action plan.

The chapter is organized by the source categories: traffic; fuel combustion in industries or homes, construction, and refuse burning. For these source categories, measures are described in terms of their:

- **effectiveness** in reducing emissions and associated impacts in the year 1992/1993 (according to the methodology used in Table 3.2); the reference data are mortality 85 (due to $PM_{10}$), and number of RSD 1.5 million in 1990 (Table 3.1);
- **cost**;
- **benefits,** including reduced mortality, RSD, and other economic benefits;
- **policy instruments and institutions** that would be needed to implement these measures;
- **time schedule** in which a particular measure can result in emissions reduction (short term, 2 years; mid-term, 2- years; long term, more than 5 years).

All emission figures, costs, and benefits represent annual estimates for 1992/1993, unless otherwise stated. The list of measures is derived from the information presented by local consultants, *URBAIR Guidebook,* and from earlier plans that have addressed segments of the air pollution problems in Kathmandu Valley. Measures to address process emissions, construction and open burning, were not addressed because of the lack of data specific to Kathmandu.

## 4.2. TRAFFIC

This section describes the effectiveness (abated emissions) and, to the extent possible, the benefits of measures such as:

- implementing an inspection and maintenance scheme and, addressing excessively polluting vehicles,
- improving fuel quality,
  - adulteration of fuel,
  - improving diesel fuel quality,
  - introducing unleaded gasoline,
  - improving the quality of lubricating oil in two-stroke engines; and
- adoption of clean vehicle emissions standards.

### *4.2.1. Implementation of a scheme for inspection & maintenance*

**Effectiveness.** Maladjustment of fuel injection or carburetors and worn-out parts not only pose a hazard to traffic safety and increase fuel consumption, they also cause large emissions. A scheme requiring annual inspection and maintenance (I&M) would result in a reduction in the emissions of $PM_{10}$, VOC (unburned hydrocarbons/HC), and CO.

A 1993 study titled, "Pollution control of motor vehicles by introducing effective maintenance/repair works" (Thapathali Campus, Institute of Engineering, 1993), conducted within the framework of the Kathmandu Valley Vehicular Emission Control Project (KVVECP), evaluated the effects of maintenance and repair on smoke levels in exhaust gases of a sample of diesel vehicles by measuring with Hartridge Smoke meters. The results suggest that simple maintenance leads to radical improvements in fuel efficiency, and smoke levels can be reduced by 20 to 50 percent in a very cost efficient manner. The results of this research support an estimate (Mehta, 1993) for Manila, and one made by the Indian Automobile Manufacturers (AIAM, 1994) for the situation in India. The KVVECP study also studied gasoline vehicles, measuring the amounts of CO and HC (VOC) in exhaust gases. The results indicate possibilities for reducing emissions at no cost.

Local measurements, therefore, support the assumption that the proposed, comprehensive, inspection and maintenance scheme would reduce emissions of $PM_{10}$, VOC, and CO by a third (35 percent reduction in tail-pipe emissions). From Table 3.2 it can be inferred that the benefits of such a scheme exceed NRs25 million.

***Table 4.1: Recommended steps in an Inspection & Maintenance scheme (Tuladhar, 1993).***

| Diesel engine | Gasoline engine |
|---|---|
| Air filter | Air filter |
| Fuel filter, tappet settings | Fuel filter, tappet settings |
| Injector Nozzle pressure | Ignition system (Spark plugs, Contact points, distributor etc.) |
| Injector pump calibration | Carburetor |
| Engine compression check up | Engine compression check up |
| Engine overhaul | Engine overhaul |

**Costs.** Vehicle-emission testing capacity is presently insufficient. The lack of capacity among government agencies can be compensated if testing is done by private firms.[3] The cost of a single test is estimated to be NRs100. This estimate is based on proposals (tests, including, roadworthiness) which have been made for Indonesia (Budirahardjo, 1994), and Manila (Baker et al, 1992). Based on the findings of the KVVECP study, it is assumed that maintenance costs will be off-set by the reduction in fuel costs associated with improved engine performance.

**Policy instruments and target groups**. A study of Thapathali Campus (1993) revealed a lack of awareness of the adverse environmental and economic effects of poor maintenance (breakdown

3 A set-up of such scheme might be:
- firms are licensed to carry out inspection;
- authorities spot-check the firms whether inspections are made properly;
- vehicles which pass the test get a sticker valid for a specific period, drivers show test report upon request;
- vehicles are spot-checked.

maintenance). This was true for both private owners, as well as fleet owners (government). This suggests the need for an awareness program which can convey the message that it pays to maintain vehicles. Eventually, inspection and maintenance could be made mandatory through a legislation which sets emissions standards (and road safety standards). The enforcement of emissions standards is the most critical component of this measure. Spot-checks by the traffic police may be the most practical approach (Mathur, 1993, Garrat, 1993).

**Term.** An awareness program could be designed and developed within one year. A mandatory inspection and maintenance scheme could be implemented within five years.

### *4.2.2. Improving fuel quality*

This measure has four components. They include addressing adulteration of gasoline, introducing low-lead and unleaded gasoline, "clean" diesel, and improving the quality of lubricating oil in two-stroke engines.

#### 4.2.2.1.Adulteration of fuel

The adulteration of gasoline by adding diesel is believed to be a common practice in Nepal. The government pricing policy has led to a large gap between the prices of diesel and gasoline, making the former much cheaper. Adulterated fuel used in motorcycles and other gasoline vehicles results in increased emissions, as well as increased wear and tear of the engines. The exact extent of this practice and its adverse environmental effects have not been quantified.

#### 4.2.2.2.Introduction of unleaded gasoline

Unleaded gasoline not only removes the problem of lead pollution in emissions, it is also a prerequisite for the introduction of strict emissions standards. An "intermediate" approach to removing all lead is to lower the lead content of gasoline.

Fuel distribution systems must ensure that unleaded and leaded fuels are not mixed. Retailers usually sell both types of fuel. This is crucial in the phase when unleaded gasoline is being introduced. The catalytic converters on new cars would be ineffective if leaded gasoline is used. Older engines may continue to use leaded fuel because of the lubrication needed for their valve seats and/or because they require a higher RON-number fuel.

**Effectiveness**. Emissions are proportional to the eventual market shares of unleaded/low-lead gasoline and, in the case of low-lead gasoline, the content of lead.

**Costs of the measure**. Gasoline, diesel oil, and fuel oils are not produced in Nepal. The Nepal Oil Corporation imports all fuel through India (Indian Oil Corporation). Therefore, there is little to no possibility of importing clean fuels until such time as clean fuels are more widely marketed in India. Recently, unleaded gasoline has been introduced in India.

Gasoline that has a lower amount of lead needs to be reformulated so that it retains the required properties (RON number). In order to obtain gasolines with sufficiently high RON numbers, the lead compound is substituted with oxygenated compounds. MTBE (Methyl-tertiary-butyl-ether) is a preferred substitute. These changes lead to an increase in production costs, typically in the range of NRs0.5-1 per liter of gasoline, depending on the local market for refinery products, required gasoline specifications and the costs of MTBE (Turner et al, 1993). It is expected that similar costs would result if the Indian petroleum industry were producing unleaded gasoline.

**Policy instruments and target groups**. Considering the supply situation, the appropriate measure would be to support the production and distribution of unleaded gasoline in India so that it can be imported to Nepal.

**Term.** Widespread availability of unleaded fuel could be implemented within five years, provided it becomes available in India.

#### 4.2.2.3.Improving diesel quality

Diesel's ignition and combustion properties explain $PM_{10}$ emission from diesel engines (Hutcheson and van Paassen, 1990, Tharby et al, 1992). Volatility (boiling range) and viscosity (including its cetane number, an indicator of the ignition properties) of fuel determine ignition and combustion and, consequently, $PM_{10}$ emission. In Nepal, the specified cetane number of diesel used for automotive purposes is 42. In the United States, Western Europe, and Japan the corresponding quality requirement varies from 48 to 50. Detergents and dispersants added to the fuel also determine its quality. These additives keep injection systems clean and have discernible effects on efficiency (Parkes, 1988).

**Effectiveness.** Improving the quality of fuel by increasing the cetane number[4] and adding detergents, results in a decrease of 10 percent in $PM_{10}$ emission, about 25 tons as an order of magnitude (AIAM, 1994, Mehta et al, 1993). A reduction in the sulfur content leads to a proportional fall in emission of $SO_2$. In addition, $PM_{10}$ emission declines because a part of the particles emitted consist of sulfates that originate from the sulfur in the fuel.

**Costs.** The cost of improving diesel fuel, particularly by increasing the cetane number, is determined by the oil-product market, refinery structure (capacity for producing light fuels, visbreaking, hydrotreating etc.), and the government's role in the national market. The government sets the price-at-the-pump for fuels.

Desulfurization of fuel at the refinery contributes the main cost. The costs per liter for a reduction from 0.7 percent to 0.2 percent are in the order of magnitude of NRs0.5 per liter. At combustion, sulfur in diesel fuel forms corrosive sulfuric acid. Therefore, a reduction in the sulfur content has a financial benefit because it reduces the costs of vehicle maintenance and repair.

The **benefit** of improving diesel quality is about NRs7.5 million.

**Policy instruments and target groups**. The barriers to the introduction of low sulfur fuel are similar to those that are encountered in the introduction of low-lead gasoline: an improvement in

[4] The physico-chemical properties - as expressed in the **cetane number** - of diesel fuel influence the magnitude of the emissions of TSP of diesel powered vehicles. The relation between these properties (such as volatility, 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 parameters that complicate the picture.

the quality of diesel fuel depends on energy policy in India. The India Oil Corporation must make the necessary investments to expand the capacity for producing improved quality diesel.

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

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

There are a large number of motorcycles and tricycles, both equipped with two-stroke mixed lubrication engines in Kathmandu Valley. These vehicles contribute about 100 tons of the $PM_{10}$ emission (through exhaust gases) from road traffic. The particles emitted by these vehicles take the form of small droplets of unburned lubrication oil. According to Shell (private communication, 1993) the lubricating oil used in most Southeast Asian countries is cheap and has poor combustion properties.

**Effectiveness.** It is assumed that using better quality lubrication oil could halve emissions (50 tons reduction). A 50 ton emissions reduction corresponds to NRs15 million (order of magnitude, data from Table 3.2).

**Costs.** Introduction of these oils will in the first estimation double the costs of lubricating oil. We estimate the annual consumption of these oils at 250 kg.[5] The total cost of low-smoke oil would be NRs12,500. The benefit would be NRs2.5 million. (Table 3.2)

**Policy instruments and target groups.** The importers of lubrication oil are the main target groups.

*4.2.3. Adoption of clean vehicle emissions standards*

Many countries with severe air pollution problems have adopted standards for allowable vehicular emissions. Current standards require vehicles which have four-stroke gasoline engines to be equipped with exhaust gas control devices, based on the use of three-way catalysts (closed loop systems). A few countries, including Austria and Taiwan, have also set standards for motorcycle emissions, requiring two-stroke engine powered vehicles to be equipped with open-loop catalysts. The latter devices control emissions of VOCs ($PM_{10}$) and CO, not $NO_x$.[6]

Regular inspection and maintenance and the availability and use of unleaded gasoline for automobiles, are prerequisites for the successful adoption of clean vehicle standards. The catalyst technology cannot be used in conjunction with leaded gasoline. The fuel's sulfur content should also be low (less than 500 ppm). Therefore, the introduction of clean vehicle standards involves a structure for producing and distributing unleaded gasoline.[7]

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5 Gasoline consumption is estimated at 28.3 x$10^3$ kl/yr. (Table 1.2). Assuming that about half is used in two-stroke engines and there is an average content of 2 to 5% lubricating oil in gasoline, brings an estimate of roughly 250 kg. of lubricating oil

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

7 To maintain the operation of the catalyst, it is absolutely necessary to avoid the use of leaded fuel. 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.

Diesel engine-powered vehicles can also be regulated. Emissions standards commonly imposed in many industrialized countries can be met by adjusting the maintenance plan and the design of motors. Tail-pipe emission treatment, as well as retrofitting buses with abatement equipment are also options. Further reduction of diesel engine emissions requires the use of exhaust gas control equipment. In addition, the quality of diesel must also be improved..

#### 4.2.3.1.Effectiveness

**Closed-loop catalytic treatment of exhaust gases** (three-way catalysts) from gasoline-engine typically reduces all exhaust emissions, including $NO_x$, CO and VOC by 85 percent. In addition, lead emissions are eliminated, because unleaded fuel is a prerequisite for the use of three-way catalysts.

**Open-loop catalytic treatment of exhaust gases** of two-stroke motorcycles generally reduces CO, VOC and $PM_{10}$ (oil mist) emissions by 90 percent. These catalysts also require the use of unleaded gasoline. An alternative would be to use well-designed and maintained four-stroke engines. We estimate that a similar emissions reduction could be obtained.

If all gasoline vehicles (including motorcycles) had been equipped with catalytic converters, the emissions would be lower by 150 tons, mortality would be reduced by about 10 lives, there would be 200,000 fewer RSD, and the overall health costs avoided would total US$75,000 (Estimated from Table 3.2). Health improvements as a result of reduced lead pollution should also be added to these benefits.

**Costs.** Due to methodological difficulties, it is not possible to calculate the total cost of introducing these standards in Kathmandu Valley. However, costs can be estimated on a vehicle-by-vehicle basis.

- The cost of **closed-loop catalytic treatments of exhaust gases** arises from the extra purchasing costs of vehicles. In the United States, this increase averages about US$400, ranging from US$300 to US$500 (Wang et al, 1993). While catalytic devices have a minor adverse effect on fuel economy, this cost is offset by an increase in the lifetime of replacement parts such as the exhaust system. The total annual cost per automobile is estimated at NRs5,000 (NRs2,500 depreciation per car, and NRs2,500 extra fuel costs).
- The cost of **open-loop catalytic treatment of exhaust gases** is related to increased purchasing costs of the equipment. Benefits include lower fuel costs due to improved operation of the engine. Taiwan adopted standards that require the use of open-loop catalytic devices which result in US$60-80 costs increase. This is offset by fuel savings (Binnie & Partners, 1992). The total annual cost is estimated at NRs3,500 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 costs of production, and the adjustment of the logistic system (modification of pump nozzles) should also be considered here. A very rough estimate of the cost is US$100 annually per vehicle (NRs2,500 depreciation of control system plus increased fuel costs in the amount of NRs2,500, depending on the subsidies/levies on gasoline).

**Policy instruments and target groups.** The groups involved in the introduction of "clean" vehicles are:
- petroleum industry and gasoline retailers (introduction of clean cars requires the availability of unleaded gasoline);
- Indian car and motorcycle industry;
- workshops that must acquire the skill for maintaining clean vehicles; and
- vehicle owners who have to pay the price.

**Term.** In practice, standards are set only for new models of cars and motorcycles. It is too expensive to equip existing vehicles with the necessary devices. Practically all new vehicles currently sold in the world market are equipped with catalytic control systems. The effect of these standards becomes apparent gradually, reflecting the rate of replacement of existing vehicles.

### *4.2.4. Improved abatement/other propulsion techniques*

The United States and Europe are considering the tightening of standards. Possibilities are:
- improving current techniques for abatement;
- improving inspection and maintenance, because a small numbers of maladjusted/worn-out cars cause disproportionally large emissions; and
- enforcing the use of "zero-pollution" vehicles (for example, electric vehicles in downtown areas.)

Diesel engines are a bottleneck in decreasing automotive emissions because, unlike gasoline engines, it is not possible to treat their exhaust gases with easily available devices such as catalytic converters. Diesel engines, however, are better with respect to CO emission.

### *4.2.5. Addressing resuspension*

Resuspension is clearly a high priority issue. Unfortunately, there is no quantitative information about measures appropriate for Kathmandu. Possible measures to tackle resuspension include improving the surfacing and periodical cleaning of roads.

### *4.2.6. Improvement of traffic management*

Traffic management includes a variety of measures such as traffic control by police or traffic lights, one-way streets, construction of new roads, and road-pricing systems. Traffic management addresses the problem of congestion. Curbside management of traffic also may improve air quality[8]. At the city level, traffic management may actually increase air pollution because it usually results in increased use of the transport system.

Although downtown air quality improves with traffic management, leading to a decline in "road-exposure," in terms of total exposure the net result may be small. Improved traffic management may have other environmental benefits such as a lessening of noise and congestion, and safer roads.

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[8] Accelerating vehicles, a dominating feature of congested traffic, emit disproportionately large amounts of pollutants.

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

A methodology to assess the costs and effectiveness of improving the Kathmandu Valley public transport system involves:

- describing a future system appropriate for Kathmandu Valley;
- assessing the performance of such a system - (passenger times kilometer);
- calculating the costs of construction;
- describing the baseline (future situation without such a system);
- estimating avoided emissions;
- outlining the non-environmental benefits; and
- designing a scheme to identify the environmental costs and benefits.

The cost of constructing a mass-transit system is high, and projects cannot be justified from an air pollution point of view alone. If proposals to build mass-transit systems are initiated from a non-environmental point of view, they should be supported in the environmental policy.

Trolleybuses are operated in Kathmandu. These are electrically powered and do not emit exhaust pollutants. This system could be expanded to provide increased public transport.

### 4.3. INDUSTRIAL COMBUSTION (EXCLUDING BRICK MANUFACTURING)

Major industries in this category include carpet manufacturers, the food industry, and metal products. These industries operate boilers that are fired with fuel oil (HSD) and agricultural wastes (e.g. rice husks).

Very little information is available about emissions from this category. Therefore it was not possible to evaluate measures such as good housekeeping practices, fuel substitution, and encouraging energy efficiency in greater detail.

### 4.4. BRICK MANUFACTURING

Brick manufacturing is a major source of pollutants in Kathmandu Valley (see Table 13 in the emissions inventory, in Appendix 3). Currently two brick producing technologies are used. The most important is the Bull's trench kiln technology (Chimney Bhatta) which accounts for about 80 percent of the brick production, and for over 95 percent of the $PM_{10}$ emission from the brick industry. The other technology is the Hoffmann (Chinese) kiln type. A third brick manufacturing technology (Vertical Shaft Brick Kiln) is currently being tested (NESS, 1995). This type of brick manufacturing is relatively clean from the air pollution point of view, but it has a high rate of brick breakage (NESS, 1995).

NESS (1995) extensively studied the economic situation of the brick industry and the problems that factory owners face. The study concluded that the availability of land and fuel are primary problems. As fuel costs are a significant portion of the cost of brick production, measures to improve the energy efficiency of kilns are beneficial to both the environment and the economy of brick manufacturing. The NESS study (1995) proposes simple techniques to scrub the flue gases in the chimneys of the Bull's trench kilns. These proposals do not fully elaborate the expected effectiveness of the device, its power consumption, the availability of scrubbing water and its effect on the draft of the chimney.

De Lange (1989) suggested a number of simple technological improvements such as improved thermal insulation, mechanical draft, etc., to improve the energy efficiency of kilns. A decrease in fuel consumption would reduce emissions as well. Replacement of coal and biomass with electricity would also be an option if consistant electricity supply was available.

### 4.5. DOMESTIC EMISSIONS AND REFUSE BURNING

Local stoves, also known as *chullas*, are the main cause of domestic emissions. The amount of emissions from these stoves is second only to brick manufacturing (see emissions inventory in Appendix 3). Traditional cooking with chullas is problematic from several perspectives. It constitutes a threat to public health (indoor pollution), particularly for women; it wastes energy; it depletes natural forest resources, and it has an adverse effect on outdoor air quality.

Traditional cooking with fuelwood and agricultural waste is extremely energy inefficient. Improved cooking stoves that have an energy-efficiency of 20 percent, as compared to traditional stoves that are 12 percent efficient (Malla and Shrestha, 1993), constitute part of a solution. The introduction of improved cooking stoves is, from an environmental viewpoint, a highly effective approach to improve air quality. There is little information about the improved stoves attractiveness to traditional households that are usually low-income, therefore no cost-effectiveness estimates have been presented here

An alternative approach to reducing the emissions from cooking is to foster the use of kerosene as a cooking fuel. A scheme for subsidizing the use of kerosene, if feasible, might be an appropriate instrument to reduce the use of fuelwood. Refuse burning can be avoided by extending the public refuse collection system.

### 4.6. CONCLUSIONS

This chapter describes a number of measures that are appropriate for improving the air quality in Kathmandu Valley. It deals with several aspects of the measures: effectiveness, costs, benefits, implementation, and the institutions involved. The benefits in terms of reduced health impacts and other damages, together with the costs of implementing each measure, provide information on how to prioritize these measures. The quantitative information presented is often characterized in order of magnitude.

Measures to address traffic emissions are dealt with in greatest detail because the traffic-related causes of pollution are clearly recognized and documented. An abatement measure that stands out from a cost-benefit point of view is the routine maintenance of vehicles. The costs to vehicle owners are offset by benefits in terms of reduced fuel costs. The benefits from reduced health damage costs should also be added.

Due to a lack of data, cost estimates are not made for measures other than those in the transport sector. This is a serious drawback because some of these sources -- particularly Bull's Trench brick kilns, and domestic use of fuelwood and agricultural waste -- are almost equally important sources of $PM_{10}$ exposure in the Kathmandu Valley.

# 5. ACTION PLAN

The following action plan is based on the cost-benefit analysis of various measures that reduce air pollution and its damages. The Plan is based on available data, the shortcomings of which have been identified throughout the text. Improving the database is necessary in order to extend the action plan to include additional measures.

The "actions" consists of two categories:

1. Technical and other measures that reduce the exposure and damage.
2. Improvement of the data base, and the regulatory and institutional basis for establishing an operative AQMS in Kathmandu Valley.

The time frame in which the actions or measures could be implemented, and would be effective, is indicated: short term (fewer than 5 years), medium term (5-10 years), long term (more than 10 years).

## 5.1. ACTIONS TO IMPROVE AIR QUALITY AND ITS MANAGEMENT

### *5.1.1. Actions to improve air quality*

Actions and measures have been proposed by the Kathmandu Valley URBAIR working groups. The list of measures proposed by the URBAIR working group is presented in Table 5.3. The proposed actions/measures have been put in the following categories:

1. Air quality monitoring
2. Inventory/dispersion modeling
3. Institutional and regulatory framework
4. Traffic management
5. Transport demand management
6. Land use planning
7. Fuel switch
8. Improved fuel quality
9. Technology improvement
10. Awareness raising
11. Further studies
12. Water supply and sanitary management
13. Solid waste management and recycling

The following sources are of equal importance both in terms of health impacts, and in reduction in visibility.

- Vehicle exhaust (diesel and gasoline)
- Domestic fuel combustion
- Resuspension from roads

- Bull's Trench brick kilns.

Vehicle exhaust is the most important source in terms of reducing health damage. Uncontrolled emissions from Himal Cement Factory are important determinants of visibility.

Table 5.1 presents a list of technical measures, with an indication of the importance of the measure to reduce pollution. Introduction in the short, medium, and long term is indicated. Proposed measures are economically feasible in the indicated time frame. The measures are not described in great detail. The list does not represent a ranking based on cost-benefit ratios.

***Table 5.1: A list of technical pollution abatement measures, important for the reduction of the air pollution effects in Kathmandu Valley (xxx more important than x).***

| Abatement measure | Short-term | Medium-term | Long-term |
|---|---|---|---|
| ***Technical measures, vehicles*** | | | |
| I/M scheme, comprehensive | xxx | | |
| Improved motorcycle technology | | xx | xx |
| Clean vehicle standards | | xx | xx |
| Improved abatement/new propulsion techniques | | | xx |
| ***Fuel quality*** | | | |
| Control adulteration | xxx | | |
| Low-lead gasoline | xx | | |
| Unleaded gasoline | | xx | |
| Improved diesel quality | xx | xx | |
| Low-smoke lub. oil, 2-stroke engines | xxx | | |
| ***Road resuspension*** | | | |
| Road cleaning, garbage collection | xxx | | |
| ***Domestic emissions*** | | | |
| Improved cooking stoves | x | xx | |
| Switch to kerosene | x | xx | |
| ***Brick industry*** | | | |
| Improved technology | x | xx | |

The success of abatement measures rests with the enforcement of the action. It is important to ensure that conditions are met for carrying out the necessary technical improvements/adjustments. This may mean ensuring sufficient workshop capacity and capability for efficient adjustment of engines, the availability of spare parts at a reasonable price, environmental education and outreach via television, newspapers and other media. Additional measures include traffic managment and transport demand management, including land use planning.

Expansion of the trolley bus system and electric vehicles in Kathmandu can also be supported from a local environmental point of view. Additionally, "Adopt-a-Street" could be used to promote private sector participation in socially responsible environmental management and awareness raising. Making streets safer for non-motorized vehicles, and pedestrians and not only for more motor vehicles is another priority.

### *5.1.2. Actions to improve the Air Quality Management System*

Actions to refine air quality management include improving the following:

- Air quality assessment,
- Assessment of damage and its costs,
- Inventory of abatement measures,
- Institutional and regulatory framework and
- Awareness among the public and policy makers.

Actions to improve air quality management are summarized in Table 5.2, together with other necessary improvements.

***Table 5.2: Actions to improve the Air Quality Management System of Kathmandu Valley.***

| | |
|---|---|
| Air pollution monitoring | Establish a monitoring system, covering:<br>- compounds such as TSP, $PM_{10}$, combustion particles, black smoke, CO, visibility, etc.<br>- sites, such as traffic exposed, city background, brick kiln area, rural, hilltop, etc.<br>- long term operation<br>- continuous monitors, where available<br>Indoor air pollution study.<br>Up-grade laboratory, establish quality control system. |
| Emissions | Improved, comprehensive fuel statistics.<br>Establish/improve emission factors for vehicles, brick kilns, domestic fuel combustion, resuspension.<br>Study particle size distribution of emissions from various sources, as well as for the ambient pollution. |
| Population exposure | Establish appropriate dispersion model for Kathmandu Valley. |
| Assessment of damage and cost | Epidemiological research, assessment of specific health costs.<br>Empirical study of tourism and environment (tourists attitudes).<br>Identification of interest of other parties in a cleaner environment. |
| Inventory of abatement measures | Effectiveness (abated/avoided emissions).<br>Costs.<br>Non-environmental environmental. |
| Institutional and regulatory framework | Involvement of the Nepal Oil Corporation.<br>Tax differentiation between clean and dirty diesel, if there areways of importing clean diesel<br>For the brick industry, develop clean technologies |
| Awareness building | Publicity campaigns on billboards and in the media to raise attention to issues, e.g. smoke-belching, health damage, and expected developments if no actions are taken).<br>Environmental education in schools.<br>Organization of environmental education courses.<br>Setting up an environmental information center.<br>Support of environmental NGOs. |

*Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.*

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| ***Category 1. Ambient Air Quality Monitoring, Inventory and Dispersion Modeling*** | | | | |
| **I. Air Quality Monitoring** | | | | |
| 1. A. Design national air quality monitoring program. | - Review national air pollution status and assessment capabilities; | ASAP | NPC/EPC, DOHM, DOTM | Monitoring ambient air quality will be trusted to DOHM with close cooperation with MOI and MOWT and NGOs |
| | - Establish field stations and base laboratory | 1995 | | |
| B. Design and establish quality assurance system (evaluation of sites, number and location) | - Tap funding agency support; | 1995 | NPC/EPC/DOTM, DOHM | |
| | -Identify needs and gaps in the existing facilities; | ASP | Donors, community, NOG, DOHM consultants, academic | |
| | -Determine air pollution impact on health | 1995 | MOH, consultants | |
| **II. Inventory and dispersion modeling** | | | | |
| 1.. Design/Develop a comprehensive emission inventory procedure including emission factor review and update, (all sources) and cost | - Coordination with academic, policy-making body, implementing agencies such as MOWT, MOI, DOHM, DOTM. | ASAP | DOHM, MOI, Academic consultants, NPC/EPC | |
| | - Funding support such as MEIP | 1995 on going | DOHM, NPC consultants | |
| 2. Improve emissions inventory of both mobile and stationary sources. | - mass balance approach | 1995 on going | Consultants, DOHM, MOI, DOTM | |
| 3. Conduct inventory of domestic emission | - Coordinate with indoor-air pollution program | S/S | academic consultants | Coordinating with donors |
| ***Category 2. Traffic Demand Management and Infrastructure Improvement*** | | | | |
| 1. Improve traffic flow<br>a. Improve existing road network<br>b. Introduce traffic man-agreement concept | - Remove obstructions (unloaded building materials, roadside vendors, alternate parking facilities, repair and service shops, etc.) | 1995 onwards | - DOR, DOTM municipalities, Traffic police | MOWT/MLD/MHPP will develop a comprehensive plan and traffic police as well as municipalities will serve as enforcing agencies |
| | - Synchronize and optimize repair roads | 1995 onwards | - DOR, DOTM municipalities | |
| | - Ensure proper coordination among different units of government for digging. | | - DOR, DOTM, NEA, NTC, NWSC, municipalities, NEA, NTC, NWSC | |
| | - Radial roads and public transportation facilities. | | DOR, UCC | |
| c. Extend/develop road network | Implement the recommendation of Urban Road Development Master Plan (JICA study report | 1993 onward | DOR, MOWT, DOTM, MHPP, municipalities | |

*Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.*

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| d. Improve facilities for non-motorized traffic | Construct pedestrian overpasses and sidewalks | 1994 onwards | DOR, municipalities, DOTM | |
| e. Implement Transport Service Rationalization Program | Study the implementation of a private car utilization restraint policy which would include:<br>- limit entry within certain areas; | | DOTM, Traffic Police, DOR | |
| | - define and mark the lanes and enforce the rules; | 1994 | | |
| | - encourage carpooling through demand management measures like parking regulations by charging a higher parking fee; | 1995 onwards | | |
| | - designate where public utility vehicles (buses, taxis, etc.) can stop. | 1994 | | |
| f. Immediate Improvement of Enforcement/Traffic Laws | Rationalize/standardize traffic laws, rules and regulations by enacting traffic code and use standard form; | 1994 | MOWT, DOR, DOTM, Traffic police | |
| | Provide proper training to enforcers drivers and require them to pass exams; | 1994 onwards | DOTM, Traffic Police | |
| | Set up monitoring and evaluation system for enforcers and for violators; | 1995 onwards | DOTM, Traffic police | |
| | Effect traffic safety seminars and traffic rules and regulations re-education | 1994 | DOTM, Traffic Police | |
| | Use mass media for information dissemination | 1995 onwards | DOTM, Traffic Police, All Media | |
| 2. Introduce and expand computerized information system at traffic police | Create technical group to evaluate existing information system and prepare plans. | Action Result 1994 | Traffic Police, MOH | |
| 3. Strengthen Traffic Safety Program | Establishment of wide walk network | 1995 | DOR, DOTM | |
| | Organize traffic safety seminars/weeks and also re-education of traffic rules and regulation. | 1994 onward | | |
| | Immediately strengthen traffic police/traffic lights/zebra crossing for traffic improvement | | DOTM, DOR, Traffic Police | |
| 4. Expansion of public transport/system | Advocate and support | 1995 | MOWT, DOTM | |
| 5. Provide environment friendly transportation | Extend trolley bus network | 1994 onwards | MOWT, NTC | |

*Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.*

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| 6. Survey present mass transit situation and improve:<br>- time schedules,<br>- junctions and stations | Implement survey results | 1994 onwards | DOTM | |
| ***Category 3. Land Use Planning and Management*** | | | | |
| 1. Land use planning to reduce transport demand | Workout strategy for dispersing facilities (shopping, etc.) so that these are closer to users and generate less traffic | S/S | MHPP, DOB, DHUD, DOTM | MHPP/MLP are the key actors |
| 2. Update land use plans/GLDP for Kathmandu Valley and revise zoning ordinates | Update land use plan and pass new zoning ordinances | S/S | MHPP, DHUD | |
| | raise awareness through training and education campaigns to make people realize the benefits of planning<br>Extend GLDP to areas where environmental standard is low | S/S | MHPP, DHUD, NGOs, municipalities | |
| 3. Conservation of open spaces | Ensure buffer zones parks and other public amenities by strict enforcement of land use policy | ASAP | MHPP, MLD, DHUD municipalities, NGOs | |
| 4. Land use policy for Industrial establishments | Develop and enforce inter and intra-industrial land use zoning | ASAP | MHPP, MOI | |
| ***Category 4. Fuel Switch/Quality Control*** | | | | |
| 1. Switch on to less polluting utility vehicles in various organizations | Tax or subsidy modification. | ASAP | MOS, MOF | Leading role should be played by MOS and NOC. |
| | Study restructuring of taxes on diesel vis-à-vis petrol with a view to encourage the use of petrol over diesel.<br>Study market implications of such modifications. | | | |
| 2. Address the problems of dilution and adulteration of fuel | Strict enforcement of laws relating to quality control of petroleum products:<br>- frequent inspection of petrol pumps or dealers and tankers;<br>- stiffer penalties for violations;<br>- start mobile laboratory van or testing fuels. | ongoing | NOC, DAO | |

*Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.*

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| | Inform public about ways to detect adulterated and diluted fuel and its effect. Use filter paper or thermometer for testing fuels. NOC has introduced a system of thermometer but it needs to be made accessible and its existence known to the consumer. | ASAP | NOC | |
| | Use NGOs and consumer protection councils for educating the public. | S/S | NOC, NGOs | |
| 3. Phasing out of lead in petrol | Study its feasibility, possibility of revision of supply to some extent, the additional cost to the consumers. | ASAP | MOS, NOC | |
| 4.. Review energy pricing policy. Consider impacts to environment (petroleum products and electricity or other fuels) | Study the issue and feasibility of removing all price distortions. Consider environmental costs. | ASAP | MOS, MOF, NOC, NPC/EPC, DOTM | |
| | Study impacts of removal of subsidies on diesel; Study the possibility of introducing pollution tax. | | | |
| ***Category 5. General Awareness Raising*** | | | | |
| 1. Awareness/information on air pollution | Use tri-media | ASAP, 1995 | MECSW, NPC/EPC, MHPP, MCI | Target groups: public through CBO, NGOs, government units |
| | Start pollution information forum. | | | |
| | Publish bulletin/newsletter. | | MOH, NGOs, EPC | |
| - Improve indoor/ outdoor air quality | Launch antismoke campaign | | MECSW, MHPP, MOH, NGOs | |
| | Arrange talk programs in public places (Haat/Bazar, schools, restaurants, etc.) | | | |
| | Indoor ventilation/improved cooking stoves | | MCI, MOH | |
| | Designate smoke-free zones | | | |
| - Promote correct value system | Include in school curriculum | | MECSW | |
| - Care for the environment/fellowmen | Media campaign to create awareness | | | |
| | Amend/Revise rules to ensure effectiveness | | | |
| | Follow-up KVVECP campaign | | MCI, NGOs, MOWT | |
| 2. Traffic Management | Train enforcers and drivers | ASAP | Traffic Police | |
| | Proper tuning of vehicles. | | DOTM | |

*Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.*

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| | Organize traffic week regularly | S/S | MECSW, TP, DOTM | |
| | Use mass media for public awareness | S/S | MCI, DOTM | |
| 3. Supply quality fuel | Information to detect diluted fuel and its effect | S/S | NOC | |
| | Introduce an appropriate system of fuel testing at petrol pumps. | S/S | NOC | |
| ***Category 6. Further Studies*** | | | | |
| 1. Air Quality Monitoring | Conduct appropriate studies which will relate to more rational emission standards | ASAP | NPC/EPC | NPC/EPC will handle every item for further study in detail in consultation with line agencies and NGOs |
| 2. Inventory Dispersion Modeling | Study re-suspension from roads and other sources | 1995 | | |
| 3. Institutional and Regulatory Framework | Study ways to strengthen legal mechanism for introducing "polluters pay" principle. | 1995 | | |
| | Study possible incentives for enforce and other staffs involved in environmental management | 1995 | | |
| | Study the possibility of accrediting private entities for vehicle inspection and emission inspection system. | 1995 | | |
| | Study the feasibility of phasing out importation of secondhand and reconditioned vehicles. | 1995 | | |
| 4. Traffic Demands/ Management | Study the implementation of a private car utilization restraint policy. | 1995 | | |
| | Study staggering of work and study hours/days and days off. | 1995 | | |
| | Study and update feasibility of extending trolley bus network | 1995 | | |
| 5. Land Use Planning | Study and update land use plans to facilitate transport demand | 1995 | | |
| 6. Fuel Switch/Quality Control | Study the feasibility of using LPG in public transport. | 1995 | | |
| | Study of market implication of taxes on diesel vis-à-vis petrol with a view to encourage the use of petrol. | 1995 | | |
| | Study the feasibility of marketing unleaded petrol and identify/evaluate other additives. | 1995 | | |
| | Study impacts of removal or phasing out of existing subsidy for diesel. | 1995 | | |
| | Study the possibility of introducing pollution tax. | 1995 | | |

***Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.***

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| 7. Research on Air Pollution Effects on Health | Effects of decrease in lead/lead-free petrol and other concomitant pollutant | 1996 | | |
| | Study on air pollution effects on cardio-vascular and respiratory diseases | 1996 | | |
| 8. Study the possibility of alternative fuel such as LPG, CNG, electric vehicles, etc. | Start R&D | 1995 | | |
| 9. Review the policies of vehicle import to the Kathmandu Valley, Nepal | Analyze present policies in comprehensive ways and correlate with the realities | 1995 | | |
| 10. Study the economic aspect of the effects of air pollution in the Valley | Explore the economic loss due to air pollution | 1995 | | |
| ***Category 7. Institutional and Regulatory Framework*** | | | | |
| 1. Introduce "polluters pay" principle through appropriate regulatory measures and serve penalties against violators | Plug and amend existing environmental legislation. | S/S | MLD, MHPP, MOWT, BSM, MOI | A high level coordinating and monitoring unit at NPC/EPC will be constituted with representation from government and private sector to supervise the overall managerial activities. |
| | Impose penalties to violators | S/S | EPC, Traffic Police, DOTM | |
| | Ensure regulation from the practical point of view | | | |
| | Amend and pass bill | ASAP | NPC/EPC, DOTM | |
| | Introduce mandatory third party insurance | ASAP | SWMRMC/MLD | |
| | Incorporate users charge. | 1995 | Municipality, | |
| | Formulate pollution standard | ASAP | NPC/EPC/DOTM | |
| | Give pressure for the localization of industries | ASAP | MOI | |
| | Introduce quality drainage management | ASAP | DWSS | |
| 2. Strengthen technical capabilities relevant government agencies, industry, municipality, SWMRMC and NGOs for environmental management | Establish and promote training institutions | S/S | MLD | |
| | Promote technical and economic capabilities | S/S | EPC | |
| | Encourage community/people participation | ASAP | MLD, TDC | |

*Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.*

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| | Increase economic benefit of the staffs. | 1995 | Relevant Govt. Agencies, NGOs | |
| | Encourage private sector involvement | ASAP | | |
| | Promote private lab for testing | ASAP | | |
| 3. Coordinate efforts among different government and non-government agencies involved in air pollution control | Strengthen existing traffic management | S/S | MLD, Traffic Police, DOTM | |
| | Execute common monitoring guidelines | ASAP | DWSS, RONAST, DOTM | |
| | Creation of one environmental body | 1995 | EPC/NPC | |
| 4. Analysis of regulation by all concerned agencies. | Pass odometer law | ASAP | MLD, EPC | |
| | Require total disclosure and technigraph for all vehicles. | ASAP | DWSS, SWMRMC, NGOs | |
| | Encourage to import standard spare parts | S/S | | |
| | Fixing parameters on air, water, noise and land pollution control. | S/S | EPC | |
| 5. Study possible incentive and funding for enforcer and other staffs involved in environmental monitoring management. | Analyze existing salary scales for merit | ASAP | EPC, MLD, DWSS, MSS, SWMRMC, municipalities, NGOS | |
| | Create a fund to provide and support economic benefit. | ASAP | | |
| | Allocate more budget. | | | |
| | Launch antismoke belching campaign. | | | |
| | Create environmental fees/fines and setup a trust fund.. | | | |
| 6. Remove jurisdictional boundaries between different institutions. | Duplication of jurisdictional boundaries and responsibilities be avoided. | S/S | MLD, MHPP, EPC | |
| | Play vital role with O&M activities | S/S | | |
| | Provide detailed guidelines and strengthen SWMRC and municipalities. | S/S | | |
| 7. Strengthen enforcement capabilities of concerned authorities | Train people or staffs and maintain coordination. | ASAP | MLD, MHPP | |

*Table 5.3. Proposed actions and measures to improve the air quality of Kathmandu Valley.*

| What | How | When | Who | Remarks |
|---|---|---|---|---|
| | Tap NGO to assist. Use media pressure. Setup hotline to report violators. | S/S | EPC | |
| 8. Strictly and uniformly implement antismoke belching campaign | Prepare a manual, strengthen implementation capability of traffic police, among others. | 1995 | EPC, MOWT, MHPP, MLD, Traffic police, DOTM | |
| | Encourage NGOs relevant government agencies to launch awareness campaigns. | ASAP | EPC, MHPP, MLD, MOE | |
| | Encourage garage testing | ASAP | DOTM | |
| | Encourage school, office to start this campaign | ASAP | MOE | |
| 9. Strict emission control for cars, motorcycles, heavy-duty vehicle, tempos | Policy, translation into implementation procedure, set time schedule | 1995 on-going | NPC/EPC Traffic Police, MOWT, DOTM | |
| 10. Address highly polluting: vehicles<br>industries<br>road maintenance<br>construction on laws;<br>use of emission control equipment/improvement | Enforce existing laws/legislation | ASAP | NPC, MOI, Traffic Police, DOTM, DOR, citizen groups, NGO consulting firms | |
| | Replacement of engines<br>Follow-up of industrial EIA procedure | on-going | | |

# 6. EXISTING LAWS AND INSTITUTIONS

### 6.1. LAWS AND REGULATIONS ON AIR POLLUTION

The development of environmental and air pollution legislation in Nepal is in its first phase. Prior to 1994, there were no laws or regulations pertaining specifically to air pollution. Economic development in Nepal has been accompanied by worsening environmental problems and there is now a growing awareness of this relationship. Statements on the need to protect the environment have been included in Five-Year Plans. An Environment Protection Council had been established under the Chairmanship of the Prime Minister, and an Environmental Protection Division exists within the National Planning Commission (NPC).

The government's environmental policies and actions were set out in the Eighth Five-Year Plan document. These may be summarized as follows:

1. adopt an integrated approach to environmental policy, with sustainability as the overall goal;
2. develop strategies for sustainability, and provide for their implementation directly through regional and local planning;
3. require proposed development projects, program, and policies to include environmental impact assessment and extended economic appraisal;
4. establish a comprehensive system of environmental law and provide for its implementation and enforcement;
5. recognize the legitimacy of local controls, implementation, and enforcement mechanisms in local environmental planning and management;
6. ensure that all national policies, development plans, budgets and decisions on investments take full account of their effects on environment;
7. provide economic incentives for conservation and sustainable use;
8. strengthen the knowledge base, and make information on environmental matters more accessible; and
9. ensure that strategies for sustainability include actions to motivate, educate and create conditions for individuals to lead their lives in a sustainable environment.

In its "Approach to the Eighth Five-Year Plan," the Government has specified policies and actions to ensure that all national policies, development plans, budgets and decisions on investments take full account of their environmental impacts. In particular, the Eighth Plan specifies that the urban environment will be improved through the control of waste, and through the establishment of water, air and noise standards.

According to His Majesty's Government, Ministry of Industry, Nepal, two basic activities for the formulation of legislation on air pollution have been recently completed and forwarded for approval by the cabinet:

a) Environmental Impact Assessment (EIA) guidelines for the industrial sector have been forwarded for approval by the cabinet. The guidelines include measures for mitigating the increased pollution generated by new industrial establishments in Nepal; and
b) Industrial Pollution Control Regulation (IPCR) for air and water discharges was drafted as an outcome of a workshop conducted by HMG/Ministry of Industry in June 1994. Concerned sectors, agencies and NGOs were involved. According to the Ministry, the draft was expected to become a regulation by November 1994.

Laws on Vehicle Pollution Control have been proposed according to recommendations from the KVVECP study. They include limits on diesel smoke from diesel vehicles (65 Hartridge Smoke Units, HSU, free acceleration test) and CO emission from gasoline vehicles (3 percent at idle). To our knowledge, standards or guidelines for air pollution concentrations have not yet been passed.

## 6.2. INSTITUTIONS INVOLVED

The following is a listing of the institutions responsible for environment.

**Coordination**
- HMG/National Planning Commission (NPC/Environment Protection Council (EPC); and
- Metropolitan Environment Improvement Program (MEIP)/World Bank.

**Monitoring**
- Department of Hydrology and Meteorology, Babarmahal, Kathmandu;
- Royal Nepal Academy of Science & Technology (RONAST), Naya Baneshwor, Kathmandu; and
- HMG / Bureau of Standards.

**Emissions Inventories**
- Department of Hydrology and Meteorology, Babarmahal, Kathmandu;
- Kathmandu Valley Vehicle Emission Control Project (the 1st phase), funded by UNDP, under Department of Transport Management, Naya Baneshwor, Kathmandu; and
- Royal Nepal Academy of Science & Technology (RONAST), Naya Baneshwor, Kathmandu.

**Legislation**
- HMG / Ministry of Law, Babarmahal, Kathmandu.

**Enforcement**
- Department of Traffic Management, Naya Baneshwor, Kathmandu; and
- Kathmandu Valley Traffic Police, Singhadurbar, Kathmandu.

The above mentioned departments are basically funded by the Government of Nepal, except for the 'Kathmandu Valley Vehicle Emission Control Project (1st phase)' which was financed by UNDP and MEIP.

Manpower, expertise, and equipment data for the organizations are are listed in Table 6.1.

***Table 6.1: Institutions and Equipment Need for Kathmandu, Nepal.***

| Name of Dept. | Manpower | Expertise | Equipment |
|---|---|---|---|
| 1. Dept. of Transport Management | 255 | 26 | • 10 smoke meters, analyzers and 4 High Volume Samplers of Envirotech Co., India, and 2 CO/HC analyzers of Horiba Co., Japan |
| 2. KTM Valley Traffic Police | 455 | 44 | • Shares the equipment from the Dept. of Management |
| 3. Thapathali Campus | 90 | 42 | • Technical vocational school owns most of the equipment for repair and maintenance of machinery and also shares equipment for vehicle emissions check from the Dept. of Transport Management. |
| 4. Dept. of Hydrology and Meteorology | 300 | 50 | • Meteorological station at Babarmahal. |
| 5. Vehicle Emission Control Project, 2nd phase (under formulation) | | | |
| 6. Dept. of Civil Aviation | | | • N.A. Fully equipped meteorological station for aviation purposes at the airport, Kathmandu. |
| 7. RONAST | 180 | 108 | • High Volume and Handy Samplers one each, and a fully equipped meteorological station at Sundari Ghat, Kirtipur, Kathmandu. |
| 8. HMG/Bureau of Standard | 80 | 68 | • Laboratory for quality control of all kinds of products |

**Note**: The equipment owned by HMG/Department of Transport Management is rotated among the enforcing organizations in the Valley.

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# APPENDICES

# PREFACE

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

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

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

This report contains the appendices to the main report.

# APPENDIX 1: AIR QUALITY STATUS, KATHMANDU VALLEY

## OUTDOOR (AMBIENT) CONCENTRATIONS

**Past measurements.** Prior to 1993, only scattered measurements of air pollution concentrations have been performed. The KVVECP (Kathmandu Valley Vehicle Exhaust Control Program) (Mathur, 1993) study identified 7 previous studies, which included some measurements (Table 1). In these studies, measurements were confined to roadside sites. Thus, the results are not representing the status of general population exposure.

Mathema et al. (1992) describes some results from measurements done, in the following manner:

> "A 1980-study carried out by Bhattarai and Shrestha (1981) on dust pollution at Kathmandu concludes that at 18 spots where the data was collected, lead content was far in excess of the reasonably acceptable level of 0.6 parts per million. At busy street and cross-roads the lead content was found to be in the range of 544 ppm (Maitighar) to 153 ppm (Tripureswor). A 1987 study on pollution in the Kathmandu City carried out experiments to determine "particulate loading" (extent of dust present in the air) in the month of September when dust pollution is expected to be low. It was found that at the three locations where measurements were recorded (Jochhen Tole, Singha Durbar, and Lazimpat) the amounts of dust particles per cubic meter of air were between 6 and 11 times the relevant US standard (MHPP, 1991(b). Similar experiments carried out by CEDA (1990) in Pokhara, Kathmandu, and Biratnagar have led to similar conclusions, during the 1989/90 India-Nepal trade impasse when vehicular traffic volume was considerably lowered due to shortage of gasoline/petrol. Davidson and Pandey (1986/p 115-119) have shown that the concentration of $SO_4$, $NO_3$ and C (organic) and lead at the curb of a busy street of Kathmandu is comparable to those in urban areas in industrialized countries."

Measurements of particles and their content of mycoflora in Kathmandu City were performed in June, October and November, 1992 (U. Sharma et al., 1992). 16 samples were collected at 16 different locations near roads, using a Millipore pump and filters (6-8 hours of sampling). The sampling method indicates that the measurements are related to measurements of Total Suspended Particle (TSP), as measured with a high volume sampler.

The particle concentration was within the range 197-524 $\mu g/m^3$, averaging 304 $\mu g/m^3$. The corresponding Air Quality Guideline of WHO is 120 $\mu g/m^3$. Thus, the measured concentrations

***Table 1: Air quality related studies in Kathmandu Valley prior to 1993 (Ref.: KVVECP study).***

| Reference of study | Year | Conclusions |
|---|---|---|
| 1. Bhattarai and Shrestha | 1980 | Kathmandu: Pb<br>Maitighar: 544 ppm<br>Tripureshwor: 153 ppm |
| 2. MHPP Pollution study | 1987 | Kathmandu: Road side dust: 6 to 11 times of U.S. Std. |
| 3. CEDA study | 1989/90 | Pokhara, Kathmandu, Biratnagar, road side dust: (SPM) higher than WHO standards. |
| 4. Davidson and Pandey | 1986 | Kathmandu: $SO_2$, $NO_x$ and Pb higher than WHO std. |
| 5. Sharma and Pradhanang | 1992 | Kathmandu: Milipore pump & micro flora SPM range: 197-524 μg/m$^3$. |
| 6. NILU Team observation | 1993 | Kathmandu: Low visibility and haze, road side SPM high |
| 7. RONAST | 1993 | Kathmandu: Road side SPM 197-775 μg/m$^3$ higher than international stds. |

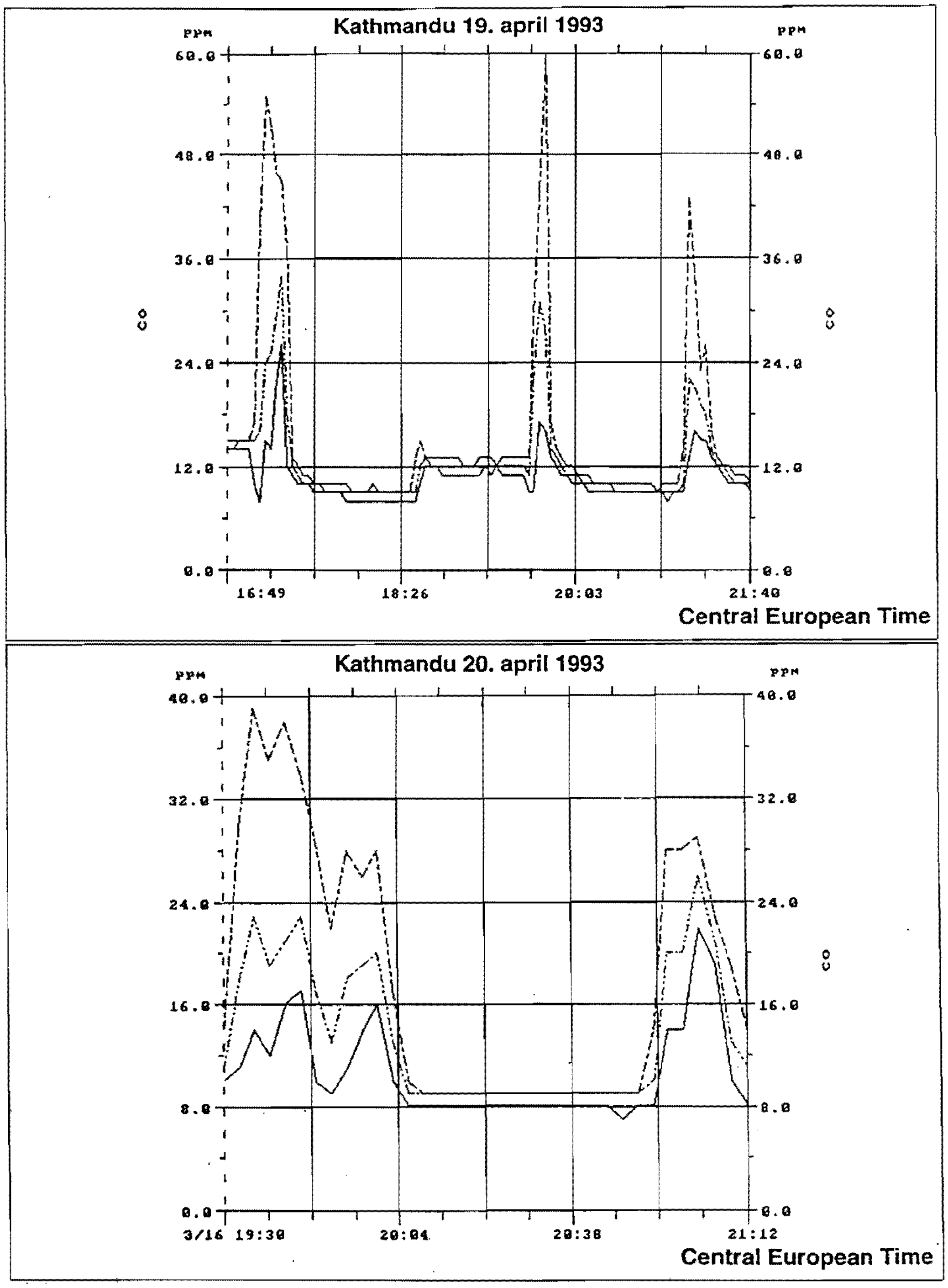
were all above this guideline. It can be expected that the TSP concentrations are considerably higher in the dry season, especially during the January-April period.

Various species of fungi were isolated from the particle samples described above. The fungi may be agents of different diseases, and some of them are allergens. The source of this mycoflora in the particles is resuspended dust on the roads. This dust is composed of dust from dirt roads and construction sites, as well as scattered refuse from human activities.

The latest study before the KVVECP measurements, the ENPHO (NGO) study, confirmed the very high TSP concentrations roadside in the Valley, with daytime concentrations up to 2258 μg/m$^3$ (at Kuleswore). This study also included $PM_{10}$ measurements giving concentrations within 50-130 μg/m$^3$. Measurements of CO, $SO_2$ and $NO_2$ gave rather low values, within WHO standards.

**NILU observations, April 1993.** During a field trip to Kathmandu 18-21 April, 1993, the CO concentrations were monitored along some road routes (Figure 1). Generally, the recorded CO concentrations in highly trafficked areas were in the range 15-20 ppm, with peaks up to 60 ppm.

*Figure 1: CO measurements performed by NILU in Kathmandu, traveling on roads by taxi, April 1993.*



**Results of measurements after 1992.** The following measurement campaigns have been carried out after 1992 (in chronological order):

- Environment & Public Health Organization (ENPHO) carried out TSP, $PM_{10}$, $NO_x$, CO, $SO_2$ and lead measurements at a total of 20 sites in Kathmandu City, in November 1992 and February 1993 (Karmacharya and Shrestha, 1993).
- The Kathmandu Valley Vehicle Exhaust Control Program (KVVECP) carried out a measurement campaign of TSP, $PM_{10}$, $NO_2$, $SO_2$, CO and lead at 14 sites during September-December 1993 (Devkota, 1993).
- Measurements by NESS (Pvt) Ltd. of $PM_{10}$ and lead at a number of sites in Kathmandu City during September-November, 1993 (Sharma et al., 1994).
- Measurements of TSP by the Hydrological and Meteorological Service at the HMS building at Babar Mahal, starting from January 1993.

In addition, visibility observations have been made at Tribhuvan International Airport since the early 1970's (see Chapter 3 of this Appendix).

**Results from the ENPHO measurements.** The measurements were carried out in two phases (Karmacharya et al., 1993):

- In November 1992, at 9 sites of various height and distance from roads, to get a general picture of the air quality of the area. 24-hour averages.
- In February, 1993, at 11 roadside sites, to get a picture of roadside exposure. 9-hour averages.

Monitoring sites are shown in Figure 2, and described in Table 2. The methods are given in Table 6. The description of the project indicates that only one sample was taken at each site. Results are given in Table 3 and 4 for phase 1 and 2 respectively.

The results indicate that TSP is the main problem compared to the WHO guideline. The measurements from phase 1 (24 hour averages) averaged 308 $\mu g/m^3$, with maximum concentration of 555 $\mu g/m^3$, at Chabahil. $PM_{10}$ also exceeded the guideline at many of the sites, but to a lesser extent than TSP. Maximum $PM_{10}$ concentration was 127 $\mu g/m^3$ (WHO guideline: 70 $\mu g/m^3$). The $SO_2$, $NO_x$ and CO measurements indicated rather low concentrations.

The lead measurements also indicated fairly low concentrations, with a maximum 24-hour value of 0.53 $\mu g/m^3$, against a long-term WHO guideline of 0.5-1 $\mu g/m^3$.

*Figure 2: ENPHO campaign measurement sites (Karmacharya et al., 1993).*

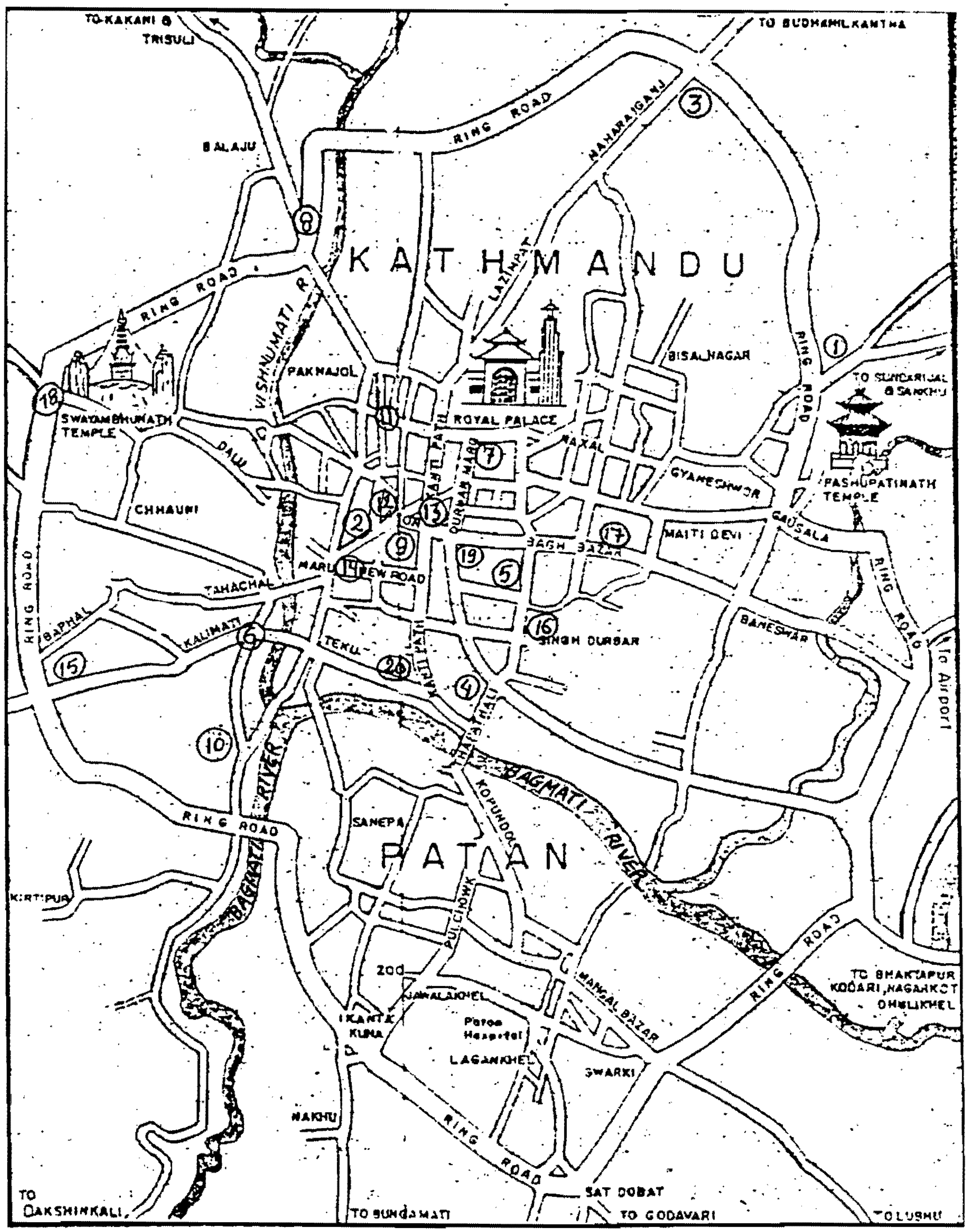


*Table 2: Description of ENPHO campaign measurement sites (Karmacharya et al., 1993).*

| Sampling station | Height (m) | Distance from closest road (m) | Distance from popular junction (m) | Direction from the popular junction (m) | Type of area | Traffic density |
|---|---|---|---|---|---|---|
| 1. Chabahil | 3 | 5 | 100 | North-East | Residential/ Market | Busy |
| 2. Indrachowk | 12 | 5 | 50 | North-West | Residential/ Market | Busy |
| 3. Maharajgunj (Ring Road) | 5 | 15 | 30 | South-East | Residential | Moderate |
| 4. Thapathali | 3 | 5 | 75 | North-West | Residential/ Market | Busy |
| 5. Putalisadak | 6 | 8 | 75 | South | Residential/ Market | Busy |
| 6. Kalimati | 10 | 5 | 25 | North | Residential/ Market | Busy |
| 7. Royal Palace | 5 | 8 | 30 | South-West | Market | Busy |
| 8. Balaju (Ring Road) | 6 | 15 | 35 | North-West | Residential/ Market | Busy |
| 9. Bir Hospital | 3 | 5 | 25 | North-West | Residential/ Market | Busy |
| 10. Kuleswor | 0.75 | 2 | Right at the junction | West | Residential /Market | Busy |
| 11. Thamel | 0.75 | 0 | Right at the junction | East | Residential/ Market | Busy |
| 12. Ason | 0.75 | 0 | Right at the junction | South-West | Residential/ Market | Low |
| 13. Nachghar (Jamal) | 0.75 | 0 | Right at the junction | North | Residential/ Market | Busy |
| 14. Kasthamandap | 0.75 | 2 | Right at the junction | South-East | Residential/ Market | Moderate |
| 15. Kalanki (Ring Road) | 0.75 | 2 | Right at the junction | North-West | Residential (outskirt) | Busy |
| 16. Singha Durbar | 0.75 | 2 | Right at the junction | South-West | Office Complex | Busy |
| 17. Dillibazar (Pipalbot) | 0.75 | 2 | Right at the junction | North | Residential/ Market | Moderate |
| 18. Swayambhoo (Ring Road) | 0.75 | 2 | Right at the junction | South-West | Residential (outskirt) | Moderate |
| 19. Ratna Park (Bus park) | 0.75 | 2 | Right at the junction | North-West | Residential | Busy |
| 20. Tripureswor | 0.75 | 2 | 50 | South-East | Residential/ Market | Busy |

The phase 2 measurements at roadside sites gave much higher concentrations. Also here, TSP and $PM_{10}$, presented the largest problem compared to guidelines.

