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Air Quality Management and Assessment Capabilities in 20 Major Cities

MARC

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MARC
Monitoring and Assessment Research Centre
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Campden Hill
London W8 7AD

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MARC
Monitoring and Assessment Research Centre
The Old Coach House, Campden Hill, London

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Contents

Foreword

Urban air quality is increasingly recognized as a major public health and environmental issue in both developed and developing nations. By the year 2000, 45 per cent of the earth's population will live in cities. Any of these urban residents might be exposed to air quality which is likely to have a detrimental effect on their health. Although effective emission abatement strategies are already available for most pollutant sources, it is the formulation and implementation of realistic, effective urban air quality management strategies which will be crucial in securing the future well-being of these urban residents.

UNEP and WHO, aware of the problems of urban air quality, considered that it would be valuable to produce a report giving a global perspective of city air quality management capabilities, based on case-studies of 20 cities, each with a projected population of between 3 and 10 million by the year 2000. UNEP and WHO commissioned the Monitoring and Assessment Research Centre (MARC) to prepare this review within the framework of the GEMS/AIR programme, and in close consultation with scientists and authorities of each city. Cities were selected to demonstrate different air quality situations and problems, topography and levels of economic development. Although their individual capacities may have developed since research on this report was first started, they can still be viewed as presenting a genuine overall picture of global management capabilities.

The purpose of this report is to both inform and advise. It is intended to provide policy-relevant information and raise awareness of innovative and effective local air quality management strategies which could be adapted and adopted by a wide range of countries with cities of similar size.

This report follows a previous UNEP/WHO study which examined the levels and sources of air pollution in cities with populations above 10 million. It is hoped that this report will provide an impetus to assist countries in developing effective, appropriate air quality management strategies which will ultimately result in a reduction in the health and environmental consequences of air pollution.

Taka Hiraishi
Assistant Executive Director
Division of Environmental Information
and Assessment
United Nations Environment Programme

W. Kreisel
Executive Director
Environment and Health
World Health Organization

Contributors

General Editor

W. P. Williams	Director, Monitoring and Assessment Research Centre (MARC), King's College London, London, U.K.

Authors

G. T. Archer*	Monitoring and Assessment Research Centre (MARC), King's College London, London, U.K.
R. Duarte-Davidson*	Monitoring and Assessment Research Centre (MARC), King's College London, London, U.K.

Principal Advisers

C. Kirkcaldy	Global Environmental Monitoring System, Programme Activity Centre, United Nations Environment Programme (UNEP), Nairobi, Kenya.
J. A. Jackson*	Monitoring and Assessment Research Centre (MARC), King's College London, London, U.K.
D. Krochmal	Institute of Organic Chemistry and Technology, Technical University of Cracow, Cracow, Poland.
D. Schwela	Division of Urban Environmental Health, World Health Organization (WHO), Geneva, Switzerland.
V. Vandeweerd	Global Environmental Monitoring System, Programme Activity Centre, United Nations Environment Programme (UNEP), Nairobi, Kenya.

City Contributors

A. L. Aggarwal	National Environmental Engineering Research Institute, Nagpur, India.
R. S. Appleby	Birmingham City Council, Birmingham, UK.
E. Bezuglaya	Main Geophysical Observatory, St Petersburg, Russian Federation.
Y-R. Chen	Ministry of the Environment, Taipei City, Taipei.
B-S. Chun	Ministry of the Environment, Kwacheon City, Republic of Korea.
C. K. Gateby	University of Nairobi, Nairobi, Kenya.
O. M. Gebizlioglu	State Institute of Statistics, Ankara, Turkey.
W.J.M. Hamman	Greater Johannesburg Transitional Metropolitan Council, Johannesburg, South Africa.
D. Krochmal	Institute of Inorganic Chemistry and Technology, Technical University of Cracow, Cracow, Poland.
S. H. Lam	Environmental Protection Branch, Hong Kong Government, Hong Kong.
V. Lipinsky	Ukraine State Committee of Hydrometeorology, Kiev, Ukraine.
F. K. Muchiri	Ministry of Labour, Nairobi, Kenya.
M. M. Nasralla	National Research Centre, Giza, Egypt.
I. Olaeta	Servicio Salud Del Ambiente Region Metropolitana, Santiago, Chile.
M. O. Oresegun	University of Ibadan, Ibadan, Nigeria.
P. J. du Plessis	ESKOM, Cleveland, South Africa.
I. C. Rajaram	Ministry of the Environment, Singapore.
J.C.J. Ribeiro	Fundacao Estadual Do Meio Ambiente, Belo Horizonte, Brazil.
I. R. Rivandeneira	Ministerio de Desarrollo Urbano Y Vivienda, Quito, Ecuador.
M. N. Tariq	University of Engineering and Technology, Lahore, Pakistan.

Other Contributors

E. Ginsburg*	Division of Urban Environmental Health, World Health Organization (WHO), Geneva, Switzerland.
L. Moskaltchuk	Belarusian Socio-Ecological Union "Chernobyl", Minsk, Republic of Belarus.
R. Helmer	Office of Operational Support, World Health Organization (WHO), Geneva, Switzerland.
P. J. Peterson*	Monitoring and Assessment Research Centre (MARC), King's College, London, UK.

Editing, Production and Design

C. J. Meads*	Monitoring and Assessment Research Centre (MARC), King's College London, UK.
F. Preston	Monitoring and Assessment Research Centre (MARC), King's College London, UK.
D. W. Cartwright	Monitoring and Assessment Research Centre (MARC), King's College London, UK.

* Former address whilst participating in the study.

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Introduction

Global Urban Air Pollution

Urban air quality is increasingly recognized as a major public health and environmental issue in both developed and developing nations; posing a substantial threat to human well-being and to the environment. By the year 2000, 45 per cent of the earth's population will live in cities; many of these urban residents will experience air quality likely to have a detrimental effect on their health (i.e., pollution levels in excess of WHO guidelines) (UN, 1992; WHO, 1987). At present, approximately half of the world's urban residents are exposed to potentially harmful amounts of sulphur dioxide (SO_2) and particulate matter (UNEP, 1991). In many cities, potentially damaging levels of carbon monoxide (CO) and lead (Pb) also exist. Furthermore, 15–20 per cent of people in the cities of the developed world could be breathing air containing concentrations of nitrogen dioxide (NO_2) likely to adversely affect their health. The main health effects of the common urban air pollutants are summarized in Appendix A.

Considerable uncertainty exists concerning dose-response to the cocktail of pollutants breathed: especially at extreme altitudes and temperatures. There is, however, sufficient evidence of detrimental effects to health and the environment to demonstrate that air pollution in many cities significantly reduces the health and quality of life of urban residents. It also results in appreciable economic costs from working days lost through illness, from the need for additional health care resources and from damage to buildings. Urban areas are major sources of air pollution, the environmental costs of which also have regional and global implications. These costs represent a significant financial penalty for many countries with poor air quality and there is clearly a widespread need to develop appropriate air quality management strategies to control emissions.

Poor or deteriorating air quality in many cities results from high levels of energy consumption; by industry, road transport and, in some cities, by domestic consumers. Poor air quality results from emissions of pollutants from within the city and from transboundary movement into the city from adjacent areas. The nature of air pollution is dependent on the source profile of a city, the presence of sunlight to promote production of secondary pollutants such as ozone (O_3), and the altitude which affects combustion processes. In some cities, adverse topographical and meteorological conditions also result in the poor dispersion of pollution and thus exacerbate its adverse impacts. The concentration and cocktail of pollution within cities and between cities therefore varies considerably; it also changes with economic and industrial developments. Details of the major air pollutants emitted from motor vehicle and industrial sources are given in Appendix B. In most cities in developed countries air pollution is predominately generated by motor vehicles; with stringent controls being imposed to limit industrial emissions. Within cities in developing countries, rapid industrialization is often combined with increases in both the human population and the numbers of road vehicles. In view of this rapid increase in the sources of emissions, and of the relative lack of effective strategies to control these emissions, air pollution problems affecting cities in developing countries are of particular concern. Urban air pollution is not a new problem and effective emission abatement strategies are available for most pollutant sources. The potential to alleviate these problems exists, but require the formulation and implementation of effective urban air quality management strategies; such strategies may have difficult technology and resource implications for poor countries. This report examines existing air quality management capabilities in 20 cities; to do this it has also been necessary to examine, in brief, the air quality situation in each of these cities. Particular importance has been attached to the capability of each city to generate and utilise decision-relevant information. A number of appropriate, albeit limited, recommendations are made on how to develop more effective and appropriate air quality management strategies. In a very few instances, some analysis and assessment had to be carried out using data which were relatively old. Nonetheless, it was decided that inclusion of these data would contribute positively to the assessments, findings and conclusions presented here.

International Responses to Urban Air Pollution

There has been growing awareness in recent years of the seriousness of global environmental degradation of which urban degeneration, including air pollution, is one aspect. In a number of developed nations air pollution has been proposed as one possible cause for the increase in certain respiratory diseases, particularly asthma, and has resulted in increased demands by urban inhabitants for better air quality and for more research. In many of the newly industrialized, and transitional economies, there is also significant, and growing, public demand for a cleaner urban environment. In many countries access to environmental data has improved and there is increasing official recognition of the need to address environmental problems. Only in a few of the poorest nations has air quality remained a largely marginal environmental issue.

Increased concern about the effects of air pollution has resulted in a greater emphasis being placed on air quality by many local and national governments and international agencies such as the United Nations Environment Programme (UNEP) and the World Health Organization (WHO). The 1992 United Nations Conference on Environment and Development (UNCED) highlighted environmental degradation in cities as one area requiring immediate attention. In the action plan for sustainable development, Agenda 21, specific recommendations were made with regards to addressing air pollution. Key issues derived from Agenda 21 were:

- The development of appropriate air quality management capacities in large cities and the establishment of adequate environmental monitoring capabilities or surveillance of environmental quality and the health status of populations;
- Improved access to environmentally-sound technologies for developing countries, including the provision of training and the development of extensive international information networks;
- Development and expansion of Earthwatch, a UN system-wide monitoring and assessment programme of which GEMS/Air is a component;
- Improvement of data collection and methods of data assessment so that national and international decisions can be based on sound information, and the strengthening of UN data collection activities, particularly of GEMS (Global Environmental Monitoring System).

The GEMS/Air Urban Air Pollution and Assessment Programme evolved from a WHO pilot air quality monitoring project in 1973 and has been jointly operated with UNEP as a component of GEMS since 1975. GEMS/Air is a co-operative programme: participating cities (currently 86 in 45 countries) manage their own networks and provide selected air quality information to the GEMS/Air data base: the only global source of information on urban air quality trends and levels.

In response to UNCED and the recommendations outlined in Agenda 21, GEMS/Air has revised its original, monitoring-focused objectives (for full details of GEMS/Air activities see the 1995 White Paper). In essence GEMS/AIR is a programme that:

- acts as a data/information broker, running the global GEMS/Air database with validated data from an ever expanding number of cities;
- produces technical information documents and provides training and technical advice on all aspects of air quality management;
- facilitates the establishment of air quality monitoring; through, for example, acting as a clearing house linking donors of air quality equipment and expertise with needy recipients;
- facilitates review, validation and optimum use of air quality data and information, including assessments, and seeks to establish codes of best practice;

- establishes/identifies regional centres/experts to coordinate and support activities according to the needs of the regions;
- conducts globally relevant assessments of urban air quality and links air quality data with other environmental, health and socio-economic data for integrated, policy-oriented assessments.

This capabilities report has been produced within the framework of GEMS/Air.

A number of the recommendations made in Agenda 21 with regard to air quality are met by this report. The development of appropriate air quality management capacities in large cities and the establishment of adequate environmental monitoring capabilities are only possible once the existing capabilities of cities are known. The report also contributes towards the revised objectives of GEMS/Air by highlighting the essential components of a rational air quality management strategy; in particular, the information required to enable appropriate decisions to be made. In addition, understanding of the practical experiences of different cities, in both developing and developed countries, can widely assist in the development of more effective air quality management programmes. This is achieved by assessing the components and methodologies required for valid monitoring of urban air quality, effective data management, reliable data dissemination and by assessing what structures must be in place to utilize these data effectively.

City Air Quality Management Capability

Overview

In order to address the problems of urban air pollution it is necessary to develop an air quality management strategy which will reduce emissions of harmful pollutants in a city and consequently improve the air quality. The range of pollutants, pollution sources and methods of imposing emissions controls are extremely wide. If the most appropriate and cost-effective measures to limit emissions are to be implemented it is first necessary to identify and obtain the information which is required for accurate decision-making. Only once this has been achieved can this information be applied to produce an air quality management strategy. The air quality management within a city can only be rational and sound when based upon adequate information about the nature, levels, sources, distribution and effects of that city's air pollution.

Air quality management capability has been defined in this report as *the capacity to generate and utilize appropriate air quality information within a coherent administrative and legislative framework, to enable the rational management of air quality*. Air quality information consists of the type and concentration of pollutants across a city, their sources, effects and extent of the population exposed to them. Accurate assessments of current air quality data management capabilities are essential in order to make maximum use of available resources, to determine whether these are adequate, and to ensure that additional resources, if required, are cost-effective and targeted towards producing the most significant improvements in urban air quality. This report develops methodologies to enable assessments of capability to be conducted in an objective manner. It therefore addresses Agenda 21's recommendation to improve data collection and methods of data assessment so that national and international decisions can be based on sound information. Evaluation of air quality monitoring capabilities also assists in identifying the potential strengths and weaknesses of air quality management in different cities and encourages the development of new approaches by raising awareness of strategies operating in other cities. The direct collaboration which has taken place between those conducting the study and the participating cities has also had the additional benefit of providing a framework from which capacity building, training provision and improved international information networks will develop. The production of this report has therefore addressed a number of the needs of cities and nations attempting to alleviate urban air quality problems.

Report structure

This report assesses the components required for effective air quality management: the information inputs which are required for decision-making; how these inputs are used and how to measure their comprehensiveness, effectiveness and appropriateness. It is, therefore, an important precursor to developing and improving existing management capabilities. The study presented here is not intended as an assessment of air quality – although some air quality and emissions data are included in order to put into context the problems and monitoring and management approaches adopted.

The report is divided into two main sections. The introductory four chapters and the appendices provide an overview of urban air quality issues and the role and extent of air quality management. The second section, chapters 5 through 22, comprises case studies of the participating cities' monitoring and management capabilities. Chapter two develops the concept of air quality management capability; identifying and summarizing its essential components and demonstrating the inter-relationships between these components. Chapter 3 addresses how air quality management capability can be assessed; in particular, through the use of indicators. This chapter describes the formulation of an index, with scores, to simply describe capability. Chapter 4 summarizes the performance of the cities in this study with respect to the different components of air quality data management capabilities and applies the assessment index developed in the previous chapter. This chapter also enables features common to the cities in this study to be identified and a wider, indeed global, perspective of urban air quality management capabilities to be obtained. The city case studies incorporate a situational analysis, a description of the monitoring networks and quality control and assurance procedures, information on institutional and legislative arrangements and details of any emissions inventory. The interactions of the air quality and emissions data with regulations and controls for each city are considered, along with relevant comment on the air quality monitoring and management capability of each city and a summary of pertinent facts. The final chapter of the report summarizes the conclusions which can be drawn from this study. There are also four appendices which describe the sources and health effects of ambient urban air pollution, monitoring methodologies, and, the assessment index in detail.

It was intended that the management capabilities of cities of approximately similar size would be addressed by this report in order to provide a baseline from which to make valid comparisons. Most of the cities participating have a projected population approaching or over 3 million by the year 2000, but generally less than 10 million. Cities with populations above 10 million (megacities), were considered by a previous study examining their levels and sources of air pollution (WHO/UNEP, 1992). Furthermore, this study examined cities with a projected population size smaller than 10 million because, as case-studies, they are of relevance to a greater number of cities: there are 101 cities with projected populations of over 3 million by the year 2000 (UN, 1992). These cities have also been selected both to provide global coverage and to demonstrate different air quality problems, topography and levels of economic development (see Figure 1.1). The choice of cities was also partly dependent on whether it was possible to obtain information. This does introduce an unavoidable bias into the selection of participants because those cities unable or unwilling to provide information may be the cities with the most limited capabilities. The populations of the participating cities are shown in Figure 1.2. The selection of cities includes some for which few data have been published in the past, despite their size and air pollution problems. Ekaterinburg and Quito have population projections smaller than 3 million inhabitants, but have been included to provide contrasting geographical and industrial circumstances. Ekaterinburg is a highly industrialized Russian city which is representative of a larger area, the Ural Region, which has a population of nearly 7 million urban inhabitants (Mnatsakanian, 1992). Quito has extreme exacerbating factors affecting air quality and its effects due to its complex topography and high altitude. Nairobi also has a projected population of under 3 million (2.7 million in 2000) but has a very rapid population growth and is expected to exceed 3 million inhabitants by the year 2005 (UN, 1992).

In summary, this report examines the components required for the identification of air pollutants in cities and the information needed for the development and implementation of the most cost-effective, appropriate air quality data management strategies to ensure levels of pollution attain, or remain at, acceptable levels. It achieves this through a detailed examination of city air quality management capability requirements and the development of an objective assessment method and includes an overview of management capability through case-studies of 20 cities. The report also considers and compares the different approaches used by cities to control emissions and provides an overview of strategies which can be adopted. It is intended to raise awareness of innovative and effective air quality management strategies used locally which could be

Figure 1.1 Cities participating in this study

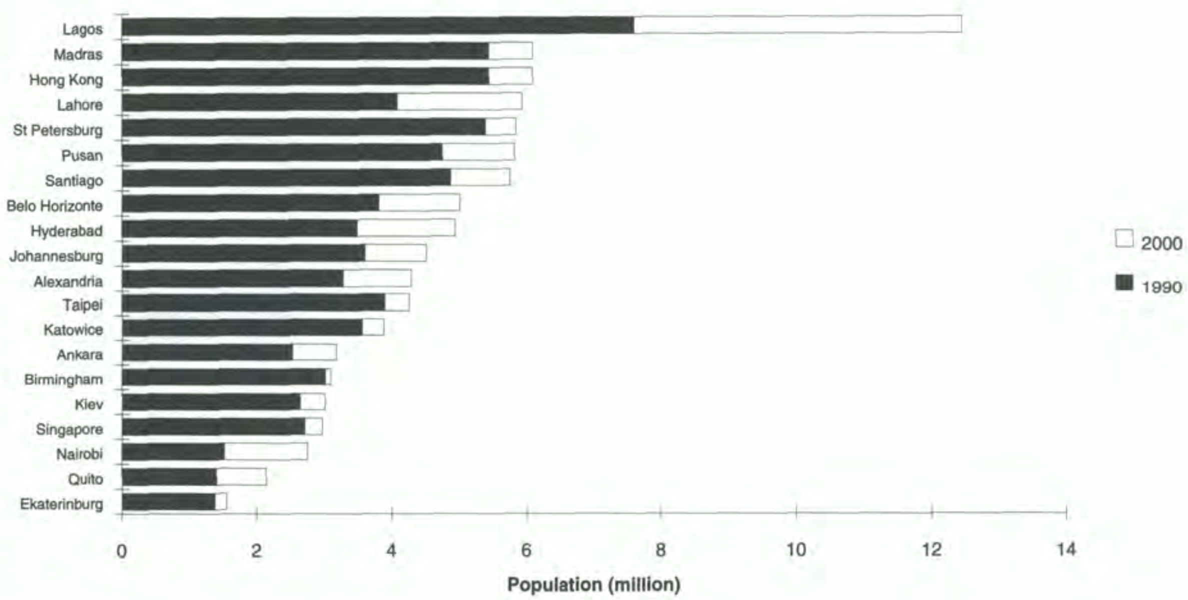

Figure 1.2 Populations of participating cities

Source: UN, 1992

adapted and adopted by a wide range of countries. Through meeting these objectives it is hoped that this report assists countries in formulating effective, appropriate air quality management and it provides policy relevant information for international programmes aimed at achieving this. The ultimate intention of the report is therefore to help to promote improvements in the quality of the air breathed by urban inhabitants and a reduction in the health and environmental consequences of air pollution.

References

Mnatsakanian, R. A. 1992 *Environmental Legacy of the Former Soviet Republics*, Centre for Human Ecology, University of Edinburgh, Edinburgh.

UN 1992 *World Urbanization Prospects*, United Nations, New York.

UNEP 1991 *Urban Air Pollution*, UNEP/GEMS Environmental Library No. 4, Nairobi.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization Regional Office for Europe, Copenhagen.

WHO/UNEP 1992 *Urban Air Pollution in Megacities of the World*, World Health Organization, United Nations Environment Programme, Blackwell, Oxford.

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Air Quality Management Capability

Introduction

The four-phase life cycle of air quality management

The Introduction to this report defined air quality management capability as being *the capacity to generate and utilize appropriate air quality information within a coherent administrative and legislative framework; to enable the rational management of air quality.* The components of air quality management capability are therefore: the human, technical and financial resources required to provide useful information on the sources, current concentrations, impacts and trends of ambient air pollution; and, the regulatory and administrative framework required to formulate, implement and enforce emission controls. Within this definition, air quality management is therefore the process by which air quality is assessed and response strategies developed and introduced. Air quality management capabilities are therefore associated with the provision of decision-relevant information for policy makers and managers and with the administrative and legislative framework to enable maintenance or attainment of acceptable air quality.

The management of an environmental issue such as urban air quality has a four phase cycle (Winsemius, 1986) which is shown in Figure 2.1. The initial stage in this cycle is associated with *problem identification*: in which there is recognition that existing air quality may be unacceptable and that information is required (generated from monitoring capabilities) to determine more precisely the nature of the problem. Having determined the type and severity of air pollution the second phase of the cycle can be initiated. In this phase, *policy is formulated* with the intention of alleviating the identified problem. Implementation of policy follows; in which the strategies to control and reduce emissions of those pollutants considered to be at unacceptable levels are enacted and enforcement procedures operated. *Implementation of policy* requires capabilities to ensure compliance and to measure the effectiveness of the strategies introduced. Assuming that the problem was correctly identified and that

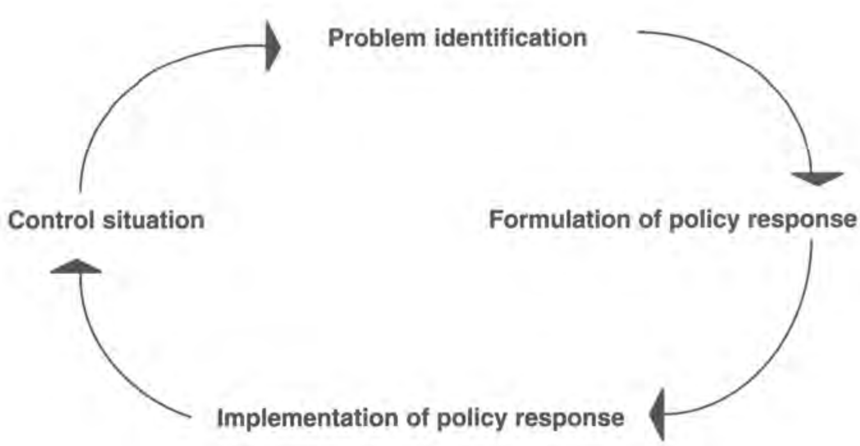


Figure 2.1 The four-phase environmental management cycle

Source: Winsemius, 1986

appropriate policy has been formulated and successfully implemented the *control situation* is achieved. At this stage, acceptable air quality is considered to have been attained by the relevant responsible authority and that the additional resources required to limit emissions further are not considered cost-effective. Although the initial problem has been resolved, management (particularly monitoring) capabilities are required to ensure that the control situation persists. Changes in the emissions profile of countries and/or cities, or additional information about the impacts of pollution, may ultimately identify new air quality issues to be resolved. New problems require that new information be generated by the existing and additional monitoring capabilities; reinitiating the management cycle.

Air quality monitoring capabilities within the cycle of an urban air pollution problem

Information generated by monitoring is required during each phase of the management cycle. Initially, monitoring capabilities assist in identifying the nature and extent of air quality problems. During the formulation of policy, they provide decision-relevant information to enable the formulation of effective, equitable emission control strategies and the development of an administrative and legislative framework. During the policy implementation phase, monitoring capabilities are required to determine whether emissions limits and air quality standards are enforced; that outcomes of the strategies introduced are successful and appropriate and to enable refinement of those policies introduced to achieve the desired outcome. Finally, once the control situation is achieved, monitoring capabilities are required to ensure that acceptable air quality is maintained. Throughout the cycle, capabilities are needed to ensure that the public remains informed of the status of their air quality. The monitoring capabilities required during each phase of the management cycle and the inter-relationships between them are shown in Figure 2.2.

The initial identification of possible air quality problems can be achieved without formal monitoring capabilities, such as ambient air measurement networks; although these do greatly assist with further assessment. In many cities, as air quality deteriorates, there are perceptible impacts from the pollution; such as reduced visibility and the soiling of clothes by smoke and dust. Further indications may include: a noticeable increase in pollution sources such as new industries with stacks or chimneys; an increase in road congestion; or anecdotal health evidence such as an increase in asthma incidence or bronchitis. These observations indicate that air quality may be poor; when they are supported by a qualitative knowledge of the principal sources of pollutants in the city they can be used to develop initial measurement capabilities to ascertain the levels of pollutants of concern. Chapter 4 of this report shows that in most cities with populations greater than three million inhabitants some measurement capabilities do exist; these can be used to determine whether air quality is likely to have any health or environmental impacts by ascertaining whether concentrations of a pollutant are in excess of WHO Guidelines. If this situation exists the second phase of the cycle – policy formulation – should be initiated.

Monitoring capabilities are essential in providing information to assist decision makers in formulating appropriate responses to reduce emissions of pollution in a city. Formulation of emission controls requires detailed information on both the status of the air quality – provided by monitoring networks – and the principal sources of pollution and their locations: quantified by an emissions inventory. These capabilities require considerable human, technical and financial resources but are essential to ensure that appropriate, effective emission control strategies are adopted. Combining the information from monitoring and emissions estimates with knowledge of dispersion characteristics for the city enables air quality models to be developed. Such models are powerful tools for air quality managers; but, they demand considerable skills, existing capabilities and financial resources to establish and operate. Air quality models are currently beyond the present capabilities of most cities.

Monitoring networks must be designed to ensure that the data produced meet the needs of intended users and are therefore of known quality; this requires the establishment of quality assurance and control procedures. Raw data must also be assessed in order to give policy-formulating decision makers a coherent picture of the air quality problems . Widely disseminated data enable the input of ideas from additional sources into policy development and provide public information. Access to air quality data and a transparent decision-making process are also important for promoting

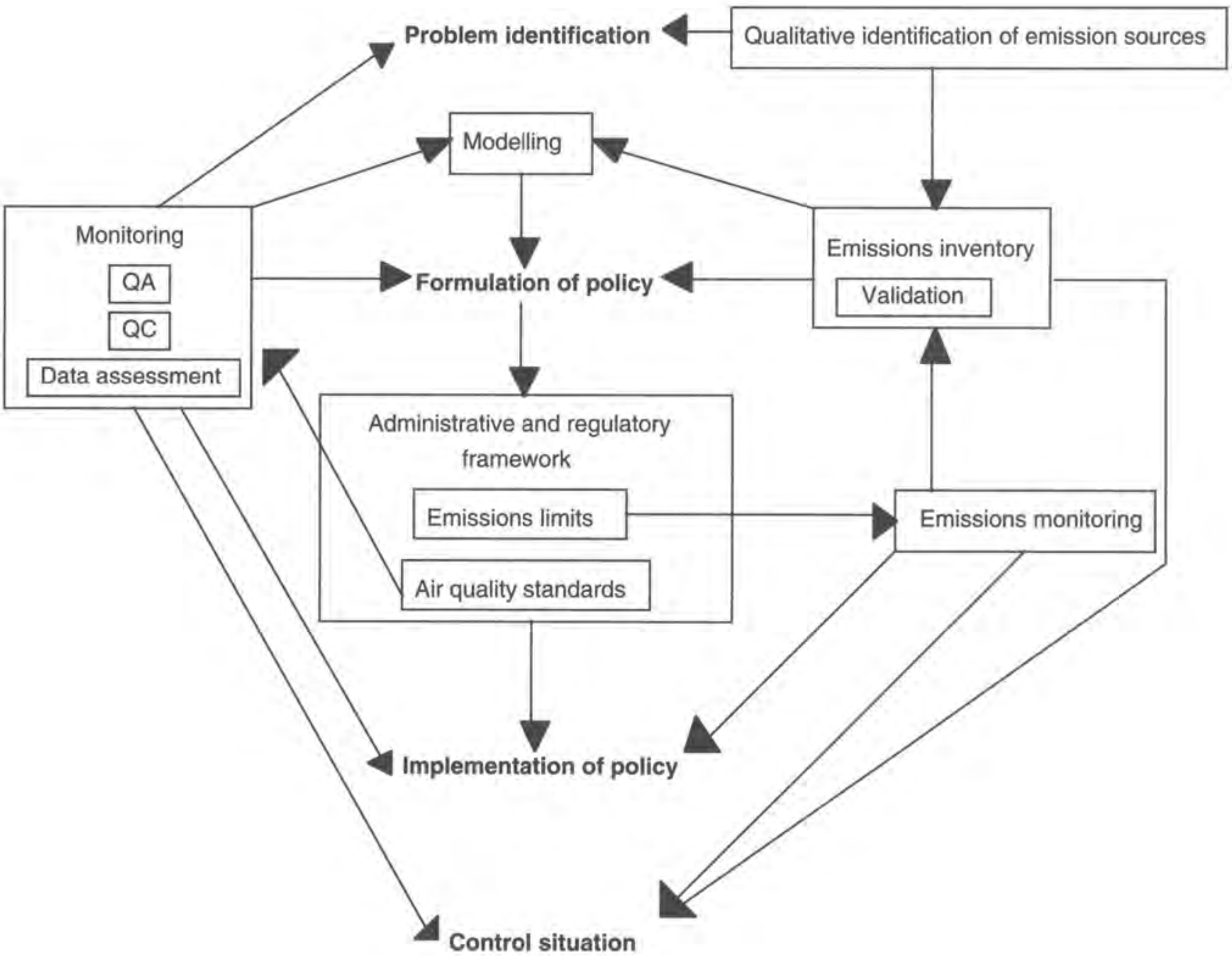


Figure 2.2 Components of air quality monitoring capability within the four-phase cycle

confidence and greater acceptance of the policies finally adopted. This ultimately influences the extent to which the policies are voluntarily enforced, their cost, and potentially their ultimate success.

There is no idealized model which can be applied to formulate an effective air quality management strategy. The nature and severity of the problems affecting different cities and their political and economic situations are too diverse to propose such a panacea. The air quality management policies adopted must be based on a number of different control strategies and must be sufficiently flexible to respond to developments in air quality problems as they are identified. It is particularly important to consider an overall view of urban air quality rather than identifying and rectifying isolated problems. Consequently, concurrent, complementary management actions are required to attain acceptably clean air. It is also important that air quality controls are incorporated as part of an integrated pollution control strategy and that emissions to other media do not increase disproportionately as a result of reducing atmospheric emissions.

Emission control strategies can be categorized into three approaches: regulatory controls, fiscal measures and policy adaptation (including land-use planning and infrastructure development, including transport management). Regulatory controls are emissions limits imposed on industry or vehicles. Fiscal measures apply the power of the market to encourage use of cleaner technology and fuels; they are often based on the concept of the "polluter pays". Infrastructure development, such as the building of ring-roads around heavily congested and polluted areas and the development of public transport to reduce vehicle usage, can reduce emissions from mobile sources. Policy tools can be used to reduce exposure to pollutants, such as by encouraging investment/relocation in polluting industries away from residential areas. The most effective air quality management strategies use a combination of these approaches and of enforcement, persuasion and incentives, to produce an equitable and appropriate reduction in emissions.

The existence of an administrative and legislative framework to ensure adherence to regulatory emission controls is an essential component of management capability; particularly in the policy implementation phase of the management cycle. Reporting, monitoring, inspection and maintenance programmes for effective control of sources require considerable technical, human and financial resources. The burden of these responsibilities usually lie, in part, with the owner of the source; creating appreciable costs, not only to ensure that emissions limits are attained, but also to demonstrate that they have been. Legislation and effective penalties to discourage willful or avoidable exceedances of emissions limits are essential if the flagrant disregard of regulations is not to become the cost-effective solution for emitters. The resource implications of regulatory controls are therefore substantial and their use should be restricted, as far as possible, to large sources and source categories (such as motor vehicles) if the costs of enforcing the regulations are not to become disproportionate to their benefit.

Information concerning the level of acceptable air quality, as defined by air quality standards, is another component of management capability: within the administrative and regulatory framework of the management process. Defining the level of acceptable air pollution is important since this significantly affects the extent of the emission controls required and provides a baseline from which to ascertain whether the input of additional resources to limit emissions is required. Most air quality standards are based on assessing the health impacts of a particular type of pollution; however, the level of the standard established should be realistic with regards existing levels of pollution and the rate at which improvements in air quality can be attained. A standard should provide a management tool which can be used progressively to improve air quality whilst remaining a realistically attainable target. It is effective only if compliance with the standard is measured and enforced; to do this requires additional monitoring capabilities and resources.

Throughout the policy implementation phase, monitoring capabilities are used to assess the performance of the regulatory emission controls adopted and to enforce them. Trends in ambient air quality and the frequency of exceedances of air quality standards provide useful indicators of air quality. Emissions inventories quantify the emissions and can be further developed by incorporating emissions monitoring data.

Assuming the previous three phases have been successfully completed, the final stage of the cycle – *the control situation* – is attained when existing air quality standards are met and adequate monitoring capabilities exist to enable constant reappraisal of the urban air pollution problem. Changes in the definition of acceptable air quality or in the emissions profile of the city can result in the identification of new problems which in turn require additional management capabilities: such as the capacity to monitor a new pollutant species, conduct an emissions inventory of its sources and to most effectively control these emissions. The information from monitoring capabilities and experience of developing previous emissions control policies can then be applied to formulate and implement additional management strategies to remedy the new problem. Maintenance of acceptable air quality for large cities or industrial areas therefore requires monitoring capabilities and management strategies that constantly evolve. However, the skills developed and the infrastructure available should result in an increasingly more effective and rapid response to new issues as they arise. The development of air quality management strategies can be rapidly accelerated through consideration of the experiences of other countries and the provision of expert advice by bodies such as WHO and UNEP. These are the primary reasons why the widest possible dissemination of information and a transparent decision-making process should be incorporated into the management plan and why there is an increasing need to pool expertise and to develop solutions widely compatible for local problems. The following sections consider each of the monitoring capabilities required to help complete the management cycle cost-effectively. In these sections the considerations which should be made in establishing monitoring and management capabilities and the resource implications of these are examined.

Ambient Air Quality Monitoring

Introduction

Measurement of ambient concentrations of pollution is an integral component of air quality management capability and can provide information to meet a number objectives, such as to:-

1. Ascertain likely consequences (primarily for health) of ambient exposure.

2. Identify the contribution of specific sources.

3. Measure the spatial distribution of pollutants.

4. Determine trends in concentration.

5. Ascertain compliance with air quality standards and guidelines.

6. Provide public information.

The operational components of the network: the derived data quality objectives, network design and management structures, selection of representative monitoring points, adoption of cost-effective instrumentation, operation and maintenance of systems, establishment of quality assurance and control procedures, data review, validation and usage are all dependent on the monitoring objective (UNEP/WHO, 1994a). The human, technical and financial resources required to achieve each of these operational components appropriately – and consequently to meet the monitoring objective cost-effectively – vary considerably. The following sections provide a brief overview of the resource implications of different monitoring methodologies and operational network components. They outline how maximum utility can be gained from the outputs of monitoring; providing decision-relevant and public information and explaining how these relate to other capabilities.

Monitoring methodology and sampling frequency

There are four instrumental methods for measuring ambient air concentrations: passive and active samplers, continuous analysers and remote sensors. An outline of these methods; their advantages, disadvantages and costs are presented in Table 2.1.

There are clearly advantages and disadvantages with all current monitoring techniques. Assessing which measurement technique is the most appropriate depends on the objective for which the measurements are to be conducted; as well as the resources available to achieve this objective: no methodology being appropriate for all circumstances and requirements. Current state-of-the-art continuous analysers and remote sensors are able to provide considerable amounts of raw data which can be used to produce excellent decision-relevant information. The instruments are, however, very expensive to purchase and maintain and require considerable technical support. Furthermore, the skills necessary to make maximum use of continuous data outputs are not always available, particularly in developing countries. Consequently, the use of automated air quality measurement networks is either not appropriate or cost-effective for most countries. Less sophisticated active and passive sampling techniques are not able to produce hourly, continuous data, but are very reliable. They also require a considerably lower level of technical support than automated samplers and are considerably cheaper to purchase and to operate. Passive and active sampling methodologies are able to provide data to meet most monitoring objectives and are therefore a more appropriate technology for most countries. **If the monitoring methodology is able to meet the objective of the network, the technique adopted is not critical. The equipment selected should therefore be based upon the availability of resources to purchase and operate instruments most effectively.**

Table 2.1 Instrumental Air Monitoring Techniques

Method	Advantages	Disadvantages	Capital cost per sampler
Passive samplers Collect an integrated sample of pollutant by diffusion with collection on a trapping medium which is subsequently analysed.	Very low cost and simple. Useful for screening and base-line studies.	Unproven for some pollutants. Integrated sample. Laboratory analysis required.	US$2-4
Active samplers Collect an integrated sample of pollutant by pumping air through the sampler and trapping the pollutant in a collecting medium which is subsequently analysed.	Low cost. Easy and reliable to operate. Historical data set in some cities.	Integrated samples. Labour intensive. Laboratory analysis required.	US$2,000-4,000
Automatic analysers Use a physical or chemical property of the pollutant to measure the concentration in continuously collected samples. Calibrations are performed using a standard of known concentration for comparison.	Proven high performance. Continuous, on-line measurement. Low direct costs.	Complex and expensive. High skills required to maintain and operate. High recurrent costs.	US$10,000 -20,000
Remote sensors Determine the average concentration of the pollutant over a fixed path spectroscopically.	Provide path or range resolved data. Useful near sources and for vertical measurements. Multi-component measurements.	Difficult to support, operate, calibrate and validate. Not always comparable with fixed point sampling analysers	>US$200,000

Source: UNEP/WHO, 1994a

For passive and active sampling instruments the sampling time and frequency adopted has significant human and recurrent cost implications in terms of collecting and analysing samples. Ideally, active samplers should monitor daily; the adaptation of equipment can make this relatively easy. However, the labour-intensive nature of this technique sometimes precludes this ideal operating approach and sampling conducted one day in six or less is sometimes adopted. Less than daily sampling periods provide accurate information on trends and the chronic health effects of pollutants, but appreciably less certain data on the incidence of acute pollution episodes. Consequently, the sampling frequency required is strongly dependent on the objective of the monitoring.

Co-location of passive, active and continuous equipment where different monitoring techniques are used provides very valuable information about the validity and comparability of the data being obtained and should be routinely conducted. Further information about monitoring methodologies is contained in Appendix C.

Quality assurance and control

Quality assurance and control (QA and QC) are essential components of air quality monitoring, ensuring that the measurements are:-

- Representative of ambient conditions.
- Accurate and precise.
- Comparable and reproducible.
- Traceable to metrology standards.
- Consistent over time (reproducible).
- Able to achieve adequate data capture.

(UNEP/WHO, 1994a)

The absolute quality of data is not critical provided the quality is **known and adequate for its intended use**. Consequently, not all monitoring data need to have the same degree of accuracy and representativeness. Quality assurance has been defined as the "system of activities that ensures that a measurement meets defined standards of quality with a stated level of confidence" (UNEP/WHO 1994a). **The QA procedures adopted should therefore reflect the level of confidence in the monitoring data required by those formulating and implementing air quality management strategies.** Once air quality data have been generated, quality control procedures ensure that the measurements obtained meet the specified level of accuracy and precision; and that data which do not are removed through the data validation process. Specific details concerning QA and QC procedures have been covered in previous GEMS/Air publications (UNEP/WHO, 1994a,b). In this study, discussion of these issues is restricted primarily to the resource implications of QA and QC and of how these procedures enhance the performance of other capabilities. Producing data of known quality, adequate for their intended use, significantly enhances the value of the data. This, however, requires considerably greater resources than those for simple monitoring and cities must carefully assess how to balance these conflicting requirements.

The training of site operators, laboratory technicians and other staff associated with the production of air quality monitoring data is a major factor in producing data of adequate quality. In countries with little experience of monitoring, trainer-training is a vital component of capacity building and helps to create the institutional knowledge so important in the development of monitoring networks. Experienced or well-trained staff are vital for the production of adequate quality data. The recruitment and retention of suitably qualified and motivated individuals can have important financial and human resource implications. The development of manuals and of detailed site-inspection records (in the appropriate language) are also important; these should be regularly checked by managers familiar with operational procedures in order to greatly enhance the performance of inexperienced/unskilled staff. Occasional visits by internal inspection teams also helps to ensure good practice and are an extremely useful means of quality assessment. Technical resources are required to perform quality controls such as instrument inspections and calibration; standards are also needed to ensure that laboratory analysis produces data of adequate quality. Support for cities developing QA/QC, such as that provided and facilitated by GEMS/Air is very important.

Data validation maximises data integrity through the removal of spurious measurements produced by equipment malfunction, contamination or human error. This is a highly skilled procedure; it must be performed with considerable caution to ensure that invalidation of extreme, but valid data, does not occur. In continuous monitoring networks with data telemetry, out-of-range or suspect data can be identified and flagged automatically. However, automatic rejection of all such data does not guarantee high data quality; active examination by skilled personnel provides a more flexible and ultimately accurate procedure. Good data validation requires time, experience and training (with human, technical and financial resource implications) but it does provide an important contribution ensuring that data are of known quality and are adequate for their intended use.

Quality assurance/quality control greatly increases the value of the outputs of monitoring and therefore enhances the decision-relevance of data. It is, therefore, an important component of air quality management. The development of workable QA and QC procedures within available resources presents, however, a major challenge to those establishing new monitoring networks; particularly in cities with little experience of ambient air quality monitoring. Technical support, both through production of manuals and training is now being provided to participants in the GEMS/Air Network. These measures should help to improve the quality of data produced by cities participating in the GEMS/Air programme. It should always be remembered that "a chain is only as strong as its weakest link" and that consequently it is important to develop QA and QC procedures in a systematic manner to ensure that attention is paid to all aspects if the data are to be of the required quality (UNEP/WHO, 1994a).

Monitoring for estimation of ambient air quality impacts

One of the primary reasons for monitoring ambient air is to provide information on pollutant concentrations as a basis for estimating their likely effects; particularly on human and environmental health. The question of which pollutants are likely to be harmful and should therefore be monitored is discussed in detail in Appendix B. The resource implications of where and how to monitor pollutants in order to meet the monitoring objectives for air quality management require further examination.

In measuring the potential health impacts of pollution it is important to determine the likely population exposure to various pollutants. The measuring instruments should therefore be located where the monitored air is representative of human exposure; for example, at sites located in residential areas not directly influenced by local sources such as busy roads and local stacks (in these areas samples should be taken at approximately head height). Monitoring sites at background urban locations such as these should be representative of the area surrounding the site and this can be determined by conducting surveys of the area using passive samplers. Although background urban sites in residential areas provide important information about the general levels of exposure, they are unlikely to represent maximum exposures which people probably experienced in an industrial area or at the kerbside of major roads and busy junctions. Monitoring at these latter sites provides additional information on the likely maximum observed concentrations for those assessing air quality within the city. In cities with very limited resources and the capacity to monitor at only a few sites it is important to make greatest use of the data which are produced. Knowledge of the siting criterion required for different monitoring objectives is therefore important in order to prioritize needs.

In many urban areas a considerable proportion of an individual's time is spent indoors; where concentrations of pollutants are often quite different from those experienced outdoors. Although there is appreciable penetration of houses by outdoor ambient air, indoor sources such as combustion processes for heating and cooking, or everyday activities such as cleaning, raise the concentration of some pollutants. Exposure to pollutants generated indoors can be a major contribution to the overall lung burden. An integrated assessment of indoor and outdoor exposure will allow the most appropriate, effective and equitable controls on exposure to be imposed. Indoor monitoring clearly requires additional measurement capabilities, but initial assessments can be performed using very basic methodologies, such as passive samplers located inside and outside the building, to determine whether more detailed measurements requiring greater resources and capabilities are needed.

Most substances with health effects are primary pollutants – or, in the case of nitrogen dioxide (NO_2) produced sufficiently rapidly from oxidation of nitrogen oxide (NO) that its distribution within a city is very closely related to the distribution of NO sources. Ozone (O_3) is a secondary pollutant produced through a complex series of photochemical reactions; monitoring for O_3, therefore, needs to be conducted with different siting criteria in order to estimate exposure within the city. Sites upwind of the city provide an indication of background levels of O_3. Urban centres generally contain lower concentrations than those measured outside the city centre, perhaps in suburban areas; this results from ozone depletion through reaction with NO which is present in higher concentrations in city centres. In areas some distance downwind of urban centres – particularly if NO concentrations are low – O_3 concentrations can become particularly elevated. This can present problems owing to the transboundary movement of pollutants to adjacent areas, or within very large cities (in terms of area); such as Los Angeles and Sydney with residential areas stretching considerable distances from the city centre. The atmospheric chemistry and dispersion of pollutants therefore needs to be considered carefully when identifying representative monitoring sites to estimate likely impacts.

Selection of the most appropriate monitoring equipment is strongly dependent on the human and financial resources available and the air quality impact to be identified. Determination of likely acute health effects *ideally* requires knowledge of the hourly daily concentrations; which can only be obtained using automatic and remote sensors. However, determination of integrated daily mean concentrations provides *more than adequate* information on possible acute health effects for most purposes and can be readily obtained from active samplers; passive samplers can also provide this information for some pollutants. Chronic health effects are usually estimated on the basis of annual mean exposure; in order to determine this any well validated sampling technique will produce equally acceptable results.

Monitoring for determination of spatial distribution

Determination of the spatial distribution of pollutants in a city is important for identifying the presence of "hot-spots": areas of elevated concentration where special local measures may be required to reduce concentrations. Spatial distribution information is also useful for estimating the overall level of exposure experienced by the city's population through combining air quality with census statistics. Spatial distribution of pollutants can only be obtained by one of three different techniques:-

1. Simultaneous monitoring at a wide number of sites.

2. Use of mobile monitoring equipment.

3. Modelling.

Simultaneous monitoring at a number of different locations can be performed relatively cheaply and with limited technical and human resources through the use of passive samplers since it is not necessary to have a high degree of time resolution. It is, however, important that the siting criteria are carefully established to ensure samplers are located at sites of a similar nature if a genuine pattern is to be obtained.

Mobile monitoring equipment has been used in a number of cities, usually in the form of trailers moved between different locations. Monitoring equipment is not readily mobile and particular care must be taken to ensure that temporary sites are appropriate and that instruments operate correctly after being transported. Quality assurance/quality control procedures must therefore be adopted and adapted to ensure that the data produced are adequate for their intended use. The use of mobile instruments does provide an additional dimension to the monitoring capability of a city; but it does not enable simultaneous measurements to be made at a number of sites and it can appreciably increase the cost of monitoring.

Models which combine information on point and line emission sources with air quality data, meteorological data and local topographic features affecting dispersion are very powerful tools for estimating, for example, spatial variations of pollution. They do, however, require careful validation using automated monitors. The resource implications of establishing a model are substantial and considerable technical skills are required to operate such a system to its maximum potential. The capabilities required to develop urban airshed models are not present in most cities. However, their application is likely to become more widespread in the future as capabilities increase and the cost and skills required to operate these models fall.

Remote sensors, owing to their mode of operation, are ideal for determining concentrations over a linear path. They cannot, however, be readily relocated and although their measurements are spatially integrated, the concentration obtained provides no more information in terms of distribution of pollutants within a city than a point monitor. For most cities a network of passive samplers therefore provides the most appropriate and effective means of ascertaining the spatial distribution of pollutants.

Monitoring for determination of trends

The location and type of monitoring and the sampling protocol are unimportant when determining trends in concentrations so long as they remain constant or comparable. Trends are usually determined as annual average concentrations or percentile values and they can be obtained using any monitoring technique. It is, however, important that if the technique is altered an inter-comparison exercise is conducted at the time of the change-over period in order to determine the relationship between the techniques so that the time series can be maintained. Similarly, it is necessary that the nature of the sites used to determine trends does not alter appreciably: such as through the building of a road close to the monitoring inlet. Long time series exist in a number of cities using active sampling techniques and it may therefore be appropriate to continue with these techniques at certain sites, even if the resources become available to install more sophisticated automatic or remote sensors.

Determination of trends requires relatively few capabilities in terms of equipment and sites, but is likely to become flawed by developments in other capabilities; consistently good QA and QC procedures are therefore important. Trend determination is particularly important during the policy implementation phase of the management cycle in order to ascertain the effectiveness of the measures being adopted; and also once the control situation is attained to ensure its maintenance. Most cities determine trends, but relatively few ensure equivalent data are compared annually. Despite the relative ease with which trend determination can be performed, inaccurate results can easily accrue which have considerable impact on policy development. Determination of trends should, therefore, be performed with particular care since the decisions which result from an observed pattern can have considerable resource implications. For this reason, trends in ambient concentration should be used in combination with those in emissions – provided through annual inventories – to ascertain the impact of, and need for additional emission controls.

Monitoring of compliance with air quality standards and guidelines

Air quality standards and guidelines are an important component of an air quality management strategy and measuring compliance with standards is essential if management is to be effective. The guidelines and standards should stipulate the siting criteria of the instruments measuring compliance. This is particularly true where international air quality standards are being adopted, such as those being adopted in the European Union. It is important to establish strict guidelines for siting criteria in order to ensure that the frequency of exceedances of AQG/S are not biased by where the monitoring is conducted; as a consequence presenting an inaccurate picture of current air quality. Although monitoring of compliance with air quality standards provides an excellent means to determine the extent of an air quality problem it is important that meeting the standard does not replace improving air quality as the principle objective. There is no doubt that monitoring compliance with standards is a very useful management tool; providing powerful information for decision makers. Consequently, extreme care must be taken to ensure that the statistics generated do not misrepresent the actual air quality.

Data Assessment and Availability

Data assessment

Ambient air quality monitoring networks developed with appropriate quality assurance and control procedures will provide considerable volumes of data of known reliability on the levels and distribution of air pollution within a city. The nature of the data from specific locations within the city – hourly, daily or longer averaged concentrations – do not, however, represent a form readily interpretable for those developing and implementing air quality management strategies. Similarly, emissions inventories producing large quantities of data on emissions of pollutants from different sources and locations are not necessarily in a readily usable form. **The conversion of raw data into statistics, indicators, indexes, graphical presentations and so forth to aid interpretation and understanding of the air quality problems in a city is therefore a fundamental component of air quality management capability and an important precursor to the development of effective and appropriate air quality management strategies**. Managers responsible for developing and implementing emission control strategies must frequently balance a number of conflicting environmental, economic and social issues. If they are presented with large quantities of raw data they are less likely to produce the most appropriate responses. Data analysis and interpretation of monitoring and emissions inventory data is therefore required for production of decision relevant information. Data assessment is also important to determine if monitoring objectives are being met; or whether changes to the network design and/or operation are required in order for more useful information to be generated. Data assessment also ensures that existing capabilities are used to their maximum potential.

In its simplest form the analysis of monitoring data involves the production of simple statistics such as means and maximum concentrations which provide an indication of the usual and extreme levels of pollution experienced. These can be supplemented by more advanced statistics such as percentile values and plots of frequency distribution which provide useful information about the range of values and occurrence of high concentrations. The usefulness of measuring the frequency and extent of exceedances of air quality standards as a measure of the effectiveness of the management strategies introduced was discussed in the previous section. Comparison of air quality with WHO guidelines also provides useful information to decision makers and the public on whether the ambient concentrations present any discernible health risk. This is discussed in more detail in the section Air Quality Guidelines and Standards.

Graphs and charts generated using computer spreadsheets provide visual representation of large quantities of data; enabling patterns and trends to be readily identified. Graphical representations of data such as time-series graphs show the extent of temporal variations, periods of worse air quality and seasonal variations. Maps of spatial distribution plotting isohyets of average concentration can be generated to identify hot-spots of particularly high pollution in which there is a need for greater emissions controls; these maps can also be compared to those showing the spatial disaggregation of emissions indicating dispersion patterns. Trends in concentrations can be readily identified by using line-graphs and the statistical significance of any pattern accordingly analysed. The use of graphs is particularly appropriate for presenting data in a readily understandable form for decision makers and the public; the availability of computers appreciably increases their ease of production.

More advanced data analysis involves the use of air quality data in combination with other variables such as meteorological data or health indicators to aid interpretation of the causes and effects of poor air quality; census statistics can also be used to estimate population exposure. Meteorological modelling can be used to determine dispersion and conversion of pollution in a city; and/or to develop predictions of air pollution episodes in order that remedial measures can be adopted prior to the event (in order to lessen the consequences). Epidemiological studies can be used to determine the relationship between exposure to air pollutants and the corresponding health effects. Studies can examine acute effects of pollutants associated with episodes of poor air quality and/or the effects of chronic exposure from breathing pollutants for long periods of time. Epidemiological studies are invaluable in providing an indication of the likely health effects of exposure to air pollution. The cocktail of pollutants breathed in different cities and confounding factors such as temperature and altitude vary considerably between locations. Guidelines such as those produced by the WHO, and the tentative dose-response relationships being determined in some countries, may not always be applicable in all cities; ideally, countries should attempt to conduct their own environmental health research.

Emissions inventories also produce large quantities of data which require assessment before they can be effectively used. Knowledge of the relative contributions of different source categories to emissions of pollutants provides valuable information for decision makers on the most effective source categories to target for emissions reductions: these can be visually represented using pie-charts or stacked-histograms (also useful for public information purposes). Identifying the contribution of particular large emitters is also very effective in both ascertaining individual processes which could be improved; and, if data are published, mobilizing public pressure to encourage unilateral action by industries concerned with their environmental image. This has been a notable, albeit indirect, consequence of the USEPA's National Air Quality and Emissions Trends Report (USEPA, 1993). Assessment of emissions to determine spatial disaggregation can help to identify areas of likely poor air quality where monitoring may be required; or combined with information about the spatial distribution of concentrations to determine dispersion and conversion characteristics of pollution within the city with the aid of modelling. Data assessment is therefore an important component of management capability; providing data in an understandable and accessible form both for the public and decision makers. It is strongly linked with monitoring and emissions inventory capabilities in the production of decision relevant information.

Air quality guidelines and standards

Ambient air quality standards and guidelines (AQS and AQG) have been established in many countries as a measure of the acceptability of air quality. The criteria used to establish standards vary considerably between countries but usually include both health criteria and considerations of what is achievable given the environmental and economic position of the country. The extent to which a country or city uses standards as statutory limits, or whether the values are simply used for reference purposes, also varies considerably. Air quality standards and air quality guidelines are useful only if they are applied as an air quality management tool; as such it is essential to measure exceedances of AQS and to use this data as one indication of changing air quality. The response of cities to levels of pollution above their AQS is a good indicator of the commitment and capability of a city to address air pollution problems. It is also a means of assessing the significance placed on the public health consequences of air pollution by national and/or local governments.

Statistics on exceedances of national, or where appropriate, WHO air quality guidelines, are a powerful indicator of the effectiveness of the current air quality management strategy in a city. Although these should not be considered in isolation. There are currently no global air quality health guidelines with which to compare national standards and actual air quality. In the absence of any other values, the WHO Air Quality Guidelines for Europe (WHO, 1987) have been increasingly adopted as a global guideline; although they were not intended for this role and as such have some limitations. The most obvious of these is that the health impacts of air quality at temperature and altitude extremes are not considered; nor is the influence of high natural suspended particulate concentrations such as those experienced in arid environments. The *lowest-observed-adverse-effect* level, including a protection factor, for a range of organic and inorganic compounds is defined in WHO guidelines; although no guidelines have been set for carcinogens which have no safe-level threshold. WHO guidelines have, nevertheless, been used in this report when considering the likely health impacts of city air quality and the appropriateness of national air quality standards in terms of health protection. Where possible we have identified their local limitations.

There are a wide range of considerations which need to be made in establishing an AQS/G:

1. Nature, severity and frequency of adverse health effects and presence of vulnerable groups;
2. The size and characteristics of the exposed population;
3. Current air quality in the country and what is attainable in terms of control technology and costs;
4. Damage to crops and wildlife;
5. Background natural abundance of the pollutant;
6. Environmental persistence;
7. Environmental degradation of pollutants to form chemicals with a greater hazard;
8. Effects caused by high/low temperatures and/or altitude.

The legal and regulatory management framework on which AQS/G values are established varies considerably between countries, and are outlined within the city specific chapters. There is a growing tendency for standards to be established on the basis of an *effects-based approach*: in which acceptable levels of pollution are set based on the impacts of air pollution on human health and the environment and an air quality management programme designed to secure these standards in the most appropriate way (DOE, 1994). The effects-based approach, complemented by source-based controls, ensures that policies are cost-effective and that environmental gains from regulatory controls are properly quantified. This approach also encourages the development of innovative emissions controls and gives impetus to industry to introduce cleaner technologies, rather than simply applying existing technologies. The most effective air quality management strategies should, therefore, use a range of emissions control strategies to achieve acceptable air quality as defined by an air quality standard.

For AQS/G to be established which take account of both chronic and acute health effects it is necessary to set averaging times appropriate for both episodic and long-term exposure. Standards or guidelines for chronic effects are usually set on the basis of annual or seasonal average values; those for acute effects should be set for averaging times for which the monitoring network is capable of generating data to measure compliance. For example, there is no value in a 1 hour air quality standard for SO_2 if monitoring is conducted using an active sampling system providing integrated daily mean values. Many countries set air quality standards for pollutants for which there is no monitoring carried out. Although these may be of long-term use if the monitoring network is expanded to measure more pollutants they are, until such a time is reached, of purely academic interest.

The AQS/G framework used by countries should be realistic about existing air quality within the city and realistic in relation to what is attainable in terms of possible improvements; as well as realistic as to the rate at which these improvements can be achieved. The recent EU Air Quality Management Framework Directive (EU 1994) adopts a particularly flexible approach in this respect by establishing long-term objectives of acceptable air quality to be met at some agreed date in the future; and short-term objectives which can be used as an impetus to reduce levels of pollution. The EU Framework Directive proposes the establishment of a *long-term limit value* (LTLV) which should be set at a no adverse-effect level with compliance to be achieved within 10 to 15 years; and *current permitted values* (CPV) which incorporate a margin of exceedance above this level which will be progressively decreased with time. In areas in which the CPV is exceeded (an area of poor air quality) programmes must be initiated to reduce levels of those pollutants above the CPV level. Where air quality is between the CPV and LTLV levels (areas of improving air quality) no increase in pollution is permitted. Areas with levels of pollution below the LTLV are considered to have good air quality and no actions are required. The EU Directive also proposes the establishment of *alert thresholds* which when breached must trigger public warnings.

The management framework proposed by the EU takes advantage of the benefits of the effects-based approach, but uses standards flexibly in order that countries can take account of their existing environmental, social and economic realities. The framework also addresses air pollution problems in those areas in which they exist; unlike a framework based on national fixed emissions limits in which problem areas are not especially targeted. Targeting can ensure that air quality resources are used most effectively. Emissions limits are extremely expensive to operate and enforce and should, if possible, be targeted to where they are most needed. The proposed EU framework could therefore be of potential benefit in many countries.

Air quality standards are an important management capability if set, used and enforced as part of an overall management strategy. In many countries, however, use of standards is limited to that of benchmark against which air quality is simply compared without affecting subsequent actions. Applied in this way the potential value of these standards is greatly reduced.

Data availability

Access to air quality data and assessments and emissions inventories combined with open management and transparent decision making are important components of management capability; linking with the other components and enhancing their effectiveness. The most appropriate form, media and method of data transmission is totally dependent on the intended recipient of this information; whether it is the general public, independent experts or decision makers. These factors also vary between countries depending on their information processing and transmission capabilities.

Information made available to the public needs to be produced in a readily understandable form such as the United States Environmental Protection Agency Pollution Standards Index, (USEPA 1992); or UK Department of the Environment Air Quality Bandings (see the chapters on Taipei and Birmingham respectively for further details) (WSL 1994). These systems classify air quality into acceptability bands; during periods of poor air quality they are accompanied by advice to sensitive individuals about remedial measures which can be taken to reduce exposure and lessen symptoms (such as remaining indoors, desisting from vigorous exercise and increasing preventative and alleviating medication). Information to the public of this type is most widely and rapidly disseminated through the media, and can also be accompanied with information on how to reduce emissions (e.g., not using cars). In extreme situations, where additional emissions controls are enforced, such as road closures and restrictions on vehicle use (as has operated in Athens and many other cities) the public also needs to be informed urgently through the media and public announcements. Ready access to air quality information by the public enhances awareness of air quality issues. This may be viewed by some authorities as unhelpful, but decisions taken to control emissions will be most effective when those who are affected – industry, vehicle owners, etc. – accept the need for, and implications of emissions controls. Enhancing public awareness therefore encourages adherence to new emissions control measures.

Information for those developing and implementing air quality management strategies needs to be concise and in a form in which it is easily interpreted by non-experts. Written reports are the most obvious media of communication and these should be widely distributed in order to enable independent assessment of the information being provided for the decision makers. The use of indicators is particular useful in this context, providing a summary of the pertinent facts and an overview of the issues to be addressed. Independent experts should have considerable input into the formation of air quality management strategies: the greater the information available to air pollution research scientists and others with an interest in these issues the larger the contribution they can make towards identifying and solving problems. Raw data, in many countries, is most readily made available through computer media such as on-line data access or floppy discs. Other information can be relayed as hard copy reports, or if the technology is available, through computer links such as the Internet.

Data communication is an extremely important component of air quality management capability and is essential for the most effective use of the information generated. In recent years, access to air quality data has generally improved; although information on levels of toxic chemicals is notably less readily available, data from emissions inventories is also sometimes with-held, particularly from individual point sources. Withholding air quality data is counterproductive to the objectives for which the information is generated, it reduces input into the decision making process and hence the effectiveness of the capabilities which have generated the data.

Emissions Estimates

Application of emissions inventories

Accurate assessment of emissions of different pollutants are an integral part of establishing equitable, cost-effective emission controls and consequently appropriate air quality management strategies. The relationship between emissions data and statutory emissions limits also provide an indication of the extent to which statutory emissions controls are adhered to. Despite the valuable information which can be obtained on the sources of pollution in a city, calculations of emissions estimates are rarely performed on a city scale even within developed nations. Chapter 4 of this report, and previous studies on megacities, indicate that this component of management capability is, on a world scale, the most limited (UNEP/WHO, 1992).

An emissions inventory is a data base of:-

1. Emissions measurements.

2. Emissions factors (values which describe the proportion of pollutants emitted by different processes, and which can be obtained from established tables).

3. Individual emission sources (such as major industrial plants and power generating facilities).

4. Activity statistics (on energy use, population, transport, industrial production, etc.).

5. Emissions estimates (derived from the above data).

Source: McInnes, 1992

Emissions can be estimated in terms of contributions from different source categories and geographical locations; enabling a broad range of information to be obtained from such an inventory. The production of emissions inventories for those developing and implementing air quality management strategies enables quantification of:-

A. The magnitude of emissions.

B. The main contributing sources.

C. The spatial distribution of pollutants (through developing models using meteorological measurements).

D. Future trends.

E. Historical trends (if inventories are conducted over a number of years).

F. Dispersion and conversion of pollutants.

G. Verification of compliance with regulatory controls.

A properly constructed emissions inventory provides important complementary information to that generated by ambient air quality monitoring. Identifying main contributory sources, spatial distribution, dispersion and conversion of pollutants as well as historic and future emissions trends are powerful tools in the formulation of policy. Once policy has been developed, and is being implemented, the magnitude of emissions and verification of compliance with regulatory controls become important further uses of emissions information. Policy adaptation throughout this period, to ensure that the control situation is attained, relies heavily on estimates of future emissions. The need for emissions estimates to assist decision makers formulate plans, enforce emissions limits and subsequently amend strategies is clear.

Construction of emissions inventories

Emissions estimates are derived by identifying the sources of pollution, measuring the extent of the polluting process (fuel combustion, evaporative emission etc.) and determining polluting potential. The magnitude of a process is measured by activity statistics. Activity statistics provide information such as the quantity of a fuel burnt or paint produced. The product of the activity statistic is then calculated using an emission factor (which estimates the amount of pollution produced per unit activity) to produce an estimate of the total amount of a pollutant produced by a particular process. If some pollution abatement technology is applied to an observed polluting process it will remove a proportion of the pollutants and consequently it will reduce total emissions. In this context an abatement factor is then incorporated into the calculation.

In designing and compiling an inventory for a pollutant it is important that the major sources are properly quantified and a decision made as to the degree of detail required. Policy makers must consider what level of resolution of emissions information is desirable and necessary; they must also consider the resource and information implications of achieving a sought level of inventory resolution. Resource and information availability as well as the objectives of inventories vary between cities; it is therefore not appropriate to specify a required level of detail, accuracy and precision (in a similar way that it is not possible to specify how many monitoring sites are required). It is, however, important that a certain minimum (default) level of accuracy and precision is achieved for each activity within an individual city inventory (in the same way that data quality objectives should be defined to meet specific monitoring objectives). There should still be flexibility in the procedures adopted to estimate emissions, and unnecessary complexity should be avoided. Above all, any assumptions and estimates made should be stated, so that there is transparency in the calculations performed. The issue of a transparent inventory compilation procedure raises the problem of the use of confidential information in constructing emissions estimates. Use of confidential information clearly restricts the use of an inventory and diverts limited resources into maintaining data security. In the absence

Example emission calculation:

Consider a power plant burning 10,000 t of lignite per annum (*this is the activity statistic*).

The emissions factor for particulate matter, and SO_2 produced from lignite are 3.5 kg t^{-1}, and 15 kg (S) t^{-1} respectively.