TSP-concentrations (9-hour day-time average) averaged almost 1400 µg/m³, with max. concentration 2258 µg/m³, at Kuleswor. $PM_{10}$ averaged almost 300 µg/m³, with maximum 498 µg/m³ at Thamel.

Again $SO_2$, $NO_x$ and CO concentrations were low, while the lead concentrations were up to 1.2 µg/m³, averaging 0.54 µg/m³. Still fairly low, but increased compared to the phase 1 sites.

These measurements, covering a number of sites in general Kathmandu City atmosphere and the roadside atmosphere, can be used to give a rough estimate of a long-term average TSP and $PM_{10}$ concentration which might represent a typical exposure value for the population in central Kathmandu City, based on the following assumptions:

***Table 3: Concentration of the pollutants (first part - 24 hour averaging time), ENPHO study.***

| Stations | TSP µg/m³ | $PM_{10}$ µg/m³ | $SO_2$ µg/m³ | $NO_x$ µg/m³ | CO mg/m³ | Pb µg/m³ |
|---|---|---|---|---|---|---|
| 1. Chabahil | 555 | 127 | <13.0 | 28 | <11 | 0.35 |
| 2. Indrachowk | 194 | 59 | <13.0 | 24 | <11 | 0.21 |
| 3. Maharajgunj (Ring Road) | 233 | 64 | <13.0 | 17 | <11 | 0.18 |
| 4. Thapathali | 206 | 74 | <13.0 | 12 | <11 | 0.31 |
| 5. Putalisadak | 267 | 92 | <13.0 | 28 | <11 | 0.37 |
| 6. Kalimati | 232 | 76 | <13.0 | 24 | <11 | 0.30 |
| 7. Royal Palace | 182 | 93 | <13.0 | 25 | <11 | 0.53 |
| 8. Balaju | 465 | 102 | <13.0 | 24 | <11 | 0.23 |
| 9. Bir Hospital | 438 | 116 | <13.0 | 36 | <11 | 0.43 |
| Average | 308 | 89 | *6.5 | 24.2 | <11 | 0.32 |
| WHO Standard | 120 | 70 | 125 | 150 | | 0.5-1.0 |

***Table 4: Concentration of the pollutants (Second part - 9 hour averaging time), ENPHO study.***

| Stations | TSP µg/m³ | $PM_{10}$ µg/m³ | $SO_2$ µg/m³ | $NO_x$ µg/m³ | CO mg/m³ | Pb µg/m³ |
|---|---|---|---|---|---|---|
| 10. Kuleswor | 2258 | 415 | 19 | 59 | <11 | 0.7 |
| 11. Thamel | 1978 | 498 | <13 | 48 | <11 | 1.2 |
| 12. Ason | 1772 | 281 | <13 | 28 | <11 | 0.5 |
| 13. Nachghar (Jamal) | 1283 | 257 | <13 | 32 | <11 | 0.9 |
| 14. Kasthamandap | 1056 | 182 | <13 | 17 | <11 | 0.4 |
| 15. Kalanki (Ring Road) | 1201 | 239 | 22 | 40 | <11 | 0.2 |
| 16. Sinha Durbar | 789 | 225 | 20 | 69 | <11 | 0.2 |
| 17. Dillibazar | 1077 | 240 | 18 | 30 | <11 | 0.5 |
| 18. Swayambhu (Ring Road) | 1161 | 258 | <13 | 26 | <11 | 0.3 |
| 19. Bus Park (Ratna Park) | 1709 | 355 | 17 | 41 | <11 | 0.6 |
| 20. Tripureswor | 1090 | 313 | <13 | 30 | <11 | 0.4 |
| Average | 1397 | 296 | 12.3 | 38 | <11 | 0.54 |

* $SO_2$ - <13 has been arbitrarily considered half of 13, i.e. 6.5.

- Consider that the average 24 hour average roadside concentration is 50 percent of the 9 hour average, i.e. 700 µg/m³ for TSP and 150 µg/m³ for $PM_{10}$.
- Consider that the average person spends 25 percent of the time roadside.
- Consider that the summer (monsoon) season average is 50 percent of the winter season average.

This results in an annual average of 300 µg/m³ for TSP and 75 µg/m³ for $PM_{10}$ for an average person living in central Kathmandu City spending 25 percent of his time roadside.

**Results from the KVVECP study.** As part of the Kathmandu Valley Vehicle Exhaust Control Program (KVVECP), measurements of TSP, $PM_{10}$, $NO_2$, $SO_2$, CO and Pb were made at a number of sites (roadside, residential, industrial). Results have been reported for the period September-December, 1993 (Devkota, 1993).

The measurement sites are shown in Figure 3 and described in Table 5. Individual results, as reported by Devkota, are annexed to this appendix. Methods are listed in Table 6.

***Table 5: Ambient Air Quality Monitoring Stations, KVVECP study.***

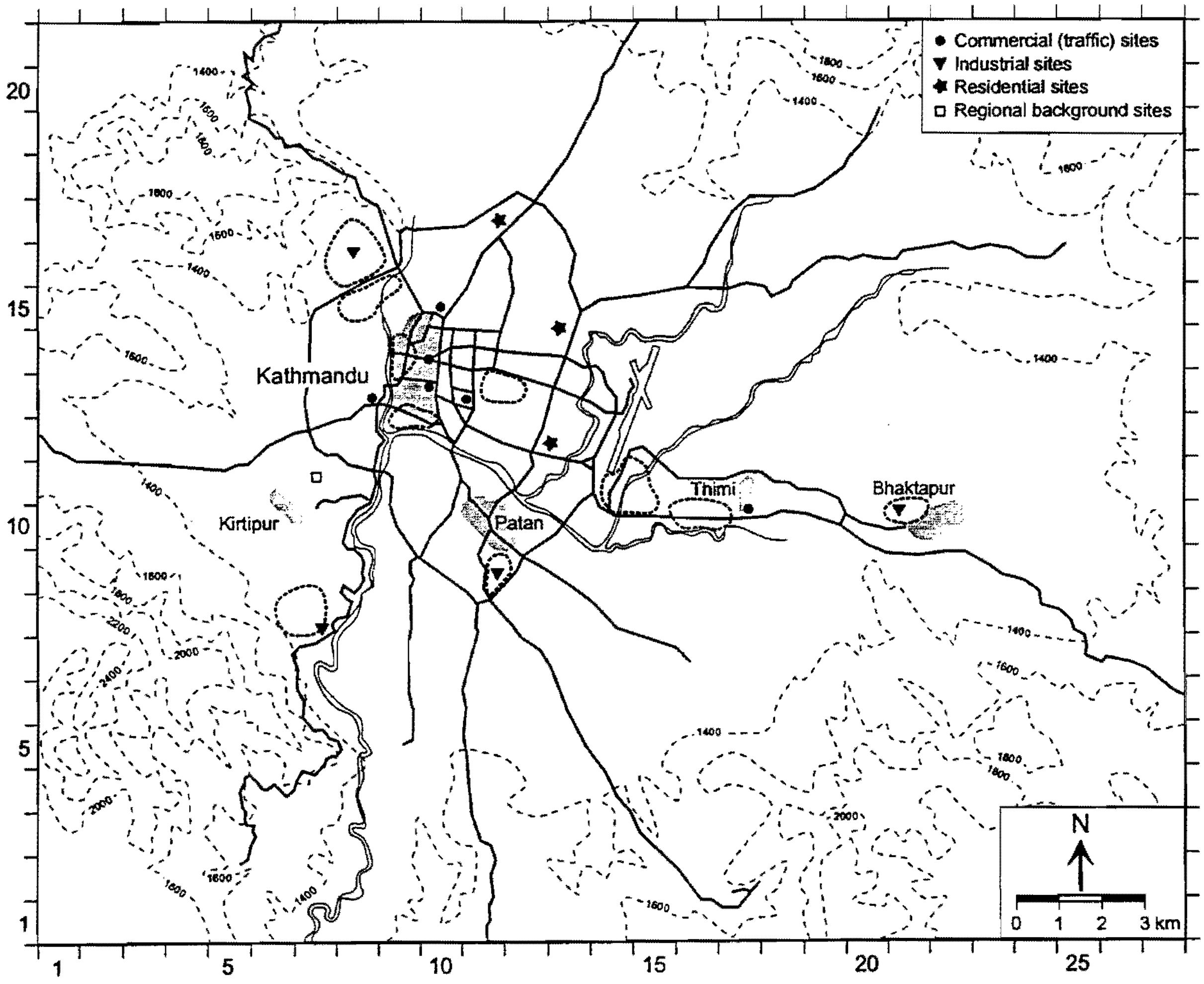
| Category | Locations | Distance from main road (m) | Height of the station (m) |
|---|---|---|---|
| 1. Commercial Areas: | | | |
| i. Heavy traffic (30-40,000 ADT) | Singha Durbar, | 2 | 3 |
| | GPO | 3 | 3 |
| ii. Medium traffic (20-30,000 ADT) | Ratnapark, | 4 | 3 |
| | Lainchaur, | 2 | 2.5 |
| | Kalimati | 3 | 3 |
| iii. Low traffic (<7000ADT) | Thimi (NTC) | 2 | 2.5 |
| 2. Residential Areas | Maharajgunj (TUTH), | 30 | 3 |
| | Naya Baneswor, | 20 | 7 |
| | Jaya Bageshwori | 15 | 8 |
| 3. Industrial Areas | Balaju, | 15 | 4 |
| | Bhaktapur, | 50 | 3 |
| | Patan Industrialized districts, | 5 | 5 |
| | Himal Cement Factory surrounding | 100 | 10 |
| 4. Regional background/control site | Tribhuvan University Kirtipur | 50 | 3 |

ADT: Average Daily Traffic

***Table 6: Monitoring methods, ENPHO and KVVECP study.***

| | |
|---|---|
| **Sampling**: | En Envirotech APM 451 Respirable Dust Sampler (Indian produce) was used as sampler for TSP, $PM_{10}$, $SO_2$ and $NO_2$. The flow rate for TSP/$PM_{10}$ was 0.8-1.2 $m^3$/min, and for $SO_2$ and $NO_x$ 1 l/min. The samples were partly 24 hour samples (midnight-to-midnight), and partly 8 hour samples during peak daytime traffic (9-10 a.m. to 5-6 p.m.). |
| **Analysis**: | |
| $SO_2$: | Pararosaniline method |
| $NO_2$: | Jacobs-Hochheiser Arsenite, Modified method |
| TSP: | Gravimetric analysis, Whatman GF/A filter ($PM_{10}$) and ceramic thimble (non-respirable fractions). |
| CO: | Roadside spot measurements with Kitegava Precision Gas Detector, Model APS. Gas Detector tubes, 5-50 ppm. |
| Heavy metals (Cr, Fe, Pb): | AAS analysis (Perkin Elmer - 2380) of the glass fibre filters. |

*Figure 3: Measurement sites, KVVECP study.*




The results of the 24-hour measurements are summarized in Table 7. Figures 4-7 show the average and maximum concentrations at the measurement sites for TSP, $PM_{10}$, $SO_2$ and $NO_2$ respectively.

*Table 7: Summary of AQ measurements, KVVECP study.*

| | Average/max 24 h conc. (µg/m$^3$) | | | | |
|---|---|---|---|---|---|
| | TSP | $PM_{10}$ | $SO_2$ | $NO_2$ | No. of days |
| **Commercial (traffic) sites** | | | | | |
| Singha Durbar (heavy traffic) | 303 / 375 | 142 / 175 | 49 / 64 | 37 / 64 | 22 (Nov./Dec.) |
| GPO (heavy) | 380 / 474 | 137 / 201 | 37 / 64 | 11 / 16 | 16 (Nov.) |
| Ratnapark (medium) | 187 / 319 | 67 / 86 | 32 / 102 | 18 / 28 | 16 (Sept.) |
| Lainchaur (medium) | 228 / 386 | 103 / 146 | 17 / 26 | 19 / 40 | 13 (Nov.) |
| Kalimati (medium) | 391 / 441 | 135 / 154 | 77 / 202 | 19 / 31 | 12 (Nov.) |
| Thimi (low) | 337 / 867 | 115 / 117 | 49 / 65 | 19 / 24 | 20 (Dec.) |
| **Residential sites** | | | | | |
| Maharajgunj | 191 / 350 | 72 / 126 | 19 / 34 | 12 / 14 | 13 (Nov.) |
| New Baneswor | 200 / 270 | 113 / 161 | 13 / 13 | 14 / 25 | 5 (Sept./Nov.) |
| Jaya Bageshwori | 228 / 273 | 112 / 132 | 110 / 225 | 49 / 126 | 10 (Dec.) |
| **Industrial areas** | | | | | |
| Balaju | 108 / 137 | 40 / 77 | 15 / 21 | 31 / 71 | 9 (Sept.) |
| Patan | 87 / 102 | 47 / 53 | 13 / 13 | 40 / 83 | 5 (Sept.) |
| Bhaktapur | 213 / 290 | 105 / 131 | 58 / 79 | 20 / 24 | 6 (Dec.) |
| Himal Cement surrounding | 430 / 560 | 166 / 194 | 57 / 65 | 38 / 58 | 5 (Dec.) |
| **Regional background site** | | | | | |
| Tribhuvan Univ. | 94 / 155 | 66 / 81 | 38 / 77 | 18 / 35 | 19 (Nov./Dec.) |

*Figure 4: TSP measurements, KVVECP study.*

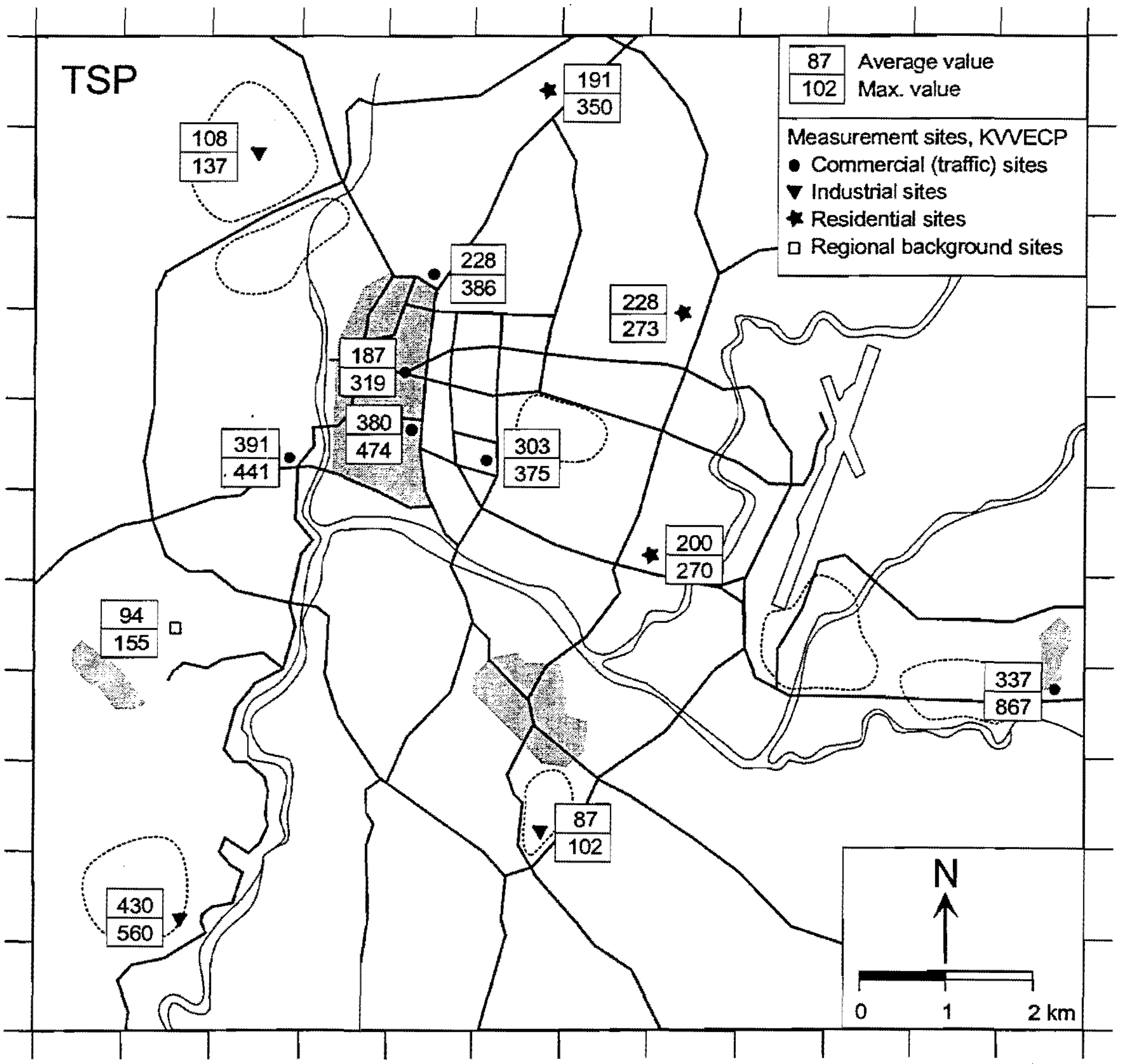


*Figure 5: $PM_{10}$ measurements, KVVECP study.*

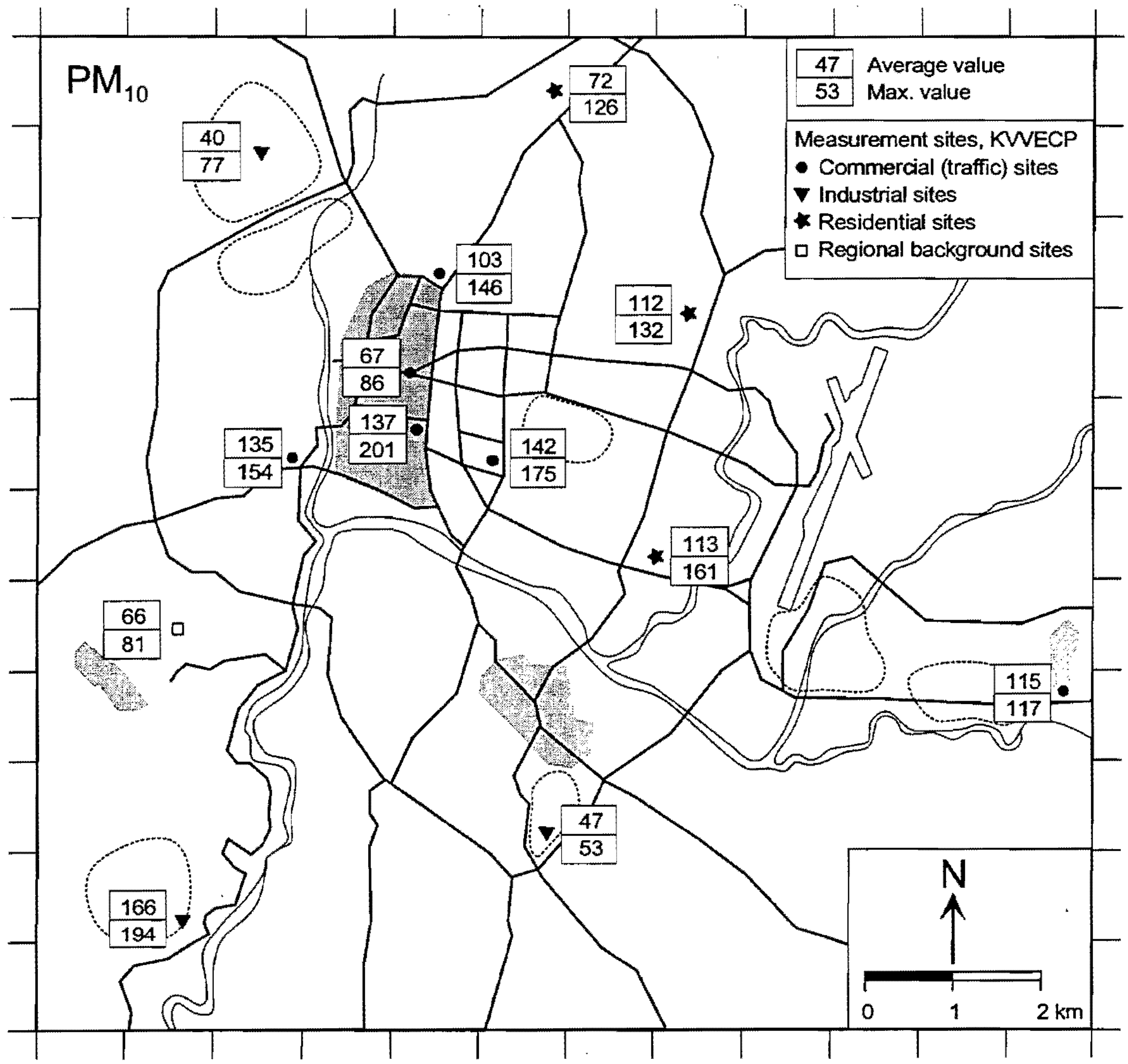


*Figure 6: $SO_2$ measurements, KVVECP study.*

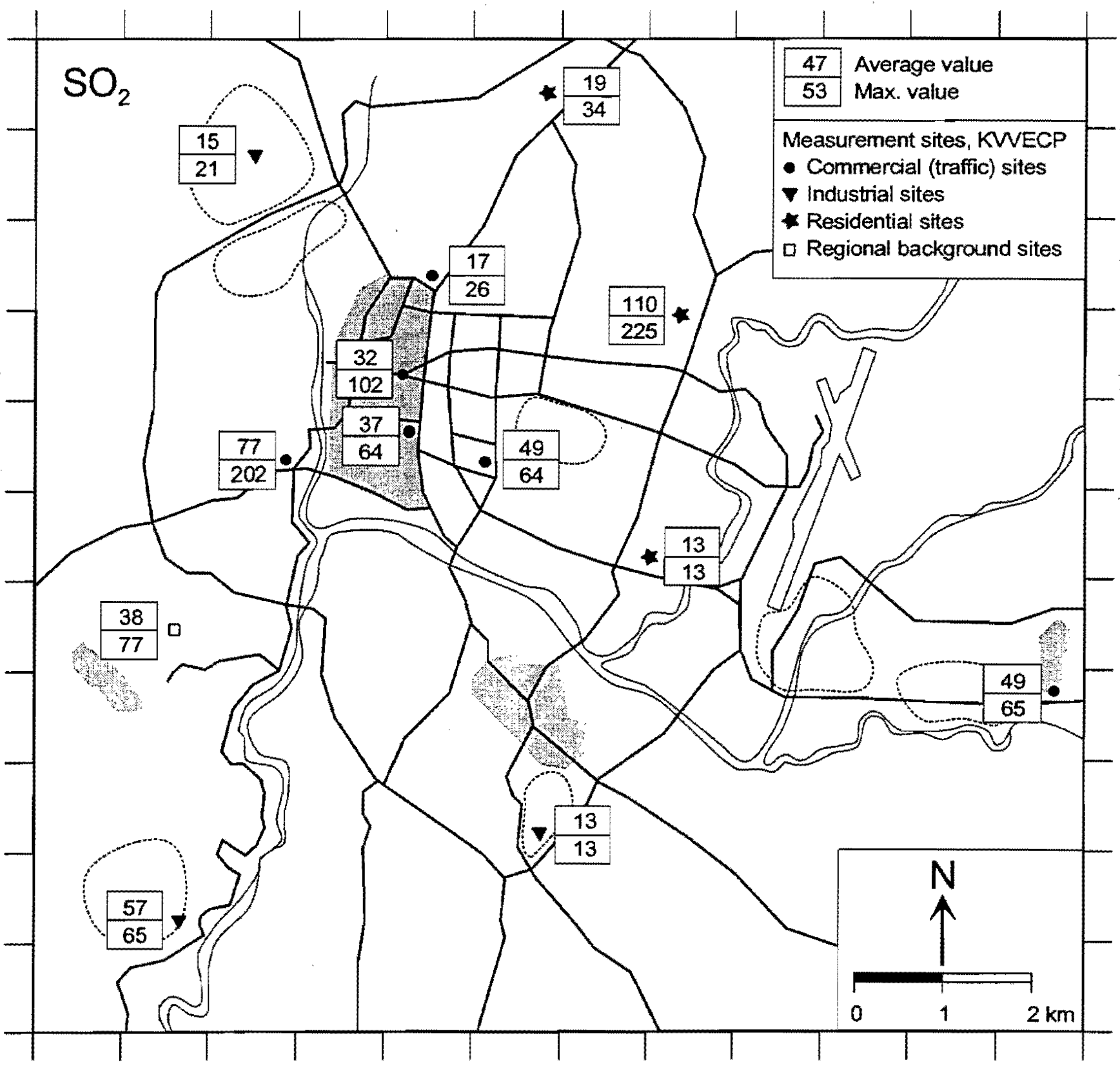
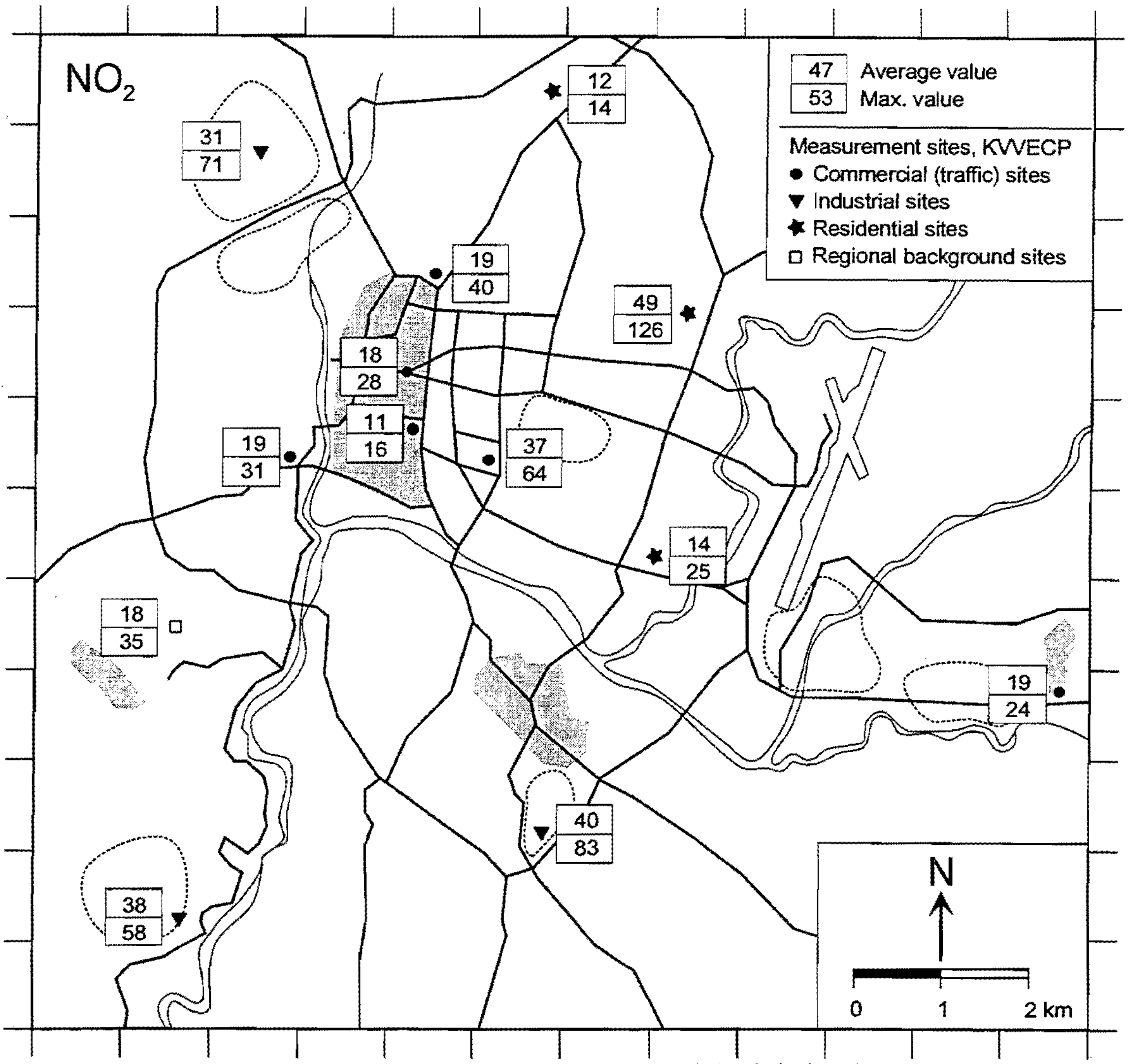


*Figure 7: $NO_2$ measurements, KVVECP study.*




For TSP, the concentration ranges for average and maximum values are 94 (background value)-430 μg/m³ and 102-867 μg/m³, respectively.