Therefore per year: 35,000 kg of Particulates and 150,000 kg of sulphur (most as SO_2) are produced respectively per year.

If the power station is fitted with pollution abatement equipment on the stack which reduces emissions of articulates and sulphur dioxide by 80 per cent, then emissions will be 7,000 and 30,000 kg respectively per year.

of alternative data sources it may not be possible to avoid the use of confidential information; if it cannot be avoided it should be minimized.

Inventory verification

The procedures by which emissions estimates are derived limits their temporal, spatial as well as absolute accuracy and precision. It is, therefore, essential that during design and compilation processes, particular care is taken to ensure that the level of uncertainty does not exceed that which is acceptable to the policy makers for whom the data is intended; and that the resources available and time required for compilation are realistic. Once the inventory has been completed it is important to conduct an emissions verification exercise to ensure that the accuracy and precision of estimates remain within acceptable parameters. Verification involves ascertaining the completeness and consistency of the data input and involves checks on:-

1. How definitions of sources and of pollutants have been applied.

2. The completeness of the data entered for each sector, sub-sector and activity.

3. The consistency of emissions factors adopted relative to those applied in other countries.

4. The consistency of emissions estimates with cities of a similar size and level of industrialization and development.

5. The consistency of the inventory at different levels of spatial disaggregation.

6. The transparency of the emissions inventory – whether the data inputs are fully traceable to their references.

Verification can also involve the use of dispersion and modelling studies to assess the inventory in relation to measured air quality; if, of course, such a model is itself well established and validated. Validating the inventory has obvious resource implications, but as with QA/QC procedures for monitoring, it is essential to produce data of known quality and to ensure that it is adequate for its intended use. Such validation enhances the usefulness of the inventory appreciably.

Inventories of specific pollutants

Constructing inventories for different pollutants presents quite different problems; and demands on resources. The following sections outline the problems of compiling inventories for the most common pollutants. It also outlines their construction requirements in terms of information and skills.

1. Sulphur dioxide

Inventories of SO_2 emissions are relatively easy to conduct and quantify since sources are almost exclusively fossil fuel burning: predominantly coal and heavy fuel oil. Sulphur dioxide emissions are predominantly determined from energy statistics such as fuel deliveries or consumption and the fuel sulphur content; with an allowance for sulphur retained in the ash and/or collected by pollution abatement processes. Energy statistics are generally available and reliable; the data produced, therefore, has a high degree of both accuracy and precision.

2. Nitrogen oxides

Oxides of nitrogen (NO_x) emissions inventories usually consider nitrogen oxide (NO) and NO_2 together as the former is readily converted into the latter in the atmosphere. NO_2 is of considerably more interest as a pollutant due to its health and acidification effects. Emissions of NO_x are more difficult to determine than those of SO_2 since emissions are dependent on combustion conditions as well as the nitrogen content of the fuel, (fuel NO_x). The information demands when compiling an NO_x inventory are therefore greater. Emissions from road transport usually represent the major source of NO_x in urban areas; consequently, it is appropriate to use more sophisticated procedures to determine emissions from this sector than simply to apply emissions factors to fuel consumption statistics (although this procedure will provide an estimate of emissions to a first approximation). More sophisticated inventories will calculate emissions from vehicles of different engine capacities and speeds; and, those engines using different engine and tail pipe technologies. Most cities will be unable to commit the necessary resources and/or access adequate capabilities to achieve this level of accuracy; likewise, many will not require this level of information.

3. Carbon monoxide

In urban areas CO emissions are predominantly produced from petrol engine motor vehicles and consequently emissions from this sector (as with NO_x inventories) should be calculated with a greater degree of sophistication. Carbon monoxide emissions from vehicles are dependent on the tuning of engines, whether engines are cold, their speed and other operating conditions. Consequently, the nature and length of journeys play an important part in the emissions produced. Rudimentary inventories, which do not require this level of information will still produce useful, if more limited data.

4. Volatile organic compounds

Emissions of volatile organic compounds (VOCs) are of particular concern in urban areas due to their photochemical ozone creation potential (PCOP). The term VOCs covers a wide range of species, the most abundant of which is methane (CH_4). Methane has a very low PCOP and is consequently not particularly important in O_3 production. Inventories to determine the potential for ozone production are therefore more usually carried out for non-methane VOCs (NMVOCs). Inventories for methane, an important greenhouse gas, can be conducted separately if required. In urban areas the source of NMVOCs is predominantly motor vehicles through emissions of unburnt petrol from the exhaust and from evaporative emissions from the fuel tank (and while refuelling); other important sources involve the use of solvents. Non-methane VOC emission estimates can be supplemented with information about VOC speciation and POCP factors to provide greater information about the production of O_3. The most important species in terms of their O_3 production potential are alkenes, aromatics, alkanes (with less than 6 carbon atoms - with the exception of 2,3 dimethylpentane-), aldehydes (except benzaldehyde) and biogenics such as isoprene. Knowledge about source and magnitude of emissions of these species will enable targeting of the most effective strategies to maximise the improvement in air quality. Determining accurate VOC inventories requires considerable data, resources and skills and many cities will not possess adequate capabilities to produce more than a first approximation of emission estimates. Performing more involved procedures to ascertain PCOP is not possible for many cities. Unless ground-level O_3 represents a serious air quality problem this type of inventory should be considered a low priority; due, not least, to its resource intensiveness.

5. Particulate matter

Quantifying emissions of particulate matter presents special problems due to the wide variety of sources from which it is produced and because of different size fractions. From a health perspective it is only respirable particulate matter, which is important: to a first approximation, PM_{10} (particulate matter with an aerodynamic diameter of less than 10 μm). The accuracy of an inventory compiled to determine the magnitude of different sources and spatial disaggregation of PM_{10} would, however, have large uncertainties and require considerable skills and information. Sources of particulate matter are numerous: motor vehicles, (particularly diesels), point source stacks and fugitive emissions including wind blown dusts, emissions from buildings via natural or fan assisted ventilation, emissions from roads due to local air turbulence and emissions from the handling of materials whilst loading or unloading. Aerosols such as sulphuric acid, ammonium nitrate and sulphate produced by atmospheric chemistry are important secondary particles. A sizeable proportion of the total aerosol mass in many urban areas comprises of airborne particulate elemental carbon derived from carbonate solids, organic carbon and particulate elemental carbon, soot (QUARG, 1993). Because of the difficulties of estimating emissions from all sources, particularly fugitive emissions and secondary particle production, it is more usual to conduct inventories only generated from combustion processes producing smoke. Inventories of particulate matter usually quantify emissions of black smoke. Smoke is generally defined as *suspended particulate of <15 μm arising from the incomplete combustion of fuel* (QUARG, 1993). Because of the different soiling capacities (blackness) of smoke produced from different sources, smoke emissions factors (by mass) are multiplied by a soiling factor (relative to that of coal), to produce a dark smoke emission factor (by mass). In this way the contribution of different fuels to the mass of particulates emitted is not dependent on their colour. The absence of fugitive emissions in these inventories means that they do not accurately represent all sources: only combustion processes. In arid environments, fugitive emissions from wind-blown soil and sand make an appreciable contribution to total mass loading. The value of conducting inventories of combustion sources of particulate matter is that these sources are more readily controlled; the data is therefore decision relevant. Inventories of particulate matter however do require considerable resources and should be developed only once experience and skills have been gained in compiling more straightforward emissions estimates; such as SO_2.

Summary

Significant capabilities are required throughout the four-phase management cycle of an air pollution problem. Initially, monitoring capabilities are required to produce data enabling the identification of air quality problems. Capabilities are then required to provide decision-relevant information: to assist in the formulation of appropriate, cost-effective strategies to control emissions; to enable the strategies adopted to be effectively implemented; to measure their success; and, if necessary, to facilitate subsequent amendments to such strategies. In the final phase of the management cycle (the control situation in which acceptable air quality has been attained), capabilities are required to ensure that this situation is maintained.

Air quality management capabilities can be broadly defined into three categories depending on their objectives:-

1. Capabilities to provide decision-relevant and public information.

2. Capabilities to utilise the above to enable more effective air quality management.

3. Supplementary capabilities which enhance the effectiveness of other capabilities.

Each category of capabilities is essential for the overall success of the management process; the individual component capabilities of each category are shown in Table 2.2.

All categories of management capabilities are equally important and produce complementary outputs enabling the most cost-effective, appropriate air quality management strategies to be introduced. Development and operation of these capabilities, however, require considerable inputs of human, technical and financial resources. In formulating emission control policies it is, therefore, important that these are recognised and that realistic proposals are adopted.

In almost all large cities the number of current or potential sources of pollution are such that local air quality management is essential to ensure that levels of pollution do not reach concentrations at which there are significant health or environmental consequences. In order to ensure positive outcomes in the most cost-effective, appropriate manner, the production of air quality management strategies based on decision-relevant information and supported by monitoring capabilities are required. As such, in cities with air quality problems (or potential problems), air quality management capabilities are a fundamental requirement for sustainable living.

References

DOE 1994 *Improving Air Quality*, Department of the Environment, London.

EU 1994 *Proposal for a Council Directive on Ambient Air Quality and Assessment*, Official Journal of the European Union, Brussels.

FOE 1994 Friends of the Earth Comparative NO_2 Monitoring Survey of Selected Sites in London, Manchester and Cardiff 1993, Friends of the Earth, London.

McInnes, G. 1992 Background Paper for the First Meeting of the UNECE Task Force on Emissions Inventories, Warren Spring Laboratories, Stevenage.

QUARG 1993 *Urban Air Quality in the United Kingdom*, First Report of the Quality of Urban Air Review Group, Department of the Environment, London.

UNEP/WHO 1994a *GEMS/Air Methodology Reviews Vol. 1: Quality Assurance in Urban Air Quality Monitoring*, WHO/EOS/94.1, UNEP/GEMS/94.A.2, United Nations Environment Programme, Nairobi.

UNEP/WHO 1994b *GEMS/Air Methodology Reviews Vol. 2: Primary Standard Calibration Methods and Network Inter-calibrations for Air Quality Monitoring*, WHO/EOS/94.2, UNEP/GEMS/94.A.3,United Nations Environment Programme, Nairobi.

Table 2.2 Air quality management capabilities

Capabilities to provide decision relevant and public information	Air quality management enabling capabilities	Supplementary capabilities enhancing the effectiveness of other capabilities
Air quality monitoring To provide information on air quality to ascertain: *Health and environmental effects* *Trends* *Spatial distribution* *Sources* *Compliance with air quality standards* *Indoor contribution to exposure* To provide public information.	**Emissions limits and product standards** To set formal limits to ensure that emissions from sources are regulated.	**Quality assurance and control/ inventory verification** To produce air quality data of known quality adequate for its intended use.
Emissions inventory To provide information on emissions to ascertain: *Magnitude* *Spatial distribution* *Source contribution* *Trends* *Projections* To provide public information.	**Air quality standards** To define the level of acceptable air quality at a given time.	**Data assessment** To produce value-added data.
Airshed modelling To enable prediction of air quality episodes. To describe concentrations across the city and dispersion characteristics. To perform what-if scenario development of emission control strategies.	**Administrative framework** To enable the effective implementation of the emission control strategies adopted.	**Data dissemination** To enhance access to the decision-making process and enable greater participation.
	Legislative framework To enable adequate penalties to be imposed to discourage breaches of emissions limits and air quality standards.	**Emissions monitoring** To ensure compliance with emissions limits To assist in verification and compilation of emissions inventories.

UNEP/WHO 1994c *GEMS/Air Methodology Reviews Vol. 3: Measurement of Suspended Particulate Matter in Ambient Air*, WHO/EOS/94.3, UNEP/GEMS/94.A.4, United Nations Environment Programme, Nairobi.

UNEP/WHO 1994d *GEMS/Air Methodology Reviews Vol. 4: Active and Passive Sampling Methodologies for Measurement of Air Quality*, WHO/EOS/94.4, UNEP/GEMS/94.A.5, United Nations Environment Programme, Nairobi.

UNEP/WHO *GEMS/Air Methodology Reviews Vol. 5: The GEMS/Air System for Collaborative Reviews*, United Nations Environment Programme, Nairobi. (In press).

USEPA 1993 *National Air Quality and Emissions Trends Report*, EPA 454/R-93-031, Office of Air Quality Planning and Standards, US Environmental Protection Agency, Research Triangle Park.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

WHO/UNEP 1992 *Urban Air Pollution in Megacities of the World*, World Health Organization, United Nations Environment Programme, Blackwell, Oxford.

Winsemius, P. 1986 *Gast in eigen huis, beschouwingen over milieumanagement, (Guest at home, reflections on environmental management)*, Samson, H. D., Tjeenk Willink, Alphen aan den Rijn, 227 pp.

WSL 1994 *Air Pollution in the UK 1992/93*, Air Monitoring Group, Warren Spring Laboratory, Stevenage.

3

Air Quality Management Capability Indicators

Assessing Air Quality Management Capability

In Chapter 1, air quality management capability was defined as *the capacity to generate and utilize appropriate air quality information within a coherent administrative and legislative framework; to enable rational management of air quality*. Chapter 2 has illustrated that there are a number of core components common to the effective formulation and implementation of an air quality management strategy. Furthermore, Chapter 2 explained how the combined presence of these core components considerably enhances the effectiveness of individual capabilities. Cities are, however, too diverse for there to be a standard package of capabilities required by each in order to sustain or attain acceptable air quality. Assessing air quality management capability therefore requires both a knowledge of the individual components of capability available in a city as well as its particular characteristics (climate, economy, topography etc.). Without this knowledge it is impossible to assess the strengths and weaknesses of existing capabilities; and to highlight areas which require priority attention.

An assessment of management capability therefore requires answers to three key questions:

1. Has the city stated the air quality objectives which it is proposing to attain/maintain and, if so, are these realistic and appropriate?

2. To what extent is the information required for decision makers to develop management strategies available to them; being used in the most effective manner; and of adequate quality for its intended use?

3. Is there an administrative and legislative framework in the city to ensure that any emission control strategies which are proposed will be implemented and enforced?

Answering these questions is crucial in order that optimum use is made of existing management capabilities and resources; and to target and prioritize the use of additional resources. Finding answers to these questions is, however, far from straightforward; as is the development of objective assessment criterion.

The first key question concerns general assessment of the presence or extent of air quality problems through the use of air quality standards. However, the application of standards as management tools for assessing the acceptability of air quality varies enormously between countries. For example, in the United States, the basis of air quality legislation is attainment of National Ambient Air Quality Standards, and emissions controls are required to ensure attainment of these by a specific date. A number of countries (including some with cities participating in this study) have also adopted the United States Environmental Protection Agency (USEPA) standards. However, few countries apply these standards in as rigid a way as the USA. Most countries use air quality standards simply as reference values with which to compare their air quality, rather than as thresholds above which action is required to reduce concentrations. What is classed as an appropriate air quality standard clearly depends on the circumstances of a particular country and the extent to which health and environmental problems caused by air pollution compare with other factors that affect well-be ing. Standards set at below a no-adverse-effect level with a margin of safety, clearly represent the lowest practical standard in any city. However, in many cities, other factors are likely to require that standards are established at concentrations significantly higher than this. It is clear that the application – not merely the existence of an air quality standard – is the important factor; this makes this assessment exercise more difficult.

The second question refers to the information available to formulate effective emission control strategies. Chapter 2 of this report stressed the importance of air quality management decisions being based on adequate information; in terms of its nature, quantity and quality. Identifying deficiencies in the available information is important in order to enable the more effective targeting of resources. This is important for local and national governments as well as international bodies, such as UNEP and WHO. As has already been stressed, the information required by a city to develop a coherent emissions control strategy are not fixed and it is not, therefore, appropriate to stipulate a set of general monitoring and management capabilities required by all cities. Nevertheless, management capabilities do comprise of a number of essential elements (see Table 2.1). The city selection criteria used for this report – cities with populations approaching and over 3 million by the year 2000, but mostly less than 10 million – means that cities of a similar size have been studied. It is, therefore, possible to describe, for example, *the minimum monitoring capabilities below which it is not possible to produce decision-relevant information for air quality management.* This level does not represent an ideal level of capability but merely that level with the potential to produce tangible benefits. These assessment criterion are developed further in this chapter.

The final question that an assessment of management capabilities needs to ask is whether enabling capabilities such as the presence of an administrative and legislative framework exist to ensure that emission control strategies can be proposed, implemented and enforced. Clearly these capabilities are dependent on the emissions controls strategies adopted; for example, if exhaust emissions limits are established for motor vehicles there is a need to establish a motor vehicle inspection and maintenance programme. The success of emissions control is heavily dependent on effective implementation; ensuring that administrative and legislative capabilities are adequate is therefore crucial.

Use of Indicators in Assessing Air Quality Management Capability

It is important when assessing the air quality management capability of a city to introduce some objectivity into the exercise; rather than to rely on a subjective assessment which can result in bias and inconsistency. One way of doing this is to use indicators. Indicators provide summarized information with an intrinsic interpretative value; they provide insight and are designed to meet specific information needs: usually for policy development. They typically perform a specific role and cannot be used for applications other than those for which they are developed. Indicators can be useful management tools and as such they are relevant to all aspects of air quality control.

Indicators are especially helpful where data sets are large, complex and consequently difficult to draw conclusions from, particularly by non-expert decision makers. This makes indicators especially appropriate for air quality management as they provide decision-relevant information without the need for a comprehensive understanding of all the available facts. Indicators, therefore, represent an important component of an information process and can have an important role in assessing air quality monitoring capabilities.

Indicator design is determined by its ultimate purpose, which is a function of the end user (target audience) of the information. There are a number of criteria which have been proposed for indicator design (Liverman et al., 1988; Peterson et al., 1993) which are especially relevant for indicators developed to assess air quality management capability. An indicator should be:

1. Transparent – aiding understanding of the functional relationship between different elements of the system of interest;

2. Realistic – presenting an accurate view of the system;

3. Scientifically valid;

4. Sensitive – responsive to changes in the system (especially over time to demonstrate trends);

5. Accessible – derived from readily available data.

The target audience for indicators of air quality management capability are those decision makers in national government or municipal authorities with responsibility for controlling the levels of air pollution in urban environments. They also have relevance for policy makers within international bodies. These indicators are intended as an aid to empower decision makers to identify deficiencies in the capabilities of cities; and to enable appropriate responses.

Air Quality Management Capability Indicators

Indicator framework

Assessing the existing air quality management capabilities of a city is essential in order to provide information for decision makers at a local, national and international level. Assessment enables the identification of strengths and omissions in current capabilities and can ensure that existing capabilities are used to their maximum potential; it also facilitates the development of additional capabilities in the most appropriate, cost-effective manner. The air quality management capability of a city has a number of components (discussed in Chapter 2), which do not readily lend themselves to the development of one key (composite) index.

In order to achieve an overall perspective of the air quality management capability of a city it is, therefore, necessary to develop indicators to assess each component of capability. Once this has been done we can then group these component indicators together into an *index* of air quality management capability which can be used to identify deficiencies, make comparisons and so forth. In this study, four sets of indicators (indices) have been developed to represent the principle components of management capability:

1. *Air quality measurement capacity index* – assessing the ambient air monitoring taking place in a city, and also the accuracy, precision and representativeness of the data produced.

2. *Data assessment and availability index* – assessing how the air quality data are processed to enhance their value and provide information in a decision-relevant form. The index also assesses the extent to which there is access to the air quality information and data through different media.

3. *Emissions estimates index* – assessment of emissions inventories conducted to determine the extent to which decision-relevant information is available about the sources of pollution in the city.

4. *Management enabling capabilities index* – assessing the administrative and legislative framework through which emissions control strategies are introduced and implemented to manage air quality.

The relationship between the different indexes and indicators are shown in Figure 3.1. Each of the four

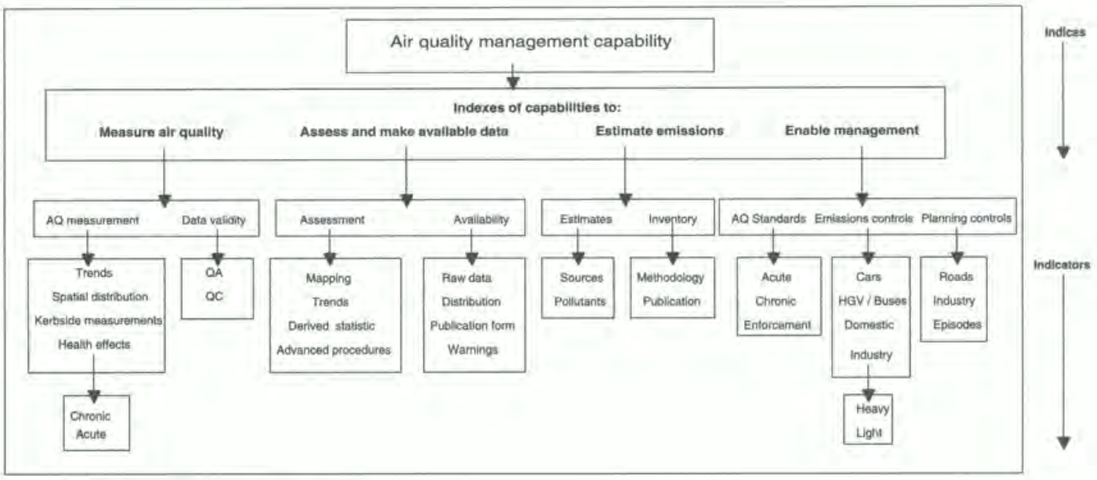


Figure 3.1 Hierarchy of indicators

component indexes consists of a number of constituent indicators. For example, the air quality measurement capability index comprises of indicators of: the data validity (QA and QC); air quality measurements taken to determine trends and spatial distribution in pollutant concentrations and health effects, both chronic and acute; and, measurements taken of kerbside concentrations. Each of the four indexes consists of a number of component indicators which are designed to **determine whether the city has any useful capacity with respect to a particular element of management capability**. City officials were asked to complete a questionnaire with Yes or No answers designed to determine what capabilities their city possessed with respect to the elements shown in Table 3.1.

For example, the indicators of data assessment reflect the data analysis performed by a city and how this analysis is achieved. In this respect, the questionnaire sent to the cities participating in this study requested them to answer Yes or No to the following questions:

Which of the following statistical or analytical procedures are calculated or conducted on air quality monitoring data:

- *Mean values (daily, monthly or annually)?*
- *Maximum values (daily, monthly or annually)?*
- *Percentiles?*
- *Exceedances of national or WHO air quality standards?*
- *Trends?*
- *Spatial distribution (mapping)?*
- *Exposure assessments?*
- *Epidemiological studies?*
- *Modelling with meteorological measurements?*
- *Prediction modelling?*
- *Are computers used in data assessment?*

The more questions to which a city gave a positive response the greater the management capability of that city with respect to data assessment. This can be quantified by allocating points for each indicator question for which Yes is answered. Some indicators (questions) were allocated more points towards the index score than others; the different weighting of questions being based on the relative importance of the capability in question. Once again using the data assessment example: one point was allocated for each type of analysis performed with the exception of measurements of exceedances of standards and the conducting of epidemiological studies for which two points were awarded each. This judgement is based on the fact that these two capabilities are more relevant to decision makers than the other procedures. If computers were used in data assessment this also scored two points. The weighting given to each indicator has been determined subjectively, but is based on sound rationale. All the indicator questions to which cities were required to answer Yes or No are shown in Appendix D together with their respective allocation of points.

The total number of indicator points available in each component index is 25. The greater the number of Yes answers in the questionnaire, the more management capabilities are possessed by a city and the higher the score of points. The scores obtained have been grouped into the bands of air quality management capability shown in Table 3.1. The different component indexes have also been combined to produce an overall assessment of management capability. Each of the four component indexes has a maximum of 25 indicator points; by adding these together an overall assessment of capability is obtained with a maximum score of 100. An equal weighting of each component index has, therefore, been given to the overall assessment. Similarly, banding of equal points width has been adopted within the component indexes and overall capability index. The banding for the overall capability index are also shown in Table 3.1.

Criteria of indicator development

With certain management capabilities it is relatively easy to design indicator questions to determine whether a capability exists; such as data assessment where a city generally either does or does not conduct a particular procedure. Developing other indicator questions is more complex; such as whether a city has adequate

Table 3.1 Bandings for the component and overall capability indices

Effectiveness of capabilities	Component index score	Overall capability index score
Minimal	0–5	0–20
Limited	6–10	21–40
Moderate	11–15	41–60
Good	16–20	61–80
Excellent	21–25	81–100

information to measure the spatial distribution of a particular pollutant when there is no clear basis as to what constitutes "adequate information". The minimum or acceptable level of capability on any aspect of air quality management is, therefore, a subjective question. However, as the cities are all of a similar size it is possible to make judgements. The indicator questions developed and applied in this report generally represent ***the minimum capability required to generate air quality information useful for decision makers***. This enables genuine deficiencies to be clearly identified: if an indicator is not met then the capability does not exist in any useful form. The choice of minimally useful capacity indicators also reflects the generally limited level of air quality management capability in cities of this size globally. In this way it is hoped that identified deficiencies (indicators which are not met) can be improved without excessive cost and with technology appropriate to all these countries. The criteria of *minimum useful capability* for indicator design, therefore, acts as the reference with which capabilities can be compared and helps to identify where resources can be most appropriately allocated.

An example of how the criteria of minimum useful capacity operates in developing indicators helps to clarify this concept. There is undoubtedly a need for a city to have the capacity to determine its spatial distribution of pollutants. However, what constitutes adequate knowledge of spatial distribution? The best information about the spatial distribution of pollutants would be derived from a network of air quality monitoring and meteorological stations, supplying data to dispersion modelling software, incorporating a data base of point, line and area emission sources from which the distribution of pollutants could be obtained in real time. However, very few cities in this study have such a modelling system and this approach certainly does not represent the *minimum* useful information for decision makers. A less sophisticated approach would be to use a network of stations across the city and produce isopleth maps of average pollutant concentrations; but the number of sites that are required to provide adequate coverage is another subjective issue. Passive samplers could also be effectively used for this purpose, but only for some pollutants, and how many to use will depend on the level of spatial disaggregation of concentration considered acceptable by the city. The indicator developed in this report requires three monitoring sites: one each in an industrial, commercial/city centre and residential area. These sites have to be operating simultaneously to produce equivalent data and to have been functioning for at least one year (for ozone the indicator uses upwind city centre and downwind locations owing to the different production mechanism of the pollutant). The information which can be obtained from a network of three sites is clearly very limited and represents a minimum useful knowledge about spatial distribution. Nevertheless, it provides those with the responsibility to manage air quality in a city with indicative information to identify some areas of elevated concentrations and make some basic assumptions about the level of exposure of the city's population to different pollutants. Clearly, additional information about pollution distribution across the city would be preferable. However, such a limited network capability does provide sufficient detail for a basic appreciation of pollutant concentrations across the city to be obtained, and helps to identify the nature and most urgently needed locations for additional monitors (if resources become available to extend the network).

The index scores which develop from answers to the indicator questions are intended to provide an indication of the capabilities of cities with respect to the main four components: air quality measurement, data availability and access, estimation of emissions and presence of management enabling capabilities. The index scores perform a dual role; identifying areas in which the city could develop capabilities more effectively and enabling cities to compare their level of capability with other cities of similar size and development. The component index scores, out of a maximum of 25, are grouped into 5 bands intended to demonstrate the extent of management capabilities both within each component index and overall. The bands describe a range of values as comprising a particular level of capability. Imprecision in the construction of the indicators and in obtaining responses from the cities should not, therefore, introduce unacceptable bias or inaccuracy into the assessment, nor excessively diminish the power of the assessment.

These indicators are intended as a focus for information and action and are, therefore, "decision relevant" (van der Born et al., 1993). They do not, however, provide any indication of when or how emission control strategies should be developed. The power of these indicator questions and the indexes created from compiled answers clearly identify deficiencies and strengths in air quality management capability. This is of particular use to those decision-makers, both in cities and international organizations, responsible for targeting resources for urban air quality management. The indicators should be used in the context for which they have been developed: as a management tool.

Indicators of measurement capacity

The index of air quality measurement capacity is intended to assess the ambient air monitoring taking place in each city, and to assess the accuracy, precision and representativeness of the data produced. There are clearly dozens of pollutants for which monitoring of air quality can be conducted; however, to enable some rationalization, monitoring capability has only been considered for the six most widely measured pollutants. Pollutants which have been given priority by the GEMS/Air Network. These pollutants are of particular health and environmental concern; they are: nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter/smoke, carbon monoxide (CO), ozone (O_3) and lead (Pb). Other pollutants, such as some polyaromatic hydrocarbons (PAHs), aerosol acid, dioxins and polychlorinated biphenyls (PCBs) are of increasing concern owing to their health implications. However, they are not widely or routinely measured in many countries and are currently considered to be of lower priority. However, as the indicators used in this report evolve with time it is possible that the capacity to measure for these pollutant species would become an integral part of a minimum capability.

The air quality measurements made in a city are dependent on monitoring objectives. There are a wide range of different monitoring objectives for which monitoring can take place; the five most frequently used and most important are:

1. Measurement of spatial distribution of pollutants within the city.

2. Measurement of trends in pollutant concentration.

3. Measurement of kerbside concentrations to indicate the contribution of road vehicles and to estimate maximum exposure to traffic-related pollutants.

4. Measurement of compliance with national air quality standards and guidelines.

5. Assessment of possible acute and chronic health effects resulting from exposure to polluted air.

Each of these objectives require different: numbers of monitoring sites, siting criteria, sampling periods, sampling frequency, data assessment procedures and data sets. Different monitoring objectives, therefore, require the use of different indicators. Indicators have been developed to determine the capabilities of cities to meet the above monitoring objectives for different pollutants. However, no indicator has been developed for measuring compliance with national standards as standards have not been established in all countries. Although this is clearly a deficiency in those countries' management capability it is not a deficiency in the ability to measure air quality; only in the management tools adopted. Indicators associated with air quality standards have been developed for the air quality management enabling capabilities index. Only monitoring which is *currently taking place regularly, at least once a week,* is considered as meeting the air quality measurement capacity index criteria. The capability to measure ambient air pollution also includes indicators of data validity and representativeness. These can be determined through examining the quality assurance and quality control (QA and QC) systems operating in the city.

Indicators of data assessment and availability

The data assessment and availability index is intended to assess the statistical operations and data assessments performed on raw data; and to assess public access to this data and information. At first sight there appears to be an overlap between this index and that of measurement capacity; for example, with the indicators to measure trends and spatial distribution. The two indexes are quite distinct, that for data assessment and availability being a measure of the data analysis performed by cities rather than those assessments for which data are available and could be conducted which are assessed by the measurement index. The indicator questions for the data assessment component are described as an example earlier in the chapter. Those for data availability ask where information is published, whether and how it is reported to the public and if warnings and advice are issued to the public during pollution episodes.

Indicators of emissions estimates

The emissions estimates index is intended to assess the information which is available about emissions in the city, how it has been determined, and to what extent this information is made available. Indicators refer to the categories of sources for which emissions estimates (an emissions inventory) have been conducted, and the pollutants for which such an inventory exists. The indicators also relate to how the inventory has been constructed, how often it is updated and, consequently, the confidence with which the estimates can be considered. The degree to which this information is made available is also considered.

Indicators of air quality management enabling capabilities

The management enabling capacity index is intended to assess the basic tools which are used to control air pollution in each city. The indicators we have developed for this index are associated with how the capabilities covered by the other three indices are applied to develop air quality control strategies. These indicators do not specifically relate to the relative success of any strategies that have been introduced. The indicators used refer to the existence and application of air quality standards and guidelines, to the presence of emissions controls and whether or not adequate capabilities exist to ensure that these are enforced. They seek to determine whether air quality information is used for planning purposes and so forth.

Conclusion

The management capabilities index provides a useful additional tool for assessing air quality management capability. The technique is useful in that it provides quantitative information which can be used to examine the relationship between the different components of management capability. The indicators outlined in this chapter are detailed in Appendix D and applied in Chapter 4 which gives an overview of air quality management capabilities in the 20 cities covered by this study. The application of the index demonstrates the value of the technique whilst showing the limitations of such an approach. The assessment of management capabilities in Chapter 4 and following city chapters does not rely exclusively on the use of indicators but also uses other qualitative and quantitative techniques. In this context the index has a valuable role in providing additional decision-relevant information.

References

Liverman, D. M., Hanson, M. E., Brown, B. J. and Meredith, R. W. 1988 Global sustainability towards measurement, *Environ. Manag.* 12, 133–143.

Peterson, P. J., Jackson, J. A. and Willcocks, A. D. 1993 WHO Consultation on the Development and Use of Environmental Health Indicators in the Management of Environmental Risks to Human Health, WHO/EHE/93.3, World Health Organization, Geneva.

van der Born, G. J., Bakkes, J. A., Helder, J. C., Swart, R. J., Hope, C. W. and Parker, J. D. E. 1993 *An Overview of Environmental Indicators – State of the Art and Perspectives, Draft Report*, National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, The University of Cambridge, Cambridge.

4

Overview of City Air Quality Management Capabilities

Introduction

This chapter presents an overview of the air quality management capabilities present in the 20 cities participating in the study. As was discussed in Chapter 1 the city-selection criterion sought to include cities of similar size, providing (as far as possible) global coverage and widely differing air quality problems, priorities, resources and available skills. Consequently, the cities participating in this study have widely differing air quality management capabilities. The objective of this chapter is, therefore, to provide a general overview of the management capabilities of the 20 cities we studied; such an overview may be useful as a global perspective of capacity in cities of similar size.

Identifying the range of management capabilities that exist is of particular value for city and national administrations and it enables them to clearly relate their capabilities to those of other cities. Omissions in capabilities are clearly identified for non-experts and decision makers through the use of tables and figures throughout this chapter. This overview can be used in conjunction with the city-specific chapters to determine those areas in which capabilities are in the greatest need of development and in which additional resources, if available, can be most effectively employed. The chapter also identifies areas of common strengths and weaknesses among cities in the same region and with similar per capita incomes. In addition, the relationship between the different elements of capability and national per capita wealth are examined using the quantitative index score developed in Chapter 3 and described in Appendix D. This chapter, therefore, provides original, decision-relevant, value-added information for policy makers in cities, national governments and international organizations; it may enable these organisations to target resources for capacity-improvement most effectively. This chapter and its conclusions are intended to assist in the *development of appropriate urban air pollution management capabilities*: a recommendation of Agenda 21 (UNEP/WHO, 1993).

The information in this chapter has been provided by the cities; from questionnaire responses which have been checked, where possible, with other available information to ensure that the data presented are correct and that the questions were fully understood. The following sections examine the capacity of each city with respect to different elements of management capability. The air quality management capability index is applied to ascertain its usefulness and appropriateness and to provide a quantitative means of assessment. The index is also used in conjunction with other indicators to facilitate an understanding of the relationships between the management capabilities of the city and the level economic development. At the end of the chapter a summary draws together the principal results and conclusions obtained from our analyses.

Air Pollution Monitoring

Monitoring objectives

The ability to measure urban air pollution concentrations is an intrinsic part of the air quality management capability of a city. There are a large number of possible monitoring objectives which fundamentally influence monitoring network design and quality assurance. The four principal objectives for which air quality measurements are conducted are to:

1. Estimate likely human and ecosystem exposure to air pollution in order to identify the likely consequences.
2. Determine compliance with statutory national or international air quality standards.
3. Provide public information – including warnings during episodes; to encourage voluntary actions to reduce emissions; and for general interest.
4. Generate information for the formulation of air quality management strategies and to monitor the progress of the plans once implemented.

There are also more technical objectives which enable these principal objectives to be met. These include identifying the spatial distribution of pollution in a city in order to more accurately assess exposure; for land

Table 4.1 Monitoring networks and objectives

City	Network present	Estimate exposure	Compliance	Public information	Forecasting	Spatial distribution
Alexandria	■	■				
Ankara	■	■	■	■		
Belo Horizonte	(1)	■	■			■
Birmingham	■	■	■	■	■	■
Ekaterinburg	■	■	■	■	■	■
Hong Kong	■	■	■	■	(a)	■
Hyderabad	■	■	■	■		
Johannesburg	■	■	■	■		
Katowice	■	■	■	■		■
Kiev	■	■	■	■	■	■
Lagos	(2)					
Lahore	■	■		■		
Madras	■	■	■	■		
Nairobi	(2)	■				■
Pusan	■	■	■	■	■	■
Quito	■	■	■	■		
Santiago	■	■	■	■	■	■
Singapore	■	■	■	■	■	■
St Petersburg	■	■	■	■	■	■
Taipei	■	■	■	■	■	■

■ Operational monitoring network / Objective of monitoring.
□ No monitoring network / Not an objective for monitoring.
(1) Currently suspended.
(2) Periodic measurements made – no formal network.

(a) Forecasting now carried out (EPD, 1996).

use and traffic management purposes and the identification of individual sources. Other technical objectives include the determination of long-term trends in pollution concentrations and the forecasting of pollution episodes to assist with the implementation and assessment of air quality management plans. The monitoring objectives of the cities participating in this study are presented in Table 4.1. For cities with more than one network, with different monitoring objectives, the data presented are combined.

Table 4.1 clearly demonstrates that operational monitoring networks exist in most of the participating cities (which is a possible reflection of their willingness to be part of this study); in only three of these cities are no routine measurements currently taking place. In Belo Horizonte the network is currently suspended but it is hoped that measurements will be reinitiated soon: the development of a new automatic network of stations is anticipated. In Lagos and Nairobi, some measurements are now being conducted as part of on-going research at universities.

Monitoring objectives in some cities are poorly defined, consequently data quality is sometimes inappropriate for the uses to which it is put. Nevertheless, identifying the level of ambient pollution to ascertain likely health consequences is an objective of all the established monitoring networks in the participating cities. In all these cities, except Alexandria, with ambient standards and operational monitoring networks, ascertaining the extent of compliance and providing public information is an objective of monitoring. Sixty per cent of the cities participating in the study have, as a monitoring objective, the measurement of the spatial distribution of pollution in their city; 40 per cent seek to forecast pollution episodes. However, in a number of cities the necessary capabilities, in terms of monitoring infrastructure, tools for data analysis or skilled staff were not available to meet these objectives; nor were plans in place to achieve these objectives in the short or medium term. The stated monitoring objectives of a city are, therefore, not always met; this discrepancy is discussed in more detail in the individual city chapters.

Air quality measurement and methodologies

The most simple, but gross, indicator of a city's ability to measure air quality is its number of established measurement sites; this is shown in Figure 4.1. As an accurate indicator of measurement capability the number of sites is, however, extremely poor. As was described in Chapter 2, the capacity to measure air quality in a city is dependent on a great many other factors. Similarly, the number of staff employed in air

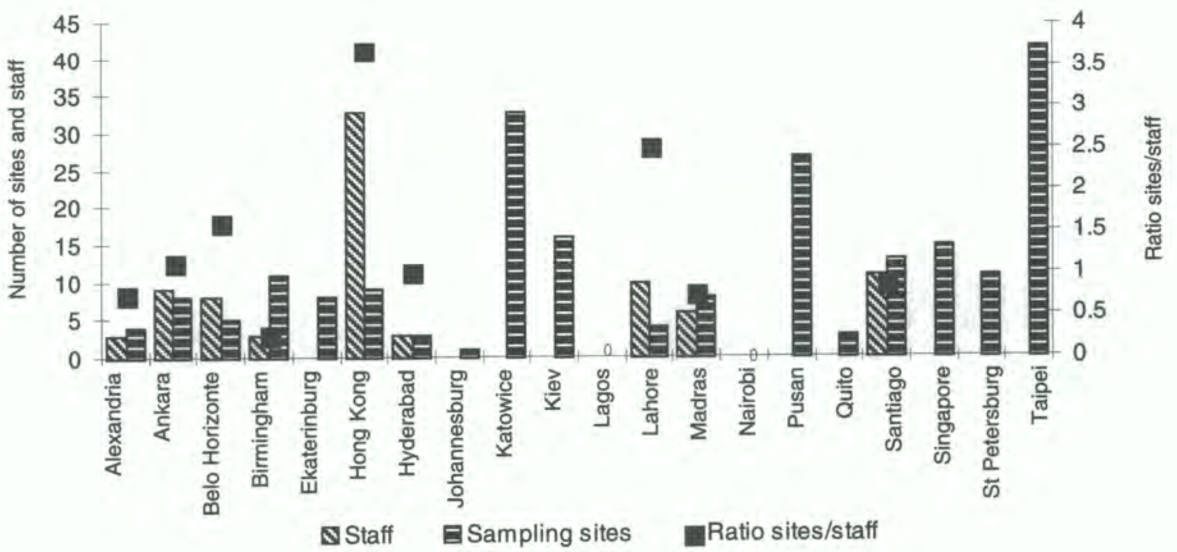


Figure 4.1 Number of staff and active and continuous sampling sites

Table 4.2 Number of sampling instruments for each compound monitored

City	NO_2	SO_2	PM	CO	O_3	Pb
Alexandria		4	4			
Ankara	2	8	8			8
Belo Horizonte(1)		3	7			
Birmingham	25	5	12	3	3	3
Ekaterinburg	8	8	8	8		7
Hong Kong	9	7	18	2	3	9
Hyderabad	3	3	3			3
Johannesburg	1	1	3		1	3
Katowice	261	261	773	8	3	740
Kiev	16	16	16			16
Lagos			NK			NK
Lahore	1	1	4	1	1	
Madras	8	8	8			
Nairobi			NK			NK
Pusan	7	27	7	7	7	
Quito	3	3	6			
Santiago	13	13	24	7	7	
Singapore	15	15	15	15	15	
St Petersburg	11	6	10	11		1
Taipei	31	31	42	31	42	42

[shaded] Compound monitored   (1) Currently suspended   PM Particulate matter   NK Not known

[unshaded] Compound not monitored

quality measurement is a poor indicator of capability because different monitoring methodologies have very different labour intensities; relative labour costs also vary enormously between cities. Obtaining accurate data on staff numbers is also extremely difficult; data which have been made available by cities on staffing are shown in Figure 4.1, but should be treated with considerable caution. In some cities there are a number of organizations responsible for conducting air quality measurements and data analysis. Obtaining staff numbers from all those involved in measurement and subsequent data assessment is difficult; consequently, Figure 4.1 shows that there is no constant relationship between the size of a network and the number of staff employed. The ratio of numbers of staff to sites varies between 0.5 and 3.5.

Table 4.2 shows the compounds routinely measured and the number of monitoring instruments available in each of the participating cities. All of these cities are currently (or have recently) making measurements of particulate matter in some form; all but two cities have made recent measurements of sulphur dioxide (SO_2). Only 45 and 50 per cent of cities in the study monitor for ozone (O_3) and carbon monoxide (CO); cities measuring these gases are usually those with the most developed -usually continuous- networks. Monitoring for nitrogen dioxide (NO_2) is more widespread; with 80 per cent of participating cities making routine measurements. Lead (Pb), by comparison, is monitored in only 60 per cent of the cities studied here and measurements have been discontinued in a number of cities when continuous monitors were introduced. In a number of these cities the decline in lead monitoring approximately coincided with the introduction of lead-free petrol and a consequent considerable reduction in lead emissions (and a view that lead pollution is no longer an important air pollution problem).

The number of monitoring instruments is included in Table 4.2 to show the relative importance and extent of monitoring for each pollutant in every city. However, data concerning the number of monitoring instruments in each city must be regarded with considerable caution since these include passive, active and continuous monitoring instruments; hence the large number of instruments to monitor NO_2, SO_2, particulate matter and Pb in Katowice which has made extensive use of passive samplers. The number of active and continuous monitoring instruments is also shown graphically in Figure 4.2. This Figure clearly emphasises the relative extent of monitoring for different pollutants in the cities participating in this study and it is probably a good indication of the relative extent of such monitoring worldwide.

The number of passive, active and continuous monitoring instruments in each city is shown in Table 4.3. A notable feature of this table is the number of cities with continuous monitoring networks but with no active or passive sampling. Although continuous monitors are able to meet almost all the objectives of a network it is relatively costly to operate sufficient continuous monitors to obtain good spatial resolution of pollutants across a city. Modelling can be used to predict the distribution of some pollutants across an urban area but few cities have this capacity and, consequently, "hot-spots" of high pollution may easily go unrecognized. Passive samplers offer a cheap,

Figure 4.2 Number of active and continuous monitoring instruments in cities participating in the study

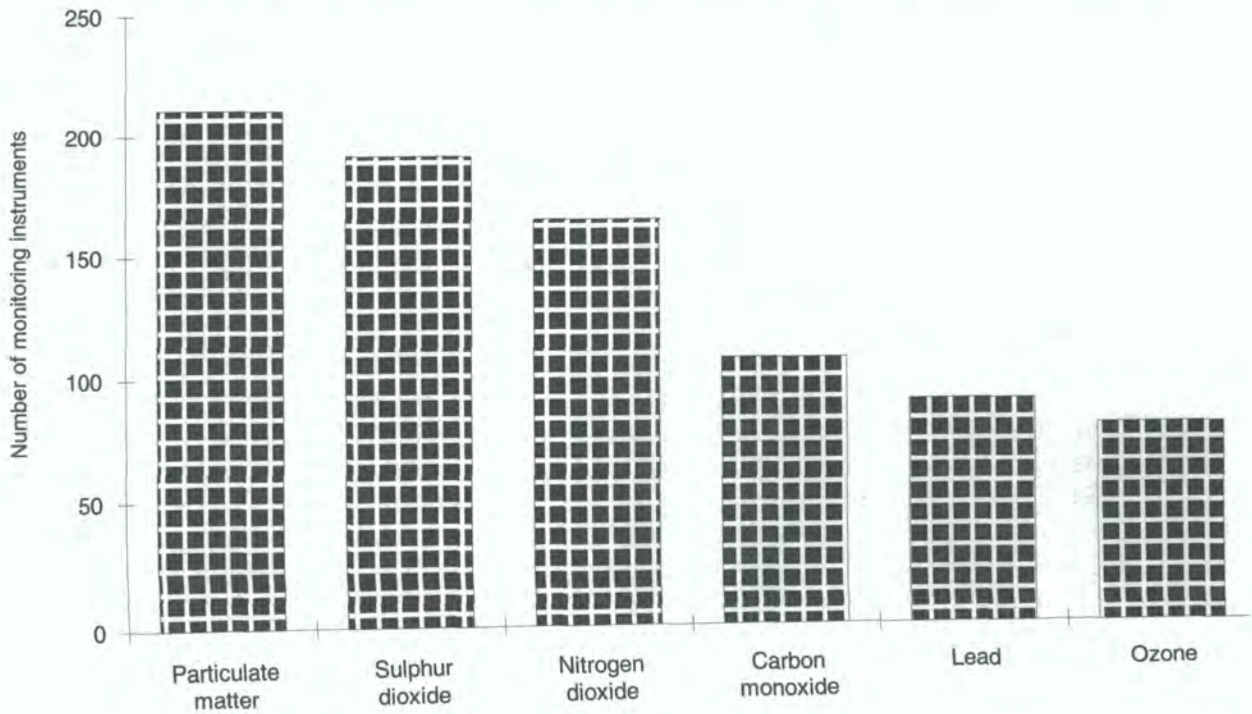


Table 4.3 Number of passive, active and continuous sampling instruments in each city

	NO_2			SO_2			PM			CO			O_3			Pb	
City	**P**	**A**	**C**	**P**	**A**	**C**	**P**	**A**	**C**	**P**	**A**	**C**	**P**	**A**	**C**	**P**	**A**
Alexandria					4			4									
Ankara			2		7				8								
Belo Horizonte					5			7									
Birmingham	20		5			5		6	5			3			3		3
Ekaterinburg		8			8			8			8						7
Hong Kong			9			7		9	9			2			3		9
Hyderabad		3			3			3									3
Johannesburg			1		1			3							1		3
Katowice	228	23	10	228	23	10	740	23	10		8				3	740	23
Kiev		16			16			16				16					16
Lagos								NK									NK
Lahore			1			2		4				1			1		
Madras		8			8			8									3
Nairobi								NK									NK
Pusan			7		20	7			7			7			7		
Quito		3			3		3	3									
Santiago		6	7		6	7	6	13	3			7			7		
Singapore			15			15			15			15			15		
St Petersburg		11			6			10			11						1
Taipei			31			31			42			31			42		22

P — Passive sampler.
A — Active sampler.
C — Continuous analyser.
NK — Not known.

effective and currently under-utilized methodology for a better characterization of the spatial distribution of air pollution in a city. The range of pollutants which can be measured using passive samplers and the accuracy of the results they produce is steadily improving. In particular, diffusive samplers for measuring NO_2 are well established and validated; NO_2 samplers capable of providing daily mean values are now commercially available. Passive samplers represent a cheap and simple methodology, appropriate for most cities, and their use should be investigated by those cities in which they are currently not used.

In many cities where continuous monitoring networks have been established active sampling measurements have been discontinued; resulting in some cases in the suspension of long historical time series. Long trends series provide invaluable information for assessing the impact of, for example, economic development or management strategies on air quality. It is obviously important that these data sets are continued and cities installing continuous monitors should therefore consider how to ensure that this is achieved. Active sampling equipment no longer needed by one city could, if made available, be profitably used elsewhere; for example, by less technologically advanced countries. The closure of active monitoring sites in cities introducing continuous measurements also generates unused active sampling equipment which is appropriate, and much needed technology for other less developed cities. The UNEP/WHO GEMS/Air Network, in conjunction with the USEPA, has now established a twinning programme in order that this equipment can continue to be used in cities with less developed air quality monitoring capacities; supported by technical assistance from the more technologically advanced donor city. It should be stressed that the monitoring methodology used is not necessarily significant, nor, to a lesser extent, is the number of monitoring sites and instruments. The capacity to generate data able to meet the objectives of the network and data needs for air quality management and public information are the only significant requirements of a monitoring programme.

The characterization of particulate matter is fundamentally dependent on the particular methodology adopted to conduct the measurement. Traditionally, in many countries, the measurement made has been of black smoke (in which the soiling capacity of air measured by reflectance is compared with a standard black smoke mixture). Another traditional method has been to measure total suspended particulate matter (TSP), also known as suspended particulate matter (SPM), using a high-volume sampler. There is now growing awareness that only particulate matter that can be deposited in the lungs can affect health and, consequently, PM_{10} (the mass fraction of particles collected by a sampler with a 50 per cent inlet cut-off at an aerodynamic diameter 10 μm) is now being increasingly used as the measure of particulate matter. Particulate matter less than 10 μm closely approximates to the ISO thoracic convention (the mass fraction of inhaled particles which penetrates beyond the larynx) (UNEP/WHO, 1994). The particulate monitoring methodologies adopted in the cities participating in this study are shown in Table 4.4; they demonstrate this wide range of techniques.

In the past it has only been possible to measure particulate matter using active sampling devices, but new state-of-the-art instruments adopt a range of techniques making continuous measurements now possible. The most common monitored fraction of particulate matter is still TSP – predominantly using high volume samplers. Particulate matter less than 10μm is measured in 45 per cent of the cities in the study using a range of techniques. Two cities – Birmingham and Santiago – are now also making measurements of $PM_{2.5}$, which are a smaller size fraction than PM_{10} and penetrate deep into the lungs more effectively than PM_{10}. Consequently, concentrations of $PM_{2.5}$ particles have been proposed as being more closely related to health effects.

Quality assurance and control

The absolute quality and representativeness of the data produced by a monitoring network is unimportant, as long as it is known and able to meet the objectives prescribed for the network. However, few cities stipulate numerical data quality objectives for their monitoring data; many do not perform site audits to ascertain whether these are being met or to ensure the accuracy and precision of the measurements made. Consequently, there is very little quantitative information available to ascertain whether the data produced by monitoring in a city are useful for air quality management or for the other applications for which they are intended. Without performing technical site reviews or audits (beyond the resources of this study) it is, therefore, extremely difficult to determine the quality of monitoring data in the participating cities. Data quality has, therefore, been assessed on the basis of the quality assurance and control procedures adopted and reported to be followed by the participating cities; it has not been possible to verify all this information independently.

Quality assurance and control procedures adopted in participating cities are summarized in Table 4.5. Where more than one network operates in a city, quality control and assurance procedures often vary

Table 4.4 Particulate matter monitoring methodologies

City	Dustfall	Black smoke	TSP	PM_{10}	$PM_{2.5}$
Alexandria			HVS		
Ankara				β-atten	
Belo Horizonte			HVS		
Birmingham		REF	LVS	TEOM	TEOM
Ekaterinburg			LVS		
Hong Kong			HVS	TEOM	
Hyderabad			HVS	LVS	
Johannesburg			LVS		
Katowice	(used)	REF		TEOM HVS	
Kiev			HVS		
Lagos	(used)		LVS		
Lahore			HVS		
Madras			HVS	LVS	
Nairobi			LVS		
Pusan			β-atten		
Quito	(used)	REF	HVS		
Santiago	(used)		HVS	DS β-atten TEOM	DS TEOM
Singapore		REF	HVS	β-atten	
St Petersburg			LVS		
Taipei				β–atten	

Shaded – Methodology used.
Unshaded – Methodology not used.
REF – Reflectance.
TMS – Transmission.
β-atten – β–attenuation.
TEOM – Tapered element oscillating micro-balance.
LVS – Low volume sampler.
HVS – High volume sampler.
DS – Dichotomous sampler.
TSP – Total suspended particulate matter / Suspended particulate matter.

Table 4.5 Quality assurance and control procedures followed

City	Calibrations and flow checks	Annual site review	Data validation	Five yearly site reviews	Inter-network comparison
Alexandria	■	□	□	□	NA
Ankara	■	■	■	■	□
Belo Horizonte	□	□	□	■	□
Birmingham	■	■	■	■	■
Ekaterinburg	■	■	■	■	□
Hong Kong	■	■	■	■	NA
Hyderabad	■	□	■	■	□
Johannesburg	■	■	□	□	NA
Katowice	■	■	■	■	■
Kiev	■	■	■	■	NA
Lagos	■	NA	■	NA	NA
Lahore	■	□	■	□	□
Madras	■	□	■	■	□
Nairobi	■	NA	■	NA	NA
Pusan	■	■	■	■	□
Quito	□	□	■	□	□
Santiago	■	■	■	□	□
Singapore	■	■	■	■	NA
St Petersburg	■	■	■	■	□
Taipei	■	□	■	■	□

■ Procedure conducted.

□ Procedure not conducted.

NA Not applicable (either no or only one monitoring network).

between networks, particularly if these are operated by different agencies. It is, therefore, difficult to make comparisons between the data produced. In Table 4.5, where more than one network exists in a city, the procedures adopted by the network with the most comprehensive quality control and assurance has been considered, This, therefore, represents a slightly positively biased picture of data quality in some of the cities. Table 4.5 indicates that 90 per cent of participating cities perform some form of calibration and flow check. This is clearly encouraging as, although this is no guarantee of producing data of acceptable, known quality, it clearly represents a desire and capacity to achieve this. Eighty-five per cent of cities report validation of data once it has been generated; although the procedures by which this is actually performed – and probably the accuracy – varies considerably between cities and even networks within the same city. Fifty-five per cent of cities report that they conduct annual site reviews or audits to check the performance of different sites in their monitoring network(s). Those cities that do not conduct annual site reviews cannot be certain of data quality and should endeavour to develop and implement new procedures to conduct such reviews. In order to assist GEMS/AIR participants WHO/UNEP are producing a guidance handbook on collaborative and internal site reviews (WHO/UNEP, in press). Thirteen of the 18 cities with established monitoring networks check the location of each site at least every five years to ensure that they are still acceptable and meet the objectives of the network. Few of the participating cities are able to check the performance of the instruments in their networks with those of other networks since there is generally only one network in each city; few cities compare measurements with one another. Inter-comparison exercises of this type are extremely valuable for identifying problems in procedures or equipment. Laboratory inter-comparisons have been performed as part of the GEMS/Air network for SO_2 (Hanssen, 1994).

Measurement capability index

A quantitative assessment of the monitoring capability of the cities participating in the study is provided by the management capability index developed in Chapter 3 and described in detail in Appendix D. An outline of the index is provided (Box 4.1), followed by the measurement index scores for the participating cities. The city scores for the other components of capability are presented in subsequent sections; the overall index scores are presented in the conclusion to this chapter.

The index scores for air quality measurement capability for each city are shown in Figure 4.3. This demonstrates that six cities were classified by the index as having excellent measurement capabilities; six were

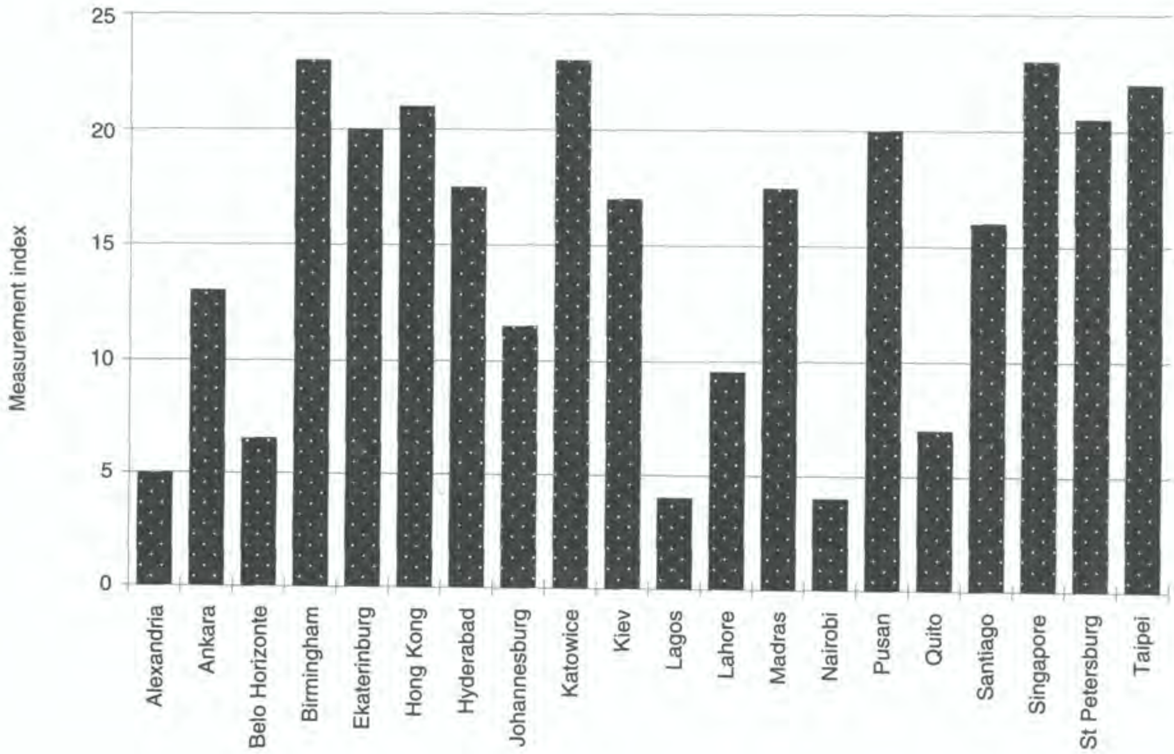


Figure 4.3 Air quality measurement index

Box 4.1 Monitoring Capability Index

The index has been developed to quantify monitoring capability and has two principal benefits over other assessment techniques:

1. It presents information in a readily accessible format to the public and non-experts in order to broaden the base of understanding and clearly identify strengths and weaknesses in cities monitoring capabilities.

2. The index can be used quantitatively to determine the association between monitoring capability and other indicators, such as those of socio-economic status.

The index, therefore, assists cities, national government and international agencies charged with developing capacity to enable the most effective targeting of resources.

Four indices have been developed and calculated corresponding to the four main components of monitoring capability. An overall capability has also been calculated by combining the scores of each component. The four component indices are the capability to:

1. Measure ambient air quality;

2. Assess and make air quality data available;

3. Estimate emissions for different source categories and pollutants and apply and disseminate the information;

4. Apply and develop air quality management tools with which to interpret the information, formulate and implement policy.

Each component comprises of a series of indicator questions (Appendix D). Each indicator which is met demonstrates a level of capability and contributing points towards each component index score. Each component index is worth a maximum of 25 points and the capability of the city is assessed according to the number of points achieved. The four component indices are also combined to give an overall capability score out of 100. The quantitative scores obtained can also be converted into qualitative classifications of capability as shown below.

Capability Index: Qualitative Classifications

Effectiveness	Component index score (25)	Overall capability index score (100)
Minimal	0–5	0–20
Limited	6–10	21–40
Moderate	11–15	41–60
Good	16–20	61–80
Excellent	21–25	81–100

good, two were moderate, three were limited and three were minimal. This is consistent with the more detailed assessment presented in Tables 4.1 to 4.5 and indicates that the index is reliable and accurate. Although more than half of the cities participating in this study have monitoring networks classified as excellent or good, this is unlikely to be representative of cities globally. The voluntary nature of participation in the study is likely to have resulted in an unavoidable bias because, for the most part, cities with good management capabilities have contributed the required information.

The criterion used in designing the indicators questions which comprise the index was the minimum capability required to generate information useful for air quality management. Scores below the maximum (25), therefore, represent gaps in the information ideally required by decision makers in formulating and implementing management strategies; an excellent rating indicates that these information gaps are very small.

Data Assessment and Dissemination

Data analysis

Producing data of known quality that are adequate for their intended use is a waste of resources unless these data are assessed and utilized in order to meet the objectives of the monitoring network. Furthermore, it is essential that the data, once validated and assessed, are then widely disseminated in appropriate formats to those decision makers with responsibility for maintaining or attaining acceptable air quality. It is also useful to disseminate this data to independent experts and the general public. Widespread access to data and information enables the provision of a broad range of inputs to the decision-making process and encourages transparent decision-making.

Table 4.6 shows the assessments which are carried out on air quality data in each of the participating cities. This table demonstrates that simple data analysis procedures, such as the production of mean and maximum values, are performed in all cities participating in our study. In all the cities with established monitoring networks, except Lahore, trends in pollutant concentrations and the frequency of exceedances of national air quality standards or WHO Guidelines are also derived. These data assessments are straightforward to conduct; where an analytical procedure is more complex it is performed less commonly. Of the participating cities, 55 per cent determine percentile values and map the spatial distribution of pollution; although published evidence of the results of these assessments are not always available. Only 25 per cent of the cities in the study report any epidemiological studies being performed. Similarly, only 25 per cent attempt to forecast episodes of air pollution: which would enable them to take preventative action to reduce emissions. More sophisticated data treatment provides appreciably enhanced value to air quality data, however, in many countries there is a stronger emphasis on producing air quality measurements than there is on the optimum use of this data. More complex data treatments significantly demand more reliable data to produce accurate, meaningful results. The relationship between measurement capability and that of data assessment and dissemination is examined in more detail using the management capability index at the end of this section.

Computers are now widely used in the analysis of air quality data; 80 per cent of the cities in the study use computers for data analysis. Those cities in which computers are still not used – St Petersburg and Ekaterinburg in the Russian Federation, Quito and Belo Horizonte in South America – are not, however, those cities with the most limited capacity in the measurement of ambient air quality. Use of computers is perhaps more a function of the availability of computer hardware (and probably foreign exchange) than of the extent of monitoring and data analysis.

Data dissemination

The mechanisms by which data are disseminated are shown in Table 4.7. In all the cities participating in this study air quality monitoring data are available through internal reports. In three quarters of these cities data are formally published; although in some countries the numbers of report copies produced are very limited and publications are not easy to obtain. Information on the levels of pollution are released through the media in over half of the cities in this study (55 per cent). However, only six of these cities issue air quality alerts during periods of poor air quality. Acute exposure to pollutants such as SO_2, particulate matter, NO_2, CO and O_3 are known to affect health, particularly that of sensitive individuals with respiratory or cardiovascular illness; public awareness of poor air quality can

Table 4.6 Air quality assessments

City	Simple statistics	Percentiles	Compliance	Trends	Mapping	Prediction modelling	Health studies
Alexandria	■		■	■			
Ankara	■		■	■			■
Belo Horizonte	■		■	■			
Birmingham	■	■	■	■	■	■	■
Ekaterinburg	■	■	■	■	■		
Hong Kong	■	■	■	■	■		
Hyderabad	■	■	■	■	■		
Johannesburg	■		■	■			
Katowice	■	■	■	■	■		
Kiev	■	■	■	■	■	■	
Lagos	■						■
Lahore	■						
Madras	■	■	■	■	■		
Nairobi	■						
Pusan	■	■	■	■	■	■	
Quito	■		■	■			
Santiago	■	■	■	■	■	■	■
Singapore	■	■	■	■	■	■	
St Petersburg	■	■	■	■	■		
Taipei	■		■	■			■

■ Assessment conducted.

□ Assessment not conducted.

enable people to take simple measures to reduce their exposure and hence risk. Public exposure reduction measures include: advising people at risk to remain indoors, to desist from exercise and to increase preventative and alleviating medication. The issuing of advice to sensitive individuals during periods of poor air quality can directly reduce the consequences of pollution episodes on health without affecting the actual levels of pollution; they represent a significant management capability.

The issuing of air pollution alerts can also enable voluntary or enforced emissions controls to be used as a remedial tool to improve air quality. The identification or, ideally, forecasting of an air pollution episode in order for an alert to be issued, requires advanced management capabilities – which explains why relatively few cities in this study (six) have established such procedures. With automated monitoring equipment, an air quality alert can be issued relatively easily when the concentration of pollution exceeds a specified level. It is, however, important that data quality is good and, in particular, that immediate data validation procedures exist and are reliable. Air pollution episodes are associated with specific meteorological conditions that result in poor pollution dispersion (temperature inversions, low wind speeds, anti-cyclonic conditions, etc.). As weather conditions are predictable so, therefore, are air pollution episodes by deriving the relationship between meteorology and air quality through modelling. Uncertainties in such models can,

Table 4.7 Data dissemination

City	Internal reports	Published reports	Reported in the media	Air quality alerts issued	Electronic data communication
Alexandria	■				
Ankara	■	■	■	■	
Belo Horizonte	■				
Birmingham	■	■	■	■	■
Ekaterinburg	■	■	■		
Hong Kong	■	■	■	(a)	■
Hyderabad	■	■			
Johannesburg	■				
Katowice	■	■			■
Kiev	■		■	■	
Lagos	■	■			
Lahore	■	■	■		
Madras	■	■			
Nairobi	■	■			
Pusan	■	■	■		■
Quito	■				
Santiago	■	■	■	■	
Singapore	■	■	■	■	
St Petersburg	■	■	■		
Taipei	■	■	■	■	

■ Air quality information available.