Granted that the measurement periods differ from site to site, the traffic sites have generally higher TSP concentrations than the other sites (except Himal Cement). However, differences between the traffic sites reflect also other parameters than just the amount of traffic. Thimi, with low traffic, has very high TSP concentrations. Local sources/conditions seem important.

For $PM_{10}$, the traffic and residential sites seem to have similar levels, higher than the industrial sites (again except Himal Cement). Actually, the Balaju and Patan sites have values similar to the regional background at Tribhuvan Univ., as was also the case for TSP.

$SO_2$ and $NO_2$ concentrations were generally low, according to the measurements, except at Kalimati ($SO_2$) and Jaya Bageshwori ($SO_2$ and $NO_2$).

The very short measurement periods at some sites reduce to some extent the general nature of these conclusions.

The measurements at the Tribhuvan Univ. indicate that the general background level of TSP was on the average some 90-100 µg/m³ in the autumn of 1993, with maximum concentrations up towards 150 µg/m³. The similar figure for $PM_{10}$ was some 50 µg/m³ (average) and 80 µg/m³ (maximum).

On top of this, sources nearby the monitoring sites gave higher concentrations. The variation from site-to-site does not seem to be explained simply by amount of traffic, or being in an industrial area.

The Himal Cement site had the highest average concentrations of TSP and $PM_{10}$, being close to the cement factory.

Relative to WHO guidelines, the TSP and $PM_{10}$ concentrations both rise to twice the guidelines. For TSP, about 70 percent of all the measurement days were above the lower guideline value (150 µg/m³), and about 50 percent of the days were above the higher guideline value (230 µg/m³). About 50 percent of the total days of measurement had $PM_{10}$ above the guideline of 70 µg/m³.

The results of the KVVECP CO measurements gave typical values below 5 ppm, and the highest value measured was 7.5 ppm, using detector tubes with range 0-50 ppm. Morning wind speeds were reported generally below 0.5 m/s. These are very low CO values considering the heavy traffic at some of the roads, and they are considerably lower than the results from the NILU measurements.

**Results from TSP measurements on the Hydrology and Meteorology Service Building.** TSP measurements were performed on the roof of the building at Babar Mahal, some 15 m above ground, from January to August 1994 (Shrestha, 1994). Results are given in Table 8, and shown in Figure 8.

The highest TSP concentrations occurred in February-April, the dry season, as expected. The TSP levels are substantially reduced on rainy days.

The results are at the same level as the KVVECP data for New Baneswar residential site from September and November 1993 (aver.: 200 µg/m³; max: 270 µg/m³; 5 sampling days).

The WHO guidelines were exceeded on the majority of the days. The highest concentration, 467 µg/m³, was more than twice the upper level of the 24-hour guideline range, 230 µg/m³.

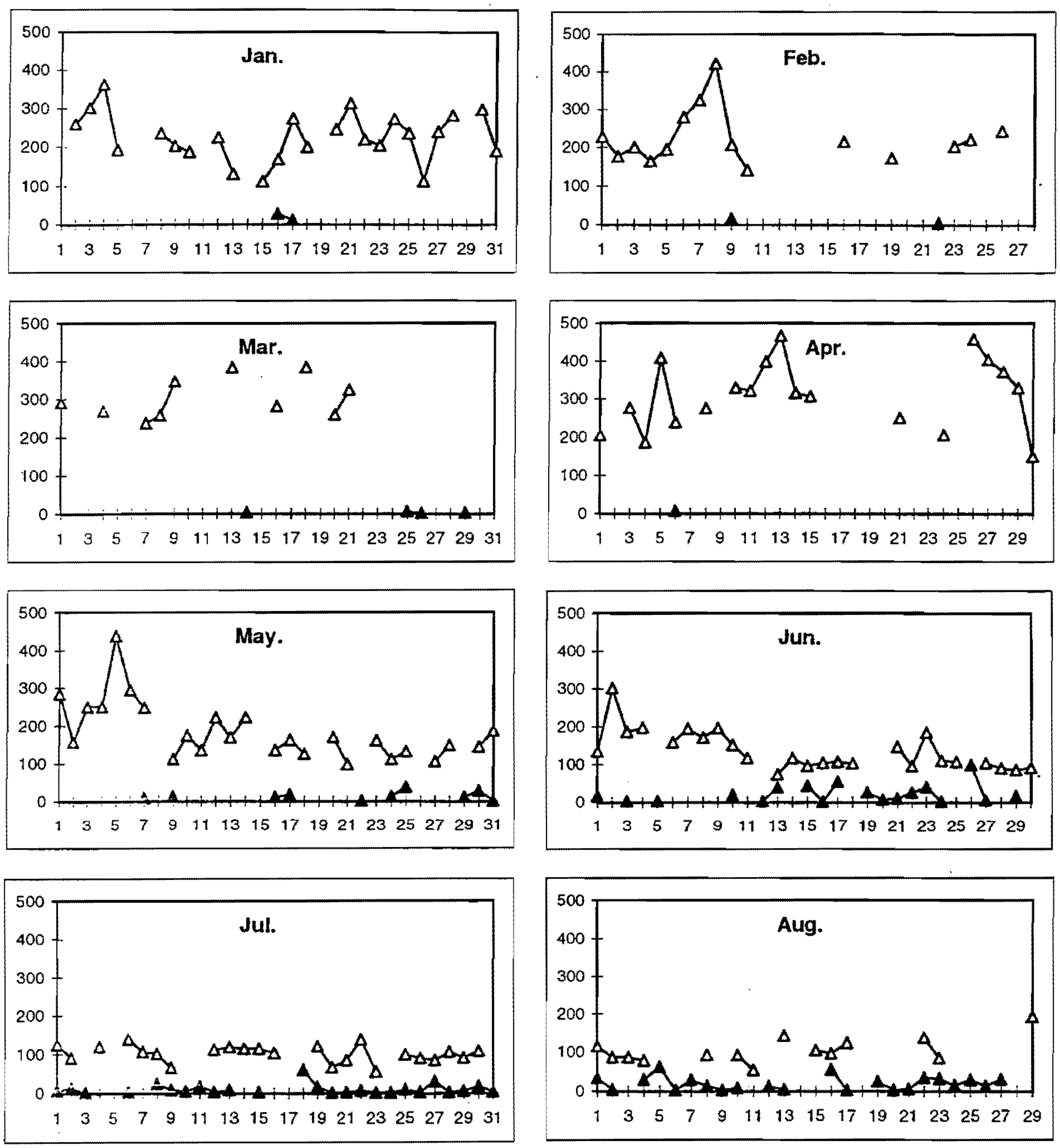
The 8-month average concentration was 200 µg/m³, compared to the WHO guideline for annual average, 60-90 µg/m³.

***Table 8: TSP measurements at Babar Mahal, 1994 (Hydr. and Met. Service Building) (Shrestha, 1994).***

| | Jan. | Feb | Mar | April | May | June | July | Aug | Avg. Jan-April | Avg. May-Aug |
|---|---|---|---|---|---|---|---|---|---|---|
| Average | 226 | 227 | 312 | 310 | 185 | 137 | 100 | 106 | 269 | 132 |
| Max. | 363 | 422 | 384 | 467 | 437 | 302 | 138 | 192 | | |
| No. of days above AQG: | | | | | | | | | | |
| -150 µg/m³ | 21 | 14 | 10 | 18 | 15 | 9 | 0 | 2 | 63* | 26* |
| -230 µg/m³ | 12 | 4 | 10 | 15 | 6 | 1 | 0 | 0 | 41* | 7* |
| No. of rainy days | 2 | 2 | 6 | 1 | 10 | 18 | 25 | 22 | 11* | 75* |
| No. of samples | 24 | 15 | 10 | 19 | 25 | 25 | 23 | 16 | 68* | 89* |

* Total no. of days.

*Figure 8: TSP measurements at Babar Mahal, 1994 (HMS building) (Shrestha, 1994).*




Results from the NESS (Pvt) Ltd campaign. The following samples were taken in 1993:

- Dust samples from roads, for lead analysis, at 10 road sites on September 10, 22 and 23, and 21 road sites on October 27 and 28.

- $PM_{10}$ samples from air at 4 sites on September 5-6, and at 9 sites on October 27 and November 1-2, using a Sibata high-volume air sampler HVS-500-5, with a 10 μm cut off slotted impactor in front.
- Monitoring of particle concentration by a Laser Dust Monitor (Japanese make) at 59 sites during November 3-19.

The measured road dust lead content is given in Table 9.

***Table 9: Lead content in street dust of Kathmandu City, 1993 (NESS study, T. Sharma et al., undated).***

| Samples | No. of sites | ppm Pb in dust | | | |
|---|---|---|---|---|---|
| | | Average | Range | Average | Range |
| September 10, 22, 23 | 10 | 275 | 50-1,187 | 140 | 81-344 |
| October 27-28 | 21 | 160 | 1-965 | - | - |

Lead, assuming mainly from lead in gasoline, is clearly present in roadside dust. The concentration of lead is typically 200-300 ppm in the >2 mm fraction, and somewhat less in the <0.2 mm fraction.

The measured $PM_{10}$ and lead concentrations in air are presented in Table 10. The values represent typical one-hour averages during daytime hours.

***Table 10: $PM_{10}$ and lead in air analyzed from samples drawn with the Sibata high-volume sampler.***

| Period | No. of sites | $PM_{10}$ (mg/m³) | | Lead (μg/m³) | |
|---|---|---|---|---|---|
| | | Average | Range | Average | Range |
| September 5-6 | 3 | | | 3.5 | 0.23-6.08 |
| October 25 and November 1-2 | 9 | 0.80 | 0.23-2.11 | 1.1 | 0.65-2.60 |

The $PM_{10}$ concentrations are very high (up to 2,100 μg/m³), much higher than those from the ENPHO and KVVECP studies. The Sibata sampler has a slotted 10 μm impactor in front of the filter where particles are collected. The function of the impactor is to hold back particles of diameter above 10 μm from the filter. It is possible, as known from experience with similar impactors, that dry dust particles are not collected with full efficiency. However, it is still difficult to explain the high $PM_{10}$ concentrations measured, when compared to those of the other studies.

The lead concentrations are also substantially higher than those measured in the ENPHO and KVVECP studies.

Based on these results, and the Laser dust monitor samples from 59 roadside sites, Otaki et al. (undated) has plotted $PM_{10}$ and lead pollution indicator values for the road network of Kathmandu City, and also a dust deposit map.

## INDOOR AIR POLLUTION EXPOSURE

High indoor air pollution exposure due to cooking practices is recognized as a potentially significant environmental health impact in Nepal (e.g. Pandey, 1984; Reid et.al., 1986; Pandey et al., 1989). The cooking practices undoubtedly also create localized outdoor air pollution problems in settlements in meteorologically shielded locations.

Extremely high TSP and CO concentrations have been measured in village houses, and a pronounced positive effect of improved cooking practices has been detected. Table 11 shows results obtained by Reid et al. (1986). Pandey et al. (1990) obtained similar results.

This situation in Kathmandu is described by Mathema et.al. (1992) as follows:

"About 82 percent of the urban households depend on fuel-wood for cooking purposes. If Kathmandu is a typical example then very few urban families have the provision of a smokeless chulo and chimney. They are increasingly becoming more dependent on kerosene. A recent study found that only 0.6 percent of families in the Kathmandu City have a smokeless chulo, 47 percent have no chimney, and 6.97 percent of those who have a chimney felt that their kitchen is still "full of smoke" (REGMI & JOSHI, 1988/p45-47).

***Table 11: Mean personal exposures to TSP and CO area concentrations by village and stove type (Reid et.al., 1986).***

| | Traditional | | Improved | | |
|---|---|---|---|---|---|
| | n | x | n | x | P (%) |
| ***TSP (mg/m³)*** | | | | | |
| Gorkha | 11 | 3.17 (2.2) | 13 | 0.87 (0.71) | <5 |
| Beni | 11 | 3.11 (2.9) | 14 | 1.37 (1.3) | <2.5 |
| Mustang | 2 | 1.75 | 2 | 0.92 | >10 |
| ***CO (ppm)*** | | | | | |
| Gorkha | 13 | 280 (230) | 14 | 70 (35) | <0.5 |
| Beni | 14 | 310 (220) | 12 | 64 (39) | <0.1 |
| Mustang | 2 | 64 | 2 | 41 | >20 |

Note that there is a statistically significant (<5%) difference between the levels for both pollutants, experienced by women cooking with improved stoves compared to traditional ones in both Middle Hill villages. There are too few samples in Mustang.

n = sample size

X = mean (geometric mean)

P = level of significance, i.e. probability that observed difference between the averages of improved and combined traditional stoves has occurred by chance based on a two-tailed t-test. All calculations are based on sample standard deviations (n-l).

Furthermore, about 36.5 percent use a Kerosene stove for cooking. The smokeless chulo, chimney and use of kerosene when used in absence of good ventilation are potential sources of indoor pollution. The fact that almost one-third of the households have their kitchen on the ground floor, a preference which is becoming very common with the advent of modern one-story house constructions, suggests that the problem of indoor smoke could spread over the rest of the house.

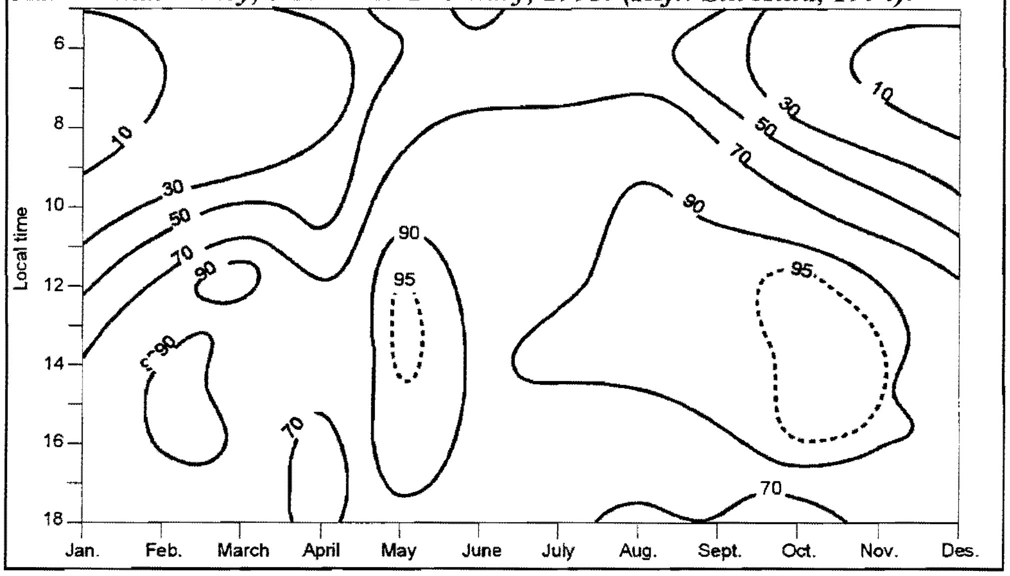
The composition of major pollutant emissions from different types of traditional fuel sources, based on an Indian study, is shown in Table 48[x] . From the table it is seen that, measured in terms of pollutants emitted from firewood, the most common form of fuel source in urban areas, appears to be the worst among the three sources shown. Assuming a 6 hours cooking period per day, an average urban household is subjected to 16 mg/cu.m. of particulate per day - a figure which is extremely high when seen in terms of its impacts on health. Shrestha states that a traditional Nepali chulo emits a high dose of Carbon Monoxide and "working in such an environment for more than ten minutes is considered poisoning" (SHRESTHA, 1986/p42)."

## VISIBILITY

The meteorological visibility of the Kathmandu Valley has been recorded at the Kathmandu airport since 1969. Shrestha (1994) has made a thorough and valuable analysis of the visibility data for the period 1969-1993, based on hourly meteorological observations and 3-hourly synoptic reports at the airport. The following text is a brief summary of Dr. Shrestha's findings.

[x] Not shown here.

*Figure 9: Fraction of days (percent) with fair-to-good visibility (>8,000 m), Kathmandu Valley, November-February, 1993. (Ref.: Shrestha, 1994).*




**Diurnal and annual variation of visibility.** The present visibility situations is such that during the period November-February the visibility is very poor before 9:00 a.m., with only 10 percent of the day with visibility >8,000 m (Figure 9). The visibility improves generally during the day, with typically good visibility in the afternoon. During the monsoon season and early fall, the visibility is generally good.

This annual variation, with improved visibility during the summer months, reflects several of the following conditions:

- generally better dispersion during summer,
- reduced resuspension during summer (wet surface),
- increased rain-out of particles,
- reduced fine particle emissions in summer (no brick industry).

**Trend of reduced visibility.** The trend towards reduced visibility in the Valley is quite dramatic for the months November-March, and particularly for December-February (Figure 10). While in the early 70's, visibility greater than 8,000 meters prevailed (at 11:45 a.m.) for 25-30 days per month, there has been a steep downwards trend since about 1980. Today, the number of days per month in December-February with good visibility at noon approaches zero!

The nature of the worsened visibility situation in the winter (dry season) is also shown by the example of Figure 11. For the month of January, this figure shows how the natural lifting of the fog and haze during the morning hours, which in the early 70's occurred around 9:00-10:00 a.m., is typically delayed until noon or early afternoon at present.

The relative humidity (RH) is an important parameter for visibility variation. Figure 13 shows the average RH as a function of time at Tribhuwan Airport in 1993.

*Figure 10: No. of days per month with fair-to-good visibility (>8,000 m), Kathmandu Valley, 1969-93. (Ref.: Shrestha, 1994).*

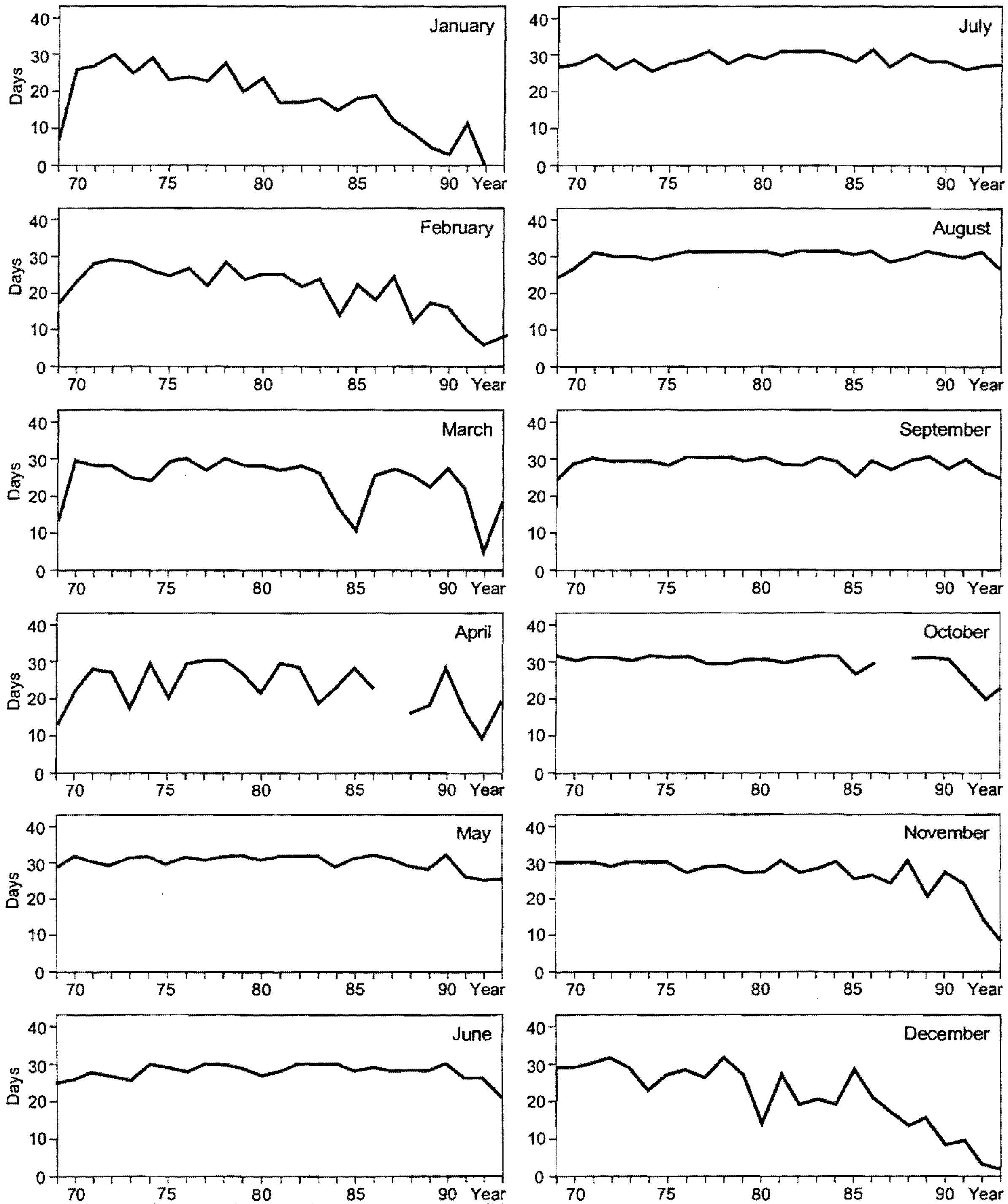


***Figure 11: No. of foggy days at 9 a.m. for the period November-February, Kathmandu Valley, 1969-93. (Ref.: Shrestha, 1994).***

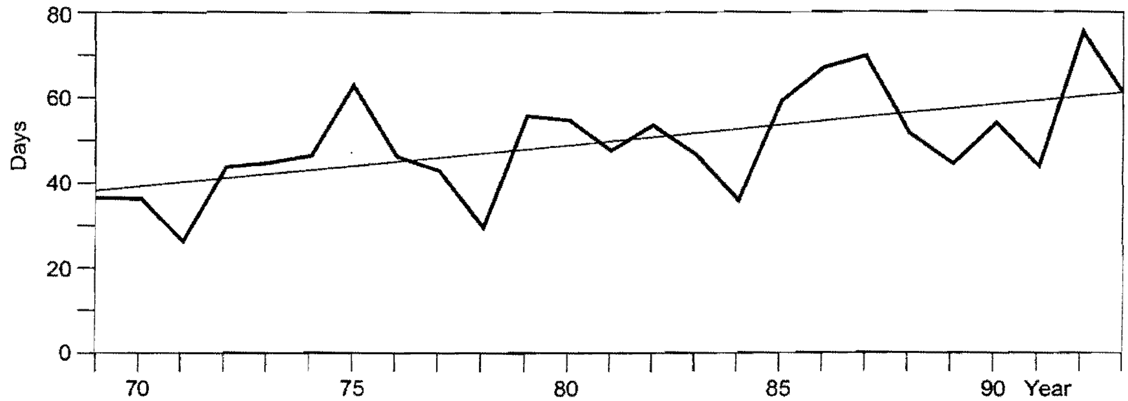



***Figure 12: No. of days in January with visibility >8,000 m, at given hours, 1970 (full line) and 1993 (dotted line) (Shrestha, 1994).***

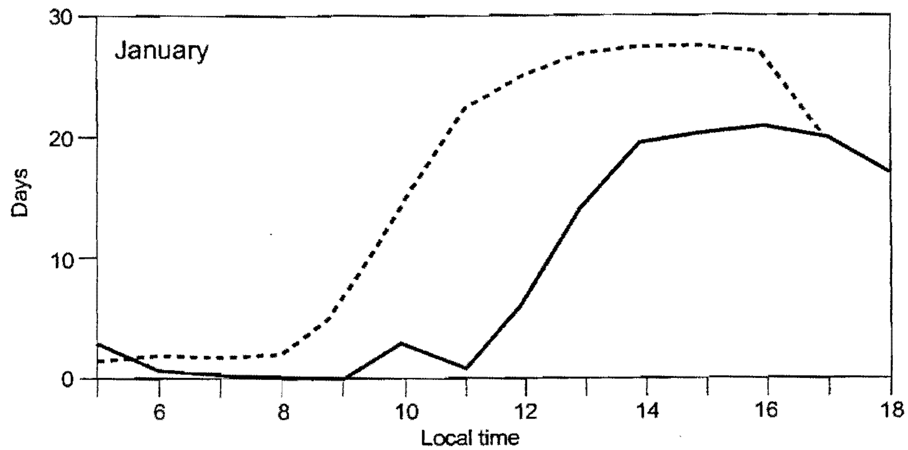
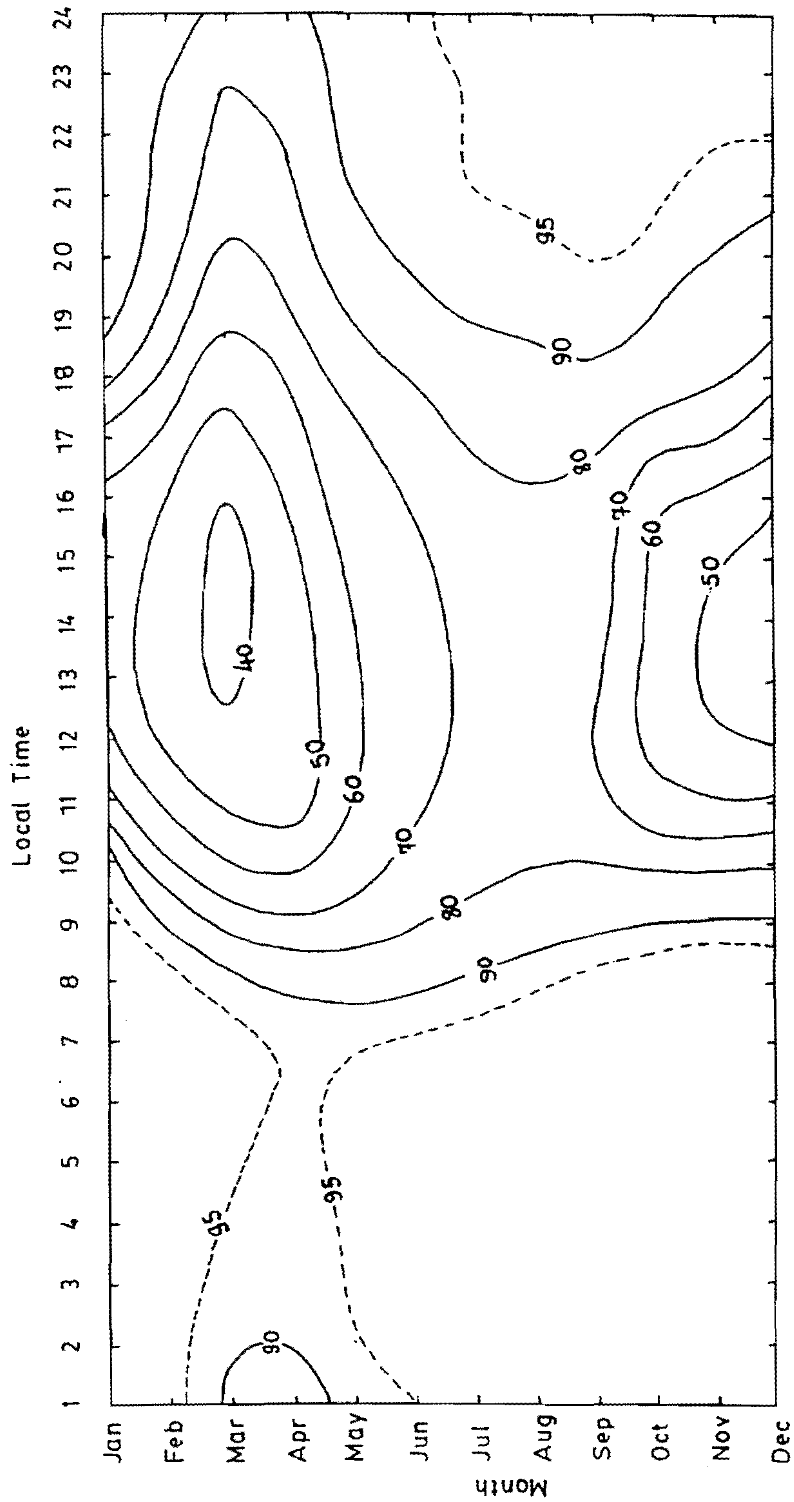


*Figure 13: Temporal variation of Relative Humidity at Tribhuwan Airport, 1993 (per cent).*



**Trend of foggy days.** Further description of the visibility situation is given in Figure 12 which shows that the number of foggy days, at 08:45 a.m., during the four winter months November-February has increased from 35-40 around 1970 to more than 60 in 1992-93.

Dr. Shrestha's analysis clearly shows the dramatically worsened visibility situation in the Kathmandu Valley. It seems clear that the reason is the increased particle concentration in the atmosphere, particularly in the fine particle fraction (diameter <1 μm). It is probable that this increase has taken place in the regional atmosphere in general, as well as for sure in the local Valley atmosphere, due to the increased industrial and commercial activities in the Valley as well as increased population, resulting in increased fine particle emissions and concentrations.

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## ANNEX: COPY OF THE KVVECP AIR QUALITY MEASUREMENTS (REF.: DEVKOTA, 1993).