□ Air quality information not available.

NA Not applicable (no monitoring network).

(a) Air quality alerts now issued (EPD, 1996).

however, be substantial, particularly in cities with complex topography. Limited modelling capabilities and the fact that accurate predictions cannot always be guaranteed means that few cities currently forecast pollution episodes. Furthermore, many of these cities would require additional emissions controls to be introduced if such forecasts suggested that an acute episode is imminent. Additional emission controls imposed during episodes can cause substantial disruption to transport and reduce industrial competitiveness and output. Currently, few city authorities are sufficiently confident of their predictions to effect such measures even for a few days.

In cities with active sampling equipment (which do not produce continuous measurements) the problems of identifying and predicting pollution episodes are even more difficult. Rising pollution levels cannot be instantaneously detected as determination of the elevated concentrations is not known until at least after the sample has been collected and analysed. It is nevertheless possible to derive simple relationships between daily air quality and meteorological measurements which enable a city to identify the climatic conditions under which pollution is likely to be significantly elevated. The uncertainties in relying on daily monitoring data to predict air quality are, however, substantially greater than using continuous measurements linked to dispersion models. Nevertheless, it is still possible to issue warnings to enable sensitive individuals to take alleviating action and to require addition emissions controls.

It is clear from this study that access to air quality information is improving, but still rather unsophisticated in most cities; most remain reliant on printed annual summary reports. On-line electronic access to air quality data bases is still very rare in the cities participating in this study; only four have this capability despite the fact that fully automated monitoring stations operate in eight of the participating cities. Similarly, information boards in city centres are not widely used; where they are they do not always provide advice on interpreting air quality data and on the actions that members of the public should take to reduce their exposure and emissions. In a number of cities the air quality monitoring data being produced could be used far more extensively; access to this information could also be made simpler.

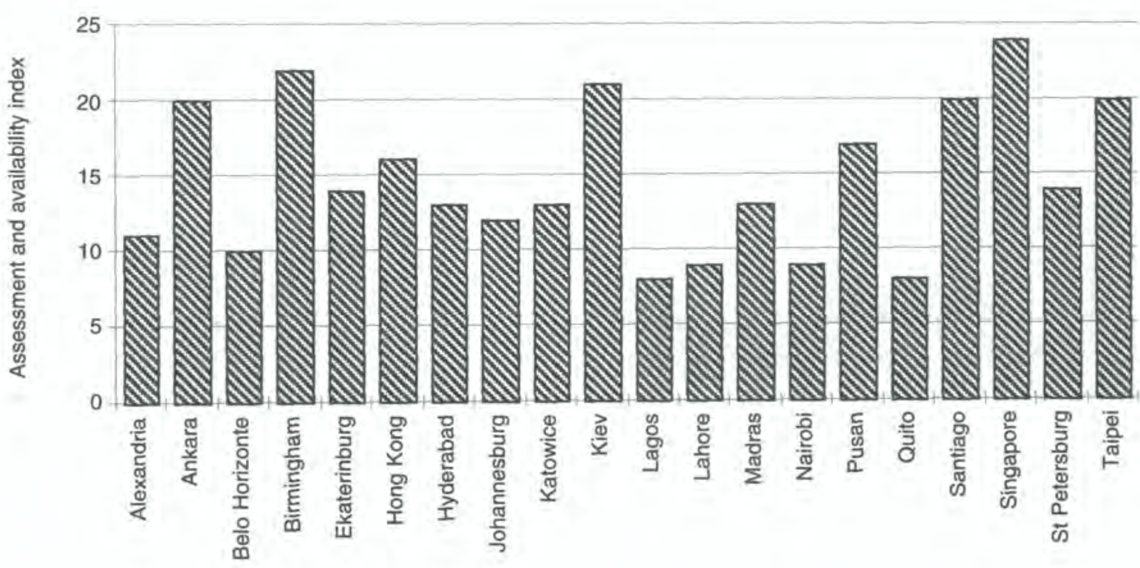


Figure 4.4 Air quality assessment and availability index scores

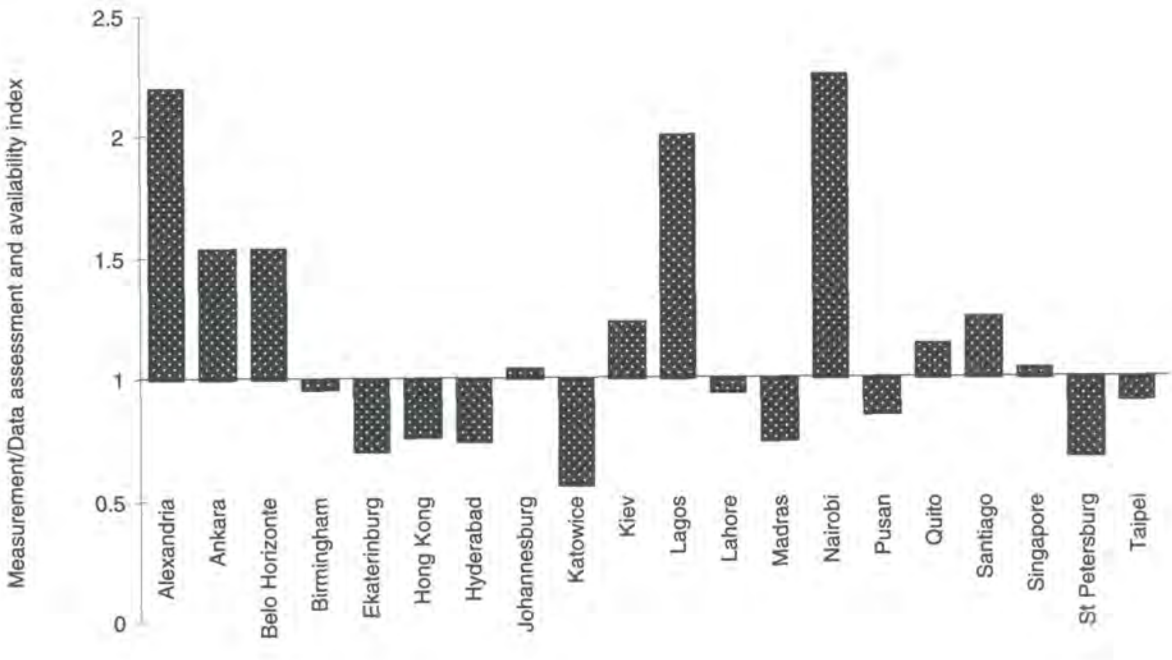


Figure 4.5 Ratio data assessment and availability to measurement indices

Figure 4.4 shows the city scores for the data assessment and availability index (see Box 4.1 and Chapter 3). The scores for this index were generally lower than those for the capability to measure ambient pollution. Only three cities make sufficient use of air quality data to be categorized as excellent; five are good, seven moderate and five limited. No cities scored below five points; none, therefore, had a minimal capability to perform data assessments and disseminate data.

Cities with good measurement capability index scores performed relatively less well in the data assessment and availability index; while those cities with very limited monitoring networks were generally found to make relatively good use of the little data available to them. The ratio of the measurement and data assessment and availability indexes for each city are shown in Figure 4.5 which clearly illustrates this point. The cities in the Russian Federation and India, as well as Katowice, are those which could make appreciably better use of their data. The cities of Lagos and Nairobi, which do not have formal monitoring networks but have university departments which have conducted some measurements, make particularly good use of the data obtained; as does Alexandria.

There could be a number of reasons for the different performances of cities in assessing and making available air quality data; for example, lack of staff, the absence of expertise and facilities (although computers are widely available for data analysis), or the absence of demand for the information generated. Air quality monitoring is an expensive exercise, particularly if the data which are generated are not used to their maximum potential.

Emissions Inventories

The production of emissions estimates through the compilation of an emissions inventory is a crucial component of air quality management capability. Quantification of pollutant emissions enables better targeting of emissions controls on major sources and source categories. It also enables the determination of the spatial distribution of emissions across the city and the identification of hot-spots of poor air quality. Table 4.8 shows the major source divisions -industrial, mobile and domestic/commercial- for which emissions estimates have been derived by each of the cities participating in this study.

Only 55 per cent of the cities in this study have made any estimates of the contribution of emissions from industrial and mobile sources and only seven cities have made estimates of emissions from domestic and commercial buildings. Among the cities in this study there is considerably less capability to estimate emissions than to measure air quality. Table 4.9 shows the pollutants for which emissions estimates have been derived in those cities with inventories.

Table 4.9 demonstrates that in the cities where emissions estimates have been derived the procedure has been performed for a wide range of pollutants.This is somewhat surprising since the information required to construct emissions inventories for different pollutants is quite different (see Chapter 2). Sulphur dioxide emissions result predominantly from coal and heavy fuel oil burning and can be estimated from the sulphur content of these fuels minus that which is retained in ash and by any emissions control equipment. Nitrogen dioxide estimates require knowledge of comb ustion conditions; as do estimates of carbon monoxide. Estimation of VOC emissions require quite different information as a large proportion of VOC emissions originate from non-combustion processes. Therefore, Table 4.9 suggests that either very comprehensive inventories have been derived in the cities, or that some of the emissions estimates in these cities have uncertain degrees of accuracy.

Table 4.8 Emissions estimates for major source categories

City	Industrial	Mobile	Domestic/Commercial
Alexandria	□	□	□
Ankara	□	■	■
Belo Horizonte	□	□	□
Birmingham[1]	■	■	■
Ekaterinburg	■	■	□
Hong Kong	■	■	■
Hyderabad	□	□	□
Johannesburg	□	□	□
Katowice	■	□	■
Kiev	■	■	□
Lagos	□	□	□
Lahore	■	■	□
Madras	□	□	□
Nairobi	□	□	□
Pusan	■	■	■
Quito	■	■	□
Santiago	■	■	■
Singapore	□	□	□
St Petersburg	■	■	□
Taipei	■	■	■

■ Emissions estimates available

□ Emissions estimates not available

(1) The Birmingham inventory is due to be published in 1995

Table 4.9 Pollutants for which emissions estimates have been derived

City	NO_2	SO_2	PM	CO	Pb	HC
Ankara	■	■	■	■	□	■
Birmingham[1]	■	■	□	□	□	□
Ekaterinburg	■	■	■	■	■	■
Hong Kong	■	■	■	■	■	■
Katowice	■	■	■	■	■	■
Kiev	■	■	■	■	■	■
Lahore	■	■	■	■	□	■
Pusan	■	■	■	■	■	■
Quito	■	■	■	■	■	■
Santiago	■	■	■	■	■	■
St Petersburg	■	■	■	■	■	■
Taipei	■	■	■	■	■	■

■ Emission estimate derived.

□ *Emission estimate not derived.*

(1) The Birmingham inventory is due to be published in 1995.

Table 4.10 suggests that the degree of certainty in the emissions estimates derived by cities is very variable. Only 58 per cent of the cities in this study which have estimates of emissions actually measured emissions; a similar percentage included non-combustion sources (VOC estimates, must also be considered with great uncertainty). Only 42 per cent of the cities with emissions estimates validated their results and published their findings in full. Unvalidated emissions inventories are equivalent to monitoring data with no quality control and assurance. They likewise produce data of unknown quality and value. It has not been possible for this study to determine the reliability of the emissions estimates produced by cities. It is important that the emissions information produced is decision relevant; this requires a minimum level of certainty. The findings of this study are that 40 per cent of these cities have no quantified emissions estimates and that the estimates derived in some of these participating cities may not be useful. The consequence of these findings for cities developing air quality management strategies is that emissions controls may be targeted inappropriately; resulting in ineffective management and a waste of resources. The apparently limited capacity of many cities to estimate emissions is quantified by the emissions estimates capabilities index (see Box 4.1, Chapter 3 and Appendix D) in which many cities achieve low scores; as shown in Figure 4.6. Using the index: nine cities have minimal capability, one limited, three moderate, six good and one excellent. In many cities there is, therefore, a major deficiency in the information available for the development of air quality management strategies.

Table 4.10 Emissions estimates validity and availability

City	Non-combustion sources	Based on some measurement	Validated	Published in full
Ankara				[shaded]
Birmingham(1)	[shaded]	[shaded]	[shaded]	[shaded]
Ekaterinburg	[shaded]	[shaded]	[shaded]	
Hong Kong		[shaded]		
Katowice		[shaded]		
Kiev	[shaded]	[shaded]		
Lahore				
Pusan	[shaded]		[shaded]	[shaded]
Quito				
Santiago	[shaded]		[shaded]	[shaded]
St Petersburg	[shaded]	[shaded]		
Taipei	[shaded]	[shaded]	[shaded]	[shaded]

[shaded] Procedure conducted.

[unshaded] Procedure not conducted.

(1) The Birmingham inventory is due to be published in 1995.

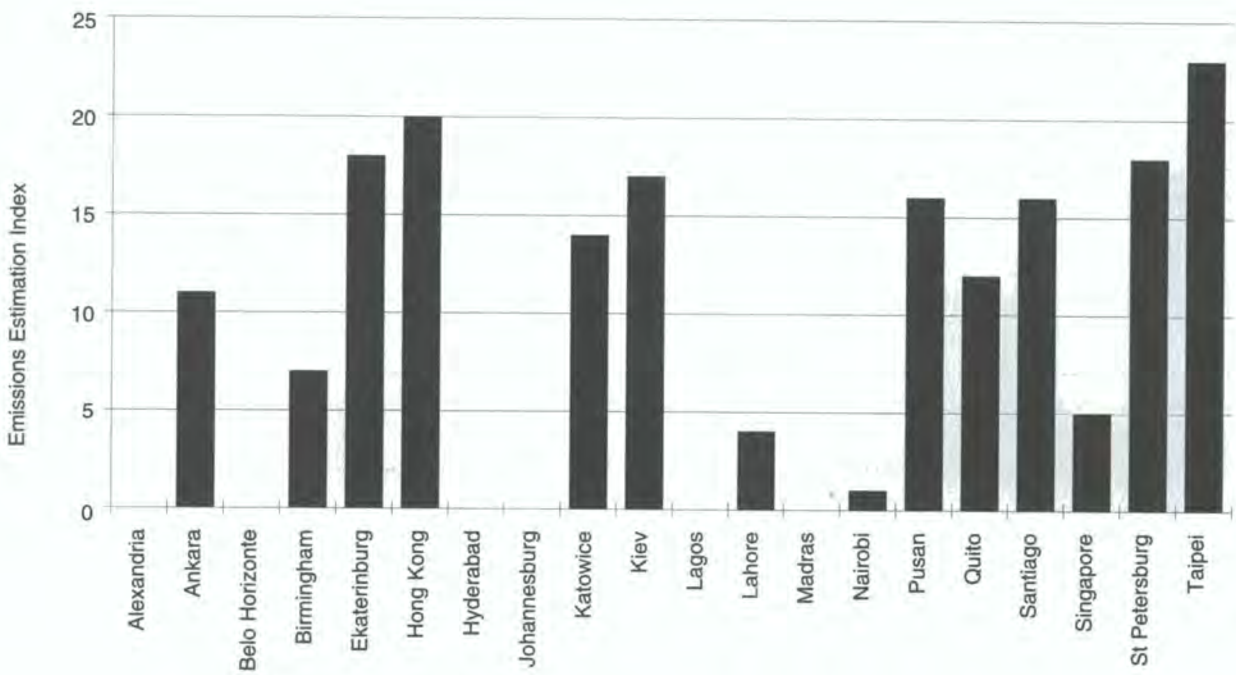


Figure 4.6 Emissions estimation capability

Air Quality Management Tools

Air quality standards

In order to assess whether it is necessary to adopt any emissions controls in a city, it is important to determine what is considered to be acceptable air quality. Once this has been established, it is equally necessary to assess whether this level is being exceeded. National ambient air quality standards to assess the acceptability of air quality are used widely; this is reflected in Table 4.11. Among the cities participating in this study only Pakistan and Kenya have currently not established ambient air quality standards; however, both of these countries have plans to do so in the future. To date, most countries have set standards for a wide range of pollutants to reflect both acute and chronic health effects of exposure (details of which are provided in the city chapters). However, the application of standards as an air quality management tool is not nearly as widespread as the presence of standards: only half the cities that have standards require that these are complied with, or take actions in order to ensure that exceedances do not routinely occur. It is evident, therefore, that in many cities there is a general absence of effective legislation or mechanisms to ensure that standards are achieved.

Emissions monitoring and control

The formulation of an air quality management strategy usually includes the introduction of emissions limits on point and/or mobile sources. During the policy implementation phase of an air quality management strategy, there is a need for emissions monitoring to ensure compliance with these limits. Emissions monitoring is, therefore, another important component of management capability. Table 4.12 shows the cities in this study which have imposed emissions controls on the principal emissions source categories, and shows the cities that conduct monitoring – or require monitoring to be conducted – to ensure that these emissions standards are met.

The left and right halves of Table 4.12 show a deficiency in the extent of emissions monitoring conducted,

Table 4.11 Air quality standards

City	Acute	Chronic	Subject to compliance	Future amendments planned
Alexandria				
Ankara	+Guideline	+Guideline		
Belo Horizonte				
Birmingham	+Guideline	+Guideline		
Ekaterinburg				
Hong Kong	Objective	Objective		
Hyderabad				
Johannesburg				
Katowice				
Kiev				
Lagos				
Lahore			NA	
Madras				
Nairobi			NA	
Pusan				
Quito				
Santiago				
Singapore				
St Petersburg				
Taipei				

[shaded box] Air quality standard set/complied with/future amendments planned.

[white box] No air quality standard/not complied with/no future amendments planned.

NA Not applicable (no standard).

An acute standard refers to an averaging time of 24 hours or less; chronic standards 1 month or greater.

relative to the number of cities which have set emissions limits. Four cities have emissions limits for industrial sources but do not conduct emissions measurements to ensure that these are enforced: Belo Horizonte, Lagos, Lahore and Santiago. Eight cities have vehicle exhaust emission regulations, but do not conduct emissions tests: Belo Horizonte, Ekaterinburg, Hyderabad, Katowice, Lagos, Lahore, Madras and St

Petersburg. The effectiveness of emissions limits is greatly reduced unless these are accompanied by an inspection and maintenance programme to ensure that these standards are enforced.

Only five cities have regulations controlling emissions from domestic sources. In one of these – Johannesburg – the controls are not in force in adjacent townships where domestic sources are significant. Domestic emissions are important in a number of the cities participating in this study; where there are significant amounts of solid fuels such as coal, wood and other forms of biomass burned. Control of domestic pollution sources is particularly difficult for a city to tackle; where traditional fuels are usually relatively cheap there is a social inertia towards the adoption of new cleaner

Table 4.12 Emissions limits and emissions monitoring

	Emissions limits and controls				Emissions monitoring		
City	**Industry**	**Cars**	**HGVs**	**Domestic**	**Industry**	**Cars**	**HGVs**
Alexandria							
Ankara		■	■	■	■	■	■
Belo Horizonte	■	■	■				
Birmingham	■	■	■	■	■	■	■
Ekaterinburg	■	■			■		
Hong Kong	■	■	■		■	■	■
Hyderabad	■	■	■		■		
Johannesburg	■		■	■	■		■
Katowice	■	■	■		■		
Kiev	■	■	■		■	■	■
Lagos	■	■	■				
Lahore	■	■	■				
Madras	■	■	■		■		
Nairobi							
Pusan	■	■	■		■	■	■
Quito							
Santiago	■	■	■			■	■
Singapore	■	■	■	■	■	■	■
St Petersburg	■	■			■		
Taipei	■	■	■	■	■	■	■

HGVs Heavy Goods Vehicles.

■ Emission limit set/emissions monitoring conducted.

☐ Emission limit not set/no emissions monitoring conducted.

fuels. In these circumstances the cost of widespread introduction of new fuels can be substantial. The city-specific chapters highlight a number of participating cities which will need to address this important pollution source in order to significantly improve their air quality. Domestic emissions contribute significantly to poor air quality in: the townships surrounding Johannesburg, Madras, Hyderabad, Lagos, Lahore and Nairobi. These cities represent those most economically disadvantaged in this study and, consequently, the least able to initiate the transition to cleaner domestic fuel use. Substantial financial support is likely to be required before substantial improvements in the air quality of these cities can occur.

Figure 4.7 shows the index score for the tools available to assist with air quality management (Box 4.1, Chapter 3 and Appendix D). Three cities have excellent ratings (Birmingham, Kiev and Taipei), six good, seven moderate, two limited and one minimal (Nairobi, where new environmental legislation is currently being drawn up).

The management tools index, and Tables 4.11 and 4.12, demonstrate that many of the cities in this study have introduced some of the management tools required to formulate and implement air quality management strategies but that their application of these tools is less effective. For example, many countries lack the capability to monitor pollutants for which ambient air quality standards have been established; there is also a discrepancy between the number of cities with emissions limits and those conducting emissions monitoring to ensure that these limits are met. Furthermore, in some countries, the appropriateness of the air quality standards and emissions limits set is questionable: this is discussed further in some city chapters. There is clearly a need for greater guidance in the formulation and implementation of air quality management strategies; in addition to capacity building to enhance the development of monitoring, emissions inventories and data assessment. Without developing all the components of air quality management capability it is exceptionally difficult for cities to meet the recommendation of Agenda 21. Support for cities in formulating and applying air quality management tools will, therefore, be required to effectively improve air quality and reduce both its health and environmental consequences.

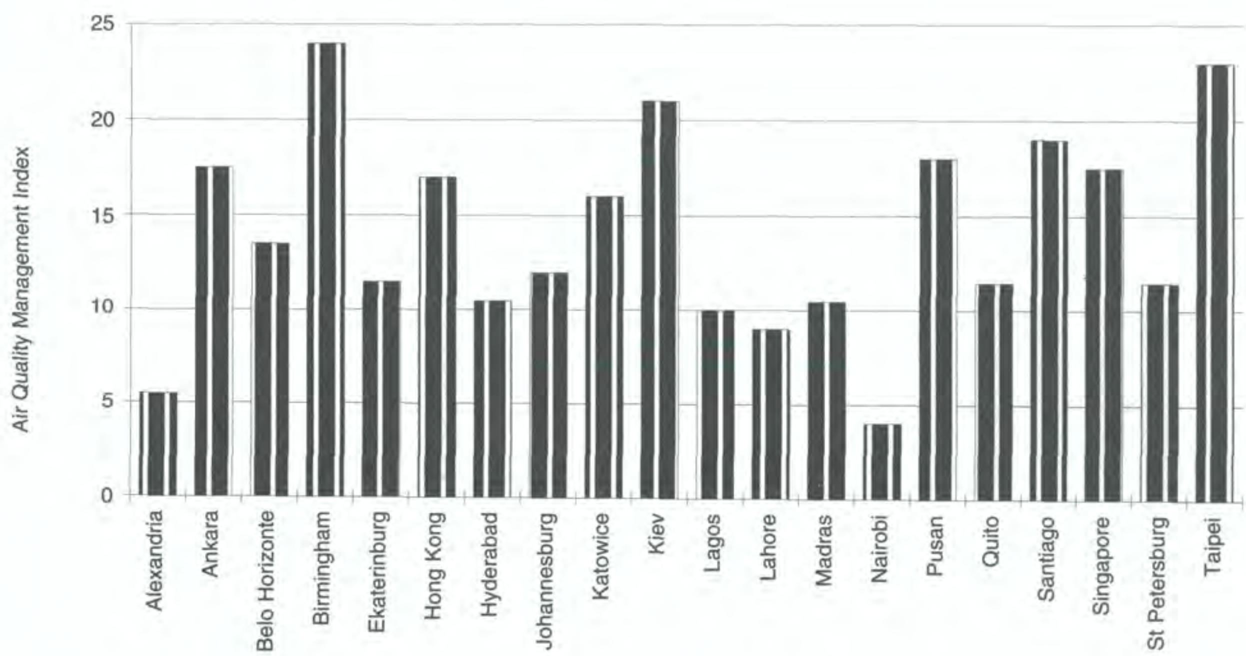


Figure 4.7 Air quality management tools index

Overall Management Capability

By combining the four component index scores of management capability an overall index out of 100 has also been developed. This provides an overview of the capacity of these cities to formulate and implement air quality management strategies. The scores for each city are shown in Figure 4.8; a wide range of scores and corresponding capabilities exist. Only one city – Taipei – achieved an excellent rating. Ten cities were rated with good overall capabilities: Ankara, Birmingham, Ekaterinburg, Hong Kong, Katowice, Kiev, Pusan, Santiago, Singapore and St Petersburg. The two Indian cities of Hyderabad and Madras were rated with moderate capabilities and six cities – Alexandria, Belo Horizonte, Johannesburg, Lagos, Lahore and Quito – have limited capabilities. Only Nairobi has minimal management capabilities according to the scale developed. Overall, the level of capability among all 20 cities averaged 53 points out of 100. By assessing the distribution of overall capability scores using the assessment index (Figure 4.9) it is clear that the capabilities present in the cities participating in this study are unlikely to be representative of all cities of a similar size. The collaborative methodology employed by this study probably means that these cities have above-average capabilities. Participation in this study required city-collaborators to complete a detailed questionnaire and to subsequently review their city-specific chapter. Cities with limited capabilities are less likely to have participated – possibly owing to concerns that to do so may have reflected poorly on them. The skewed nature of the overall participants' capability does not, however, diminish the power of the study since the range of capacities among the participating cities is comprehensive. In attempting to determine global capability a study involving more cities would be essential. Nevertheless, this chapter demonstrates clearly the principal features of the state of global air quality management capability. The range of management capabilities in cities is extremely wide and it is encouraging that in all but one of the participating cities air quality management capability is better than minimal.

The relatively limited capabilities of the four African cities in this study is unsurprising as these rapidly growing metropolises have far more extensive and

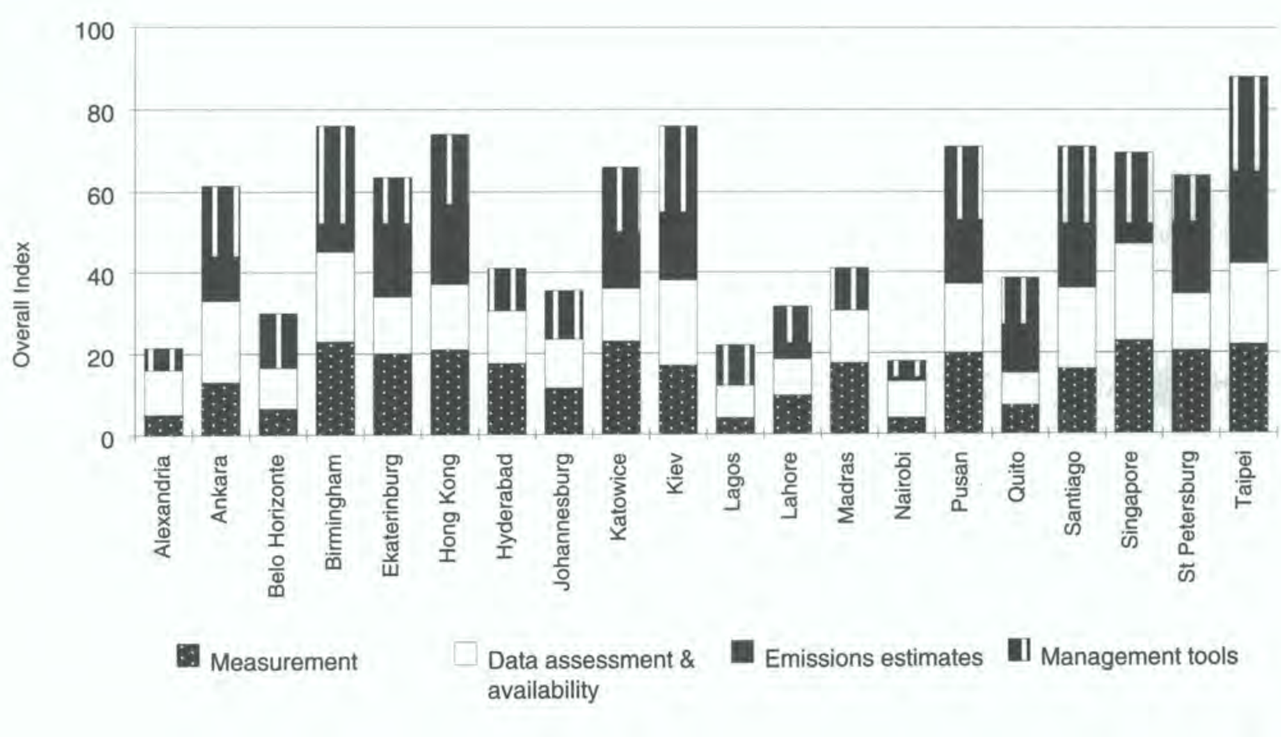


Figure 4.8 Overall air quality management capabilities

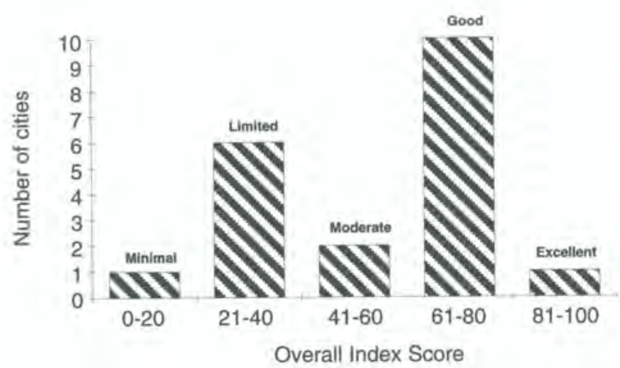


Figure 4.9 Distribution of overall management capability

immediate social, economic and environmental problems than air pollution. It is perhaps understandable that, to date, little emphasis has been placed on air quality management. Air quality management capabilities and improved air quality in these cities clearly, and increasingly, require attention and external assistance. The overall contribution of each component index to the total score is shown in Figure 4.9. Each of the four component indices contribute a quarter of the potential points to the overall index score. However, this is not reflected in the contribution that each index makes to actual city scores. Figure 4.10 shows that an approximately equal contribution to the overall scores of all the cities was made by the measurement, assessment and availability and management tools indices (27–28 per cent); but that only 17 per cent of the total points were contributed through the emissions estimation component index – although there are obviously wide variations between cities as shown in Figure 4.8. This supports the previous assertion that the capacity to estimate emissions is generally much poorer than the other elements of management capability.

The greater capability of cities to measure air quality rather than to estimate emissions, is likely to be due to two reasons:

1. Greater emphasis has been placed by cities on measuring air quality than estimating emissions.

2. The skills required to estimate emissions relative to those required to measure air quality are not available in many countries.

Alternatively, the index could be biased; it could be more difficult to meet the criteria of the indicator questions in the emissions inventory index than those in the ambient air quality measurement index. This is not a likely scenario, however, since Tables 4.9 to 4.11 confirm the generally poor knowledge of emissions in many cities. In order for many cities to develop effective management strategies it is, therefore, necessary to pay special attention to the development of emissions inventories. The GEMS/Air Programme is currently developing software to enable emissions estimates to be calculated by cities with little current information. This software should contribute significantly to the capability of cities to manage their air quality.

The use of an index to quantify management capability enables a number of different relationships to be defined through its application. Figure 4.11(a) shows the relationship between the wealth of a nation and the overall city air quality management capability index score. The wealth of a nation has been measured by Purchasing Power Parities (PPP), which use conversion factors for national currencies instead of exchange rates to measure national wealth per person. Measured in US Dollars, PPP is considered to have greater international comparability than Gross Domestic Product (GDP). The relationship between PPP and management capability is approximately linear (on a logarithmic ordinate scale) – monitoring capability increases with wealth. However, the same plot on a linear scale, shown in Figure 4.11(b), demonstrates a more surprising feature. There is an apparent threshold, at a PPP of about US$7,000 per capita, above which overall management capability does not increase significantly with the wealth of a country. This suggests that, once

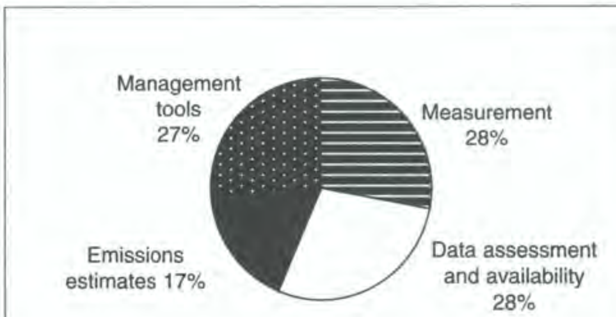


Figure 4.10 Contribution of capability components to the overall totals for all cities

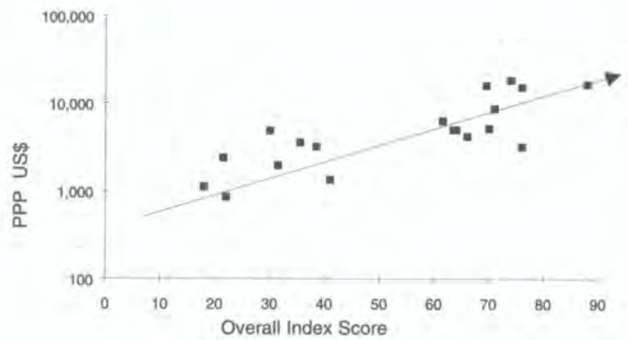


Figure 4.11(a) Effect of national wealth on city management capability (logarithmic scale)

the wealth of a country exceeds about US$7,000 PPP per capita, expenditure on air quality management is no longer dependent on the availability of resources but on other factors; one of which is likely to be air quality. Other factors may concern political will and demands to manage or improve air quality. It should, however, be stressed that the data set is small; these relationships may result from the nature of the index and the type of indicator questions used in its development. Such findings are, at this stage, tentative.

The relationship between the individual component indices of management capability and per capita national wealth varies as is shown in Figure 4.12. The measurement, emissions estimates and management tools indices show the similar linear relationship with

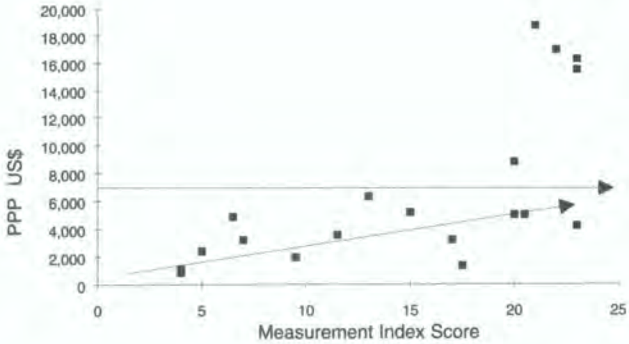


Figure 4.11(b) Effect of national wealth on city management capability

PPP as the overall index score (Figure 4.11). The emissions estimates index relationship has significantly more scatter. The relationship between the data assessment and availability index and PPP is only linear below US$10,000 per capita; anything above this value and the index score is independent of wealth. This suggests that once cities become relatively wealthy the constraining factor, on what data assessment is performed and how data are disseminated, is not likely to be financial. Factors which do influence the performance of wealthier cities in assessing and disseminating air quality data are not certain. The openness of the government is certainly important in the extent to which information is made available. The importance of environmental issues – and air quality in particular – relative to other problems, is also likely to be influential. The reasons for this relationship are undoubtedly city-specific and those cities which perform relatively poorly in assessing and disseminating data relative to their management capabilities (Figure 4.5) should examine whether better use could be made of their air quality data. It should, however, again be stressed that the data sets are small and that the relationships outlined could be due to the character of the assessment and availability index.

Summary

This chapter has drawn together the information supplied by the collaborating cities to provide a global perspective of management capability, and to identify those areas in which there is the greatest lack of capacity both generally and specifically. Only Hong Kong, Kiev, Pusan, Santiago and Taipei have good or excellent scores in every element of management capability. Birmingham will also achieve this distinction once its emissions inventory is completed in 1995. Only Taipei achieved an excellent overall management capability rating. It is apparent that few cities in this study possess all the required capabilities for effective air quality management; most cities do however possess some level of useful capability. The existing capabilities can, in many cases, be augmented without extensive and expensive monitoring hardware; perhaps the most effective route is through training for capacity building. There is a clear need for greater support and guidance from both national and international bodies to support the formulation and implementation of air quality management strategies.

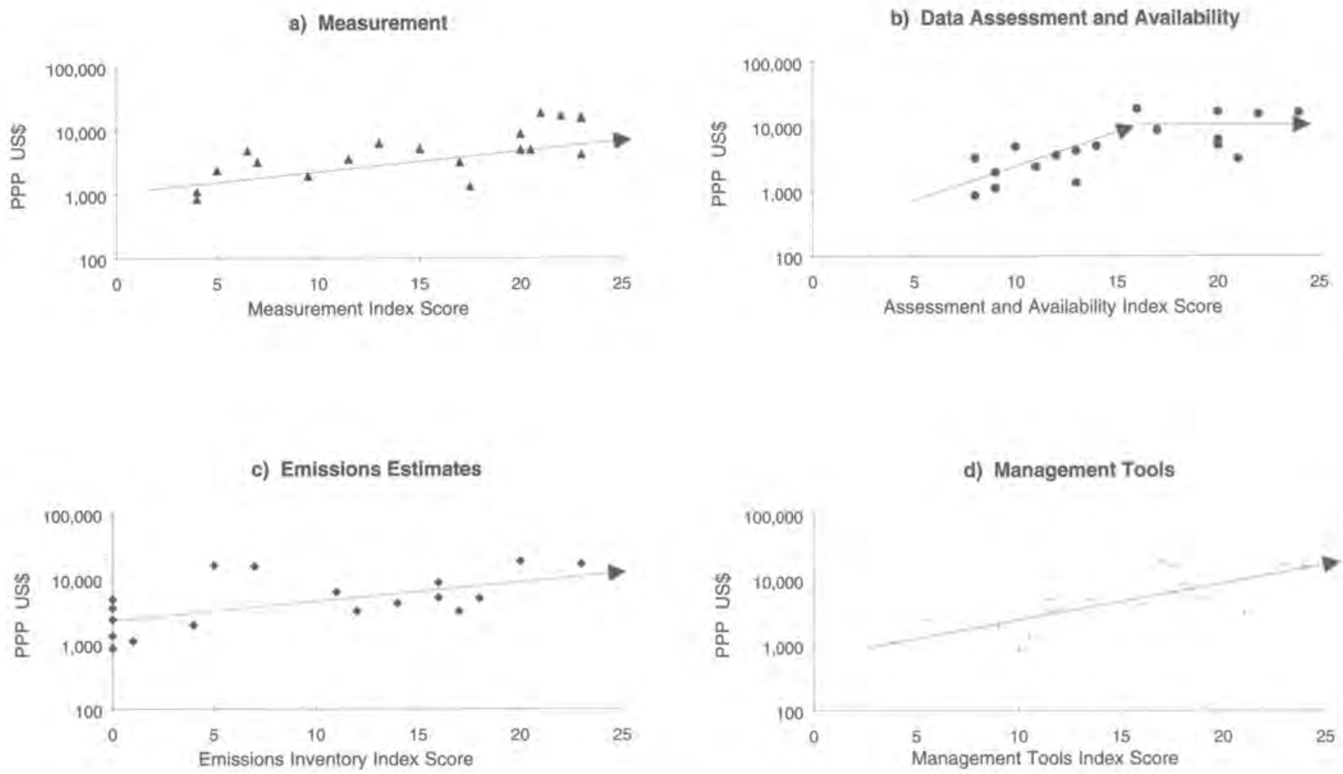


Figure 4.12 Air quality monitoring component indices relationship with national per capita wealth

The overall performance of the cities was as below:

Excellent	Taipei
Good	Ankara, Birmingham, Ekaterinburg, Hong Kong, Katowice, Kiev, Pusan, Santiago, Singapore, St Petersburg.
Moderate	Hyderabad and Madras.
Limited	Alexandria, Belo Horizonte, Johannesburg, Lagos, Lahore and Quito.
Minimal	Nairobi.

The performance of each city with respect to the four component elements of management capability are shown in Figure 4.13 and summarized below:

- Eighty-five per cent of cities in the study have established operational monitoring networks. The most common monitoring objective is to estimate exposure to pollution in the city in order to ascertain likely health effects and measure compliance with air quality standards. Use of air quality information, specifically in the development and implementation of air quality management strategies, is less widespread.

- Monitoring of particulate matter (usually TSP) and SO_2 is the most common monitoring conducted; O_3 is monitored the least. Active sampling techniques were the most widely used methodology, but continuous monitoring instruments are used in half of the cities. Only Birmingham and Katowice made any use of passive samplers for monitoring gaseous pollutants; dust fall was measured in other countries.

- Most cities in this study carry out routine calibration and flow checks to ensure the accuracy of the monitoring data, but less cities formally validate the results obtained and very few have established formal data quality objectives or conduct technical reviews or site audits. For many cities it is therefore difficult to determine the quality of the monitoring data – or whether they are adequate for their intended purpose.

- Assessments carried out on the monitoring data were generally limited to simple statistics, percentiles, trends and exceedances of air quality standards. Very few cities conduct more sophisticated data treatments, such as epidemiological studies, forecasting of pollution episodes and dispersion or exposure modelling (although computers were used for data analysis in 80 per cent of the cities). In general, cities do not make optimum use of the air quality data which are produced.

- Access to air quality information in most cities is available through published reports, usually annual summaries, and via the media in over half the participating cities. Only 6 of the 20 cities in the study, however, issue alerts during periods of poor air quality.

- Generally, estimation of emissions is the most limited component of management capability. Only 60 per cent of the cities participating in this study have calculated any emissions estimates. Furthermore, in most cities in which estimates have been derived, few are validated and most do not include non-combustion sources. In many cities which have constructed emissions estimates these must therefore be considered, particularly for some pollutants, to be first approximations and of unknown quality.

- Air quality standards to define the level of acceptable air quality have been established in all but two of the countries collaborating in this study. Compliance with these standards through remedial emissions control action is required in less than half of these countries and enforced in even less. In a number of cities, standards have been established for which no monitoring is carried out. The application of air quality standards is, therefore, substantially less widespread than their existence.

- The use of emissions controls for industrial and mobile sources of pollution within cities is widespread. But only in significantly less cities is a serious attempt made to ensure that these standards are met. Emissions controls on domestic sources are only implemented in 25 per cent of participating cities; although domestic sources contribute significantly to poor air quality in about half of the cities.

- In many countries there is no single body or ministry with responsibility for maintaining acceptable air quality. This results in a slow and disjointed decision-making process. The presence of effective municipal government supported by national legislation is a feature of those cities with the most developed management capabilities; and, best air quality.

The general picture presented is that very few cities have adequate capabilities to characterize their air quality sufficiently to formulate the most appropriate emission control strategies; but that most cities have some useful capacity to assist with this. Many cities have, or are introducing, strategies to control emissions; generally, however, these are reliant on regulatory emissions limits which are widely ignored owing to the absence of formal emissions monitoring and reporting procedures. Similarly, ambient air quality standards which have been introduced are not widely enforced. The reasons for the absence of a coherent air quality management strategy varies between countries, but is frequently due to five major reasons:

1. The lack of the necessary expertise and capabilities to formulate policies.

2. Low priority given to reducing air pollution when compared with other social and environmental problems.

3. Insufficient financial resources and/or concern over the economic consequences of introducing policies to control emissions.

4. Inadequate political will.

5. An administrative framework in which responsibility for air quality is divided between a number of government ministries and local administrations, thus complicating policy making.

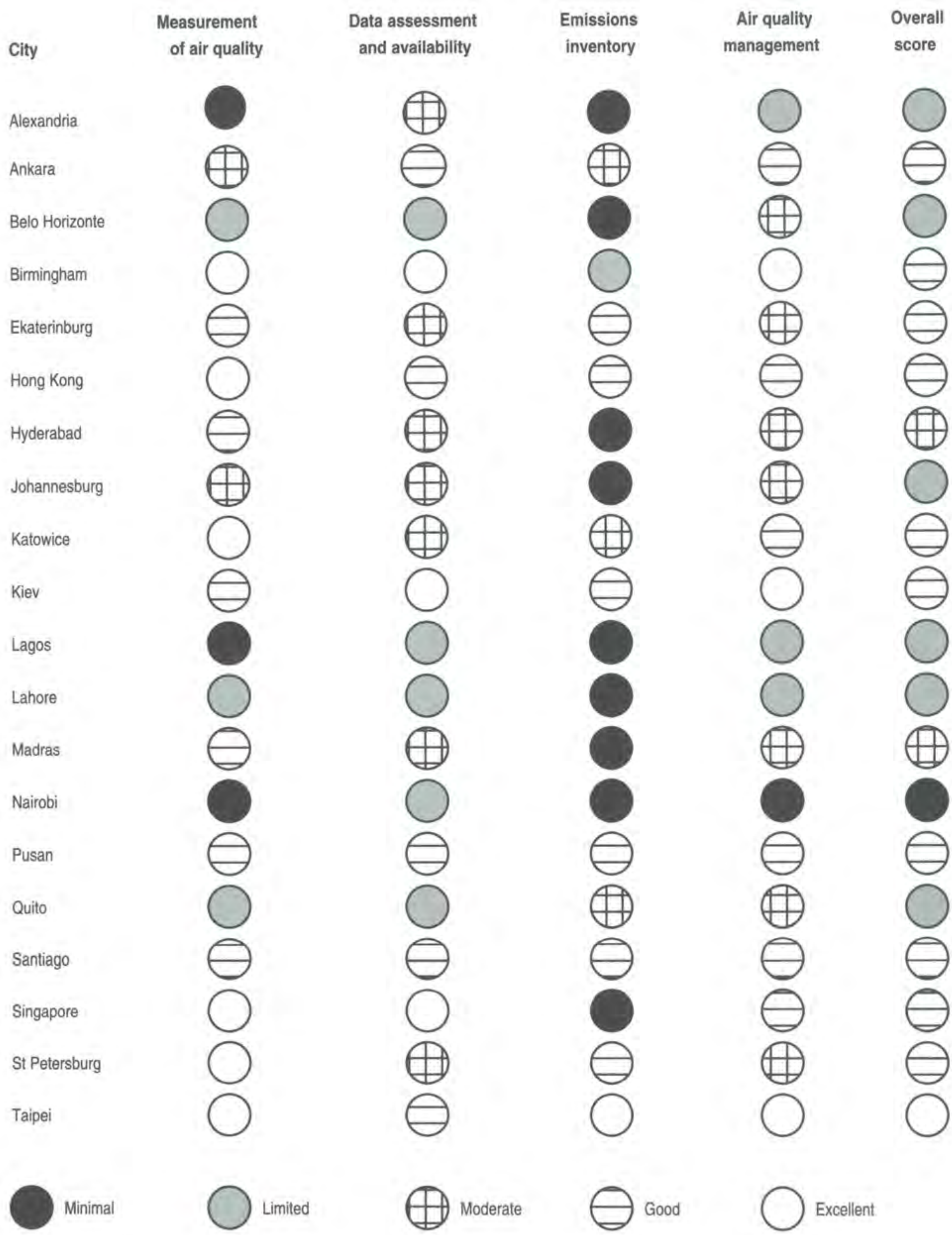


Figure 4.13 City management capabilities

The broad health effects of exposure to polluted air are now known, although the dose–response is more uncertain. Cities in which there is a clear indication that air quality is likely to have significant health implications should urgently be determining the extent of these problems. Where these problems are found to be severe, resources should be made available to develop appropriate air quality management capabilities. The next section of this report examines in detail the management capabilities of the 20 cities participating in this study, and includes comments to assist these cities in most effectively improving their capabilities.

Addendum : *The scores given in this chapter relate to information collected and analysed up to, and including, 1994. Recent information shows that some cities now have increased their management capabilities, and this has been indicated under the individual city headings.*

References

Hanssen, J. E. 1994 *Laboratory Inter-comparison of SO_2 Analysis in GEMS/Air*, Norwegian Institute for Air Research, Kjeller.

UN 1992 *World Urbanization Prospects 1992*, United Nations, New York.

UNEP 1993 *United Nations Environment Programme Environmental Data Repor*t 1993–94, Blackwell Publishers, Oxford.

UNEP/WHO 1993 *GEMS/Air – A Global Programme for Urban Air Quality Monitoring and Assessment*, United Nations Environment Programme, Nairobi.

UNEP/WHO 1994 *GEMS/Air Methodology Review Vol. 3: Measurement of Suspended Particulate Matter in Ambient Air*, UNEP/GEMS/94.A.4, WHO/EOS/94.3, United Nations Environment Programme, Nairobi.

UNEP/WHO *GEMS/Air Methodology Reviews Vol. 5: The GEMS/Air System for Collaborative and Internal Site Reviews*, United Nations Environment Programme, Nairobi. (In press).

United Nations 1993 *Statistical Yearbook 1993*, United Nations, New York.

5

Alexandria

Statistical Summary

Country: Egypt
Estimated population 1990 (millions): 3.28
Projected population 2000 (millions): 4.29
Map reference: 31°15'N, 29°50'E
Area (km²): 104
Altitude (m): 0
Climate: Mediterranean/arid
Average temperature range (C): 9.1–21.4
Annual mean precipitation (mm): 62

Situational Analysis

Alexandria extends as a narrow strip of land a few kilometres wide for about 50 km along the Mediterranean coast of Egypt. It is surrounded by the Western Desert and Agamy hills to the west, Delta Valley to the East and Lake Marrut to the south-east. The western part of the city is predominantly industrial; the central area is mixed commercial, industrial and residential; and, the eastern part is mostly residential with industrial outskirts. The prevailing wind is on-shore from a north-westerly direction; emissions from the industrial sector to the west of the city are therefore regularly blown across the city.

Industrial development in Egypt is concentrated in the major urban centres of Alexandria and Cairo/Giza. Most of Egypt's population live on a very limited part of the country's total land area, most of which is desert. Within the El-Max industrial area in west Alexandria there is a high concentration of petrochemical industries including refineries, sodium chloride, chlorine and sodium carbonate plants. There is also a large iron and steel works and a cement plant, which is a major source of particulate matter. Other major industries include food and drink manufacturing and wood and paper products. Industry predominantly burns kerosene and fuel oils, with some use of natural gas. Electricity in Alexandria is generated by both natural gas and oil burning facilities within the city.

Monitoring for sulphur dioxide (SO_2), smoke and total suspended particulates (TSP) has been conducted in Alexandria since 1984; as part of a national network operated by the Ministry of Health (MoH). In 1990, the highest annual average concentrations of SO_2 and smoke were experienced at the city centre/commercial site: measurements averaged 83 and 33 $\mu g\ m^{-3}$ respectively. The SO_2 value exceeded the World Health Organization (WHO) annual guideline (50 $\mu g\ m^{-3}$) (WHO, 1987) and the Egyptian National Standard (60 $\mu g\ m^{-3}$). The smoke value is below WHO guidelines. The highest daily values for SO_2 were experienced at the site located in the residential area and were 180 $\mu g\ m^{-3}$; this is above the WHO guideline (125 $\mu g\ m^{-3}$) but below the Egyptian Standard (200 $\mu g\ m^{-3}$). Daily smoke concentrations were highest in the residential and commercial/city centre areas, at 228 $\mu g\ m^{-3}$ and 233 $\mu g\ m^{-3}$ respectively; these measures are approximately double the WHO guideline value (125 $\mu g\ m^{-3}$). The annual mean smoke concentrations for each monitoring site in Alexandria are shown in Figure 5.1. The highest annual mean and daily TSP concentrations were recorded at a site located in the industrial area; they were 1,089 $\mu g\ m^{-3}$ and 1,940 $\mu g\ m^{-3}$ respectively (WHO 24-hour guideline is 120 $\mu g\ m^{-3}$). These data indicate that smoke and SO_2 concentrations have reached or exceed WHO guidelines and are therefore potentially harmful to the health of some residents of Alexandria. TSP values are, however, deceptive due to the arid climate and the high concentrations of fugitive desert dust; this is discussed further in the "Comment" section.

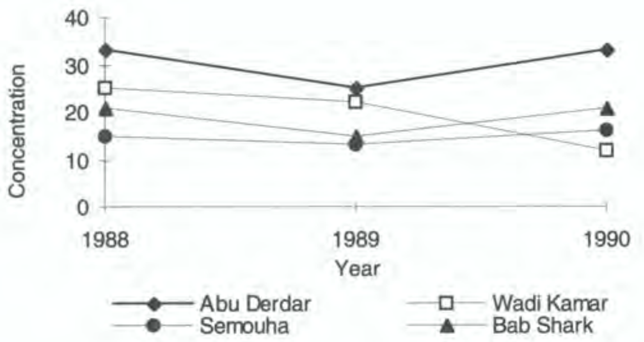


Figure 5.1 Annual mean smoke concentrations in Alexandria (µg m^{-3})

N.B. Prior to 1987 reported concentrations were approximately an order of magnitude higher

Source: Nasralla, 1994

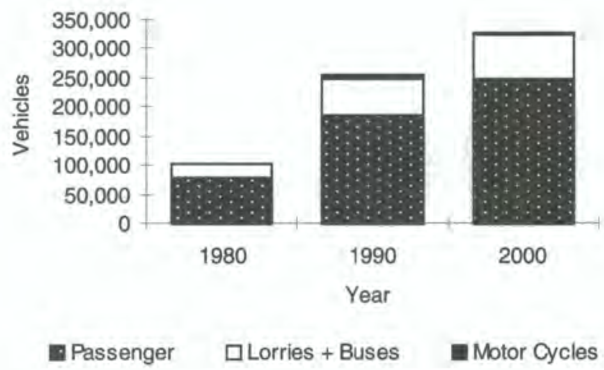


Figure 5.2 Vehicle numbers in 1980, 1990 and 2000 (projected) in Alexandria

Source: Nasralla, 1994

There is a need for monitoring of lead (Pb), carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (O_3) to be conducted in Alexandria. Vehicle numbers and fuel consumption continue to increase at a substantial rate (see Figure 5.2); they represent an unquantified, but probably major, source of pollution in the city. The combination of relatively warm winters with a short heating season of three months from November to February and the predominant use of natural gas for domestic heating does not produce an appreciable increase in SO_2 and smoke concentrations during winter (Figure 5.3).

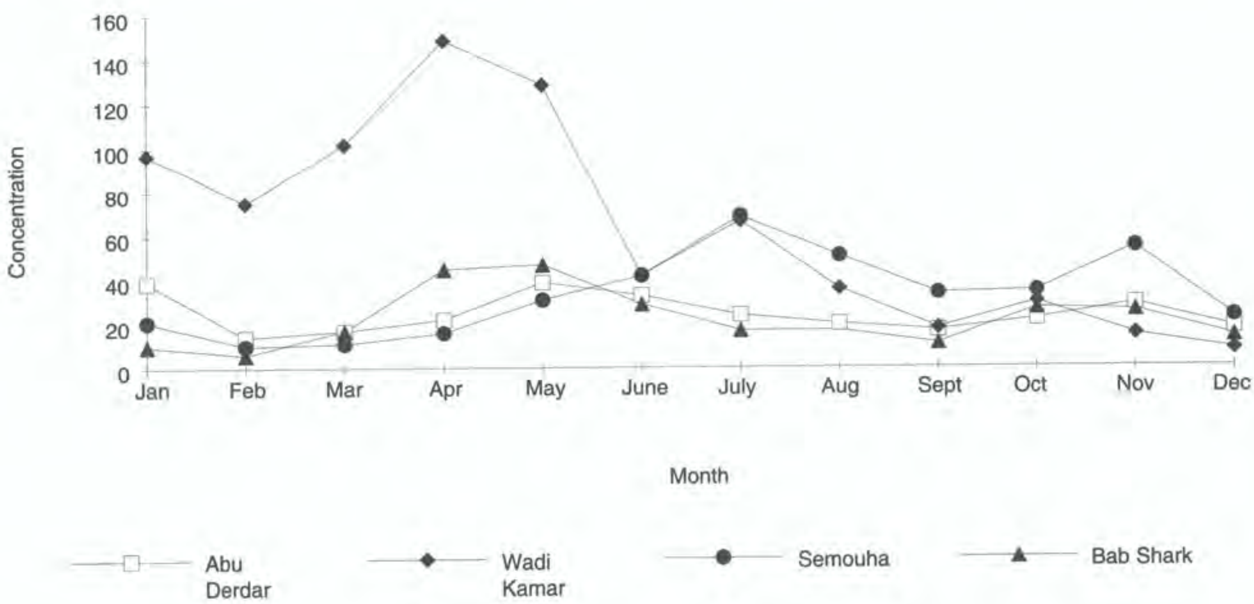


Figure 5.3 Monthly mean sulphur dioxide concentrations in Alexandria, 1990 (µg m^{-3})

Source: Nasralla, 1994

Monitoring Networks

Air quality monitoring in Egypt is conducted by the National Air Pollution Monitoring Network, which is administered by the Environmental Monitoring and Occupational Health Centre of the Ministry of Health (MoH). There are four sites in Alexandria which have been sampling since 1984: the Wadi Kamar site in the El-Max industrial area; the Abu Derdar and Bab Shark sites in the mixed residential/commercial city centre; and the Semouha site in a residential district to the east of the commercial centre (see Figure 5.4). These sites monitor for SO_2 by the acidimetric technique; for smoke by collection on cellulose filters and measurement by reflectometry; and, for TSP by high volume sampler. During a visit by a WHO consultant in 1987, serious shortcomings were identified in the procedures followed by the site operators and in sample analysis (Commins, 1987). Monitoring sites have since been audited (Nasralla, 1994) and improvements in sampling protocols have been made. Large uncertainties, however, remain concerning data quality, particularly of measurements made before 1987. For example, it was identified that no correction was made for ammonia neutralization of the acid in the SO_2 analysis, as a result measurement would have determined net air acidity rather than SO_2 concentrations.

Instrument calibration is restricted to the checking of flow rates on the high-volume TSP sampler; few formal quality assurance procedures operate. Therefore, it is not possible to determine the validity of the data collected. Data are currently published through internal bulletins which are available on request and cover the years up to 1990; monitoring is continuing but there is a lag in processing the data. There are no specific, stated monitoring objectives beyond measuring ambient concentrations in different parts of the city. Daily values are determined, monthly mean and maximum concentrations derived and in turn exceedances of national air quality standards are determined. The use of computers has recently been introduced for data assessment which should aid interpretation and ease the performance of data analysis.

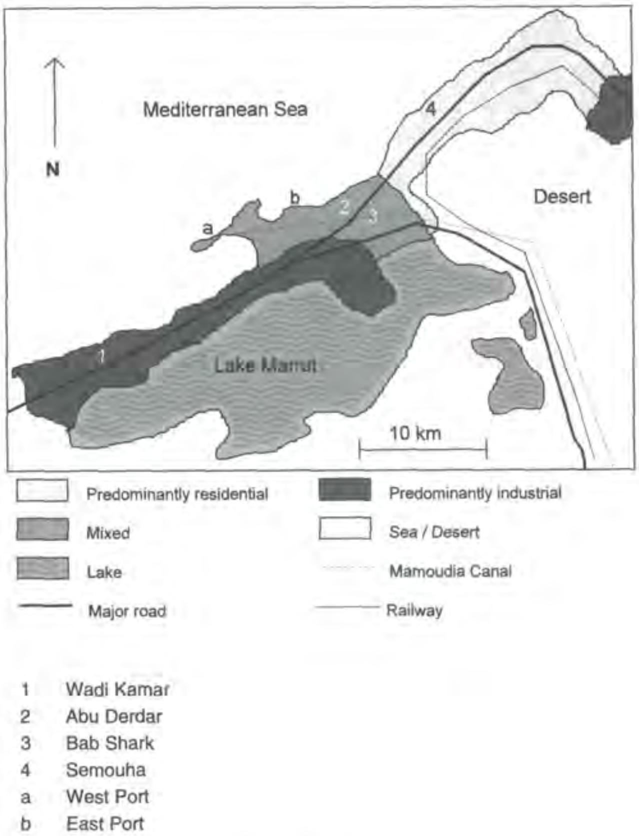


Figure 5.4 Sketch map of Alexandria

Source: Nasralla, 1994

Emissions Inventories

No emissions inventory has been conducted for Alexandria and it is therefore extremely difficult to estimate the relative importance of different sources of air pollution. Fuel consumption statistics are available and could be used with emissions factors to estimate emissions from combustion sources (Table 5.1). These statistics are, however, incomplete and emissions from manufacturing, such as those originating from the petrochemical industries, could not be estimated using these values alone. Nevertheless, these fuel consumption figures are adequate to demonstrate that domestic sources do not contribute significantly to total emissions. That heavy oil burning by industry is likely to be a very significant source of SO_2 and particulate matter; and, that the rapidly increasing number of vehicles (Figure 5.2), especially buses, will also contribute appreciably to concentrations of particulate matter. All vehicles are also likely to contribute significantly to CO and NO_2 levels; and petrol-engined cars to Pb emissions.

Table 5.1 Fuel consumption in Alexandria (tonnes)

	Vehicles	Industry and power stations	Domestic
Leaded Petrol	363,000	–	–
Diesel	409,000	nk	–
Natural gas	–	11,000	11,000
Kerosene	–	167,000	nk
Heavy oil	–	1,120,000	–

nk not known

– not applicable

Source: Nasralla, 1994

Air Quality Management

There is increasing recognition in Egypt for the need to effectively manage air quality. Industrialization and the rapid increase in vehicle numbers, together with very limited emissions controls, have ed to ever worsening air quality. Often in excess of WHO guidelines, poor air quality through acid dry deposition has also been proposed as a likely source of the accelerated degradation of Egypt's ancient monuments.

The National Report on Environment and Development produced for the United Nations Conference on Environment and Development in 1992 refers to a number of proposed air quality programmes. These programmes include technical and field studies on pollution caused by transportation, and cover:

- identifying the most important factors of pollution and the criteria of fresh air;
- drawing up effective air anti-pollution programmes and making appropriate recommendations for a sound maintenance system;
- determining the acceptable degree of pollution generated per car and applying it to all other means of transport;
- establishing technical car inspection units.

Source: Egyptian Environmental Affairs Agency, 1992

These programmes are of a general nature and demonstrate raised awareness of the consequences of uncontrolled vehicle-generated pollution. The National Environment and Development Report also highlights a number of approaches to limit industrial emissions. These include: facilitating the import of dust filters; renovation of boilers in commercial electricity generating stations; fitting of stacks and equipment to aid combustion efficiency.

Current air pollution control legislation is relatively old and limited; but it is not completely ineffective: between 1986 and 1990, 92,127 vehicles were fined for "heavy fume" emissions (Egyptian Environmental Affairs Agency, 1992). Planning controls are now increasingly being applied to control industrial emissions. The siting of major emissions sources is being more closely controlled, and planning consent for new industrial plant now requires the installation of pollution control devices – although there is no pollution control inspectorate or emissions regulations to measure whether they are effectively operated. There are currently no controls on existing industrial emissions sources (Noweir, 1987).

In February 1994 the government proposed a Clean Air Act to be introduced in 1995. At the time of writing this report details of the new act were still being finalized. This act proposes that all cars will be inspected for hydrocarbon and CO emissions and diesel vehicles for smoke from 1995. Industrial emission limits are also to be introduced in 1995 and emissions inspections will begin three years later: to be enforced with penalties for exceedances from the beginning of 1998. Although the introduction of a Clean Air Act will not, on its own, improve air quality it represents a commitment to manage air quality and to protect health and the environment. It will, of course, need to be adequately enforced.

One measure already adopted to improve air quality has been a recent reduction in the lead content of petrol from 0.8 g l^{-1} to 0.45 g l^{-1}; there are plans for a further reduction in 1997 to 0.15 g l^{-1} (the European Union maximum permitted content). No studies on blood lead levels in Alexandria have been made, however, a study comparing rural and urban population blood levels was conducted in Cairo and found urban blood lead levels to be an average of 1.5 times higher rural blood lead levels (Nasralla et al., 1984). Furthermore, the blood of heavily exposed traffic policemen contained an average of 63 μg (Pb) dl^{-1}; considerably greater than the

WHO 98th percentile blood lead guideline of 20 μg (Pb) dl^{-1}. Although these findings cannot be extrapolated directly to other Egyptian cities such as Alexandria, they illustrate the need for the reduction in the lead content of petrol. This has now been initiated and will considerably reduce lead exposure.

Air quality standards exist for SO_2, smoke and TSP (200, 150 and 150 μg m^{-3} respectively, as a daily maximum) and are broadly similar to the WHO guidelines (125, 125 and 120 μg m^{-3} respectively). There is also an annual mean guideline for SO_2 of 60 μg m^{-3}; this is comparable with the WHO value of 50 μg m^{-3}. As stated above, the number of exceedances of the national guideline are calculated: in 1989, the most recent year for which data were provided, only the Semouha site in Alexandria exceeded the SO_2 guideline (5 times). The smoke guideline was exceeded once at the Abu Derdar site. Air quality standards are not currently enforceable by law and exist only to provide an indication of air quality at different sites.

Comment

Air quality monitoring in Alexandria is limited to measurements of smoke, TSP and SO_2 but the range of pollutants measured is increasing, to include for example NO_2 and O_3. Considerable efforts have been made in the last few years to improve the quality of the data produced.While uncertainty remains over the quality of the data, measured concentrations of SO_2, smoke and TSP are all higher than the WHO Guidelines and therefore have potentially negative health effects.