Table 2 : Ambient Air Quality Monitoring in Commercial Area - Heavy Traffic (GPO Complex)

| Date | Pollutants ug/m³ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 3/11/93 | 201 | 273 | 474 | 16 | 29 | 24 | |
| 5/11/93 | 157 | 213 | 370 | 15 | 18 | 8 | |
| 6/11/93 | 152 | 590 | 742 | 29 | 13 | 8 | Holiday |
| 7/11/93 | 172 | 414 | 586 | 30 | 13 | 8 | |
| 8/11/93 | 200 | 527 | 727 | 22 | 46 | 8 | Holiday |
| 9/11/93 | 168 | 632 | 800 | 25 | 14 | 7 | |
| 10/11/93 | 99 | 267 | 366 | 10 | 46 | 22 | |
| 11/11/93 | 172 | 665 | 837 | 19 | 35 | 8 | 12- 8.30 |
| 12/11/93 | 121 | 79 | 200 | 17 | 13 | 8 | 8.30-4.30 |
| 12/11/93 | 173 | 1399 | 1572 | 17 | 13 | 8 | 5-12 pm |
| 12/11/93 | 138 | 257 | 395 | 23 | 13 | 7 | |
| 13/11/93 | 106 | 527 | 633 | 12 | 13 | 8 | Holiday |
| 14/11/93 | 129 | 367 | 496 | 25 | 13 | 8 | Hoilday |
| 16/11/93 | 108 | 229 | 337 | 9 | 13 | 24 | |
| 17/11/93 | 152 | 431 | 583 | 41 | 13 | 7 | |
| 18/11/93 | 142 | 179 | 321 | 11 | 35 | 24 | |
| 19/11/93 | 179 | 409 | 588 | 22 | 81 | 8 | |
| 20/11/93 | 135 | 265 | 403 | 11 | 64 | 24 | Holiday |
| 21/11/93 | 179 | 697 | 876 | 35 | 162 | 8 | |

<u>(I) Range</u> :

| | | |
|---|---|---|
| SPM | : | 321 - 474 (24 h) |
| | : | 200 - 1572 (8 h) |
| $PM_{10}$ | : | 99 - 201 (24 h) |
| | : | 106 - 200 (8 h) |
| $NO_2$ | : | 9 - 16 (24 h) |
| | : | 12 - 41 (8 h) |
| $SO_2$ | : | 13 - 64 (24 h) |
| | : | 13 - 162 (8 h) |

<u>(II) Average</u> :

| | | |
|---|---|---|
| SPM | : | 380 (24 h), 682 (8 h) |
| $PM_{10}$ | : | 137 (24 h), 157 (8 h) |
| $NO_2$ | : | 11 (24 h), 24 (8 h) |
| $SO_2$ | : | 37 (24 h), 33 (8 h) |

Table 3 Ambient Air Quality Monitoring in Commcercial Area - Heavy Traffic, Singha Durbar

| Date | Pollutants ug/m$^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | SPM | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 23/11/93 | 146 | 236 | 382 | 31 | 93 | 19 | |
| 24/11/93 | 180 | 419 | 599 | 52 | 99 | 8 | |
| 25/11/93 | 123 | 252 | 375 | 27 | 46 | 24 | |
| 26/11/93 | 152 | 713 | 865 | 45 | 51 | 8 | |
| 27/11/93 | 112 | 105 | 217 | 29 | 31 | 19 | Holiday |
| 28/11/93 | 113 | 161 | 274 | 49 | 13 | 8 | 5-12 pm |
| 29/11/93 | 132 | 957 | 1089 | 39 | 67 | 8 | |
| 30/11/93 | 127 | 107 | 234 | 26 | 64 | 24 | |
| 01/12/93 | 102 | 201 | 303 | 75 | 188 | 20 | |
| 02/12/93 | 167 | 208 | 375 | 88 | 61 | 24 | |
| 03/12/93 | 112 | 219 | 331 | 52 | 69 | 10 | |
| 04/12/93 | 120 | 292 | 412 | 34 | 80 | 8 | Holiday |
| 05/12/93 | 134 | 216 | 350 | 41 | 95 | 8 | |
| 06/12/93 | 165 | 97 | 262 | 24 | 35 | 24 | |
| 07/12/93 | 170 | 341 | 511 | 45 | 93 | 8 | |
| 08/12/93 | 119 | 120 | 239 | 20 | 51 | 24 | |
| 09/12/93 | 143 | 332 | 475 | 40 | 85 | 8 | |
| 10/12/93 | 121 | 137 | 308 | 22 | 45 | 24 | |
| 11/12/93 | 128 | 241 | 369 | 33 | 74 | 8 | Holiday |
| 12/12/93 | 164 | 213 | 377 | 68 | 59 | 8 | |
| 13/12/93 | 175 | 256 | 331 | 55 | 41 | 24 | |
| 14/12/93 | 214 | 169 | 383 | 101 | 37 | 20 | |

<u>I. Range:</u>

| | | |
|---|---|---|
| TSP | : | 234 - 375 (24 h) |
| | : | 274 - 1089 (8 h) |
| $PM_{10}$ | : | 119 - 175 (24 h) |
| | : | 113 - 180 (8 h) |
| $NO_2$ | : | 20 - 88 (24 h) |
| | : | 33 - 686 (8 h) |
| $SO_2$ | : | 35 - 64 (24 h) |
| | : | 13 - 99 (8 h) |

<u>II. Average:</u>

| | | |
|---|---|---|
| TSP | : | 303 (24 h), 532 (8 h) |
| $PM_{10}$ | : | 142 (24 h), 144 (8 h) |
| $NO_2$ | : | 37 (24 h), 45 (8 h) |
| $SO_2$ | : | 49 (24 h), 72 (8 h) |

Table 4 Ambient Air Quality Monitoring in Commercial Area - Medium Traffic Kalimati

| Date | Pollutants | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | | | | ug/$m^3$ | | | |
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 20/11/93 | 114 | 241 | 355 | 22 | 64 | 24 | |
| 21/11/93 | 110 | 492 | 602 | 40 | 57 | 8 | Holiday |
| 22/11/93 | 134 | 243 | 377 | 27 | 45 | 14 | |
| 23/11/93 | 164 | 533 | 697 | 48 | 103 | 8 | |
| 24/11/93 | 154 | 282 | 436 | 31 | 24 | 24 | |
| 25/11/93 | 179 | 861 | 1040 | 51 | 35 | 8 | |
| 26/11/93 | 137 | 194 | 331 | 12 | 202 | 24 | |
| 27/11/93 | 170 | 469 | 639 | 45 | 23 | 8 | Holiday |
| 28/11/93 | 122 | 450 | 572 | 28 | 131 | 8 | |
| 29/11/93 | 133 | 308 | 441 | 12 | 16 | 24 | |
| 30/11/93 | 168 | 534 | 702 | 26 | 100 | 8 | |
| 01/12/93 | 165 | 721 | 886 | 9 | 163 | 8 | |

**I. Range:**

| | | | |
|---|---|---|---|
| TSP | : | 331 - 441 | (24 h) |
| | : | 377 - 1040 | (8 h) |
| $PM_{10}$ | : | 114 - 154 | (24 h) |
| | : | 110 - 179 | (8 h) |
| $NO_2$ | : | 12 - 31 | (24 h) |
| | : | 10 - 51 | (8 h) |
| $SO_2$ | : | 16 - 202 | (24 h) |
| | : | 13 - 163 | (8 h) |

**II. Average:**

| | | | |
|---|---|---|---|
| TSP | : | 391 (24 h), | 734 (8 h) |
| $PM_{10}$ | : | 135 (24 h), | 154 (8 h) |
| $NO_2$ | : | 19 (24 h), | 35 (8 h) |
| $SO_2$ | : | 77 (24 h), | 71 (8 h) |

Table 5 Ambient Air Quality Monitored in Commercial Area- Medium Traffic (Ranipokhari Traffic Complex).

| Date | Pollutants ug/m³ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 10/9/93 | 67 | 252 | 319 | 17 | 13 | 24 | |
| 15/9/93 | 59 | 87 | 146 | 6 | 16 | 24 | Rainfall |
| 13/9/93 | 57 | 91 | 148 | 28 | 102 | 19 | Rainfall |
| 05/9/93 | 46 | 10 | 56 | 24 | 13 | 16 | Rainfall |
| 17/9/93 | 86 | 181 | 267 | 15 | 16 | 24 | |
| 18/9/93 | 76 | 307 | 383 | 30 | 20 | 10 | Holiday |
| 08/9/93 | 100 | 139 | 239 | 29 | 13 | 8 | Rainfall |
| 09/9/93 | 114 | 386 | 500 | 32 | 13 | 8 | |
| 11/9/93 | 56 | 156 | 212 | 35 | 13 | 8 | Holiday |
| 12/9/93 | 78 | 212 | 290 | 28 | 14 | 8 | |
| 06/9/93 | n.a | n.a. | n.a. | 29 | 13 | 7 | Rainfall |
| 14/9/93 | 67 | 115 | 182 | 33 | 21 | 7 | |
| 16/9/93 | 75 | 309 | 384 | 25 | 13 | 8 | |
| 19/9/93 | 78 | 242 | 320 | 21 | 13 | 8 | Rainfall |
| 20/9/93 | 100 | 211 | 321 | 20 | 17 | 8 | Rainfall |
| 21/9/93 | 109 | 59 | 168 | 11 | 22 | 10 | NepalBanda |

I. Range:

| | | | |
|---|---|---|---|
| TSP | : | 56 - 319 | (24 h) |
| | : | 182 - 500 | (8 h) |
| $PM_{10}$ | : | 57 - 86 | (24 h) |
| | : | 67 - 114 | (8 h) |
| $SO_2$ | : | 13 - 102 | (24 h) |
| | : | 13 - 22 | (8 h) |
| $NO_2$ | : | 6 - 28 | (24 h) |
| | : | 11 - 35 | (8 h) |

II. Average :

| | | | |
|---|---|---|---|
| SPM | : | 187 (24 h), | 300 (8 h) |
| $PM_{10}$ | : | 67 (24 h), | 74 (8 h) |
| $SO_2$ | : | 32 (24 h), | 27 (8 h) |
| $NO_2$ | : | 18 (24 h), | 19 (8 h) |

Table 6 Ambient Air Quality Monitoring in Commercial Area - Medium Traffic (Lainchaur DOMG)

| Date | Pollutants ug/m³ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 6/11/93 | 78 | 129 | 207 | 19 | 13 | 24 | Holiday |
| 7/11/93 | 82 | 201 | 283 | 18 | 13 | 8 | |
| 8/11/93 | 100 | 74 | 174 | 14 | 26 | 24 | Holiday |
| 9/11/93 | 82 | 261 | 343 | 18 | 13 | 7 | |
| 10/11/93 | 146 | 240 | 386 | 12 | 23 | 24 | |
| 11/11/93 | 115 | 242 | 357 | 36 | 13 | 8 | |
| 12/11/93 | 103 | 91 | 194 | 40 | 13 | 24 | |
| 13/11/93 | 116 | 221 | 337 | 12 | 13 | 8 | Holiday |
| 14/11/93 | 64 | 157 | 221 | 14 | 13 | 8 | Holiday |
| 16/11/93 | 67 | 96 | 163 | 10 | 13 | 24 | |
| 17/11/93 | 87 | 158 | 245 | 23 | 13 | 8 | |
| 18/11/93 | 121 | 125 | 246 | 19 | 13 | 24 | |
| 19/11/93 | 151 | 630 | 781 | 27 | 178 | 6 | |

(I) Range :

| | | |
|---|---|---|
| TSP | : | 163 - 386 (24 h) |
| | : | 221 - 781 (8 h) |
| $PM_{10}$ | : | 67 - 146 (24 h) |
| | : | 64 - 151 (8 h) |
| $NO_2$ | : | 10 - 40 (24 h) |
| | : | 12 - 36 (8 h) |
| $SO_2$ | : | 13 - 26 (24 h) |
| | : | 13 - 178 (8 h) |

(II) Average :

| | | | |
|---|---|---|---|
| TSP | : | 228 (24 h), | 367 (8 h) |
| $PM_{10}$ | : | 103 (24 h), | 100 (8 h) |
| $NO_2$ | : | 19 (24 h), | 25 (8 h) |
| $SO_2$ | : | 17 (24 h), | 38 (8 h) |

Table 7 Ambient Air Quality Monitoring in Low Traffic - Thimi

| Date | Pollutants ug/m³ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 20/11/93 | 114 | 241 | 355 | n.a | n.a | 24 | Holiday |
| 21/11/93 | 115 | 70 | 185 | 24 | 35 | 22 | |
| 22/11/93 | 138 | 273 | 411 | 32 | 87 | 8 | |
| 23/11/93 | 117 | 102 | 219 | 19 | 49 | 24 | |
| 24/11/93 | 136 | 233 | 369 | 43 | 23 | 8 | |
| 25/11/93 | 111 | 66 | 177 | 24 | 45 | 24 | |
| 26/11/93 | 141 | 192 | 333 | 48 | 15 | 8 | |
| 28/11/93 | 158 | 203 | 361 | 32 | 70 | 8 | 5-12 pm |
| 29/11/93 | 104 | 381 | 485 | 13 | 118 | 8 | |
| 30/11/93 | 115 | 104 | 219 | 10 | 65 | 24 | |
| 01/12/93 | 124 | 327 | 451 | 36 | 132 | 8 | |
| 02/12/93 | 115 | 752 | 867 | 20 | 45 | 24 | |
| 04/12/93 | 81 | 94 | 175 | 30 | 57 | 18 | |
| 05/12/93 | 263 | 288 | 551 | 116 | 69 | 8 | Holiday |
| 06/12/93 | 243 | 274 | 517 | 77 | 184 | 8 | |
| 07/12/93 | 208 | 165 | 373 | 18 | 79 | 16 | |
| 08/12/93 | 214 | 669 | 883 | 58 | 73 | 8 | |
| 09/12/93 | 118 | 561 | 679 | 31 | 59 | 8 | |
| 10/12/93 | 132 | 351 | 483 | 32 | 72 | 8 | |
| 11/12/93 | 132 | 594 | 726 | 22 | 70 | 8 | Holiday |

**I. Range:**

| | | |
|---|---|---|
| TSP | : | 185 - 867 (24 h) |
| | : | 333 - 883 (8 h) |
| $PM_{10}$ | : | 111 - 117 (24 h) |
| | : | 104 - 263 (8 h) |
| $NO_2$ | : | 10 - 24 (24 h) |
| | : | 13 - 116 (8 h) |
| $SO_2$ | : | 35 - 65 (24 h) |
| | : | 15 - 184 (8 h) |

**II. Average:**

| | | |
|---|---|---|
| TSP | : | 337 (24 h), 521 (8 h) |
| $PM_{10}$ | : | 115 (24 h), 159 (8 h) |
| $NO_2$ | : | 19 (24 h), 45 (8 h) |
| $SO_2$ | : | 49 (24 h), 81 (8 h) |

Table 8 Ambient Air Quality Monitoring in Residential Area (TUTH, Maharajgunj)

| Date | Pollutants ug/m$^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 3/11/93 | 126 | 224 | 350 | 16 | 13 | 24 | |
| 4/11/93 | 36 | 50 | 86 | n.a | n.a | 8 | |
| 5/11/93 | 32 | 54 | 86 | 14 | . | 8 | Saturday |
| 6/11/93 | 51 | 84 | 135 | 14 | 13 | 24 | |
| 7/11/93 | 55 | 49 | 104 | 19 | 34 | 8 | Holiday |
| 8/11/93 | 68 | 52 | 120 | 20 | 13 | 16 | |
| 9/11/93 | 60 | 98 | 158 | 55 | 13 | 5 | |
| 10/11/93 | 56 | 106 | 162 | 9 | 13 | 24 | |
| 11/11/93 | 76 | 42 | 118 | 16 | 16 | 8 | |
| 12/11/93 | 56 | 59 | 115 | 10 | 13 | 24 | Hoilday |
| 13/11/93 | 67 | 35 | 102 | 16 | 13 | 6 | Holiday |
| 14/11/93 | 44 | 19 | 63 | 12 | 13 | 8 | |
| 16/11/93 | 39 | 19 | 58 | 11 | 13 | 16 | |

(I) Range :

| | | |
|---|---|---|
| TSP | : | 115 - 350 (24 h) |
| | : | 63 - 118 (8 h) |
| $PM_{10}$ | : | 51 - 126 (24 h) |
| | : | 32 - 76 (8 h) |
| $NO_2$ | : | 9 - 14 (24 h) |
| | : | 12 - 19 (8 h) |
| $SO_2$ | : | 13 - 34 (24 h) |
| | : | 13 - 13 (8 h) |

(II) Average :

| | | |
|---|---|---|
| SPM | : | 191 (24 h), 93 (8 h) |
| $PM_{10}$ | : | 72 (24 h), 49 (8 h) |
| $NO_2$ | : | 12 (24 h), 15 (8 h) |
| $SO_2$ | : | 19 (24 h), 13 (8 h) |

Table 9 Ambient air Quality Monitoring in Residential Area - Naya Baneshwor.

| Date | Pollutants ug/$m^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | SPM | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 01/9/93 | 27 | 48 | 75 | 25 | 13 | 24 | Rainfall |
| 02/9/93 | 19 | 16 | 35 | 57 | 14 | 8 | Rainfall |
| 03/9/93 | 43 | 21 | 64 | 66 | 13 | 8 | Rainfall |
| 11/11/93 | 150 | 120 | 270 | 9 | 13 | 24 | |
| 13/11/93 | 161 | 161 | 254 | 9 | 13 | 24 | |

I. Range:

| | | |
|---|---|---|
| TSP | : | 75 - 270 (24 h) |
| | : | 35 - 64 (8 h) |
| $PM_{10}$ | : | 27 - 161 (24 h) |
| | : | 19 - 43 (8 h) |
| $SO_2$ | : | 0 - 13 (24 h) |
| | : | 13 - 14 (8 h) |
| $NO_2$ | : | 0 - 25 (24 h) |
| | : | 57 - 66 (8 h) |

II. Average :

| | | | |
|---|---|---|---|
| SPM | : | 200 (24 h), | 50 (8 h) |
| $PM_{10}$ | : | 113 (24 h), | 31 (8 h) |
| $SO_2$ | : | 13 (24 h), | 14 (8 h) |
| $NO_2$ | : | 25 (24 h), | 62 (8 h) |

Table 10 Ambient Air Quality Monitoring in Residential Area - Jaya Bageshwori (Chabahill)

| Date | Pollutants ug/m³ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | SPM | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 07/12/93 | 131 | 230 | 361 | 28 | 71 | 8 | |
| 08/12/93 | 108 | 125 | 233 | 20 | 23 | 24 | |
| 09/12/93 | 123 | 231 | 354 | 34 | 164 | 8 | |
| 10/12/93 | 95 | 76 | 171 | 17 | 23 | 8 | |
| 12/12/93 | 132 | 468 | 600 | 126 | 225 | 24 | |
| 13/12/93 | 132 | 141 | 273 | 11 | 41 | 5 | |
| 15/12/93 | 109 | 193 | 302 | 30 | 65 | 24 | |
| 17/12/93 | 93 | 142 | 235 | 23 | 49 | 20 | |
| 18/12/93 | 145 | 118 | 265 | 27 | 55 | 20 | |
| 19/12/93 | 115 | 292 | 307 | 53 | 121 | 20 | |
| | | | | | | 8 | |

**I. Range:**

| | | | |
|---|---|---|---|
| TSP | : | 171 - 273 | (24 h) |
| | : | 307 - 361 | (8 h) |
| $PM_{10}$ | : | 95 - 132 | (24 h) |
| | : | 123 - 131 | (8 h) |
| $NO_2$ | : | 17 - 341 | (24 h) |
| | : | 28 - 53 | (8 h) |
| $SO_2$ | : | 23 - 41 | (24 h) |
| | : | 71 - 164 | (8 h) |

**II. Average:**

| | | |
|---|---|---|
| TSP | : | 228 (24 h), 341 (8 h), 267 (20 h) |
| $PM_{10}$ | : | 112 (24 h), 116 (8 h), 123 (20 h) |
| $NO_2$ | : | 49 (24 h), 38 (8 h), 37 (20 h) |
| $SO_2$ | : | 29 (24 h), 119 (8 h), 56 (20 h) |

Table 11 Ambient Air Quality Monitoring in Industrial Area - Balaju (BID).

| Date | Pollutants ug/$m^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 01/9/93 | 21 | 50 | 71 | 71 | 13 | 24 | Rainfall |
| 10/9/93 | 77 | 60 | 137 | 11 | 13.4 | 24 | |
| 13/9/93 | 32 | 81 | 113 | 14 | 21 | 24 | |
| 16/9/93 | 30 | 79 | 109 | 28 | 13 | 22 | |
| 17/9/93 | 46 | 116 | 162 | 34 | 26 | 8 | |
| 18/9/93 | 35 | 75 | 110 | 21 | 21 | 8 | |
| 02/9/93 | 42 | 14 | 56 | 63 | 13 | 8 | Rainfall |
| 09/9/93 | 35 | 72 | 107 | 8 | 13 | 8 | |
| 05/9/93 | n.a. | n.a. | n.a. | 42 | 13 | 6 | Rainfall |

I. Range:

| | | |
|---|---|---|
| TSP | : | 71 - 137 (24 h) |
| | : | 56 - 162 (8 h) |
| $PM_{10}$ | : | 21 - 77 (24 h) |
| | : | 35 - 46 (8 h) |
| $SO_2$ | : | 13 - 21 (24 h) |
| | : | 13 - 26 (8 h) |
| $NO_2$ | : | 11 - 71 (24 h) |
| | : | 8 - 63 (8 h) |

II. Average :

| | | | |
|---|---|---|---|
| TSP | : | 108 (24 h), | 109 (8 h) |
| $PM_{10}$ | : | 40 (24 h), | 40 (8 h) |
| $SO_2$ | : | 15 (24 h), | 17 (8 h) |
| $NO_2$ | : | 31 (24 h), | 34 (8 h) |

Table 12 Ambient Air Quality Monitoring in Industrial Area - Patan (PID)

| Date | Pollutants ug/m$^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | TSP | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 01/9/93 | 53 | 37 | 90 | 83 | 13 | 24 | Rainfall |
| 10/9/93 | 36 | 33 | 69 | 26 | 13 | 24 | |
| 13/9/93 | 53 | 49 | 102 | 12 | 13 | 21 | Rainfall |
| 02/9/93 | 64 | 61 | 125 | 69 | 13 | 8 | Rainfall |
| 05/9/93 | n.a | n.a. | n.a. | 80 | 13 | 8 | Rainfall |

I. Range:

| | | |
|---|---|---|
| TSP | : | 69 - 102 (24 h) |
| | : | 0 - 125 (8 h) |
| $PM_{10}$ | : | 36 - 53 (24 h) |
| | : | 0 - 64 (8 h) |
| $SO_2$ | : | 13 - 13 (24 h) |
| | : | 13 - 13 (8 h) |
| $NO_2$ | : | 12 - 83 (24 h) |
| | : | 69 - 80 (8 h) |

II. Average :

| | | | |
|---|---|---|---|
| TSP | : | 87 (24 h), | 125 (8 h) |
| $PM_{10}$ | : | 47 (24 h), | 64 (8 h) |
| $SO_2$ | : | 13 (24 h), | 13 (8 h) |
| $NO_2$ | : | 40 (24 h), | 75 (8 h) |

Table 13 Ambient Air Quality Monitoring in Bhaktapur Industrial Areas

| Date | Pollutants $ug/m^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | SPM | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 12/12/93 | 104 | 186 | 290 | 19 | 79 | 20 | |
| 13/12/93 | 122 | 107 | 229 | 21 | 59 | 8 | |
| 14/12/93 | 95 | 64 | 159 | 19 | 38 | 20 | |
| 15/12/93 | 94 | 74 | 168 | 18 | 48 | 20 | |
| 18/12/93 | 131 | 104 | 235 | 24 | 67 | 20 | |
| 19/12/93 | 169 | 625 | 794 | 78 | 101 | 8 | |

**I. Range:**

| | | |
|---|---|---|
| TSP | : | 159 - 290 (20 h) |
| | : | 229 - 794 (8 h) |
| $PM_{10}$ | : | 94 - 131 (20 h) |
| | : | 122 - 169 (8 h) |
| $NO_2$ | : | 18 - 24 (20 h) |
| | : | 21 - 78 (8 h) |
| $SO_2$ | : | 38 - 79 (20 h) |
| | : | 59 - 101 (8 h) |

**II. Average:**

| | | |
|---|---|---|
| TSP | : | 213 (20 h), 512 (8 h) |
| $PM_{10}$ | : | 137 (20 h), 146 (8 h) |
| $NO_2$ | : | 20 (20 h), 50 (8 h) |
| $SO_2$ | : | 58 (20 h), 80 (8 h) |

Table 14 Ambient Air Quality Monitoring in Around Himal Cement Factory

| Date | Pollutants ug/$m^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | SPM | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 15/12/93 | 157 | 373 | 560 | 38 | 45 | 24 | |
| 16/12/93 | 147 | 158 | 305 | 17 | 61 | 24 | |
| 17/12/93 | 127 | 1093 | 1220 | 131 | 238 | 3 | |
| 18/12/93 | 215 | 329 | 544 | 54 | 120 | 8 | |
| 19/12/93 | 194 | 230 | 424 | 58 | 65 | 24 | |

**I. Range:**

TSP : 305 - 560 (24 h)

$PM_{10}$ : 147 - 194 (24 h)

$NO_2$ : 17 - 58 (24 h)

$SO_2$ : 45 - 65 (24 h)

**II. Average:**

TSP : 430 (24 h)
$PM_{10}$ : 166 (24 h)
$NO_2$ : 38 (24 h)
$SO_2$ : 57 (24 h)

Table 15 Ambient Air Quality Monitoring in Regional Background Control site - Tribhuvan University, Kirtipur.

| Date | Pollutants ug/$m^3$ | | | | | Sampling hour | Remark |
|---|---|---|---|---|---|---|---|
| | SPM | | | $NO_2$ | $SO_2$ | | |
| | $PM_{10}$ | Particle | TOTAL | | | | |
| 18/11/93 | 75 | 17 | 92 | 14 | 13 | 24 | |
| 21/11/93 | 39 | 38 | 77 | 23 | 21 | 8 | |
| 22/11/93 | 35 | 23 | 68 | 50 | 35 | 8 | |
| 23/11/93 | 41 | 39 | 80 | 26 | 35 | 8 | |
| 24/11/93 | 64 | 53 | 117 | 16 | 20 | 8 | |
| 25/11/93 | 19 | 55 | 74 | 17 | 26 | 8 | |
| 26/11/93 | 59 | 19 | 78 | 19 | 63 | 5 | |
| 27/11/93 | 83 | 18 | 103 | 9 | 13 | 8 | Holiday |
| 29/11/93 | 64 | 13 | 77 | 11 | 35 | 24 | |
| 01/12/93 | 29 | 16 | 45 | 10 | 77 | 24 | |
| 02/12/93 | 57 | 03 | 60 | 20 | 40 | 8 | |
| 06/12/93 | 75 | 22 | 97 | 20 | 32 | 24 | |
| 07/12/93 | 58 | 46 | 104 | 38 | 76 | 8 | |
| 08/12/93 | 69 | 12 | 81 | 82 | 70 | 8 | |
| 09/12/93 | 52 | 31 | 83 | 45 | 80 | 8 | |
| 12/12/93 | 73 | 24 | 97 | 35 | 39 | 24 | |
| 14/12/93 | 81 | 74 | 155 | 20 | 33 | 24 | |
| 16/12/93 | 113 | 169 | 282 | 90 | 260 | 3 | |
| 19/12/93 | 136 | 96 | 232 | 83 | 285 | 3 | |

<u>I. Range:</u>

| | | | |
|---|---|---|---|
| TSP | : | 45 - 155 | (24 h) |
| | : | 68 - 117 | (8 h) |
| $PM_{10}$ | : | 64 - 81 | (24 h) |
| | : | 19 - 83 | (8 h) |
| $NO_2$ | : | 10 - 35 | (24 h) |
| | : | 9 - 82 | (8 h) |
| $SO_2$ | : | 13 - 77 | (24 h) |
| | : | 13 - 80 | (8 h) |

<u>II. Average:</u>

| | | |
|---|---|---|
| TSP | : | 94 (24 h), 84 (8 h) |
| $PM_{10}$ | : | 66 (24 h), 52 (8 h) |
| $NO_2$ | : | 18 (24 h), 33 (8 h) |
| $SO_2$ | : | 38 (24 h), 42 (8 h) |

# APPENDIX 2
# AIR QUALITY GUIDELINES

Nepalese air quality guidelines/standards have not yet been established. WHO air quality guidelines and standards are listed in Table 1.

*Table 1: WHO Air Quality Guidelines/Standards (WHO, 1977a, 1977b, 1978, 1979, 1987)*

| Parameter | | 10 minutes | 15 minutes | 30 minutes | 1 hour | 8 hours | 24 hours | 1 year | Year of standard |
|---|---|---|---|---|---|---|---|---|---|
| $SO_2$ | μg/m³ | 500 | | | 350 | | 125[a] | 50[a] | 1987 |
| $SO_2$ | μg/m³ | | | | | | 100-150 | 40-60 | 1979 |
| BS[b] | μg/m³ | | | | | | 125[a] | 50[a] | 1987 |
| BS[b] | μg/m³ | | | | | | 100-150 | 40-60 | 1979 |
| TSP | μg/m³ | | | | | | 120[a] | | 1987 |
| TSP | μg/m³ | | | | | | 150-230 | 60-90 | 1979 |
| $PM_{10}$ | μg/m³ | | | | | | 70[a] | | 1987 |
| Lead | μg/m³ | | | | | | | 0.5-1 | 1987, 1977[b] |
| CO | mg/m³ | | 100 | 60 | 30 | 10 | | | 1987 |
| $NO_2$ | μg/m³ | | | | 400 | | 150 | | 1987 |
| $NO_2$ | μg/m³ | | | | 190-320[c] | | | | 1977[b] |
| $O_3$ | μg/m³ | | | | 150-200 | 100-120 | | | 1987 |
| $O_3$ | μg/m³ | | | | 100-200 | | | | 1978 |

**Notes** (WHO/UNEP 1992):

*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** (WHO/UNEP 1992)

**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 μm in aerodynamic diameter) -- the mass of particulate matter collected by a sampler having an inlet with 50 per cent penetration at 10 μm aerodynamic diameter determined gravimetrically divided by the total volume sampled.

**TP** (Thoracic particles, as $PM_{10}$

**IP** (Inhalable particles, as $PM_{10}$).

# APPENDIX 3
# EMISSIONS INVENTORY

## INTRODUCTION

Two fairly comprehensive emissions inventories have been previously worked out for Kathmandu Valley, namely by Devkota (1992) and by Shrestha and Malla (1993).

Both investigations covered emissions from most of the main air pollution sources in the Valley: road vehicles, brick and cement industry, households, other industries (e.g. potters), aircraft. Shrestha only considered the emissions from "energy use", and not industrial process emissions. None of them considered resuspension from roads and other open surface construction, or refuse burning. Both treated the compounds TSP, CO, $SO_2$, $NO_x$, VOC and $CO_2$. Devkota attempted also to estimate emissions of benzene specifically, and of PAH from road traffic.