A comparison of TSP concentrations in arid climates with the WHO European guidelines is probably not valid because the health effects of high concentrations of particulate matter from naturally occurring dust is not well understood. The highest TSP 24-hour daily maximum value recorded in Alexandria exceeds the WHO European Guideline by a factor of sixteen but is this is probably misleading. A comparison of the WHO thoracic particle standard with measurements in Alexandria of particulate matter less than 10 μm (PM_{10}) would be more valid; this is not possible, however, as PM_{10} is not measured in Alexandria. Differences in the composition of particulate matter in Europe and Egypt could also lead to deceptive conclusions when using WHO European guidelines as the reference values for the health effects of smoke concentrations in Egypt. There is a high proportion of sand particles (which are relatively transparent) within smoke samples in Egypt; compared to Europe where the reflectance to particulate matter concentration calibration was performed. This not only leads to poor inter-comparisons of ambient particulate matter concentrations between the gravimetric TSP methodology and reflectance, but more importantly, can also result in an underestimation of the anthropogenic black smoke content of samples through the dilution of the filter darkness with sand. In these circumstances, the WHO European health guideline may underestimate the effects of black smoke upon respiratory health because there may be a high proportion of non-dark particulate matter in a sample. Exceeding the WHO smoke guideline in Alexandria may therefore have a greater impact upon health than it would in Europe. Uncertainties in extrapolating the health effects of exposure to particulate matter in arid climates from those in more temperate climes can only be overcome by more research, such as epidemiological studies examining acute and chronic effects of exposure to high concentrations of particulate matter in areas with naturally high background dust concentrations. Egypt is ideally located for research of this type and could contribute appreciably to the understanding of the health effects of inhalation of particulate matter.

The National Report on Environment and Development and visiting WHO consultants (Harris, 1983; Commins, 1987) have highlighted deficiencies in the air quality information available to decision makers and the public. These deficiencies need to be remedied in order to devise the most appropriate air quality management strategies. There is only a relatively small amount of air quality data for Alexandria and this is of unknown validity. The extent of ammonia neutralization in the Acidimetric Technique for measuring SO_2 is unknown and will result in an underestimate of SO_2 concentrations. The need for the monitoring lead has been highlighted by the high blood Pb levels found in Cairo. It would be useful to determine ambient concentrations of Pb in Alexandria and to compare them with those in Cairo; this would give an indication of whether there is similar problem in Alexandria now or whether, as vehicle numbers increase, there will be in the future. The rise in road traffic combined with extensive petrochemical industries emphasize the need for NO_2 and O_3 monitoring; this is planned.

An emissions inventory is needed to provide essential information on the major sources of the air pollution in Alexandria; particularly for setting emissions limits from vehicles and industry for the Clean Air Act. No emissions inventory has been conducted in any Egyptian city; the relative importance of different sources of pollution, and estimates of fugitive dust in TSP, are unknown. Thus, formulating the most appropriate, effective air quality management strategies will be extremely difficult. Even the quantification of emissions through a rudimentary emissions inventory would provide data of considerable decision relevance.

Previous reports from WHO consultants have also highlighted the need for training to assist the MoH to improve the range and validity of the air quality measurements (Harris, 1983; Commins, 1987). This training could include development of written operating and quality control and assurance procedures. The training of staff is an essential element of capacity building and would enable the MoH to develop its monitoring programme in a more effective manner. The Egyptian government has demonstrated an interest in developing strategies for controlling air pollution. The Clean Air Act provides the mechanism by which effective emissions controls can be adopted but will require effective enforcement for maximum impact. The details of this forthcoming legislation will be extremely significant in determining the appropriateness and effectiveness of future strategies. It is particularly important that realistic, attainable emissions limits are set which will reduce the ambient concentration of pollution and that administrative structures are put in place to implement the new limits (supported by penalties which are sufficiently stringent to encourage compliance). The financial implications of the pollution control equipment required should also be considered. The National Environment and Development Report also contains a number of sound proposals to control vehicle and industrial emissions.

Summary

- Daily measurements of SO_2, TSP and smoke have been undertaken at four sites in Alexandria since 1984. The reliability of the data is, however, unknown and the data are unpublished.
- There is no emissions inventory for Alexandria and no emissions limits on industrial sources.
- Growth in motor vehicles, coupled with industrialization, is likely to worsen air quality appreciably in Alexandria for many pollutants in the future.
- There is presently very little air quality management in Alexandria, although a new Clean Air Act for Egypt has been proposed which should take effect in 1995.
- There is an overwhelming need for additional training of staff to assist the Ministry of Health to develop its monitoring capabilities.

References

Commins, B. 1987 *Air Pollution in Egypt*, (EGY/CEH/001), WHO Regional Office for the Eastern Mediterranean, Alexandria.

Egyptian Environmental Affairs Agency 1992 *National Report on Environment and Development in Egypt*, Egyptian Environmental Affairs Agency, Cairo.

Harris, R. M. 1983 *Assignment Report: Consultancy in Air Pollution with the Ministry of Health, Cairo, Egypt 7–17 December 1983*, (WHO EM/MS/341, EGY/RCE/00/RB), WHO Regional Office for the Eastern Mediterranean, Alexandria.

Nasralla, M. M., Shakour, A. A. and Said, E. A. 1984 Effect of lead exposure on traffic policemen, *Egyptian Journal of Industrial Medicine* **8**, 87–104.

Nasralla, M. M. 1994 Personal communication, Air Pollution Research Department, National Research Centre, Cairo.

Noweir, M. H. 1987 Overview of air pollution in Egypt, *The Journal of the Egyptian Public Health Association* **62**, 253–271.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

6

Ankara

Statistical Summary

Country: Turkey
Estimated population 1990 (millions): 2.83
Projected population 2000 (millions): 3.18
Map reference: 40°N, 33°E
Area (km^2): 3,395
Altitude (m): 750–1,000
Climate: Steppe
Average temperature range (C): -0.2 to 23.2
Annual mean precipitation (mm): 370

Situational Analysis

Ankara is particularly susceptible to periods of poor air quality owing to a combination of the city's industrial and socio-economic activities and its demographic, meteorological and topographical features. Ankara is located in a basin on the Central Anatolian Plateau surrounded, except to the west, by hills and mountains. There has been considerable urbanization in the past 30 years. The climate is typically continental with cold, semi-moist winters (average temperatures falling to below freezing) and hot dry summers. Low temperatures and low wind speeds lead to frequent foggy days: on average five per month in winter (World Bank, 1990). Under these conditions temperature inversions regularly occur, trapping the polluted air within the basin and resulting in air pollution episodes.

The population of Ankara has grown at an average annual rate of 5.8 per cent since 1935, although the current rate is about half this value. This increase has predominantly resulted from rural to urban migration. Many migrant families have settled in the northern and eastern parts of the city; on north-south facing valleys which had provided channels enabling the free movement of air driven by the predominant north or north-westerly wind. These settlement districts, known as gecekondus (settled overnight), have become an important winter source of pollution through extensive coal burning for domestic cooking and space heating. The annual variation concentrations of sulphur dioxide (SO_2) and particulate matter less than 10 µm (PM_{10}) are shown in Figure 6.1.

Turkish lignite coal is the fuel predominantly used in Ankara and it is particularly rich in sulphur (1.3 to 3.5 per cent sulphur by mass) and ash; consequently it is highly polluting. Plans continue to be introduced to limit its use (which will be discussed in the section on air quality management), nevertheless, the widespread use of lignite continues to produce potentially harmful levels of SO_2 and particulate matter. Figure 6.2 demonstrates that there has been an appreciable decrease in SO_2 concentrations in recent years through the introduction of new cleaner fuels such as natural gas. The winter monthly average values are, nevertheless, appreciably higher than WHO European acute 24-hour guidelines for SO_2 and PM_{10} (thoracic particles): 125 and 70 µg m^{-3} respectively (Figure 6.1).

No mapping of the spatial distribution of pollution within Ankara has been performed. However, examination of the annual mean and maximum values of PM_{10} (Figure 6.3) measured at seven sites with good data capture in 1993 indicate quite wide variation between different parts of the city.

Economic changes undertaken in the 1980s have altered the structure of the economy, the rate of growth and, consequently, demand within the energy sector. The World Bank, in 1987, estimated that energy demand in Turkey would grow at an annual rate of 5.4 per cent per annum in subsequent years; with

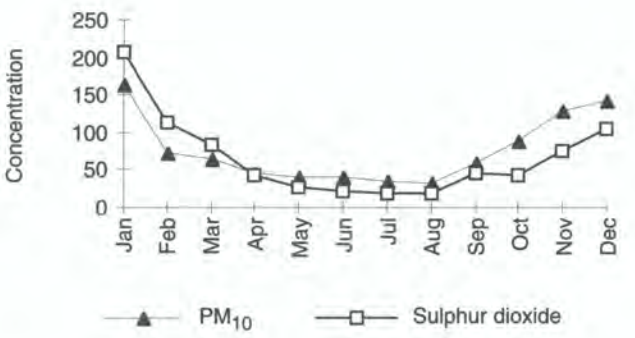


Figure 6.1 Annual variation in SO_2 and PM_{10} 1993 ($\mu g\ m^{-3}$)

Source: State Institute of Statistics, Republic of Turkey, 1994

a shift in economic activity from agriculture to industry, particularly towards the development of energy-intensive capital goods production. Ankara currently has a relatively small manufacturing sector, but emissions from point sources are projected to increase with greater industrialization. Although only 12.5 per cent of employment in Ankara is in industry, the city nevertheless has some major industrial plants, including a cement factory, asphalt plants, sugar and gunpowder factories and two gas plants. Most of the industry is located in the west of the city.

The economic growth experienced during the last decade has led to a rapid increase in vehicle numbers. Between 1981 and 1991 the number of passenger and commercial vehicles increased by about 150 per cent (OECD, 1992). This has resulted in an additional major

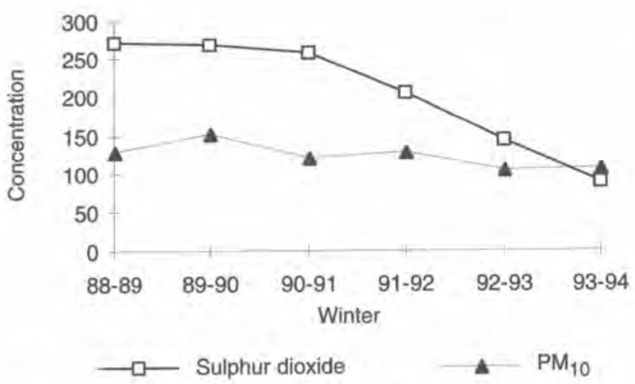


Figure 6.2 Trends in winter SO_2 and PM_{10}, Ankara 1988–1989 to 1993–1994 ($\mu g\ m^{-3}$)

Source: State Institute of Statistics, Republic of Turkey, 1994

source of air pollution in Ankara from road transport. The growth in motor vehicles registered in Ankara between 1990–1993 is shown in Figure 6.4. Dependence on cars for transport in Ankara is being reduced by the introduction of two mass transport schemes; the more widespread use of buses is being encouraged. The first 15 km of the Ankara metro will be completed in 1995 and the planned 55 km finished by 2015. A light railway is also being introduced: 8.5 km of line was finished in 1993 and now carries 300,000 passengers daily.

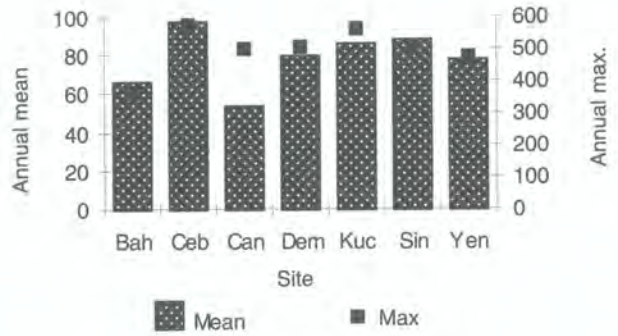
Nitrogen dioxide (NO_2) has been measured since 1992. Monthly mean concentrations, between October 1993 and June 1994, at two sites ranged between 22 and 118 $\mu g\ m^{-3}$. The WHO European Guidelines for 24-hour exposure to NO_2 is 150 $\mu g\ m^{-3}$ (WHO, 1987). At some sites at certain times of the year it is therefore clear that this guideline is being regularly exceeded. There are no data for carbon monoxide (CO) or ozone (O_3). A policy initiated in 1986 of converting small engine vehicles from petrol to diesel will result in lower lead, oxides of nitrogen (NO_x) and CO emissions, but will increase those of SO_2 and PM_{10} which are the most serious pollutants in Ankara. Few measurements of lead have been made, but those which have range between 0.2 and 1.4 $\mu g\ m^{-3}$ per month; these are of the same order as WHO guidelines (0.5 to 1.0 $\mu g\ m^{-3}$ annual average).

Monitoring Networks

Air quality monitoring

Air quality monitoring has been conducted in residential districts of Ankara for smoke and SO_2 using active sampling bubblers since 1970. In 1986, the monitoring programme was updated: PM_{10} was measured using beta-ray absorption and SO_2 using instrumental conductivity. There are currently eight monitoring sites, two of which were fitted with chemiluminescence detectors measuring nitrogen oxides in 1992. The objective of the monitoring programme is to determine the pollution levels of the measured species in residential areas of the city in order for the authorities in Ankara to develop appropriate measures to control this pollution.

Monitoring is conducted by the General Directorate of Primary Health Care of the Ministry of Health. This

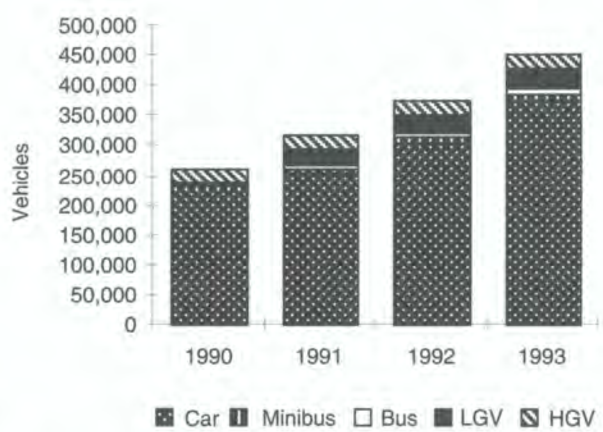


Bah: Bahcalievler
Ceb Cebeci
Can: Cankaya
Dem: Demetevler
Kuc: Kucukesat
Sin: Sinhiya
Yen: Yenidoga

Figure 6.3 Annual mean and maximum PM_{10} 1993 ($\mu g\ m^{-3}$)

Source: State Institute of Statistics, Republic of Turkey, 1994

Directorate has a staff of five engineers/graduates and three technicians at the Refik Saydam Hygiene Centre. Data are sent for assessment to the State Institute of Statistics which calculates the daily, monthly and annual average values (used in the determination of trends) and the number of exceedances of Turkish air quality standards. Data analysis is performed using computers and published in internal bulletins.



HGV Heavy Goods Vehicles.
LGV Light Goods Vehicles.

Figure 6.4 Motor vehicles in Ankara 1990–1993

Source: State Institute of Statistics, Republic of Turkey, 1994

The quality control/assurance programme includes periodic maintenance, calibration by standard solutions or dynamic calibration using permeation tubes fortnightly and data validation. Inter-comparison is also carried out by the simultaneous measurement of different instruments using reference samples.

Health effect studies

A number of epidemiological studies have been conducted in Ankara on the health effects of the air pollution (World Bank, 1990). Good facilities exist for this kind of study, particularly in the Department of Chest Disease and Tuberculosis of the University of Ankara. A 1982-1983 study conducted on a panel of 600 school children in Ankara and 112 controls from outside the city found, among other things, a difference in the prevalence of persistent winter coughs, bronchitis and pneumonia between these two groups. Lung function in adults has been studied at the University of Ankara and the Ministry of Health produces morbidity and mortality statistics which can be used to detect seasonal variations, although confounding factors such as temperature also need to be considered.

Blood lead levels have been measured at Ankara University in 460 persons not occupationally exposed to lead and who had been resident in the city centre for more than 10 years. The mean blood lead level of these long-term residents was 16.5 $\mu g\ dl^{-1}$, significantly higher than in a control area where the mean blood lead concentration was 10.5 $\mu g\ dl^{-1}$. World Health Organization guidelines (WHO, 1987) suggest that the median blood lead concentration in a population should be about 10 $\mu g\ dl^{-1}$. On this basis, the control population are, to a first approximation, at the no-effect threshold while Ankara residents are above this level.

Few studies have been conducted on the cancer incidence and mutagenicity of air pollutants in Ankara; with the exception of occupational exposure to asbestos. One such study has been conducted using an Ames Salmonella Assay at the Department of Biology, Middle East Technical University. The mutagenicity of air pollutants in Ankara air was found to be higher than in other major cities of the world where similar studies have taken place, and notable differences were found between different parts of the city.

Emissions Inventories

No emissions inventory has been conducted in Ankara although one is planned by the State Statistics Institute which is currently developing the necessary methodology. Some estimates of non-industrial emissions have been made and these are shown in Table 6.1, although no details are available as to how the estimates were derived. These estimates do not include emissions from industrial sources which is a serious limitation.

Air Quality Management

Institutional management structure

Responsibility for controlling air pollution resides with a number of bodies within Turkey (Environmental Problems Foundation of Turkey, 1989b):-

1. *Ministry of the Environment*: the main body responsible for co-ordination between the other institutions charged with environmental protection, emissions control and monitoring.
2. *Refik Saydam Hygiene Centre*: attached to the Ministry of Health; responsible for monitoring ambient air, analysis of stack samples and daily reporting of air quality to the Provincial Government of Ankara and other relevant institutions.
3. *Ministry of Energy and National Resources*: contains one department dealing with air pollution.
4. *General Directorate of Highways*: under the 1983 Highway Traffic Act this Directorate was given authority to establish and operate motor vehicle inspection stations. Plans are still being formulated and it is proposed the systems will measure CO, smoke, hydrocarbons, NO_x and lead in exhaust fumes.
5. *State Planning Organization*: formulates and co-ordinates economic and social development activities within five-year plans, including the integration of environmental policies within these.
6. *Turkish Council of Scientific and Technical Research (TUBITAK)*: part of the Prime Minister's Office; funds environmental research on issues including the health effects of air pollution, efficient fuel use and energy efficiency. There are plans to establish a committee on Air Pollution Research within TUBITAK.
7. *Ankara Provincial Government through the Provincial Health Council*: each year announces measures to be taken within Ankara to lower air pollution as well as what air pollution level constitutes an emergency; and response strategies.

Table 6.1 Estimated non-industrial emissions from combustion sources, Ankara, 1990 (tonnes)

	SPM	SO_2	NO_x	HC	CO
Transport	1,160 (6%)	870–3,151 (1–6%)	25,290 (87%)	54,000 (91%)	311,650 (92%)
Household	20,100 (94%)	56,500–58,510 (94–99%)	3,650 (13%)	5,700 (9%)	27,700 (8%)
Total	21,260	57,370–61,661	28,940	59,700	339,350

Where two values are given the range represents the two different sources for this table. These estimates assume no emissions control policies were introduced.

Source: Japan International Co-operation Agency, 1986; Environmental Problems Foundation of Turkey, 1989a

8. *Directorate of Electricity, Gas and Omnibus*: involved in studies on the development of a city gas plant for district heating and on reducing pollution from automobiles.

9. *Ankara Master Plan Bureau*: develops plans for the Ankara Metropolitan Area including remedial actions to control air pollution. The Urban Reconstruction Directorate is in charge of implementing the plan, including approval of building and construction permits.

10. *Municipality Police Directorate*: inspects and maintains boilers and combustion systems and can require motor vehicle owners to repair polluting (usually smoky) vehicles.

There are even more organizations with peripheral interests in air quality. The *General Directorate of State Meteorological Works* is responsible for weather forecasting and observations. The *General Directorate of the Turkish Coal Board* is charged with the distribution of coal and ensuring that the best quality domestic supplies are provided to Ankara; in co-ordination with the *Ankara Municipality*. The *General Directorate of Mineral Analysis and Research* conducts research on fuels and combustion. The *Department of Energy and Ministry of Education, Youth and Sports* is in charge of training boiler operators. This large number of organizations, involved at different levels of government, makes the development of a coherent, concerted air quality management strategy complicated; consultations involve a wide variety and number of bodies with conflicting interests and priorities.

There are also a number of non-governmental organizations (NGOs) with an interest in air pollution problems. These include the *Environmental Foundation of Turkey* which is involved in problem identification and solutions through making legislative proposals and public education and the *Turkish Association for Natural Protection*, which is associated with related international bodies.

Within the city of Ankara the Provincial Government is the principal organization with responsibility to prevent environmental pollution.

Remedial actions undertaken

The main measures implemented in Ankara to reduce levels of SO_2 and particulates have been associated with reducing the domestic use of Turkish lignite. A number of strategies have been implemented to encourage this reduction, including a requirement imposed on the *General Directorate of the Turkish Coal Board* to supply the highest quality Turkish coal to Ankara: in order to lower emissions of SO_2 and particulates per ton of lignite burnt. The use of better quality imported coal, mostly from South Africa, the former Soviet Union and China, is also being encouraged: taking advantage of the currently depressed price of coal on the international market. A comparison of Turkish lignite and imported coal is given in Table 6.2.

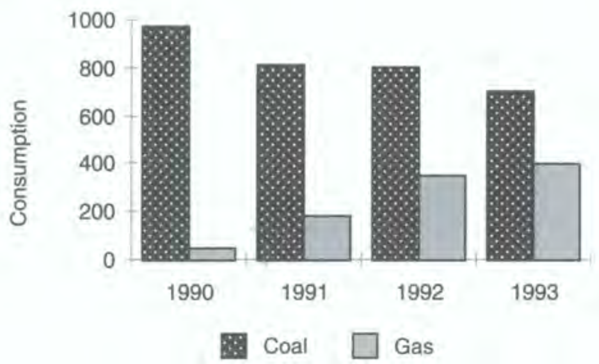
Another measure employed to reduce the use of Turkish lignite has been the extension of a high-pressure gas supply to some parts of the city; this project has been financed by the World Bank. By the middle of 1991, about 110,000 buildings had been connected to the gas mains and this is intended to rise to 250,000 buildings by the end of the scheme. It has been estimated that, by 1992, this project alone will reduce emissions of particulate matter by about 25 per cent and sulphur dioxide by over 10 per cent (OECD, 1992; Japan International Co-operation Agency, 1986; Environmental Problems Foundation of Turkey, 1989a). Ankara is also considering the more widespread use of district heating systems and the use of

Table 6.2 Comparison of Turkish lignite and imported coal

	Turkish lignite	Imported coal
Sulphur content (per cent)	2 (1 to 6)	0.6 to 0.9 max.
Volatiles (per cent)	17 to 20	13 to 18
Ash (per cent)	16 (10 to 41)	17 to 19 max.
Heat content (kcal kg^{-1})	2,800 to 45,000 (1,000 to 5,750)	6,500
Moisture (per cent)	15 to 30 (3 to 50)	6 to 8
Cost (TL ton^{-1}) 1990	14,000	120,000

Figures in brackets are the range of values.
Coal imported from South Africa has a higher sulphur and ash content than that from Russia, but lower moisture content.

Source: World Bank, 1990; State Institute of Statistics, Republic of Turkey, 1994



Coal consumption thousand tonnes a^{-1}; gas consumption million m^3 a^{-1}.

Figure 6.5 Imported coal used by domestic consumers and natural gas consumption in Ankara, 1990–1993

Source: State Institute of Statistics, Republic of Turkey, 1994

combustible briquettes of lignite mixed with SO_2 absorbing gypsum. It is now illegal in Ankara to use, sell or handle any solid or liquid fuels not formally approved by the relevant authorities. Figure 6.5 shows the growth in natural gas consumption in Ankara as well as the 1990-1993 decline in the use of imported coal for domestic purposes; this decline mirroring the wider reduction in the use of coal. From 1994 onwards the Government of Ankara has also specified that ratios of high quality Turkish lignite with imported coal be used for domestic heating.

Emissions from buses in Ankara are being reduced by introducing of engines that run on compressed natural gas; and, by the more widespread use of particle traps and other similar tail-pipe technology. The development of additional public transport infrastructure, such as the metro and light railway, will also reduce dependence upon private cars. Since January 1993, the Provincial Government of Ankara has also required annual exhaust gas emission tests for all motor vehicles; which are then issued with an emission control stamp.

Legislative framework

The 1983 Environment Law provides the legal framework for protection and improvement of the environment in Turkey; the 1986 Regulation for the Protection of Air Quality is the main legislation controlling air pollution. This law is intended to control emissions of soot, smoke, dust, gas, aerosols and vapour into the atmosphere in order to protect human health and the environment. The law stipulates specific long and short-term limits for various air pollutants. This is shown in Table 6.3; the EC Limit and some US EPA Primary Standards are included for comparison. The Turkish long and short-term standards are similar in magnitude to the EC limit values and US EPA primary standards. Short-term standards are maximum daily concentrations or 95th percentile values; long-term limit values are the arithmetic mean of the annual concentration. The Turkish authorities have also developed standards for a number of pollutants for which no monitoring capability currently exists; these include CO, O_3, hydrocarbons, hydrogen chloride (HCl), hydrogen sulphide (H2S) and cadmium (Cd). The most notable difference between Turkish and EC air quality standards is in the extent to which they are enforced. Where EC limit values are exceeded the country must take action to prevent subsequent exceedances by implementing local air quality management strategies; exceedances of Turkish air quality standards for SO_2 and PM_{10} have occurred routinely at a number of monitoring sites in recent years, although the frequency of such events is falling. The number of exceedances of Turkish air quality standards for SO_2 between 1990 and 1993 are shown in Figure 6.6.

The Turkish authorities have also set target limits for SO_2 and particulate matter at a lower level than the air quality standards, presumably as long-term objectives. These are compared, in Table 6.4, with WHO European Guidelines which are recognized as being values at which no health effects are likely to be observed. Emissions from industry are controlled by the Air Quality Protection Regulations of 1986. The purpose of the regulations is to "bring under control emissions in the form of soot, smoke, dust, gases, steam and aerosols released into the atmosphere as a result of activities of all kinds and to protect human beings and their environment from hazards arising from pollution of the air; to eliminate the undesirable effects on the environment owing to air pollution that cause significant harm to public and neighbourly relations and ensure that such effects do not occur". The legislation does not, however, stipulate emissions limits in order to ensure the stated air quality limits are not exceeded.

Table 6.3 Comparison of Turkish and EC limit air quality standards (μg m^{-3})

Pollutant	Long-term limit	EC standard Annual limit value	Short-term limit	EC standard Daily limit value
SO_2 (a)	150 (b) or 250 (c) and 250 (d)	80 (e) or 120 (f) and 130 (g),(d) or 180 (h),(d)	400 and 900 (r)	350 (i) or 150 (j) and 900 (r)
PM_{10}	150 (b) or 200 (c) and 200 (c)	75 (k)	300 (b) or 400 (c)	260 (k)
CO	10,000	10,000 (k),(l)	30,000	40,000 (k)
NO_2	100	50 (m)	300	200 (n)
NO	200	–	600	–
O_3	–	–	240 (r)	360 (p)
Hydrocarbons	–	–	140 and 180 (r)	–
Chlorine	100	–	300	–
HCl and inorganic gaseous chlorides	100	–	300	–
H_2S	–	–	40 and 100 (r)	150 (q)
Pb	2 and 500 (s)	2	–	–
Cd and compounds	0.04 and 7.5 (s)	0.01–0.02 (q)	–	–
HF and inorganic gaseous fluorides	–	–	10 and 30 (r)	–
Thallium and compounds in settling dust	10 (s)	–	–	–

(a) Turkish standard is SO_2 + SO_3.
(b) General area.
(c) Industrial area.
(d) Winter season average.
(e) If smoke >40 μg m^{-3}.
(f) If smoke <40 μg m^{-3}.
(g) If smoke >60 μg m^{-3}.
(h) If smoke <60 μg m^{-3}.
(i) 98th percentile of daily values if smoke <150 μg m^{-3}.
(j) 98th percentile of daily values if smoke >150 μg m^{-3}.
(k) US EPA primary standard (no EC limit) 1-hour maximum.
(l) 8-hour average.
(m) 50th percentile of 1-hour means (guide value – no limit value set).
(n) 98th percentile of 1-hour means.
(p) 1-hour population warning level.
(q) WHO guideline (no EC limit).
(r) 1-hour maximum.
(s) μg m^{-2} day^{-1} in settled dust.

Source: World Bank, 1990; State Institute of Statistics, Republic of Turkey, 1994

Emissions from motor vehicles are controlled by regulations and established emissions limits. A commission overseeing the introduction of a vehicle inspection programme was established in May 1989. Emissions limits for CO of 2–3 per cent and for hydrocarbons of 220–290 ppm have been set. It has been said of the inspection programme operated in Turkey, that it is neither strictly adhered to nor generally enforced (Environmental Problems Foundation of Turkey, 1989a). However, in Ankara, the Provincial Government now require all vehicles to have an emissions control stamp. The exhaust emission limits are

Figure 6.6 Exceedances of Turkish sulphur dioxide air quality standards, 1990–1993

Source: State Institute of Statistics, Republic of Turkey, 1994

rigorous and relatively low, being set at 4.5 per cent CO for vehicles first used after August 1983; 6 per cent for vehicles first used between August 1975 and August 1983; and 1,200 ppm for vehicles first used before August 1975. The lead content of Turkish gasoline has been steadily decreasing since a limit was initially introduced in 1977 at 0.94 g (Pb) l^{-1}. The limit is currently 0.40 and 0.15 g l^{-1} for super and normal gasoline respectively. The normal gasoline lead content is the same as that permitted in the EC. Unleaded petrol is now available at all petrol stations in Ankara and is becoming more widely available throughout Turkey.

Comment

The causes of air quality problems in Ankara, and the adopted solutions, are similar to those of London in the 1960s. Air quality problems are predominantly caused by the domestic burning of low-grade coal and are particularly acute during the winter in weather characterized by low wind speeds and the formation of temperature inversions. These factors combine to cause high concentrations of particulate matter and SO_2 (and its secondary products). Furthermore, in London in the 1960s and currently in Ankara, these problems are, for the most part, being remedied by increasing the domestic use of cleaner fuels.

Ankara is a smaller city than London and has considerably less polluting industry than London had in 1952. Therefore, Ankara has not experienced, and is unlikely to experience, an air pollution episode of the severity of that in London in December 1952. There is, however, evidence from monitoring and epidemiological studies that levels of SO_2 and PM_{10} do affect the health of Ankara residents. The measures introduced by the provincial and national governments to reduce the domestic consumption of Turkish lignite coal are significantly reducing concentrations of both SO_2 and PM_{10} in Ankara It is, however, vital that this is not offset by the current expansion of industry and the growth of vehicle emissions. The introduction and enforcement of vehicle exhaust emissions tests by the Ankara Provincial Government is important.

Table 6.4 Comparison of Turkish Target Limits and WHO guidelines (µg m^{-3})

	SO_2		PM_{10}	
	Turkish Target	WHO	Turkish Target	WHO
Annual	60	50	60	50(a)
Winter (Oct–Mar)	120	–	120	–
Daily	150	125	150	70(b)
1 hour	450	350	–	–

(a) TSP (no PM_{10}).

(b) Thoracic particles (equivalent to PM_{10}).

Source: World Bank, 1990

A World Bank report in 1990, following discussions with the Turkish authorities, noted a "reluctance to adopt aggressive pollution control measures", based upon the belief that:

- environmental and economic development goals are incompatible;
- there are high investment costs for pollution control measures in conditions of scarcity of foreign exchange and competition for scarce capital within the country;
- ambiguities which surround the costs of pollution in terms of health hazard and overall reduced welfare are separate issues from the effects of widespread poverty;
- there are ineffective economic incentives and institutions – governmental, legal, economic and social – to support pollution reduction policies.

The World Bank, through providing funding for the expansion of natural gas supplies in Ankara, is helping address the problem of air quality through the development of infrastructure. The potential of fiscal policies to encourage the use of less polluting energy sources remains relatively unused and could be introduced to generate revenue for other air quality management strategies in the future. Turkey is actively pursuing an application to join the European Union (EU). The current air quality in Ankara appears to be still below those levels which are considered acceptable by EU, and as such Turkey would be required to take remedial action to ensure EU Limit values were not exceeded. Some positive steps have been taken; in particular, the use of better quality imported coal and of the highest quality Turkish lignite. These policies could be reinforced by a number of strategies including the imposition of emissions controls on industry with incentives and penalties to encourage greater use of cleaner fuels. The success of the policies already implemented in Ankara are apparent by the trends in the number of exceedances of Turkish air quality standards over the past four years (see Figure 6.6). However, additional emission control strategies will be required; particularly to continue reducing concentrations of PM_{10}, SO_2 and NO_2.

Difficulties in implementing stringent air pollution abatement strategies are probably, at least partially, a consequence of the large number of departments and levels of government responsible for managing different aspects of air quality. The introduction of more streamlined administration could be considered by the Turkish authorities as a way of accelerating the decision-making process. The OECD suggested, among other recommendations, in a report on *Environmental Policies in Turkey* (OECD, 1992), the establishment of a single agency with responsibility and accountability for all environmental matters. The OECD proposed that specific tasks could be delegated from this agency to local authorities "*where this does not conflict between a municipalities role in economic development and enforcement of environmental regulations*". Conflicting interests within those bodies responsible for air quality in Ankara, and confusion over where responsibility lies, have limited the extent to which air quality management policies have been implemented. A number of very progressive policies to control emissions from domestic sources. However, penalties levied against polluting facilities are often too low to encourage adherence to limits and state enterprises are not prosecuted for non-payment.