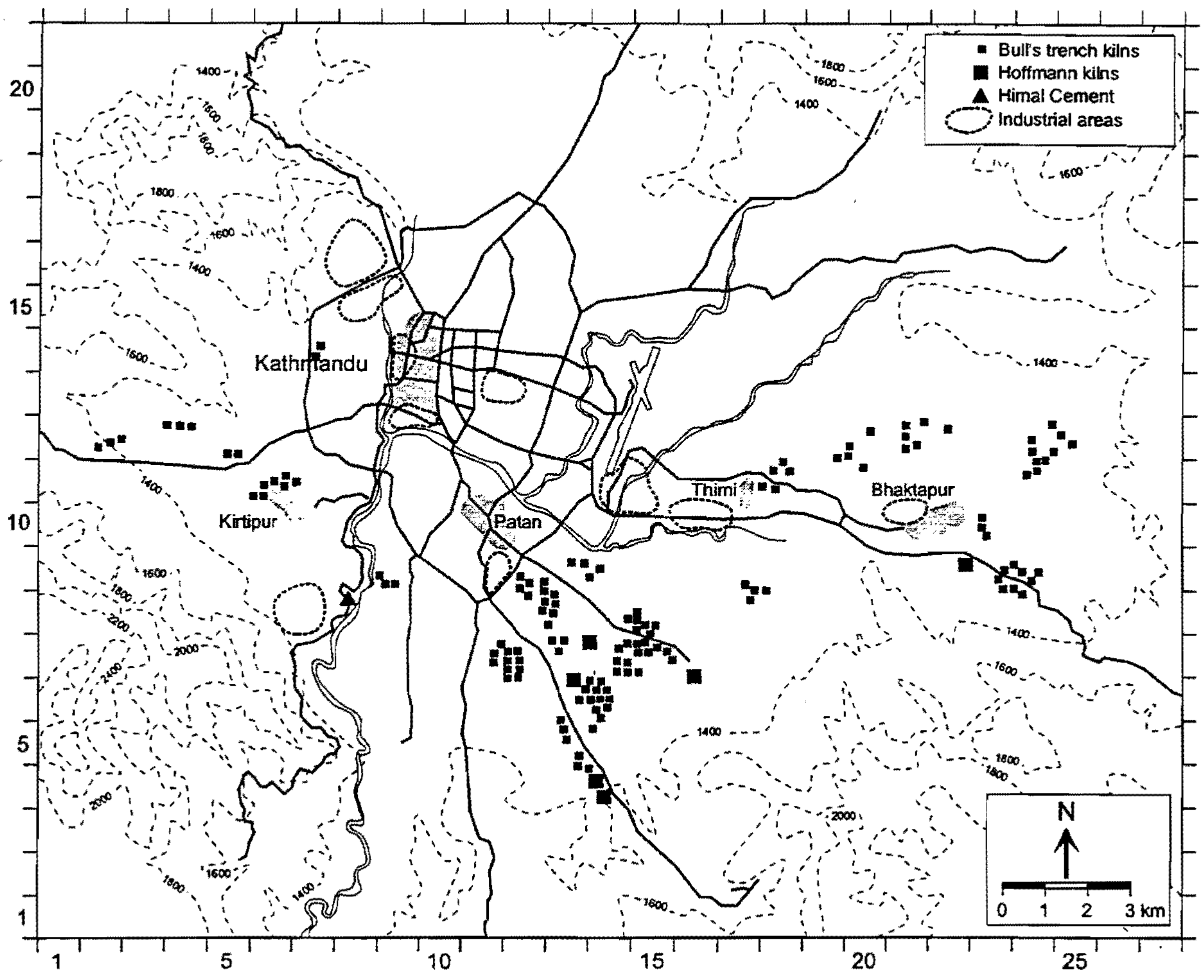
The following comprehensive emission survey is based on the works of Devkota (1992) and Shrestha and Malla (1993). The JICA Study on Kathmandu Valley Urban Road Development (JICA, 1992) gave valuable data on the distribution of traffic on the road network of the Valley. RONAST, through the URBAIR contract on data collection, also provided data on traffic, fuels, production etc. used in the following.

In addition, the following investigations of the industry and its emissions have been used:

- Bhattarai (1993): Paper on Industrial Contribution to Air Quality, presented at the URBAIR Workshop in December, 1993.
- Thapa, Shrestha and Karki (1993): A Survey of Brick Industries in the Kathmandu Valley.
- NESS Ltd. (1995): Assessment of the Applicability of Indian Cleaner Process Technology for Small Scale Brick Kiln Industries of Kathmandu Valley.

Gridded emission fields (emissions distributed in a $km^2$ grid net) were produced using the supporting software programs for the KILDER dispersion modeling program system, developed by NILU (Gram and Bøhler, 1992). The $km^2$ distribution of area source emissions was based on traffic distribution and population distribution data. The area selected for air pollution modeling, and thus for emission inventorying, is shown in Figure 1. It consists of a 27x21 $km^2$ grid, covering the full area of the Valley.

*Figure 1: Kathmandu Valley air quality modeling area.*




**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 total population of the URBAIR modeling area for Kathmandu Valley is 1,063,000 inhabitants for the year 1991.

This is the number used by JICA in the transportation study. The basis for distributing the population into $km^2$ grids is given by Table 1 and Figure 2, with reference to the JICA transportation study. The further distribution into $km^2$ grids was done subjectively, based on the distribution of villages within each square kilometer.

The resulting distribution of the total population is given in Figure 3.

*Figure 2: "Traffic zones" of Kathmandu Valley. (Ref.: JICA, 1992).*

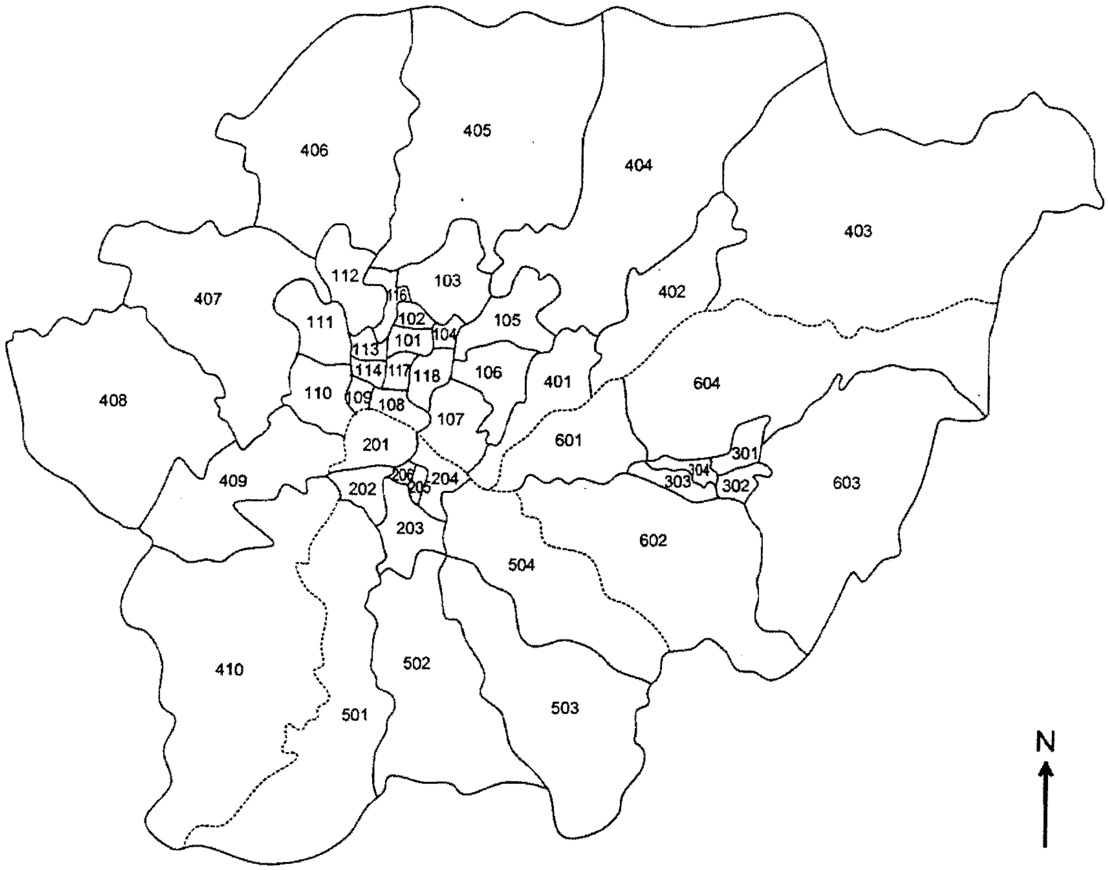


***Figure 3: Distribution of the Kathmandu Valley population within the km² grids of the modeling area, 1990/91. (In tens of inhabitants.)***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J=21 | . | . | . | . | . | . | 68. | 118. | 186. | 169. | 169. | 105. | 105. | 174. | 140. | 105. | 70. | 52. | 106. | . | . | 71. | 71. | . | 158. | . | . |
| J=20 | . | 18. | . | . | . | . | 34. | 85. | 102. | 135. | 135. | 174. | 209. | 209. | 174. | 174. | 105. | 35. | 71. | 106. | 141. | 79. | 108. | 79. | 79. | 79. | . |
| J=19 | . | 35. | 18. | 18. | 18. | 18. | 35. | 85. | 51. | 85. | 220. | 174. | 105. | 315. | 157. | 123. | 141. | 71. | 106. | 71. | 156. | 102. | 88. | 158. | 79. | 158. | . |
| J=18 | . | 35. | 53. | 35. | 35. | 35. | 35. | 35. | 272. | 406. | 278. | 271. | 464. | 446. | 158. | 814. | 438. | 177. | 247. | 114. | 102. | 117. | 158. | 158. | 158. | 237. | . |
| J=17 | . | 18. | 88. | 88. | 71. | 88. | 88. | 35. | 433. | 406. | 779. | 490. | 446. | 446. | 220. | 673. | 332. | 141. | 106. | 117. | 117. | 117. | 97. | 167. | 158. | 316. | 79. |
| J=16 | . | . | 71. | 71. | 53. | 71. | 106. | 71. | 292. | 893. | 1049. | 913. | 769. | 560. | 561. | 112. | 141. | 177. | 129. | 117. | 138. | 63. | 54. | 18. | 18. | 97. | 97. |
| J=15 | . | 62. | 124. | 80. | 66. | 124. | 141. | 106. | 98. | 2716. | 4546. | 415. | 1231. | 585. | 522. | 298. | 526. | 156. | 117. | 120. | 72. | 72. | 81. | 63. | 45. | 63. | 72. |
| J=14 | . | 155. | 155. | 124. | 186. | 133. | 141. | 371. | 902. | 3164. | 2671. | 1329. | 1008. | 710. | 497. | 369. | 142. | 154. | 197. | 236. | 126. | 81. | 72. | 72. | 90. | 89. | 102. |
| J=13 | . | 124. | 155. | 155. | 248. | 239. | 176. | 276. | 902. | 1219. | 559. | 930. | 989. | 824. | 785. | 106. | 146. | 316. | 373. | 290. | 144. | 90. | 90. | 358. | 134. | 83. | 125. |
| J=12 | . | 155. | 186. | 248. | 248. | 191. | 456. | 162. | 162. | 694. | 519. | 648. | 758. | 1385. | 302. | 110. | 261. | 448. | 299. | 251. | 419. | 319. | 277. | 693. | 186. | 78. | 93. |
| J=11 | . | 62. | 186. | 193. | 197. | 216. | 323. | 216. | 296. | 732. | 944. | 2477. | 1121. | 256. | 125. | 144. | 272. | 267. | 229. | 479. | 864. | 1233. | 976. | 498. | 55. | 62. | 109. |
| J=10 | . | 31. | 112. | 108. | 216. | 269. | 132. | 201. | 148. | 428. | 506. | 1004. | 841. | 228. | 228. | 182. | 171. | 171. | 149. | 256. | 128. | 273. | 64. | 86. | 62. | 93. | 125. |
| J= 9 | . | . | 54. | 54. | 162. | 81. | 25. | 98. | 94. | 219. | 287. | 383. | 383. | 171. | 285. | 228. | 185. | 214. | 171. | 171. | 85. | 53. | 85. | 43. | 93. | 125. | 93. |
| J= 8 | . | . | 12. | 39. | 39. | 52. | 37. | 49. | 73. | 67. | 179. | 27. | 203. | 155. | 86. | 157. | 342. | 86. | 121. | 64. | 64. | 43. | 53. | 32. | 31. | 31. | 16. |
| J= 7 | . | . | 12. | 12. | 25. | 49. | 25. | 37. | 73. | 90. | 170. | 161. | 323. | 434. | 123. | 189. | 86. | 114. | 96. | 21. | 32. | 32. | 43. | 21. | 8. | 23. | 8. |
| J= 6 | . | . | 25. | 25. | 37. | 31. | 37. | 49. | 74. | 22. | 202. | 188. | 269. | 135. | 289. | 101. | 57. | 57. | 142. | 53. | 21. | 21. | 21. | 21. | 19. | 16. | . |
| J= 5 | . | . | . | 12. | 49. | 25. | 49. | 49. | 49. | . | 121. | 242. | 161. | 99. | 230. | 109. | 54. | 72. | 61. | 29. | . | . | 11. | 11. | 11. | . | . |
| J= 4 | . | . | . | 25. | 37. | 37. | 37. | 25. | 37. | . | 69. | 215. | 94. | 108. | 63. | 72. | 72. | 109. | 54. | . | . | . | . | . | . | . | . |
| J= 3 | . | . | . | 6. | 25. | 12. | 25. | 31. | 37. | . | 67. | 188. | 161. | 81. | 54. | 36. | 36. | 36. | . | . | . | . | . | . | . | . | . |
| J= 2 | . | . | . | 12. | 18. | 37. | 12. | 36. | 17. | . | 11. | 161. | 81. | 54. | 81. | 18. | . | . | . | . | . | . | . | . | . | . | . |
| J= 1 | . | . | . | 6. | 25. | 25. | 18. | 18. | 22. | . | . | . | 13. | 27. | 27. | . | . | . | . | . | . | . | . | . | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

The distribution between urban/rural populations is 62-38 percent for Kathmandu district, 53-47 percent for Lalitpur district, and 35-65 percent for Bakthapur.

*Table 1: Population of "traffic zones", as given in Figure 2. (Ref.: JICA 1992).*

| Zone | 1991 | Zone | 1991 | Zone | 1991 | Zone | 1991 | Zone | 1991 | Zone | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **101** | 6,691 | **201** | 25,925 | **301** | 16,099 | **401** | 10,985 | **501** | 21,273 | **601** | 31,919 |
| **102** | 8,288 | **202** | 11,757 | **302** | 9,794 | **402** | 15,015 | **502** | 32,270 | **602** | 29,991 |
| **103** | 29,749 | **203** | 15,300 | **303** | 18,752 | **403** | 26,878 | **503** | 21,148 | **603** | 24,282 |
| **104** | 8,592 | **204** | 28,019 | **304** | 16,477 | **404** | 29,291 | **504** | 29,626 | **604** | 25,783 |
| **105** | 37,380 | **205** | 15,856 | | | **405** | 36,807 | | | | |
| **106** | 24,831 | **206** | 20,346 | | | **406** | 25,886 | | | | |
| **107** | 41,213 | | | | | **407** | 24,868 | | | | |
| **108** | 9,983 | | | | | **408** | 31,633 | | | | |
| **109** | 20,329 | | | | | **409** | 33,674 | | | | |
| **110** | 30,074 | | | | | **410** | 19,304 | | | | |
| **111** | 19,491 | | | | | | | | | | |
| **112** | 20,281 | | | | | | | | | | |
| **113** | 28,813 | | | | | | | | | | |
| **114** | 45,330 | | | | | | | | | | |
| **115** | 19,190 | | | | | | | | | | |
| **116** | 19,208 | | | | | | | | | | |
| **117** | 12,753 | | | | | | | | | | |
| **118** | 32,068 | | | | | | | | | | |
| | | | | | **SUM all zones 1,175,197** | | | | | | |

## FUEL CONSUMPTION

The fuel sale and consumption data for Kathmandu Valley in the available references are given in Tables 2 and 3. There are wide discrepancies between the various reported numbers.

Gasoline (MS) is considered to be used almost exclusively for road traffic. The amount varies between about 11,000 and 28,000 kl/yr. It appears that Shrestha arrived at his number by asking a

*Table 2: Fuel sale and consumption data (Liquid fuels), kl, for Kathmandu Valley.*

| | Gasoline (MS) | Sector | HSD | Sector | LDO | Sector | SKO | Sector |
|---|---|---|---|---|---|---|---|---|
| **Shrestha and Malla (1993)** | 28,015 | T | 22,955 | T | 359 | T | 35,000 | H |
| Estimated | | | 564 | I | | | 315 | I |
| Consumption, 1992/93 | | | | | | | 702 | C |
| **Total** | 28,015 | | 23,519 | | 359 | | 36,045 | |
| **Devkota (1992)** | 20,093 | T | 70,317 | ? | | | 60,826 | ? |
| "Consumption" | | | ("Diesel") | | | | | |
| NOC, 1990/91 | | | | | | | | |
| **Gautam et al. (1994)** | 11,098 | T | 21,825 | T? | 1,320 | | 38,600 | |
| NOC sales, 1992/93 | | | | | ("Fuel oil") | | | |
| **KVVECP final report** | 14,250 | T | 27,000 | T? | | | | |
| 1990 | | | ("Diesel") | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T | Traffic | H | Household | HSD | High speed diesel | SKO | Kerosene |
| I | Industrial | C | Commercial | LDO | Light diesel oil | | |

number of vehicle operators about how much gasoline they use annually, and using the average number thus arrived at for the entire operating vehicle fleet. He arrived at the operating vehicle fleet by assuming that a certain fraction of the registered vehicles in each category is actually in normal operation (Table 6). On the basis of fuel efficiency figures, he also arrived at average vehicle-kilometers traveled annually (and daily) per vehicle (see Table 7), which seems reasonable. Shrestha's gasoline consumption data was used in the following analysis.

Motor diesel (HSD) may be used for other purposes than for road vehicles. Three of the references give figures which agree fairly closely with HSD consumption for traffic.

Devkota's much higher total number may reflect, if correct, that HSD is used to a large extent also for other purposes, e.g. industrial/commercial. Shrestha does not report much use of HSD in industry.

***Table 3: Fuel consumption data (solid fuels), Kathmandu Valley ($10^3$ t/yr). Commercial, industrial (excl. brick and cement) and household.***

| | Shrestha and Malla (1993) 1992/93 | Devkota (1992) 1990/91 |
|---|---|---|
| Fuel wood | 122.0 H | |
| | 17.2 I | |
| | 0.5 C | |
| Coal | 4.8 I | |
| Charcoal | 0.5 H | |
| | 0.6 C | |
| Agricultural residue | 45.4 H | 35-60 I |
| Animal waste | 3.0 H | |

***Table 4: Estimated Annual Per Capita Consumption of Fuels in Urban and Rural Areas of Kathmandu Valley in 1992/93. (Ref.: Shrestha and Malla, 1993).***

| Area | Fuelwood (kg) | Kerosene (l) | Agricultural Residues (kg) | Animal Waste (kg) | Char-coal (kg) | LPG (kg) |
|---|---|---|---|---|---|---|
| Urban[1] | 93.5 | 34.5 | 7.5 | 0.0 | 0.8 | 6.3 |
| Rural[2] | 115.0 | 23.7 | 75.74 | 5.7 | 0.0 | 0.0 |

1 Source: Malla (1993) 2 Source: Shrestha (1993)

***Table 5: Fuel consumption in the cement and brick industry (tons/year) Kathmandu Valley.***

| | Brick | | | | Cement |
|---|---|---|---|---|---|
| | Bull's trench (NESS, 1995) | | | Chinese[2] | Himal |
| | ave/ kiln 1994 | no. of kilns | Total | (Shresta, '93) 1992/93 | (Shrestha, '93) 1992/93 |
| Coal | 318.8 | 130 | 41.444 | 4.093[1] | 17.096 |
| Lignite | 4.5 | | 585 | | |
| Fuel wood | 43.9 | | 5.707 | | |
| Saw dust | 20.5 | | 2.665 | | |
| Rice husk | 101.0 | | 13.130 | | |
| Tire scrap | 0.3 | | 39 | | |

1 Consumption in HHBF and BBF brick factories.

2 Devkota reports 1 ton of coal per 8,000 bricks.

*Table 6: Registered vehicle population, Bagmati.*

| | | Shrestha and Malla 92/93 | | | RONAST | JICA | Devkota |
|---|---|---|---|---|---|---|---|
| | Gasoline/ Diesel | Reg. number | Operating fraction | Operating vehicles | Reg. April 93 | Reg. 90/91 | "No. of vehicles" |
| Car | G | 16,522 | 0.61 | 10,105 | 20,273 | 18,000 | 19,535 |
| Jeep | G | 5,522 | 0.61 | 3,368 | | +883 (CD/UN) | |
| Minibus | D | 1,322 | ? | 372 | 1,333 | | |
| Bus | D | 715 | ? | 110 | 773 | 7,069 | 7,397 |
| Truck | D | 3,114 | 0.44 | 693 | 3,231 | | |
| Tractor | D | 1,917 | 0.50 | 959 | 1,587 | 1,729 | 1,864 |
| 3 wheeler | G | 3,175 | 0.50 | 1,588 | | | |
| 3 wheeler | D | 669 | 0.50 | 335 | | | |
| 2 wheeler | G | 35,002 | 0.80 | 28,000 | 36,129 | 24,211 | 26,121 |

***Table 7: Estimated Annual Average Fuel Consumption and Average Number of Kilometers Traveled Per Vehicle in Transport Sector by Vehicle Types in 1992/93. Ref.: Shrestha and Malla, 1993.***

| Vehicle Type | Fuel Type | Sample Size | Mean of Average Fuel Consumption | Fuel Efficiency | | Average km traveled per vehicle | |
|---|---|---|---|---|---|---|---|
| | | | (l) | (km/l) | (l/10 km) | Annually | Daily |
| Truck | Diesel | 15 | 8,704 | 4.5 | 2.2 | 39,168 | 107 |
| Bus | Diesel | 10 | 8,418 | 3.0 | 3.3 | 25,254 | 69 |
| Minibus | Diesel | 17 | 7,373 | 4.5 | 2.2 | 33,178 | 91 |
| Jeep | Diesel | 20 | 2,315 | 8.0 | 1.25 | 18,520 | 51 |
| Tractor | Diesel | 4 | 4,785 | 4.4 | 2.3 | 21,054 | 58 |
| Car | Gasoline | 61 | 1,595 | 10.6 | 0.94 | 16,907 | 46 |
| 3-Wheeler | Diesel | 9 | 2,592 | 12.5 | 0.8 | 32,400 | 89 |
| 3-Wheeler | Gasoline | 16 | 1,479 | 11.0 | 0.9 | 16,269 | 45 |
| 2-Wheeler | Gasoline | 42 | 341 | 45.5 | 0.22 | 15,515 | 43 |

As for HSD for road traffic, Shrestha's estimation is selected here for use in the emissions survey of this study. We leave the question open that there also may be a substantial use of HSD for other purposes.

Diesel oil (LDO) is reported to be used only to a small extent, in industry. Only Shrestha is reporting this, based on CBS (1993). Cottage industries with less than 10 employees are, however, not included in that survey.

The consumption of kerosene seems to be around 37,000-39,000 kl annually, as reported by Shrestha and Gautam. Devkota's much larger SKO number is not taken into account in the following analysis.

Data reported on consumption of solid fuels is given in Table 3 (cement and brick industry excluded, which is shown in Table 5).

Regarding fuel consumption in households, the estimate of per capita consumption for rural and urban populations as estimated by Shrestha and Malla (1993) is given in Table 4.

Devkota (1992) has given somewhat higher domestic fuel consumption data, based on investigation of the fuel use in 10 families living near Thankot: 175 kg of fuelwood per capita and 157 kg of agricultural residue per capita.

Shrestha (1993) is used in this study as the main source of information on solid fuel consumption. One figure from Devkota (1992) is added, which concerns the estimated amount of fuel used by local potters (12-15 tons per potter per year, 3 000-4 000 units).

For fuel consumption in the Bull's Trench brick kiln industry, NESS (1995) is used as the primary source, while for the Chinese kilns and Himal cement, Shrestha has reported consumption figures. For the Chinese kilns, the reported number from Shrestha concerns two of the 6 factories. Devkota reports the use of 1 ton of coal per production of 8 000 bricks, based on data from the Harisidhhi factory.

### TRAFFIC ACTIVITY AND ITS SPATIAL DISTRIBUTION

The total traffic activity of Kathmandu Valley has been calculated here, based upon the data reported by Shrestha (1993) on average fuel consumption and average kilometers traveled annually per vehicle class, and the number of operating vehicles in the Valley.

Traffic data reported by the JICA Urban Road Development Study (JICA, 1992) and by RONAST (1994) have been used here to distribute the traffic activity spatially, in the $km^2$ grid net.

The various data reported on the total number of registered vehicles in the Valley are given in Table 6. Shrestha's estimate of the fraction of vehicles actually operating is also given.

Considering that the data represent different years, there is fair agreement between the sources. One notable discrepancy is that Shrestha and RONAST give a substantially lower number of registered buses and trucks than JICA and Devkota. The former are the most recent data.

Table 7 gives Shrestha's data on average fuel consumption, fuel efficiency and resulting average kilometers traveled per vehicle class. Shrestha's figures in Table 8 give the traffic activity data for the year 1992/93. This total traffic activity corresponds to the total consumption of gasoline and motor diesel in traffic as given in Table 2 (Shrestha and Malla 1993).

***Table 8: Traffic Activity in Kathmandu, 1992-93***

| Vehicle fuel | veh- km/yr (millions) |
|---|---|
| **Gasoline** | |
| Cars, taxis | 170.8 |
| 3-wheelers (TC) | 25.8 |
| 2-wheelers (MC) | 434.4 |
| Subtotal | 631.0 |
| **Diesel** | |
| Jeeps | 62.4 |
| Minibuses | 12.3 |
| Buses | 2.8 |
| Trucks | 27.1 |
| Tractors | 20.2 |
| 3-wheelers (TC) | 10.9 |
| Subtotal | 135.7 |
| **Total** | **766.7** |

The average vehicle composition of the traffic has also been reported by others (Table 9). There may be some discrepancy between the various authors regarding the classification of vehicles. The main discrepancy in the results of Table 7 is that Shrestha has a very high relative number for MC activity, at the expense of Tempo (3-wheelers) activity. His sum for Tempo and MC is, however, in fair agreement with other sources. The problem seems to be that Shrestha has based himself on a too low average driving distance for the Tempos and too long distance for the MC's.

*Table 9: Composition of vehicle categories in Kathmandu traffic.*

| | JICA (1992) Daily | Giri (1993) Rush-hour | Devkota (1992) Rush-hour | Shrestha (1993) Daily |
|---|---|---|---|---|
| PC/taxi (G) | 32.5 (20.0+12.5) | 20.4 | 25 | 22.3 |
| Jeep (Pickup) (D) | | | 7 | 8.1 |
| Minibus/trolley (D) | 8.1 | 14.6 | 8 | 2.0 |
| Trucks/tractors (D) | 4.9 | 2.3 (incl. bus) | 4 | 6.2 |
| Tempo (G/D) | 21.8 | 62.6 | 22 | 4.8 |
| MC (G) | 30.0 | | 22 | 56.6 |

JICA: Based upon 29 counting locations, 1992.
Giri: Based upon 33 counting locations, 1993.
Devkota: Based upon 22 counting locations, 1992.
Shrestha: Based upon an analysis of total traffic activity based on fuel consumption, annual average driving distance and number of operating vehicles.

The data give basis for the estimates in Table 10 of average vehicle composition of Kathmandu Valley traffic.

The vehicle composition in the traffic varies substantially between roads. Streets in the center have very high tempo/MC percentage, while the proportion of trucks is high on the Ring Road (10-15 percent).

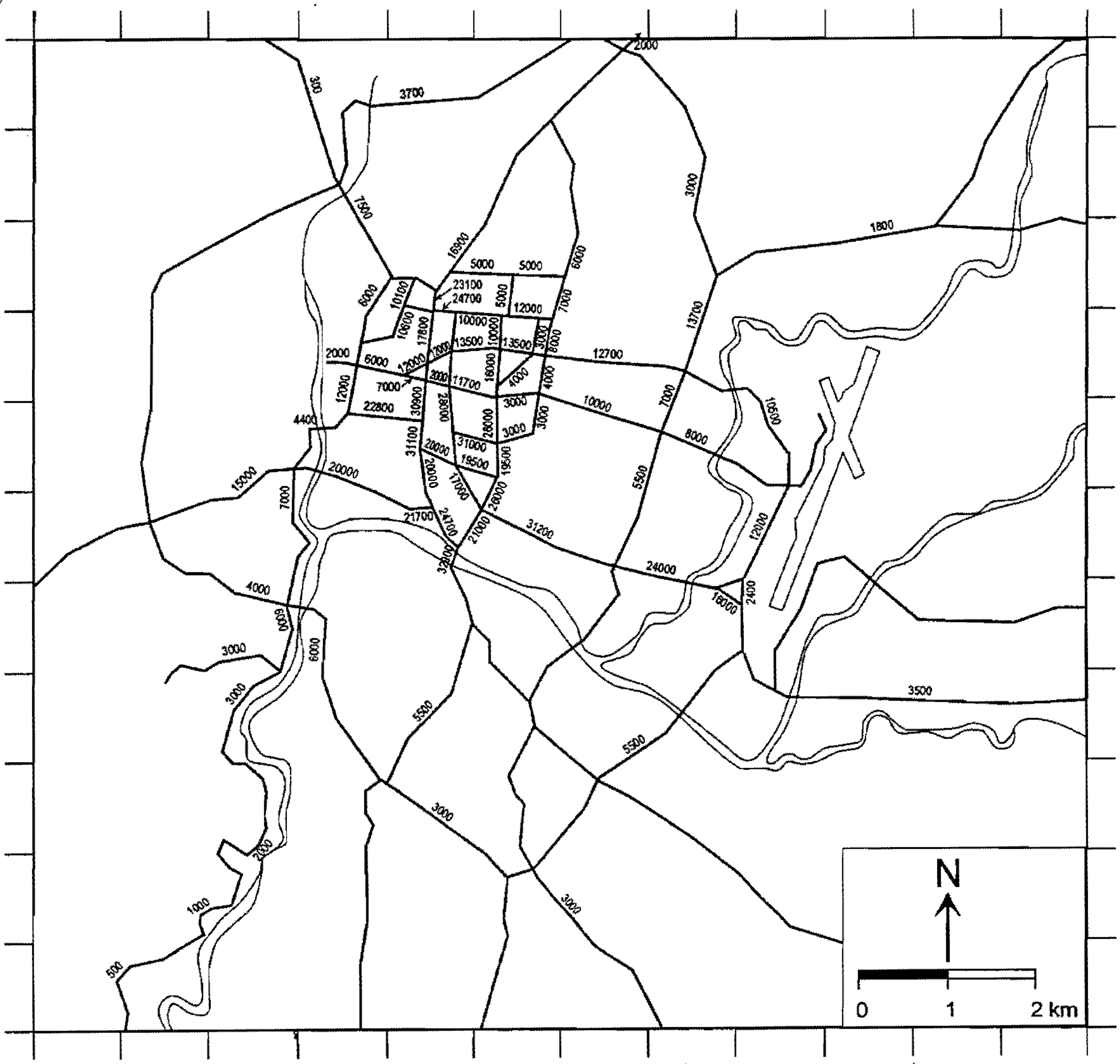
In this study, account is not taken of this variation. The average composition is used as a basis for calculating composite vehicle emission factors for gasoline and diesel separately.

The traffic data has been used to distribute the traffic on the main road system as shown in Figure 4, which gives the estimated annual average daily traffic (AADT) numbers on some of the main roads.

***Table 10: Average Vehicle Composition of Kathmandu Valley Traffic***

| | |
|---|---|
| Car/taxi | 25% |
| Jeep/minibus/tractor | 15% |
| Bus | 2% |
| Truck | 5% |
| Tempo (TC) | 25% |
| Motorcycle (MC) | 28% |

***Figure 4: The main road system of Kathmandu Valley with some of the traffic data used in this study.***




### EMISSION FACTORS

The selection of the emission factors used in this URBAIR calculation for fuel combustion and road vehicles in Kathmandu Valley was based on the following data sources:

- 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).
- Particle emission factors described in Appendix 5.

- Particle emission factors for road vehicles, as deduced from smoke meter measurements in the KVVECP study.

The selected emission factors for fuel combustion, road vehicles and industry are shown in Tables 11 and 12.

The emission factors for Nepal/ Kathmandu conditions may differ substantially from those

***Table 11: Emission factors used for URBAIR, Kathmandu Valley. Fuel combustion, refuse burning and road vehicles.***

| | TSP | | $PM_{10}$/TSP | $SO_2$ | $NO_X$ | %S max. |
|---|---|---|---|---|---|---|
| **Fuel combustion (kg/t)** | | | | | | |
| Residual oil (OF): ind./comm. | 1.25S+0.38[1] | | 0.85 | 20S | 7 | 4 |
| Distillate oil: ind./comm. | 0.28 | | 0.5 | 20S | 2.84 | HSD: 1[4] |
| (HSD, LDO): residential | 0.36 → 1.6[2] | | 0.5 | 20S | 2.6 | LDO: 1.8[5] |
| 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 | |
| Fuelwood: ind. | 3.6 | | 0.5 | | | |
| Coal: dom./comm. | 10 | | 0.5 | | | 1.8[6] |
| Charcoal: dom/comm. | 20 | | 0.5 | | | |
| Agri. residue | 10 | | 0.5 | | | |
| Anim. waste | 10 | | 0.5 | | | |
| Refuse burning, open | 37 | | 1 | 0.5 | 3 | |
| **Road vehicles (g/km)** | **A** | **B** | | | | |
| Gasoline: Cars | 0.2 | | 1 | | 2.7 | 83 Octane (RON) 0.25[3] |
| MC/TC | 0.5 | | 1 | | 0.07 | 93 Octane (RON) 0.20 |
| Diesel: Cars, jeeps, tractors | 0.6 | 0.9 | 1 | | 1.4 | 1[4] |
| Minibuses, tempos | 0.9 | 1.5 | 1 | | 13 | |
| Buses, trucks | 2.0 | 3.0 | | | 13 | |

1) S: sulfur content, in %
2) Well → poorly maintained furnaces
3) Actual S content in 87 RON gasoline, according to IOC Ltd quality certificate: 0.009%
4) Actual S content, according to IOC Ltd quality certificate: 0.20%
5) Actual S content, according to IOC Ltd quality certificate: <1%
6) NESS (1995)
A Used for Manila, Jakarta, Bombay
B Proposed and used for Kathmandu Valley.

given in the tables.

For road vehicles, observations of vehicle exhaust in the Valley indicate that a substantial part of the fleet has very high emissions. There are indications that this is partly due to fuel adulteration. Steadman et al. (1993) have made exhaust measurements with a remote sampling technique on Kathmandu vehicles, also finding large emission factors. It should be mentioned that the measurement site was on a slightly uphill road. The fraction of "grass polluters" was 16 percent and 25 percent for HC and CO respectively. Also, their measurements showed high opacity readings, i.e. particle emissions. Very high opacity readings have also been measured for the Kathmandu vehicle fleet as part of the KVVECP study. These measurements cannot be used to calculate exhaust particle emission factors. They indicate, however, that the real particle emission factors for Kathmandu vehicles may be substantially higher than those given in Table 11.

Also, the particle emission factors for the various uses of solid fuels in Kathmandu, such as fuelwood, coal, charcoal, agricultural residue and animal refuse are not well determined.

***Table 12: Emission factors (kg/ton) for brick and cement industries (US EPA AP42).***

| | TSP | $PM_{10}$/TSP | $SO_2$ | $NO_x$ | CO | %S | F | Pb |
|---|---|---|---|---|---|---|---|---|
| **Brick industries** | | | | | | | | |
| Bull's trench | | | | | | | | |
| per ton of bricks | 9.42 | 0.25 | 6.06S | 1.18 | 1.19 | | 0.5 | |
| per ton of fuel | | | | | | | | |
| - coal (bituminous) | | | | | | | | |
| - wood and bark | | | | | | | | |
| - lignite | | | | | | | | |
| Chinese (Hoffman Bhatta) | | | | | | | | |
| **Portland Cement** | | | | | | | | |
| Dry process, uncontrolled | | | | | | | | |
| Dry process, kiln | 128 | 0.42 | 5.4[1]+3.6S[2] | 1.4 | | | | 0.06 |
| Clinker cooler | 4.6 | 0.09 | | | | | | |
| Dryers, grinders, etc. | 48 | | | | | | | |

1. From mineral source. 2. From coal.

**Particle emissions from Kathmandu diesel vehicles.** The particle emission factors for diesel vehicles used in the URBAIR study for Manila, Bombay and Jakarta, are, as described in Appendix 5, based upon available literature, especially the measurements made on diesel vehicles in Manila. The emission factor for trucks, 2 g/km, was based upon some 20 percent of the trucks being "smoke belchers", with an emission factor up to 8 g/km.

Observations in the Kathmandu traffic and the smoke testing results from the KVVECP study (Table 13) indicate that more than 75 percent of the vehicles in each class have smoke emissions of more than 75 HSU, and some 55 percent have emissions over 85 HSU. The test is done for free acceleration of the engine and does not represent the smoke emissions during driving. However, there is a correlation between smoke emissions during free acceleration and during normal driving.

In Table 14, emissions in g/km are estimated from HSU units, based on certain conditions. These g/km figures represent estimates of emissions during "smoking conditions."

For loaded buses and trucks in the Kathmandu topography, it may be a valid estimate that smoking conditions for the vehicle occur more than 50 percent of the time of operation.

***Table 13: Summary of diesel vehicle smoke test results (Ref.: KVVECP study).***

| Vehicle type | Distribution (%) of tested vehicles in smoke (HSU) level ranges | | | | |
|---|---|---|---|---|---|
| | <65 | 66-75 | 76-85 | 86-95 | 96-100 |
| Tempo | 2 | 14 | 16 | 55 | 13 |
| Car | 19 | 6 | 6 | 62 | 6 |
| Jeeps/st.wgn. | 2 | 7 | 25 | 59 | 6 |
| Mini buses | 4 | 5 | 28 | 56 | 7 |
| Mini trucks | 13 | 14 | 24 | 44 | 4 |
| Buses | 4 | 13 | 44 | 39 | 0 |
| Trucks | 4 | 8 | 40 | 44 | 4 |
| Average | 7 | 10 | 26 | 51 | 6 |

HSU: Hartridge Smoke Units.

Combining data from Tables 13 and 14, the average particle emission during "smoking conditions" for Kathmandu trucks is 4.3 g/km for light truck (0.2 l fuel/km) and 8.6 g/km for a heavy truck (0.4 l fuel/km).

Assuming that the average specific fuel consumption by trucks and buses in Kathmandu Valley is 0.3 l/km, that "smoking conditions" for the total traffic activity of the Valley occur for 25-50 percent of the time, and that the emission factor for the rest of the time is 1 g/km, the average truck/bus emission factor for Kathmandu is calculated to 2.5-3.7 g/km.

*Table 14: Particle emission factor (g/km) for diesel trucks, estimated from HSU data.*

| Hartridge Smoke Units | Particle emissions g/m³ | g/km 1) 40 l engine 2000 rpm 40 km/h | g/km 2) Light truck 0.2 l/km | g/km 2) Heavy truck 0.4 l/km |
|---|---|---|---|---|
| 30 | 0.13 | 1.6 | 0.8 | 1.6 |
| 65 | 0.42 | 5.0 | 2.5 | 5.0 |
| 75 | 0.55 | 6.6 | 3.3 | 6.6 |
| 85 | 0.72 | 8.6 | 4.3 | 8.6 |
| 95 | 1.0 | 12.0 | 6.0 | 12.0 |

1) Based upon 12 $m^3$ air/km (4 l engine, 2000 rpm, 40 km/h).
2) Based upon 0.03 g fuel/g air.

This figure is supported by the emission factor presented by Dr. Mathur of IIT New Delhi in the KVVECP Summary Report, namely 11 kg particles/1,000 liters of diesel, corresponding to 3.7 g/km for a fuel consumption of 0.22 l/km.

Table 13 shows that the HSU distribution is nearly the same for all diesel vehicle types, showing that all the vehicle types are dominated by smoking vehicles. The reason for this condition in the Kathmandu Valley is probably two-fold: i) old, poorly maintained vehicles, and ii) poor fuel quality.

The above considerations are a basis for increasing the emission factors for particles from diesel vehicles in Kathmandu Valley, relative to those used for Manila, Jakarta and Bombay. Both factors are shown in Table 11.

## EMISSIONS FROM INDUSTRY

The locations of the Bull's Trench kilns, the Chinese kilns and Himal Cement factory are shown in Figure 1.

**The brick industry.** The brick production data used in this study is shown in Table 15.

*Table 15: Brick Production Data*

| Area | No. of units | Total production million bricks 1993 | 1994 | Typical stack height/diam (m) |
|---|---|---|---|---|
| **Bull's Trench (Thapa et al. 1993; NESS, 1995)** | | | | |
| Kathmandu | 15 | 24.75 | | |
| Lalitpur | 74 | 209.5 | | 10/0.5 |
| Bhaktapur | 41 | 127.0 | | |
| Total | 130 | 361.0 | 450 | |
| **Chinese (Thapa et al., 1993)** | | | | |
| Lahtpur | 5 | 53.00 | | 65/1.65 |
| Bhaktapur | 1 | 20.00 | | |
| Total | 6 | 73.00 | | |

**Bull's Trench kilns.** The emissions from these kilns have been estimated most recently by the NESS study (1995). The emissions originate mainly from the combustion of the fuel used, the most important of which are coal, fuelwood and rice husk. Handling of the bricks gives rise to particle emissions (resuspension). All fuels give substantial particle emissions, due to the inefficient combustion conditions in the kiln. The coal also gives rise to emissions of sulfur and other trace elements.

Coal analysis results from 1994 gave an average ash and sulfur content of 18 percent and 1.77 percent respectively (Table 16).

***Table 16: Coal analysis results, 1994 (NESS, 1995).***

| | Moisture (%) | Volatile (%) | Ash (%) | Fixed carbon (%) | Sulfur (%) | Calorific value (kcal/kg) |
|---|---|---|---|---|---|---|
| Range (n=6) | 0.3-6.2 | 7.3-37 | 1.9-73 | 20-60 | 0.3-4.4 | 5,750-7,460 |
| Average | 4.15 | 27.12 | 18.02 | 50.72 | 1.77 | 6,708 |

The emissions were calculated by 3 methods:

- Based on brick production, using USEPA AP42 emission factors (the weight of a brick is approx. 2 kg).
- Based on fuel consumption, using USEPA AP42 emission factors.
- Based on emission measurements from Bull's Trench kilns in India.

***Table 17: Total emissions from Bull's Trench kilns in Kathmandu Valley 1994 (tons/yr) (NESS, 1995).***

| Method | Particles (SP) | $SO_2$ | CO | VOC | $NO_x$ | F |
|---|---|---|---|---|---|---|
| A. Based on brick production | 15,862 | 6,435 | 1,442 | 405 | 631 | 451 |
| B. Based on fuel combustion | 5,144 | 1,536 | 2,547 | 524 | 119 | |
| C. Based on emission measurements, India | 4,438 | 4.8 | 16,384 | 2,373 | 0.8 | |

The AP42 emission factors are given in Table 12. The emission results (Table 17) show wide discrepancies between the methods:

- Particles: Methods B and C agrees fairly well while method A gives very large emissions. Incidentally, using the AP42 factor for method A (9.42 kg/ton, 450 mill bricks and 2 kg/brick) gives 8,478 tons of particles, while 15,876 tons is reported by the NESS study.
- $SO_2$: The methods disagree basically. Method C results indicate that the sulfur released from the coal is absorbed on the brick surfaces.
- $NO_x$: The methods disagree basically. Method C results (together with high CO emissions) indicate poor combustion conditions.

Based on this, we use an estimate of 5,000 tons of particles emitted annually from Bull's trench kilns. The emission of $SO_2$ cannot be estimated with confidence, due to the available data.

**Chinese (Hoffmann Bhatta) kilns.** No specific information is available on the emissions from these kilns in Kathmandu Valley. Also, total fuel and other input consumption data are not available. Shrestha (1993) has reported coal consumption for two of the factories, namely HHBF and BBF (4,093 tons in 1992/93).

Devkota (1992) reports that 1,000 kg of coal is required to produce 8,000 bricks (data from the HHBF factory). In addition, 15 tons of fuelwood is used annually for firing, which is negligible. Using the 1,000 kg/8,000 bricks figure, it is calculated that the Chinese kilns use a total of some 9,100 tons of coal annually.

**The Himal Cement Factory**. The factory has a production capacity of 360 tons per day (Bhattarai, 1993), by 2 vertical shaft kilns. Stack data are as follows (Bhattarai, 1993):

- Number of stacks: 2
- Height: 33.5 m
- Flue gas velocity: 5.7 m/s
- Flue gas temperature: 120°C
- Stack diameter: unknown

The production has normally been some 45,000-50,000 tons annually in the period 1986-91 (Devkota, 1992), with a coal consumption of some 6,000-8,000 tons annually. In the most recent years, production has increased, and Shrestha (1993) reports a coal consumption of some 17,000 tons for 1992/93.

According to Bhattarai (1993) the Himal Cement Co estimated that prior to the planned installation of effective particle emission control equipment in 1994, there was an average particle emission of 2.85 tons daily from the stack, and around 10 tons from lime stone handling at the quarry. In addition, there were substantial dust emissions from material handling and transport within the factory area.

The pollution control equipment, which includes bag filters and wet scrubbers, was planned to be in operation as of December 1994.

**Other industries.** There is a total of 2,174 industrial establishments in Kathmandu Valley, presumably with more than 10 employees. Devkota (1992) has described the level of industrialization in the Valley.

There are 3 designated "industrial districts" in the Valley: Balaju (0.35 $km^2$), the oldest one, Patan (0.14 $km^2$) and Bhaktapur (0.04 $km^2$). Besides these districts, the emergence of new industries along the "Ribbon zones", i.e. Kathmandu-Thankot and Kathmandu-Bhaktapur transportation corridors, and also in the southern part of Lalitpur district, is a matter of concern (see Figure 1 for location).

Devkota reported the following numbers of industrial establishments: in Balaju, 71 units; in Patan, 103 units, and in Bhaktapur, 27 units. He included the numbers of cottage industries shown in Table 18.

*Table 18: Cottage Industries*

| "Cottage industries" (at mid-91) | Kathmandu | Lalitpur | Bhaktapur |
|---|---|---|---|
| Plastic and rubber | 79 | 5 | 4 |
| Metal crafting | 409 | 97 | 7 |
| Al, brass, Cu | 32 | 9 | - |

Another major cottage industry in terms of number is backyard pottery, of which there may be several thousand in operation during the dry season.

Bhattarai (1993) describes briefly the dying industry (carpet and textile) in terms of air pollution emissions. They use boilers to generate steam. Previously, rice husk was mainly used as feed stock for the boilers, but now there is a transition towards the use of diesel oil (HSD). A recent survey of 19 industries gave that 12 of them used diesel.

Boilers are also used in other industries such as flour mills and leather mills. Presumably, there is a transition towards diesel also in such industries.

Devkota estimated the amount of rice husk used by potters in up-draft kilns. The annual demand per potter may be 12,000-15,000 kg of biomass.

These "other" industries definitely represent air pollution problems localized to the areas immediately adjacent. In addition, they represent a total emissions from combustion of diesel and rice husk, and to some extent of process emissions, which should be taken into account in the total emission survey for the Valley. Their contribution to the background pollution of the Valley, and thus their effect on visibility, should be considered.

RONAST (1994) reports a total diesel consumption of 7.83 mill liters by these smaller industries in the Valley in 1992. Dairy products, textile processing and carpet/rugs were the largest industrial users.

With reference to the HMG/Ministry of Industry, RONAST (1994) reports the TSP emissions from distributed industries in Table 19.

***Table 19: Industrial TSP Emissions***

| Type of industry | No. of units | TSP in tons/yr |
|---|---|---|
| Beverages/distilleries | 3 | 5 |
| Textile processing | 85 | 8 |
| Knitting mills | 25 | 5 |
| Carpet and rugs | 1109 | 144 |
| Paper and products | 3 | 0.3 |
| Animal feed | 13 | 65 |
| Plastic products | 38 | 8 |
| Soap and detergents | 4 | 5 |
| Marbles | 1 | 67 |
| Dry battery | 1 | 880 |

## TOTAL EMISSIONS

Table 20 gives the estimated emissions of TSP, $PM_{10}$, $SO_2$ and $NO_x$ associated with the various source categories, fuels, vehicle types and industries.

In the previous text, the quality of the data sources and the emission numbers have been briefly discussed. It is clear that the estimated emission figures given in Table 14 have a limited accuracy. For instance, brick industry emissions are not well determined. However, they are believed to be useful to give the first estimate of the importance of the various source categories, as contributors to the various air pollution problems of the Kathmandu Valley, such as:

- roadside pollution by suspended particles and $PM_{10}$ (respirable particles),
- general air pollution exposure of the population,
- reduced visibility.

Dispersion modeling will clarify which sources contribute most to these problems. One important point in this respect is the fact that the brick industry is in operation only during the October to March period, i.e. half the year, while the other sources are in operation during the whole year. For the reduced visibility problem, this means that the brick industry is even more important, may be twice as important relatively, than indicated by the emission figures of Table 20.

The emissions inventory of Table 20 itself, together with observations in the Valley, indicate the most important sources as shown in Table 21.

### SPATIAL EMISSION DISTRIBUTION

The total emissions from each source category have been distributed within the km2 grid net based on:

- the actual location of point sources (e.g. Himal Cement Factory, brick kilns and industrial areas; see Figure 1)
- the population distribution
- the cooking practices of the urban and rural population
- the traffic activity distribution.

The **traffic activity** was distributed as follows:

- The traffic activity (veh.km/yr) on the roads with known traffic count was calculated (vehicles x road length), and distributed in the grid system according to the actual location of the road sections.
- This traffic activity accounted for about 50 percent of the total traffic activity, as calculated from the fuel consumption (Shrestha and Malla, 1993).
- The difference was distributed within the grid net, proportional to the population distribution, with an additional weight put on the highly populated city center areas.
- The emissions from the total traffic activity in each grid square were calculated by first calculating composite emission factors for gasoline and diesel vehicles respectively, by combining the emission factors of Table 11 and the average vehicle composition in Table 10.

***Table 20: Estimated emissions from air pollution sources in Kathmandu Valley, 1992/93 (tons/yr).***

| | TSP | $PM_{10}$ | $SO_2$ |
|---|---|---|---|
| **Vehicles** | | | |
| Gasoline: Cars/taxis | 38.4 | - | |
| TC | 67.5 | - | 4.2-105[1] |
| MC | 107.5 | - | |
| Diesel: Jeeps | 68.4 | - | |
| Minibuses | 22.5 | - | |
| Buses | 45.0 | - | 78-390[1] |
| Trucks | 114 | - | |
| Tractors | 21.6 | - | |
| TC | 85.8 | - | |
| Sum vehicle exhaust | 570 | 570 | 82-495[1] |
| Resuspension from roads | 1,530.0 | ~400 | 0 |
| **Fuel combustion** | | | |
| Industrial/commercial (excl. brick/cement): | 61.9 | 31 | |
| Fuelwood | | | |
| Coal | 48 | 24 | 172 |
| Charcoal | 20 | 10 | |
| HSD | 1.8 | 2 | |
| LDO/FO? | | | |
| Kerosene/LPG | 0.1 | | |
| Agri. residue | 450.0 | 225 | |
| Sum industrial/commercial | 582.0 | 292 | |
| Domestic: Fuelwood | 1,832.0 | 916 | |
| Agri. residue | 454.0 | 227 | |
| Anim. waste | 30.0 | 15 | |
| Kerosene/LPG | 2.3 | 2.3 | |
| Charcoal | 10.0 | 5 | |
| Sum domestic | 2,328.0 | 1,165 | |
| **Brick industry** | | | |
| Bull's Trench | 5,000.0 | 1,250 | 4.8-4,465[2] |
| Chinese | 180.0 | 45 | |
| Sum brick | 5,180.0 | 1295 | |
| **Himal Cement:** Stack | ~2,000.0 | ~400 | 615 |
| Diffuse dust | ~4,000.0 | ~400 | |
| **Miscellaneous** | | | |
| Refuse burning | 385 | 190 | |
| Construction | | | |
| **Sum** | **16,565.0** | **4,712** | |

1 High value: Based on max. allowable S content
Low value: Based on actual S content, according to IOC Ltd. certificate

2 NESS (1995): Estimates based on different methods.

Those composite emission factors were calculated to be:

- gasoline: 0.39 g/km
- diesel: 1.65 g/km

The emissions from the **Bull's trench kilns** were distributed in the grid net according to their actual location. An average emission figure for each kiln was calculated, and the emissions from each grid square calculated by multiplying this average emission figure by the number of kilns in the square.

***Table 21: Important particulate sources***

| | TSP | $PM_{10}$ |
|---|---|---|
| Roadside pollution | • Resuspension | • Gasoline exhaust<br>• Diesel exhaust<br>• Resuspension |
| General population exposure | • Domestic fuel combustion<br>• Brick industry (mainly Bull Trench)<br>• Resuspension | • Domestic fuel combustion<br>• Brick industry (mainly Bull's trench)<br>• Vehicle exhaust<br>• Resuspension |
| Reduced visibility | • Bull's trench brick kilns<br>• Domestic fuel combustion<br>• Vehicle exhaust | |

Figures 5-9 give the resulting TSP emission distributions from each of the area-distributed source categories, as kg/h (averaged over the winter half-year, October-March, 1992/93.

The following ratios are used for $PM_{10}$/TSP:

- Vehicle exhaust: 1.0
- Resuspension from roads: 0.25
- Fuel/refuse combustion: 0.5
- Brick industry: 0.25
- Himal Cement, stack: 0.2
- Himal Cement, diffuse: 0.1

***Figure 5: TSP emission from road vehicle exhaust, Kathmandu Valley. Winter half-year emission, 1992/93. Constant emission, calculated as kg/hour. Unit: kg/hour per km² grid.***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J=21 | . | . | . | . | . | 12. | 14. | 17. | 27. | 24. | 24. | 15. | 15. | 28. | 93. | 15. | 10. | 7. | 15. | . | . | 10. | 10. | . | 23. | . | . |
| J=20 | . | 3. | . | . | . | 10. | 5. | 12. | 15. | 19. | 19. | 25. | 30. | 104. | 25. | 25. | 15. | 5. | 10. | 15. | 20. | 11. | 15. | 11. | 11. | 11. | . |
| J=19 | . | 5. | 3. | 3. | 3. | 13. | 14. | 12. | 7. | 12. | 32. | 25. | 40. | 94. | 23. | 18. | 20. | 10. | 15. | 10. | 22. | 15. | 13. | 23. | 11. | 23. | . |
| J=18 | . | 5. | 8. | 5. | 5. | 5. | 9. | 19. | 41. | 58. | 40. | 123. | 140. | 64. | 23. | 116. | 63. | 25. | 35. | 16. | 15. | 17. | 23. | 23. | 23. | 34. | . |
| J=17 | . | 3. | 13. | 13. | 10. | 13. | 13. | 5. | 122. | 176. | 252. | 217. | 253. | 64. | 31. | 96. | 48. | 20. | 15. | 17. | 17. | 17. | 14. | 24. | 23. | 45. | 11. |
| J=16 | . | . | 10. | 10. | 8. | 10. | 15. | 10. | 325. | 135. | 1344. | 1013. | 845. | 80. | 80. | 16. | 20. | 25. | 18. | 17. | 20. | 9. | 8. | 3. | 3. | 14. | 14. |
| J=15 | . | 9. | 18. | 11. | 9. | 18. | 193. | 187. | 15. | 1236. | 4978. | 641. | 1401. | 275. | 166. | 100. | 110. | 22. | 17. | 17. | 10. | 10. | 12. | 9. | 6. | 9. | 10. |
| J=14 | . | 22. | 22. | 18. | 27. | 19. | 164. | 167. | 220. | 5381. | 4385. | 1956. | 1827. | 306. | 71. | 53. | 20. | 22. | 28. | 34. | 18. | 12. | 10. | 10. | 13. | 13. | 15. |
| J=13 | . | 18. | 22. | 22. | 36. | 34. | 169. | 80. | 1020. | 3383. | 2936. | 1226. | 651. | 548. | 352. | 15. | 21. | 45. | 53. | 42. | 21. | 13. | 13. | 51. | 42. | 12. | 18. |
| J=12 | 82. | 125. | 114. | 36. | 55. | 111. | 488. | 525. | 690. | 1237. | 2031. | 1187. | 564. | 1072. | 97. | 16. | 37. | 64. | 43. | 36. | 60. | 46. | 40. | 122. | 27. | 11. | 13. |
| J=11 | . | 9. | 42. | 130. | 149. | 118. | 46. | 196. | 559. | 399. | 1107. | 2363. | 1490. | 743. | 68. | 89. | 103. | 74. | 66. | 69. | 124. | 1176. | 954. | 71. | 8. | 9. | 16. |
| J=10 | . | 4. | 16. | 15. | 31. | 39. | 39. | 138. | 216. | 340. | 974. | 195. | 349. | 283. | 160. | 153. | 148. | 137. | 153. | 179. | 98. | 146. | 9. | 12. | 9. | 13. | 18. |
| J= 9 | . | . | 8. | 8. | 23. | 12. | 4. | 128. | 13. | 306. | 335. | 360. | 55. | 24. | 41. | 33. | 26. | 31. | 24. | 52. | 76. | 58. | 66. | 33. | 13. | 18. | 13. |
| J= 8 | . | . | 2. | 6. | 6. | 7. | 5. | 79. | 10. | 10. | 227. | 215. | 29. | 22. | 12. | 22. | 49. | 12. | 17. | 9. | 9. | 6. | 8. | 39. | 29. | 4. | 2. |
| J= 7 | . | . | 2. | 2. | 4. | 7. | 41. | 7. | 10. | 13. | 24. | 92. | 128. | 62. | 18. | 27. | 12. | 16. | 14. | 3. | 5. | 5. | 6. | 3. | 31. | 37. | 14. |
| J= 6 | . | . | 4. | 4. | 5. | 4. | 21. | 7. | 11. | 3. | 29. | 27. | 147. | 19. | 41. | 14. | 8. | 8. | 20. | 8. | 3. | 3. | 3. | 3. | 3. | 2. | 19. |
| J= 5 | . | . | . | 2. | 7. | 4. | 19. | 19. | 7. | . | 17. | 35. | 34. | 112. | 33. | 16. | 8. | 10. | 9. | 4. | . | . | 2. | 2. | 2. | . | . |
| J= 4 | . | . | . | 4. | 5. | 34. | 29. | 4. | 5. | . | 10. | 31. | 13. | 117. | 16. | 10. | 10. | 16. | 8. | . | . | . | . | . | . | . | . |
| J= 3 | . | . | . | 1. | 4. | 18. | 4. | 4. | 5. | . | 10. | 27. | 23. | 12. | 101. | 5. | 5. | 5. | . | . | . | . | . | . | . | . | . |
| J= 2 | . | . | . | 2. | 3. | 12. | 2. | 5. | 2. | . | 2. | 23. | 12. | 8. | 35. | 63. | 12. | 5. | . | . | . | . | . | . | . | . | . |
| J= 1 | . | . | . | 1. | 4. | 4. | 3. | 3. | 3. | . | . | . | 2. | 4. | 4. | 18. | 25. | . | . | . | . | . | . | . | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

***Figure 6: TSP emission from resuspension from roads, Kathmandu Valley. Winter half year emission, 1992/93. Constant emission, calculated as kg/hour. Unit: kg/hour per km² grid.***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J=21 | . | . | . | . | . | 3. | 4. | 4. | 7. | 6. | 6. | 4. | 4. | 7. | 24. | 4. | 3. | 2. | 4. | . | . | 3. | 3. | . | 6. | . | . |
| J=20 | . | 1. | . | . | . | 3. | 1. | 3. | 4. | 5. | 5. | 7. | 8. | 27. | 7. | 7. | 4. | 1. | 3. | 4. | 5. | 3. | 4. | 3. | 3. | 3. | . |
| J=19 | . | 1. | 1. | 1. | 1. | 4. | 4. | 3. | 2. | 3. | 8. | 7. | 10. | 25. | 6. | 5. | 5. | 3. | 4. | 3. | 6. | 4. | 3. | 6. | 3. | 6. | . |
| J=18 | . | 1. | 2. | 1. | 1. | 1. | 2. | 5. | 11. | 15. | 10. | 32. | 37. | 17. | 6. | 31. | 16. | 7. | 9. | 4. | 4. | 4. | 6. | 6. | 6. | 9. | . |
| J=17 | . | 1. | 3. | 3. | 3. | 3. | 3. | 1. | 32. | 46. | 66. | 57. | 66. | 17. | 8. | 25. | 12. | 5. | 4. | 4. | 4. | 4. | 4. | 6. | 6. | 12. | 3. |
| J=16 | . | . | 3. | 3. | 2. | 3. | 4. | 3. | 85. | 35. | 352. | 265. | 221. | 21. | 21. | 4. | 5. | 7. | 5. | 4. | 5. | 2. | 2. | 1. | 1. | 4. | 4. |
| J=15 | . | 2. | 5. | 3. | 2. | 5. | 50. | 49. | 4. | 324. | 1304. | 168. | 367. | 72. | 44. | 26. | 29. | 6. | 4. | 4. | 3. | 3. | 3. | 2. | 2. | 2. | 3. |
| J=14 | . | 6. | 6. | 5. | 7. | 5. | 43. | 44. | 58. | 1410. | 1149. | 513. | 479. | 80. | 19. | 14. | 5. | 6. | 7. | 9. | 5. | 3. | 3. | 3. | 3. | 3. | 4. |
| J=13 | . | 5. | 6. | 6. | 9. | 9. | 44. | 21. | 267. | 886. | 769. | 321. | 171. | 143. | 92. | 4. | 5. | 12. | 14. | 11. | 5. | 3. | 3. | 13. | 11. | 3. | 5. |
| J=12 | 21. | 33. | 30. | 9. | 14. | 29. | 128. | 138. | 181. | 324. | 532. | 311. | 148. | 281. | 25. | 4. | 10. | 17. | 11. | 9. | 16. | 12. | 10. | 32. | 7. | 3. | 4. |
| J=11 | . | 2. | 11. | 34. | 39. | 31. | 12. | 51. | 147. | 105. | 290. | 619. | 390. | 195. | 18. | 23. | 27. | 19. | 17. | 18. | 32. | 308. | 250. | 19. | 2. | 2. | 4. |
| J=10 | . | 1. | 4. | 4. | 8. | 10. | 10. | 36. | 57. | 89. | 255. | 51. | 91. | 74. | 42. | 40. | 39. | 36. | 40. | 47. | 26. | 38. | 2. | 3. | 2. | 4. | 5. |
| J= 9 | . | . | 2. | 2. | 6. | 3. | 1. | 33. | 4. | 80. | 88. | 94. | 14. | 6. | 11. | 9. | 7. | 8. | 6. | 14. | 20. | 15. | 17. | 9. | 4. | 5. | 4. |
| J= 8 | . | . | . | 1. | 1. | 2. | 1. | 21. | 3. | 3. | 59. | 56. | 8. | 6. | 3. | 6. | 13. | 3. | 5. | 2. | 2. | 2. | 2. | 10. | 7. | 1. | 1. |
| J= 7 | . | . | . | . | 1. | 2. | 11. | 2. | 3. | 3. | 6. | 24. | 33. | 16. | 5. | 7. | 3. | 4. | 4. | 1. | 1. | 1. | 2. | 1. | 8. | 10. | 4. |
| J= 6 | . | . | 1. | 1. | 1. | 1. | 6. | 2. | 3. | 1. | 8. | 7. | 39. | 5. | 11. | 4. | 2. | 2. | 5. | 2. | 1. | 1. | 1. | 1. | 1. | 1. | 5. |
| J= 5 | . | . | . | . | 2. | 1. | 5. | 5. | 2. | . | 5. | 9. | 9. | 29. | 9. | 4. | 2. | 3. | 2. | 1. | . | . | . | . | . | . | . |
| J= 4 | . | . | . | 1. | 1. | 9. | 8. | 1. | 1. | . | 3. | 8. | 4. | 31. | 4. | 3. | 3. | 4. | 2. | . | . | . | . | . | . | . | . |
| J= 3 | . | . | . | . | 1. | 5. | 1. | 1. | 1. | . | 3. | 7. | 6. | 3. | 27. | 1. | 1. | 1. | . | . | . | . | . | . | . | . | . |
| J= 2 | . | . | . | . | 1. | 3. | . | 1. | 1. | . | . | 6. | 3. | 2. | 9. | 16. | 3. | 1. | . | . | . | . | . | . | . | . | . |
| J= 1 | . | . | . | . | 1. | 1. | 1. | 1. | 1. | . | . | . | 1. | 1. | 1. | 5. | 7. | . | . | . | . | . | . | . | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

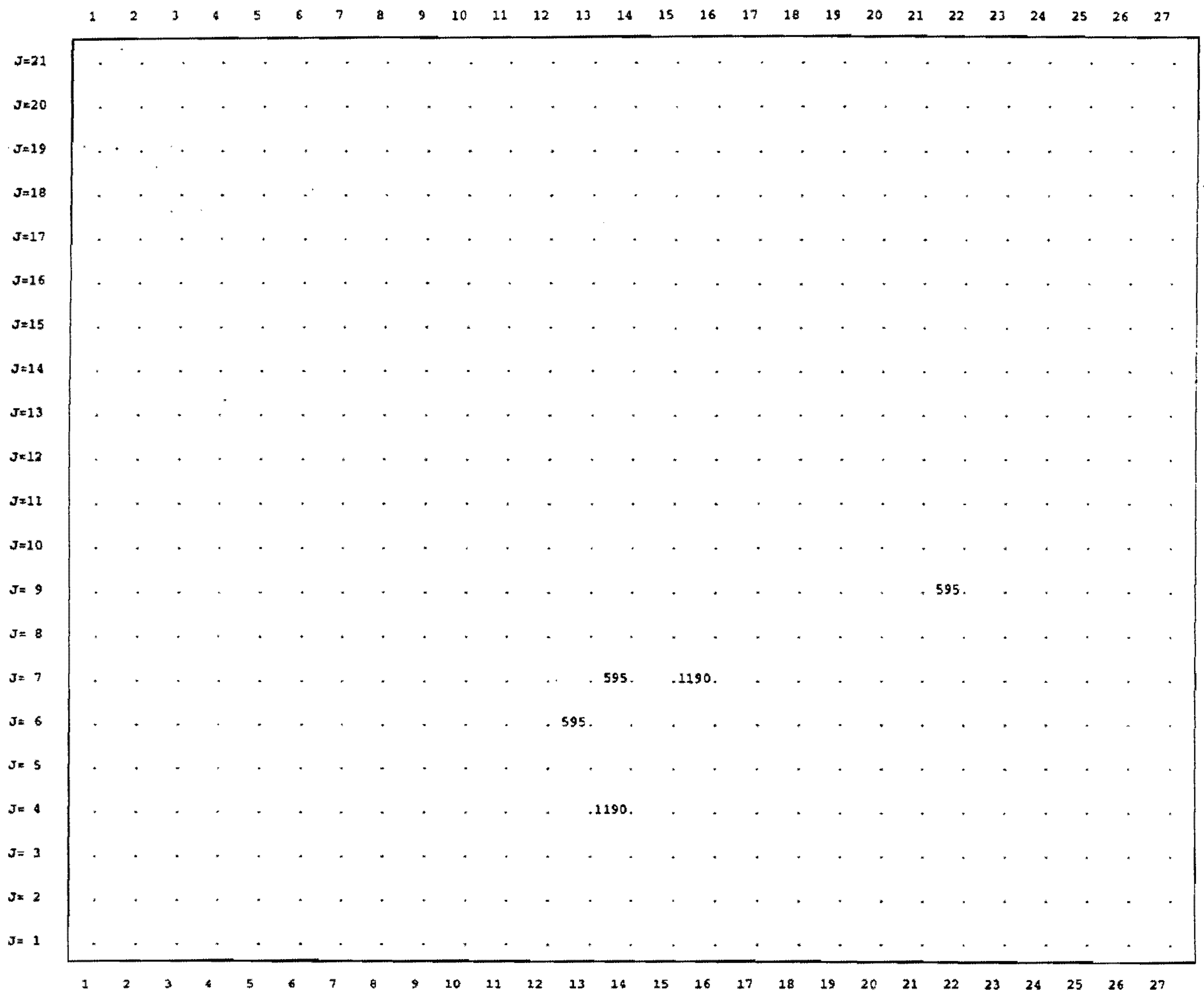
***Figure 7: TSP emission from domestic and industrial fuels, (excl. brick and cement industry), Kathmandu Valley. Winter half year emission, 1992/93. Constant emission, calculated as kg/hour. Unit: kg/hour per km² grid.***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J=21 | . | . | . | . | . | . | 302. | 529. | 831. | 755. | 755. | 467. | 467. | 779. | 623. | 467. | 312. | 233. | 473. | . | . | 315. | 315. | . | 706. | . | . |
| J=20 | . | 79. | . | . | . | . | 151. | 378. | 453. | 604. | 604. | 779. | 934. | 934. | 779. | 779. | 467. | 156. | 315. | 473. | 630. | 353. | 483. | 353. | 353. | 353. | . |
| J=19 | . | 158. | 79. | 79. | 79. | 79. | 154. | 381. | 227. | 378. | 984. | 779. | 467. | 1406. | 703. | 550. | 629. | 315. | 473. | 315. | 696. | 455. | 391. | 706. | 353. | 706. | . |
| J=18 | . | 158. | 236. | 158. | 158. | 158. | 158. | 158. | 1214. | 1811. | 1242. | 1209. | 2070. | 1992. | 704. | 1817. | 1956. | 788. | 1103. | 510. | 455. | 521. | 706. | 706. | 706. | 1059. | . |
| J=17 | . | 79. | 394. | 394. | 315. | 394. | 394. | 158. | 1933. | 1811. | 3478. | 2186. | 1992. | 1992. | 983. | 3004. | 1483. | 630. | 473. | 521. | 521. | 521. | 433. | 746. | 706. | 1412. | 353. |
| J=16 | . | . | 315. | 315. | 236. | 315. | 472. | 315. | 1305. | 1993. | 2341. | 2038. | 3431. | 2500. | 2503. | 500. | 630. | 789. | 575. | 521. | 616. | 281. | 241. | 80. | 80. | 433. | 433. |
| J=15 | . | 277. | 554. | 355. | 296. | 551. | 630. | 472. | 435. | 2693. | 4510. | 1854. | 2748. | 2612. | 2332. | 1330. | 2346. | 698. | 521. | 536. | 321. | 321. | 361. | 281. | 200. | 281. | 321. |
| J=14 | . | 692. | 692. | 554. | 831. | 592. | 630. | 1657. | 2014. | 3138. | 2649. | 2966. | 2249. | 3170. | 2217. | 1647. | 633. | 688. | 877. | 1052. | 562. | 361. | 321. | 321. | 401. | 396. | 457. |
| J=13 | . | 554. | 692. | 692. | 1108. | 1067. | 788. | 1231. | 2014. | 2721. | 2495. | 2076. | 2207. | 1840. | 3503. | 475. | 650. | 1413. | 1667. | 1296. | 642. | 401. | 401. | 1598. | 600. | 369. | 556. |
| J=12 | . | 692. | 831. | 1108. | 1108. | 854. | 2036. | 721. | 721. | 3096. | 2315. | 2893. | 3385. | 3091. | 1346. | 492. | 1167. | 2000. | 1333. | 1121. | 1872. | 1425. | 1238. | 3094. | 829. | 347. | 417. |
| J=11 | . | 277. | 831. | 860. | 878. | 962. | 1443. | 962. | 1322. | 3269. | 2108. | 5530. | 2502. | 1142. | 558. | 643. | 1215. | 1191. | 1024. | 2137. | 1928. | 2752. | 2179. | 2221. | 243. | 278. | 487. |
| J=10 | . | 138. | 499. | 481. | 962. | 1203. | 591. | 899. | 658. | 1912. | 2258. | 2240. | 1876. | 1017. | 1017. | 811. | 763. | 763. | 667. | 1144. | 572. | 1218. | 286. | 383. | 278. | 417. | 556. |
| J= 9 | . | . | 241. | 241. | 721. | 361. | 110. | 439. | 420. | 978. | 1283. | 1708. | 1708. | 763. | 1272. | 1017. | 826. | 953. | 763. | 763. | 381. | 238. | 381. | 191. | 417. | 556. | 417. |
| J= 8 | . | . | 55. | 175. | 175. | 230. | 165. | 220. | 327. | 300. | 800. | 120. | 907. | 692. | 382. | 700. | 1526. | 382. | 540. | 286. | 286. | 191. | 238. | 143. | 139. | 139. | 70. |
| J= 7 | . | . | 55. | 55. | 110. | 220. | 110. | 165. | 327. | 400. | 760. | 721. | 1441. | 1937. | 548. | 844. | 382. | 508. | 429. | 95. | 143. | 143. | 191. | 95. | 35. | 104. | 35. |
| J= 6 | . | . | 110. | 110. | 165. | 137. | 165. | 220. | 329. | 100. | 900. | 840. | 1200. | 604. | 1291. | 450. | 254. | 254. | 636. | 238. | 95. | 95. | 95. | 95. | 83. | 70. | . |
| J= 5 | . | . | . | 55. | 220. | 110. | 220. | 220. | 220. | . | 540. | 1080. | 721. | 441. | 1028. | 484. | 242. | 323. | 271. | 127. | . | . | 48. | 48. | 48. | . | . |
| J= 4 | . | . | . | 110. | 165. | 165. | 165. | 110. | 165. | . | 310. | 960. | 420. | 480. | 282. | 323. | 323. | 484. | 242. | . | . | . | . | . | . | . | . |
| J= 3 | . | . | . | 27. | 110. | 55. | 110. | 137. | 165. | . | 300. | 840. | 721. | 360. | 240. | 162. | 162. | 162. | . | . | . | . | . | . | . | . | . |
| J= 2 | . | . | . | 55. | 82. | 165. | 55. | 160. | 77. | . | 50. | 721. | 360. | 240. | 360. | 81. | . | . | . | . | . | . | . | . | . | . | . |
| J= 1 | . | . | . | 27. | 110. | 110. | 82. | 82. | 100. | . | . | . | 60. | 120. | 120. | . | . | . | . | . | . | . | . | . | . | . | . |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

***Figure 8: TSP emission from** Bull's trench brick kilns, **Kathmandu Valley. Winter half year emission, 1992/93. Constant emission, calculated as kg/hour. Unit: kg/hour per km² grid.***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| J=21 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=20 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=19 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=18 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=17 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=16 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=15 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=14 | | | | | | | 1740. | | | | | | | | | | | | | | | | | | | | |
| J=13 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J=12 | | 2610. | | 2610. | 1740. | | | | | | | | | | | | | | | 2610. | 4350. | 870. | | 3480. | 1740. | | |
| J=11 | | | | | | 5220. | 870. | | | | | | | | | | | 4350. | 870. | 870. | 1740. | | | 3480. | | | |
| J=10 | | | | | | | | | | | | | | | | | | | | | | | 2610. | | | | |
| J= 9 | | | | | | | | | 2610. | | | 4350. | 1740. | 1740. | | | 1740. | 870. | | | | | 3480. | 1740. | | | |
| J= 8 | | | | | | | | | | | | 2610. | 3480. | 870. | 5220. | | 870. | | | | | | | 1740. | | | |
| J= 7 | | | | | | | | | | | 2610. | 6960. | 2610. | 5220. | 6960. | | | | | | | | | | | | |
| J= 6 | | | | | | | | | | | | | 2610. | 8700. | | | | | | | | | | | | | |
| J= 5 | | | | | | | | | | | | | 2610. | 870. | | | | | | | | | | | | | |
| J= 4 | | | | | | | | | | | | | 870. | 870. | | | | | | | | | | | | | |
| J= 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J= 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J= 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |

***Figure 9:* TSP emission from** *Chinese (Hoffman Bhatta) brick kilns,* **Kathmandu Valley. Winter half year emission, 1992/93. Constant emission, calculated as kg/hour. Unit: kg/hour per km$^2$ grid.**

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# APPENDIX 4
# EMISSION FACTORS, PARTICLES

## INTRODUCTION

Emission factors (emitted amount of pollutant per quantity of combusted fuel, or per kilometer driven, or per produced unit of product) are important input data to emissions 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 emissions 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 into account 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, relevant as a basis for selection of factors to be used in South-East Asian cities.*

| 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 |

**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 US EPA/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, the EPA factor of 0.33 g/km was selected for such vehicles, taking into account generally poor maintenance in South-East Asian cities.
- Heavy duty trucks: Only the USEPA has 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 emission 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 US EPA, we also take into consideration the factor 2 g/km used in the

*Table 2: Selected emission factors (g/km) for particles from road vehicles used in URBAIR.*

| Vehicles class | Gasoline | Diesel |
|---|---|---|
| Passenger cars/taxies | 0.2 | 0.6 |
| Utility vehicles/light trucks | 0.33 | 0.9 |
| Motorcycles/tricycles | 0.5 | |
| Trucks/buses | | 2.0 |

VECP study in Manila, which indicates evidence for very large emissions from such vehicles.
- 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 USA, as also measured by Larssen and Heintzenberg (1983) on Norwegian vehicles. This is supported by 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 in the table 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) are 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 (Ref.: US EPA, AP 42). (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 | |

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.

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# APPENDIX 5: SPREADSHEET FOR CALCULATING EFFECTS OF CONTROL MEASURES ON EMISSIONS

### EMISSIONS SPREADSHEET

The spreadsheet is shown in Figure 1. (Example: TSP emission, Kathmandu Valley, Base Case Scenario, 1993.) 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:

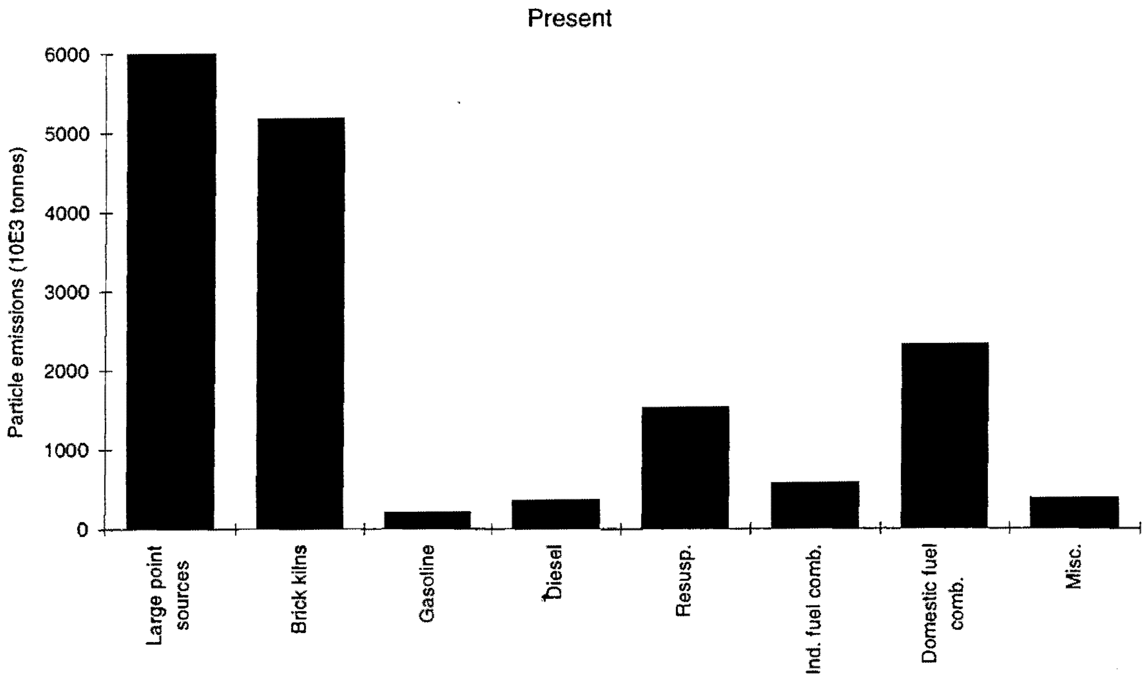
**Columns**

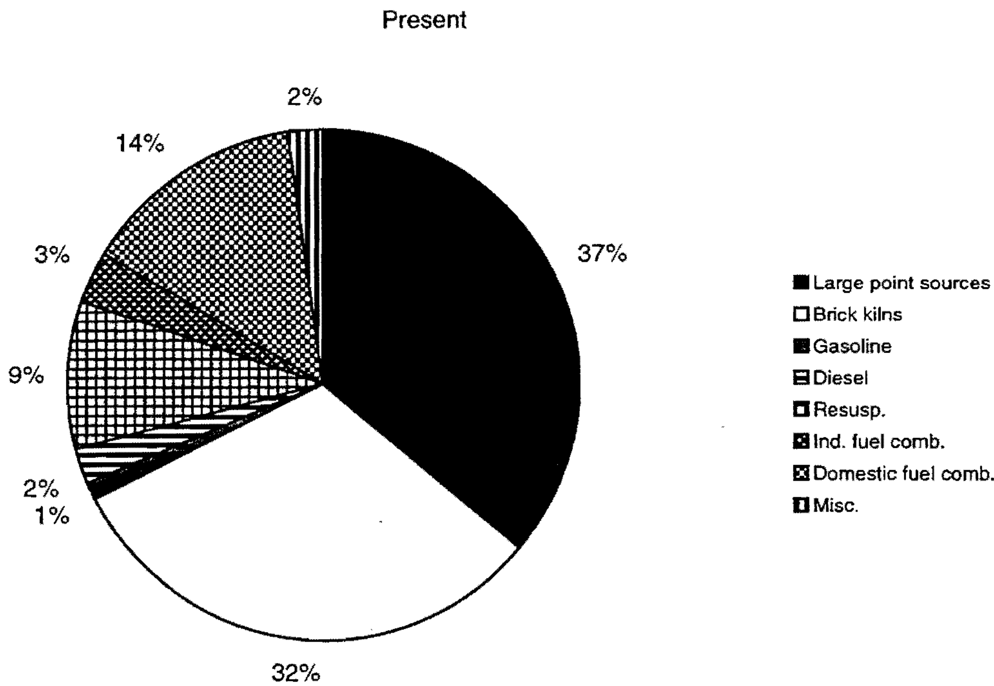
a) q: Emission factor, g/km for vehicles, kg/m$^3$ or kg/ton for fuel combustion and process emissions. For vehicles, emission factors are given for "existing" and "new" technology.
b) F,T: Amount of "activity"
   T (vehicle-km) for traffic activity
   F (m$^3$ or ton) for fuel consumption in industrial 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

*Figure 1: URBAIR spreadsheet for emissions calculations, Kathmandu Valley, TSP, base case 1993*

| | Emission factor | Amount | Base-case Emissions | Control measures | | | Modified emissions | Relative emissions per category | Relative emissions total |
|---|---|---|---|---|---|---|---|---|---|
| **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) |
| Himal Cement – Dry kiln | | | 2000 | 1.00 | 1.00 | 1.00 | 2000 | | 33.3 |
| Clinker Cooler | | | 0 | 1.00 | 1.00 | 1.00 | 0 | | 0.0 |
| Dryers, grinders, etc. | | | 4000 | 1.00 | 1.00 | 1.00 | 4000 | | 66.7 |
| Quarry | | | 0 | 1.00 | 1.00 | 1.00 | 0 | | 0.0 |
| | | | 0 | 1.00 | 1.00 | 1.00 | 0 | | 0.0 |
| | | | 0 | 1.00 | 1.00 | 1.00 | 0 | | 0.0 |
| **Sum large point sources** | | | 6000 | | | | 6000 | | 100.0 |
| **Modified emissions/emissions, point sourc.** | | | | | | | 1 | | |
| **DISCRETE AREA SOURCES** | | | | | | | | | |
| **Local Brick** | | | | | | | | | |
| ***Chinese kilns*** | | 146.0 | | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| Coal | 20.00 | 9.1 | 182.00 | 1.00 | 1.00 | 1.00 | 182.00 | 3.5 | 1.7 |
| ***Bull Trench kilns*** | | | 5000.00 | 1.00 | 1.00 | 1.00 | 5000.00 | 96.5 | 47.3 |
| Coal | | 42.0 | | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| Fuel wood | | 5.7 | | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| Other (mainly rice husk) | | 15.8 | | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| **Sum discrete area sources** | | | 5182.00 | | | | 5182 | 100.0 | 49.0 |
| **Modified emissions/emissions, discr. area sourc.** | | | | | | | 1 | | |
| **DISTRIBUTED AREA SOURCES** | | | | | | | | | |
| **Vehicles** | q (g/km) | T (10E6 vehkm/a) | TSP (t/a) | fq | fT | f- | qT fq fTf (10E3 tonnes) | (dqT fq fTf) (percent) | (dqT fq fTf) (percent) |
| **Gasoline exhaust** | | | | | | | | | |
| Cars, taxis | 0.20 | 192 | 38.4 | 1 | 1 | 1 | 38.4 | 6.7 | 0.4 |
| 3-wheelers (TC) | 0.50 | 135 | 67.5 | 1 | 1 | 1 | 67.5 | 11.8 | 0.6 |
| 2-wheelers (MC) | 0.50 | 215 | 107.5 | 1 | 1 | 1 | 107.5 | 18.8 | 1.0 |
| Sum gasoline | | 542 | 213.4 | | | | 213.4 | | 2.0 |
| Modified emissions/emissions, gasoline | | | | | | | 1.0 | | |
| **Diesel exhaust** | | | | | | | | | |
| Jeeps | 0.9 | 76 | 68.4 | 1 | 1 | 1 | 68.4 | 12.0 | 0.6 |
| Minibuses | 1.5 | 15 | 22.5 | 1 | 1 | 1 | 22.5 | 3.9 | 0.2 |
| Buses | 3.0 | 15 | 45.0 | 1 | 1 | 1 | 45.0 | 7.9 | 0.4 |
| Trucks | 3.0 | 38 | 114.0 | 1 | 1 | 1 | 114.0 | 20.0 | 1.1 |
| Tractors | 0.9 | 24 | 21.6 | 1 | 1 | 1 | 21.6 | 3.8 | 0.2 |
| 3-wheelers (TC) | 1.5 | 57 | 85.5 | 1 | 1 | 1 | 85.5 | 15.0 | 0.8 |
| Sum diesel | | 225 | 357.0 | | | | 357.0 | | 3.4 |
| Modified emissions/emissions, diesel | | | | | | | 1.0 | | |
| Sum total vehicle exhaust | | 767 | 570.4 | | | | 570.4 | 100.0 | 5.4 |
| Modified emissions/emissions, total vehicle exhaust | | | | | | | 1.00 | | |
| **Resuspension from roads** | 2.0 | 767 | 1534.0 | 1 | 1 | 1 | 1534.0 | | 14.5 |
| **Sum total vehicles (exh.+resusp.)** | | | 2104.4 | | | | 2104.4 | | 19.9 |
| **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/commercial** | | | | | | | | | |
| Diesel HSD | 0.28 | | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| Fuel oil LDO | | | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.0 | 0.0 |
| Coal | 10.00 | 4.8 | 48.00 | 1.00 | 1.00 | 1.00 | 48.00 | 1.7 | 0.5 |
| Charcoal | 20.00 | 1.0 | 20.00 | 1.00 | 1.00 | 1.00 | 20.00 | 0.7 | 0.2 |
| Fuelwood | 3.60 | 17.2 | 61.92 | 1.00 | 1.00 | 1.00 | 61.92 | 2.1 | 0.6 |
| Agri. residue | 10.00 | 45.0 | 450.00 | 1.00 | 1.00 | 1.00 | 450.00 | 15.5 | 4.3 |
| Kerosene/LPG | 0.06 | 1.0 | 0.06 | 1.00 | 1.00 | 1.00 | 0.06 | 0.0 | 0.0 |
| Sum industrial | | | 579.98 | | | | 579.98 | | 5.5 |
| Modified emissions/emissions, industrial | | | | | | | 1.00 | | |
| **Domestic** | | | | | | | | | |
| Fuel wood | 15.00 | 122.1 | 1831.50 | 1.00 | 1.00 | 1.00 | 1831.50 | 63.0 | 17.3 |
| Agri. residue | 10.00 | 45.4 | 454.00 | 1.00 | 1.00 | 1.00 | 454.00 | 15.6 | 4.3 |
| Anim. waste | 10.00 | 3.0 | 30.00 | 1.00 | 1.00 | 1.00 | 30.00 | 1.0 | 0.3 |
| Kerosene | 0.06 | 35.0 | 2.10 | 1.00 | 1.00 | 1.00 | 2.10 | 0.1 | 0.0 |
| LPG | 0.06 | 4.0 | 0.24 | 1.00 | 1.00 | 1.00 | 0.24 | 0.0 | 0.0 |
| Charcoal | 20.00 | 0.5 | 10.00 | 1.00 | 1.00 | 1.00 | 10.00 | 0.3 | 0.1 |
| Sum domestic | | | 2327.84 | | | | 2327.84 | | 22.0 |
| Modified emissions/emissions, domestic | | | | | | | 1.00 | | |
| **Sum fuel combustion** | | | 2907.82 | | | | 2907.82 | 100.0 | 27.5 |
| **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) |
| **Refuse burning** | 37 | 10.4 | 384.8 | 1 | 1 | 1 | 384.8 | 100.0 | 3.6 |
| **Construction** | | | | | | | | | |
| **Resuspension, open surfaces** | | | | | | | | | |
| **Sum miscellaneous** | | | 384.8 | 1 | 1 | 1 | 384.80 | 100.0 | 3.6 |
| **Modified emissions/emissions, misc.** | | | | | | | 1.00 | | |
| **Sum total distributed area sources** | | | 10579.02 | | | | 10579.02 | | 100.00 |
| **Modified emissions/emissions, distr. area sources** | | | | | | | 1.00 | | |

*Figure 2: Emission sources*



g) d(qFfqfFf): Relative emissions contributions, all categories summed.

**Rows**

a) Separate rows for each source type and category, "existing" and "new" technology.
b) Modified emission/emissions: Ratio between modified and base case emissions.

# APPENDIX 6
# 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 Kathmandu Valley:

- Meteorological measurements in and near the city.
- Activities/population data for Kathmandu Valley:
  - — 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 DKI Jakarta. 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 ($\mu g/dl$).
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
   c) etc.

**Valuation**

1. Mortality.
   a) **Willingness to Pay**. In U.S.A. 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. $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 $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 $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 U.S.A. the valuation of 1 death case is $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 U.S.A., based on surveys among respondents, indicate that the willingness to pay to prevent a day of illness is ca. $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.A. estimate is ca. $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 U.S.A. and the city.

**Other Impacts**.

1. **Buildings**. An estimate by Jackson et al is that prevented cleaning costs per household per year are $42 for a reduction in TSP concentration, from 235 μg/m3 to 115 μg/m3. This would imply a benefit of $0.35 per household per μg/m3 reduction. This figure could be corrected for wage differences between U.S.A. 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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ABSTRACT

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

This report contains appendices on air quality measurements, emission factors and inventory, exposure calculations, etc.


NORWEGIAN TITLE


| KEYWORDS | | |
|---|---|---|
| Air Pollution | Management | Kathmandu Valley |


ABSTRACT (in Norwegian)

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|---|---|---|
| | *B* | *Restricted distribution* |
| | *C* | *Classified (not to be distributed)* |

The World Bank

Metropolitan Environmental Improvement Program
Environment and Natural Resources Division
Asia Technical Department, The World Bank
1818 H Street, NW
Washington, DC 20433
telephone: (202) 458-2726
facsimile: (202) 522-1664