The monitoring networks within Ankara for SO_2 and PM_{10} are adequate for the city's needs. However, expanding the number of pollutants monitored, particularly those derived from traffic, to include CO and O_3 would add important information, as would increasing the number of sites measuring lead and NO_2 . There are excellent research facilities conducting epidemiological studies on the health impacts of the air pollution and better use could be made of the air quality data which are being collected for this. Other potentially important uses of the air quality data would be to determine the spatial distribution of pollution in Ankara and to use modelling with meteorological measurements. These uses would enable the prediction of air pollution episodes so that public warnings could be issued during periods of particularly high concentrations. There is currently no emissions inventory in Ankara and therefore the relative importance of the different sources of pollution are not well recognized. The commitment of the authorities to conduct an emissions inventory is positive and once the methodology has been developed it will provide important additional information about the sources of pollution in Ankara.

Summary

- Ankara experiences high concentrations of wintertime SO_2 and PM_{10} owing to the combination of widespread use of poor quality Turkish lignite coal and the occurrence of frequent winter temperature inversions.
- There is generally thought to be appreciable emissions from motor vehicles; blood lead levels above those recommended by the WHO indicate that this is likely. Little monitoring for traffic-derived pollutants is conducted.
- Monitoring is routinely conducted in Ankara for SO_2 and PM_{10} with some recent albeit limited monitoring for NO_2.
- No emissions inventory has been conducted in Ankara although one is planned.
- Remedial actions to control SO_2 and particulate matter emissions have concentrated on improving the quality of coal burnt in Ankara and increasing the availability of natural gas.
- There has been a decline in exceedances of Turkish Air Quality Standards for SO_2 and PM_{10} levels over the past few years, although concentrations during the winter are still regularly above these levels.

References

Environmental Problems Foundation of Turkey 1989a *Air Pollution Study – Turkey*, Environmental Problems Foundation of Turkey, Ankara.

Environmental Problems Foundation of Turkey 1989b *Environmental Profile of Turkey*, Environmental Problems Foundation of Turkey, Ankara.

Japan International Co-operation Agency 1986 *The Study on Ankara Air Pollution Control Project*, Japan International Co-operation Agency, Tokyo.

OECD 1992 *Environmental Policies in Turkey*, Organisation for Economic Co-operation and Development, Paris.

State Institute of Statistics 1994 Personal communication, State Institute of Statistics, Republic of Turkey.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

World Bank 1987 *Energy Sector Adjustment Loan Report*, World Bank, Washington DC.

World Bank 1990 *Issues in Air Pollution in Ankara*, Environment Working Paper No. 38, World Bank, Washington DC.

7

Belo Horizonte

Statistical Summary

Country: Brazil
Estimated population 1990 (millions): 2.41
Projected population 2000 (millions): 3.08
Map reference: 19°54'S, 43°54'W
Area (km²): 335
Altitude (m): 850
Climate: Sub-tropical
Average temperature range (C): 12–38
Annual mean precipitation (mm): 1,454

Situational Analysis

Belo Horizonte is the capital of the State of Minas Gerais and is the third largest city in Brazil, after São Paulo and Rio de Janeiro. The Região Metropolitana de Belo Horizonte (RMBH) is the economic centre of Minas Gerais and covers 18 municipalities; many of which have serious water and atmospheric pollution problems caused by the rapid growth in industry, population and traffic. In terms of atmospheric contamination the most affected areas are those between Betim, Contagem and Belo Horizonte; as well as the municipalities of Pedro Leopoldo and Vespasiano (Figure 7.1) (Liu et al., 1992). The city of Belo Horizonte is located in a mountainous region lying north of Serra do Curral; the lower part of the city is located beside the man-made lake of Represa de Pampulha (Figure 7.1). The temperature remains high throughout the year with two distinct seasons: a dry season from April to September and a rainy season from October to March.

Most industry in the area is located west of Belo Horizonte in Contagem. The main industries are textiles, chemicals, non-metallic mineral products such as pottery and glass, metal, concrete and asphalt, as well as food and manufacturing. The major fuel used by industry is fuel oil; electricity and charcoal are used to a lesser extent. Gas and electricity are the primary domestic fuels for cooking. Space heating of houses is not required owing to the constant high temperatures which prevail throughout the city.

The main air pollution problems in the city can be attributed to traffic emissions. Buses and cars are the main forms of transport in Belo Horizonte and numbers are increasing rapidly; although railways, metro and tram systems are also in operation. Vehicles use unleaded petrol, diesel and alcohol; ethanol is also used as a petrol additive.

Limited air quality monitoring has been carried out in Belo Horizonte. Total suspended particulates (TSPs) were monitored from 1984 to 1992 with a three-year break between 1989 and mid-1991 when sampling was suspended. Sulphur dioxide (SO_2) has been monitored for a period of one year only (between 1992 and 1993). So far no measurements have been taken of: inhalable particles (PM_{10}), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3) or lead (Pb).

The lack of data on ambient concentrations, coupled with the absence of recent emissions data, means that there is insufficient information to analyse the local air pollution situation. However, from all the available data it is clear that Belo Horizonte has a problem with TSP: levels often exceed the national annual standard of 80 $\mu g\ m^{-3}$ (Figure 7.2). There are marked seasonal fluctuations in TSP concentrations, these being generally lower during the rainy season (December to February) and higher during the dry season (June to September) (Figure 7.3).

Sulphur dioxide concentrations are generally below the national air quality standard, although this is based on

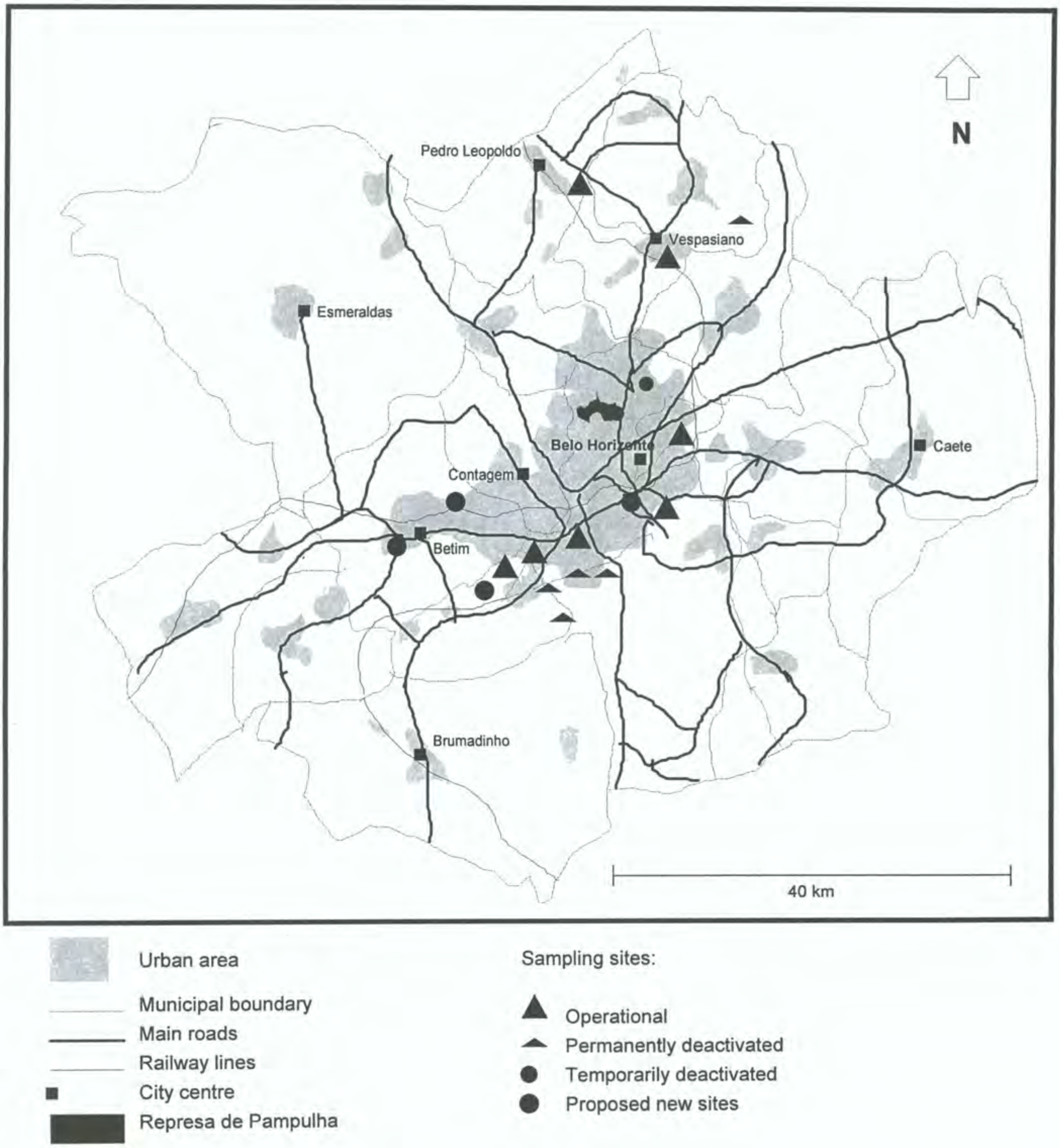
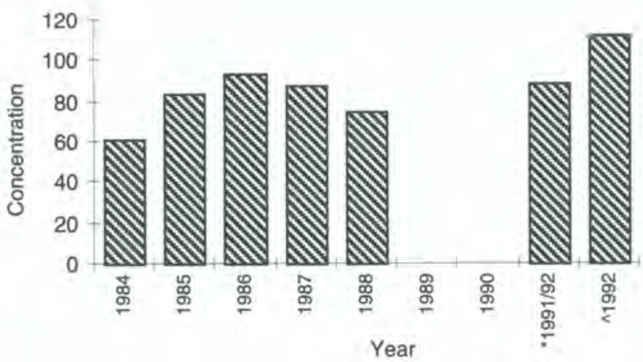


Figure 7.1 Sketch map of the Metropolitan Region of Belo Horizonte and sampling sites for 1988

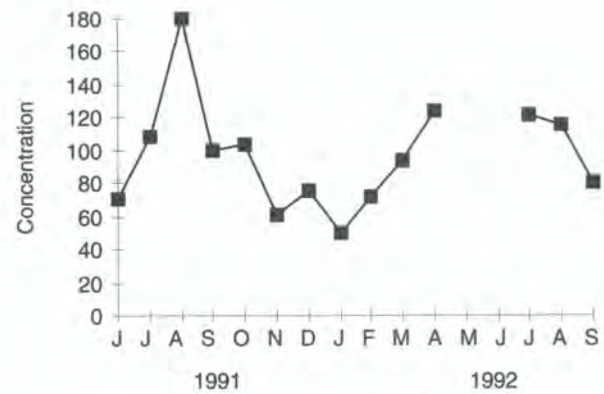
Source: FEAM, 1994



No measurements taken in 1989 or 1990; the number of sampling sites on which these average values are based varied between 3 and 12 (see Table 7.2 for further details); * Mean data for October 1991 to September 1992; ^ Mean data for February 1992 to February 1993.

Figure 7.2 TSP annual average concentrations for the city of Belo Horizonte (μg m^{-3})

Source: Liu et al., 1992 and FEAM, 1994



Monthly mean concentrations are mean values of all the sites in which more than 3 samples were made for each month and for sites which operated for longer than 3 months in the year; at no site are data available for 12 consecutive months.

Figure 7.3 Monthly mean TSP concentrations for the city of Belo Horizonte, June 1991–September 1992 (μg m^{-3})

Source: Liu et al., 1992

a limited number of measurements. Further measurements would be required to determine the full extent of the problem. The most recent data available on air quality for Belo Horizonte are those produced by the Região Metropolitana de Belo Horizonte network (RMBH) from October 1991 to September 1992; and, by the City Hall of Belo Horizonte (CBH) from February 1992 to February 1993. Mean values for TSP and SO_2 concentrations for residential, commercial, kerbside and industrial locations are summarized in Table 7.1.

Table 7.1 TSP and SO_2 concentrations at seven sampling locations in Belo Horizonte, October 1991–February 1993 (μg m^{-3})

	RMBH (Oct 91–Sep 92)		CBH (Feb 92–Feb 93)	
	TSP		TSP	SO_2
Network	Annual mean	Daily maximum	Annual mean (or range)	Annual mean
Residential	79	604	(68–121)	21
Commercial	69	165	81	80
Kerbside	87	561	144	47
Industrial	100	432		-

Note that sampling sites are not at the same locations for both networks. The CBH did not monitor at an industrial site.

Source: FEAM, 1994

Average annual TSP levels and maximum daily TSP concentrations, between October 1991 and February 1993, are above or very near the national standard at all locations; with the exception of those measured by the commercial site operated by RMBH which complied with current legislation and with the WHO guideline range of 60–90 μg m^{-3} for annual mean and 150–230 μg m^{-3} for daily maximum concentrations (WHO, 1979).

Total sulphation (TS) rates (instead of SO_2) were measured by RMBH for a period of five years, from 1984 to 1988, and during that time annual mean values at all sites were always below the Canadian reference value of 0.5 mg SO_3/100 cm^2/day (Liu et al., 1992). Data are compared with the Canadian value because there is no national standard or guideline for TS in Brazil.

Annual mean levels of SO_2 have only been measured by the CBH for one consecutive year at three sites (February 1992 to February 1993). From the limited data available, SO_2 does not seem to present a problem at the residential, commercial or kerbside locations (Table 7.1). However, although concentrations at the commercial site are within the national annual standard they are well above the WHO guideline range of 40–60 μg m^{-3} (WHO, 1979) set for this compound. So far no measurements have been taken at an industrial location. Further analysis of this compound would be necessary to determine more accurately whether SO_2 concentrations in ambient air present a problem in some parts of the city.

Monitoring Networks

Região Metropolitana de Belo Horizonte network

The Fundação Centro Technologico de Minas Gerais (CETEC) established a monitoring network in June 1984: the Região Metropolitana de Belo Horizonte network (RMBH). This network was set up following a request from the State Council for Environmental Politics, Conselho Estadual de Politica Ambiental (COPAM), to measure TSPs and total sulphation (TS) rates, to determine spatial and temporal variations of these compounds and to establish whether the values measured fell below national regulations.

The sampling network was suspended at the end of 1988 and recommenced in June 1991 for a period of one year. The Fundação Estadual do Meio Ambiente (FEAM) is currently awaiting financial aid to establish an automatic network and hopes to continue monitoring in the near future. Discussion in this chapter will refer to the monitoring carried out between 1984 and 1992. Sampling sites were set up in industrial, kerbside, commercial and residential areas. While the network was operational the number of monitoring sites varied between 2 and 12. Sampling locations for 1988 are presented in Figure 7.1. During 1988: seven sites were operational; five site were temporarily deactivated due to technical difficulties; monitoring at two sites was permanently discontinued; and, four further sites were projected to start operating.

Sample collection and analysis and equipment maintenance were the responsibility of CETEC. Total suspended particulates were collected as daily values using high-volume sampling techniques and were then measured gravimetrically. The number of samples and sampling sites are presented in Table 7.2. The sampling protocol is to collect 24-hour samples every sixth day; however, Table 7.2 shows that it was not always possible to achieve this; although the percentage data capture did increase considerably from 1984 to 1988.

Total sulphation rates were also measured between 1984 to 1988. Because total sulphation is an indirect way of measuring sulphur compounds in the atmosphere, and because of the difficulty in making comparisons between different SO_2 monitoring methodologies due to the lack of data availability for TS from other countries, TS measurements were suspended in 1988. Although the RMBH intends to move towards SO_2 monitoring, so far no SO_2 monitoring has been conducted.

The City Hall of Belo Horizonte network

Between February 1992 and February 1993 the City Hall of Belo Horizonte (CBH) conducted a one-year project to measure ambient air concentrations of TSP and SO_2. Total suspended particulate sampling and analysis were carried out according to the same methodologies used by the RMBH network. Sulphur dioxide was sampled for 24 hours every 15 days using bubblers, and analysed by spectrophotometry using the

Table 7.2 Number of TSP sampling sites and samples collected by RMBH network each year

Year	1984	1985	1986	1987	1988	Oct 1991 to Sep 1992
Number of sampling sites	10	12	10	7	7	5
Number of samples collected	131	290	230	260	306	na
Data capture – per cent (assuming one day in six sampling protocol)	22	40	38	61	73	na

na = information not available.

Source: Liu et al., 1992

pararosaniline procedure. Five sampling sites were employed; these were located in residential, commercial and kerbside areas.

Quality assurance and data reporting

No quality control or quality assurance procedures were followed by either of the monitoring networks discussed above although some calibrations are performed. Data were processed manually and presented as daily, monthly and annual mean values by the RMBH network and as annual means by the CBH network. Data are not widely available to the public or reported in scientific journals although they are available on request. Data from the RMBH network have been presented at two conferences held in 1985 and 1992 (Esteves and Costa, 1985; Liu et al., 1992). Information on the monitoring network and methodology have also been published in an internal bulletin produced by CETEC (Costa, 1986; Tolentino, 1989). Data from CBH have not been published to date.

Emissions Inventories

No emissions inventories have been conducted for the city of Belo Horizonte since 1980; emission estimates are, however, available for the comparable cities of São Paulo and Rio de Janeiro. In both cities concentrations of SO_2 presented a problem owing to the high-sulphur oil and coal used by industry (WHO/UNEP, 1992). In São Paulo, a switch to low-sulphur fuel biomass, natural gas and electricity has resulted in a significant decline in SO_2 emissions in ambient air since the early 1980s. Emissions from large industries and diesel cars are probably the main sources of SPM in both cities. Caution should however be employed in extrapolating further emissions data from these two cities to Belo Horizonte as their industrial activities and fuel consumption differs considerably.

Air Quality Management

Each state in Brazil has the authority to lay down requirements for environmental control. Additionally, there is a general framework for environmental control drawn up by the federal government which is valid in those regions with no legislation of their own (IUAPPA, 1991). Air quality standards applicable to the State of Minas Gerais are those issued by the federal government: summarized in Table 7.3. Although these standards are law they are not subject to enforcement. Standards are within the European guideline ranges established by WHO, with the exception of SO_2 which has a daily maximum (365 $\mu g\ m^{-3}$) and annual mean (80 $\mu g\ m^{-3}$). The PM_{10} standards are the same as the USA Federal limits (WHO/UNEP, 1992).

The control of emissions from stationary sources varies in accordance with: state development policy; the extent of existing pollution; and/or, the polluting potential of a source (IUAPPA, 1991). In some of the more developed regions of Brazil, emission standards

Table 7.3 Air quality standards applicable to Belo Horizonte

Pollutant	Hourly maximum [(a)]	8-hourly mean	Daily maximum[(a)]	Annual mean
SPM	–	–	240	80
Black smoke	–	–	150	60
PM_{10}	–	–	150	50
SO_2	–	–	365	80
NO_2	320	–	–	–
CO[(b)]	35	9	–	–
O_3	160	–	–	–

Values as $\mu g\ m^{-3}$, unless otherwise specified.

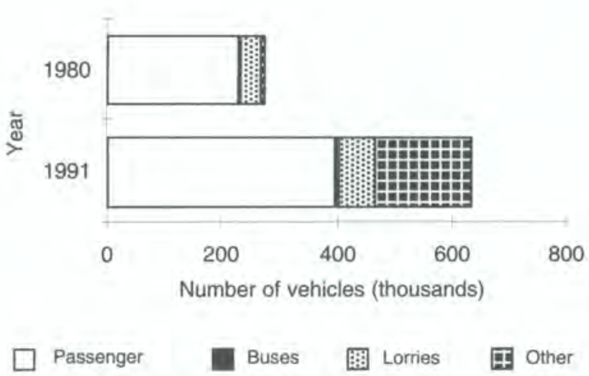
(a) Hourly and daily maximum should not be exceeded more than once a year.

(b) Values given as ppm.

Source: FEAM, 1994

are based on reasonable control technology; more stringent levels of control are enforced on potentially high sources of pollution and/or in areas where air quality standards are often exceeded (IUAPPA, 1991). The city of Belo Horizonte has established standards to control industrial emissions. If emission standards are exceeded the company responsible may be given a warning, fined or even forced to close. However, companies are not policed regarding their actual emission discharges and to date little has been done to control polluting industries. There are no strategic plans for reducing emissions by industry; nor are there any local regulations on domestic emissions.

The main air pollution problem in Belo Horizonte is believed to be caused by vehicle emissions; this source will become even more significant in the future as vehicle numbers continue to rise (FEAM, 1994). Vehicle registration numbers have more than doubled in the past 10 years, from a total of over 271,000 in 1980 to 634,000 in 1991 (Figure 7.4). In order to address the CO problem and other traffic-related emissions (NO_x, hydrocarbons and O_3), in 1986, the National Environmental Council enacted a resolution establishing a nation-wide Programme for Controlling Air Pollution from Motor Vehicles (known as PROCONVE). Emission limits for light and heavy-duty vehicles were set and have, over a number of years, been progressively tightened. These standards



Others includes motorcycles, commercial light vehicles, agricultural and construction machines.

Figure 7.4 Total vehicle numbers in Belo Horizonte for 1980 and 1991

Source: FEAM, 1994

Table 7.4 Emission limit for Brazilian alcohol- and petrol-fuelled light-duty vehicles (g km^{-1} unless specified)

	June 1988	January 1992	January 1997
CO	24	12	2
PM_{10}(a)	–	0.05	0.05
Hydrocarbons	2.1	1.2	0.3
NO_x	2.0	1.4	0.6
Aldehydes	–	0.15	0.03
Idle CO(b)	3.0	2.5	0.5

Limits only applicable to new vehicles.

(a) Only for diesel vehicles.

(b) Value as per cent volume; only for alcohol and gasoline (78 per cent gasoline and 22 per cent ethanol) vehicles.

Source: Faiz et al., 1992

have now reached the control levels currently in force in the USA for light-duty vehicles and in western Europe for diesel vehicles (IUAPPA, 1991). Tables 7.4 and 7.5 present the emission limits for light and heavy-duty vehicles respectively; including prospective changes up to the year 2002. Until 1991, exhaust emissions standards were such that they could be met by engine modifications alone. However, from 1992 onwards new vehicles require the use of open-loop catalytic converters to meet the tighter emissions standards. Standards similar to those already established in the US will take effect as from 1997, requiring 3-way catalytic converters (Faiz et al., 1992).

Brazil is one of the few countries, together with Zimbabwe, Kenya and the USA, that has extensively used ethanol as fuel. The increase in the use of alcohol-fuel occurred during the 1970s as a result of a combination of factors including rising oil prices, high interest rates and a crash in the world's sugar market. These economic factors encouraged the Brazilian government to invest in reducing petroleum imports. The government did this by introducing incentives encouraging the use of alcohol-fuel by both consumers and the car manufacturing industry; including a guarantee that pump prices of ethanol would not rise above 65 per cent of the price of gasoline. As a consequence the car industry started producing ethanol powered vehicles and by 1986, despite initial engine redesign problems, ethanol vehicles comprised approximately

90 per cent of all new car sales (Faiz et al., 1992). During the late 1980s the government began to increase the price of ethanol from 40 per cent of that of gasoline towards the 65 per cent limit. This policy, together with the suspension of credit subsidies for distilleries, was followed by a rapid fall in ethanol-fuelled vehicle purchases. However, these incentives have been restored since then; regaining public confidence and increasing the use of ethanol. Twenty-two per cent anhydrous ethanol is currently added to petrol, reducing the sulphur content of the fuel, as well as significantly reducing emissions of other pollutants such as CO, hydrocarbons, particles and sulphur oxides (IUAPPA, 1991). Ethanol is considered a cleaner-burning fuel than gasoline, but can result in excessive emissions of aldehydes. To take this into account, from 1992, new standards have been introduced to limit emissions of aldehydes as well as those of hydrocarbons, CO and NO_x (Table 7.5).

Table 7.5 Emission limits for heavy duty vehicles

<table>
<tr><th rowspan="3">Type of emission</th><th rowspan="3">Effective from</th><th rowspan="3">Applied for</th><th colspan="5">Emission limit</th></tr>
<tr><th>K(1)</th><th colspan="4">G/kWh</th></tr>
<tr><th>Smoke</th><th>CO</th><th>HC</th><th>NO_x</th><th>Particles</th></tr>
<tr><td rowspan="13">Exhaust</td><td>Oct 1987</td><td>Urban diesel buses</td><td rowspan="6">2.5</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Jan 1989</td><td>All diesel vehicles</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Jan 1994</td><td>All imported vehicles(4)</td><td rowspan="2">4.9</td><td rowspan="2">1.2</td><td rowspan="2">9</td><td rowspan="2">0.7/0.4(2)</td></tr>
<tr><td rowspan="2">Mar 1994</td><td>80% of national urban buses(4)</td></tr>
<tr><td>20% of national urban buses and
80% among other national diesel vehicles</td><td rowspan="2">11.2</td><td rowspan="2">2.4</td><td rowspan="2">14.4</td><td rowspan="2">–</td></tr>
<tr><td rowspan="2">Jan 1996</td><td>20% of national vehicles(4)</td></tr>
<tr><td>80% of national vehicles(4)</td><td rowspan="2">–</td><td rowspan="2">4.9</td><td rowspan="2">1.2</td><td rowspan="2">9</td><td rowspan="2">0.7/0.4(2)</td></tr>
<tr><td rowspan="3">Jan 1998</td><td>20% of national urban buses(4)</td></tr>
<tr><td>80% of national urban buses(4)</td><td rowspan="3">–</td><td rowspan="3">4.0(4)</td><td rowspan="3">1.1(4)</td><td rowspan="3">7.0(4)</td><td rowspan="3">0.15(3)</td></tr>
<tr><td>All imported vehicles(4)</td></tr>
<tr><td rowspan="2">Jan 2000</td><td>80% of national vehicles(4)</td></tr>
<tr><td>20% of national vehicles(4)</td><td rowspan="2">–</td><td>4.9</td><td>1.2</td><td>9.0</td><td>0.7/0.4(2)</td></tr>
<tr><td>Jan 2002</td><td>All vehicles(4)</td><td>4.0(3)</td><td>1.1(3)</td><td>7.0(3)</td><td>0.15(3)</td></tr>
<tr><td rowspan="5">Crankcase</td><td>Jan 1988</td><td>Urban diesel buses</td><td colspan="5" rowspan="3">Emission nil under any condition of engine operation</td></tr>
<tr><td>Jan 1989</td><td>All Otto cycle vehicles</td></tr>
<tr><td>Jul 1989</td><td>All natural aspiration diesel vehicles</td></tr>
<tr><td>Jan 1993</td><td>All turbocharger diesel vehicles</td><td colspan="5">Emission nil or included in the HC emission exhaust</td></tr>
<tr><td>Jan 1996</td><td>All turbocharger diesel vehicles</td><td colspan="5">Emission nil under any condition of engine operation</td></tr>
</table>

(1) $K = C \times \sqrt{G}$ where C = carbonic concentration (g m^{-3}) and G = nominal air flux (l s^{-1}). Applied to diesel vehicles only.

(2) 0.7 g/kWh to engines with power up to 85 kW and 0.4 g/kWh to engines with power greater than 85 kW. Applied to diesel vehicles only.

(3) To be confirmed by CONAMA until December 1994.

(4) Otto and diesel vehicles.

Limits only applicable to new vehicles.

Source: CETESB, 1994

Comment

Information on ambient air quality in Belo Horizonte is limited, with TSP the only pollutant to have a long time-series of measurements. TSP was monitored from 1984 to 1988; however, monitoring was frequently discontinued because of technical problems and limited resources; resulting in a high occurrence of days when no sampling was actually undertaken. Furthermore, sampling locations were often moved and few quality control or assurance procedures were followed. As a consequence, the sequences of TSP data contain gaps, there are inconsistencies, and the data are of relatively unknown quality and must therefore be considered with caution. One year of SO_2 measurements have been made; no data on concentrations of other pollutants are available.

No emissions inventory has been conducted in Belo Horizonte since 1980. The absence of recent emissions data, coupled with the limited information on ambient concentrations, means that there are insufficient data to analyse the local air quality situation and to develop appropriate air quality management strategies. Industry and emissions from diesel-powered engines are probably the main sources of TSP in the city. Other Brazilian cities such as Rio de Janeiro and São Paulo have experienced severe SO_2 problems due to the high sulphur content of fuel oil (of up to 5 per cent) and coal (up to 3 per cent) used by industry (WHO/UNEP, 1992). Although 1992-1993 annual mean SO_2 concentrations measured in Belo Horizonte were at or below the federal air quality standard (80 $\mu g\ m^{-3}$) they were still significantly higher than the WHO Air Quality Guideline (40–60 $\mu g\ m^{-3}$) (WHO, 1987). With further industrialization SO_2 concentrations are liable to increase and the greater use of fuels with a lower sulphur content, as adopted in São Paulo in the early 1980s, may need to be considered (WHO/UNEP, 1992). Further monitoring of SO_2 is essential to determine the current ambient concentration and to observe future trends; it is especially important to introduce sampling sites into industrial zones.

Levels of NO_x, CO and O_3 may be a problem in the city owing to the constant high ambient temperature, intense insulation, topography and the increasing number of vehicles in the city centre (encouraging photochemical reactions and therefore O_3 formation). Although no information is currently available on lead concentrations for Belo Horizonte, the long-term policy of gradually reducing the tetraethyl lead content of the local (alcohol-blended) petrol combined with the widespread use of alcohol-fuelled vehicles probably means that high lead emissions are unlikely. However, emissions of some hydrocarbons, particularly aldehydes, are likely to increase with car ownership. The introduction of more stringent emissions limits for light and heavy-duty vehicles should help towards stabilizing emissions and future ambient concentrations. However, the likely increase in vehicle numbers and distances travelled mean that an overall reduction in motor vehicle emissions will be difficult to achieve. Emissions controls are, at present, only imposed upon new vehicles; limits and inspection procedures may need to be introduced for all vehicles – particularly if their numbers continue to expand rapidly.

It is important to recommence monitoring for SPM and SO_2; to increase the monitoring capability of the city and to obtain information on ambient air concentrations of other relevant pollutants such as PM_{10}, CO, hydrocarbons, NO_2 and O_3. This information should then be considered alongside meteorological data such as dispersion conditions and frequency of inversions. Regular monitoring would allow the determination of the extent of the air pollution problem in Belo Horizonte, as well as spatial and temporal trends. Monitoring would also assist in the formulation and refinement of air quality policies; tracking the degree of success following the introduction of new legislation aimed at reducing emissions. However, the quality of the data should also be known; improved data quality, in addition to quantity, is important.

The Região Metropolitana de Belo Horizonte is committed to establishing a permanent air quality monitoring network measuring SPM, SO_2, NO_2, CO, PM_{10} and O_3. This authority is also aware of the importance of having an adequate air quality management capability. At present the RMBH is seeking financial assistance for this air quality programme. The use of active and passive samplers may be preferable to the establishment of an automatic monitoring network as these samplers are cheaper to set up and have lower running costs. Lower costs may, in turn, allow for the establishment of a greater number of sampling sites and therefore provide a more representative picture of air pollution problems in different areas of the city. Unless there is strong technical support and long-term financial backing it is difficult to continuously operate an automatic network, resulting in the generation of inconsistent data sets. An emissions inventory would also be a good air quality management tool; determining which are the main pollution sources to be targeted for pollution reduction. Targeting emissions sources identified by an emissions inventory can achieve, in the most efficient manner, an overall reduction in the ambient air concentrations.

Summary

- Suspended particulate matter has been monitored at various locations in the city from 1984 until 1992. Sulphur dioxide measurements were also taken for a period of one year in 1991/92. The quality of the data generated is not known.
- Suspended particulate matter concentrations are high at most sampling locations. Sulphur dioxide concentrations are generally within the federal air quality standards although significantly above WHO Guidelines.
- No monitoring has yet been carried out to determine levels of NO_2, PM_{10}, O_3, CO or Pb. However, there is a plan to introduce an automatic monitoring network to measure many these compounds; financial assistance needs to be found.
- No emissions inventory has been conducted for Belo Horizonte since 1980.
- Ambient air quality standards and emissions standards exist, but compliance by industry is unknown due to lack of monitoring facilities and resources.
- Vehicle emissions for new vehicles have been set by central government. These have become more stringent over the years and should contribute towards reducing, or at least stabilizing, current emissions from vehicles.

References

CETESB 1994 *Questionnaire response: Air Quality Standards questionnaire*, Companhia de Tecnologia de Saneamento Ambiental, São Paulo.

Costa, D. M. 1986 *Monitoracão da qualidade do ar na Região Metropolitana de Belo Horizonte/RMBH Belo Horizonte*, CETEC.

Esteves, O. A. and Costa, C. C. 1985 *Poluicão atmosferica na Região Metropolitana de Belo Horizonte. Fontes industrials, medicões ambientais, In; Simposio Situacão Ambiental e Qualidade de Vida na Região Metropolitana de Belo Horizonte*, Associacão Brasileira de Geologia de Engenharia e Instituto de Geociências – UFMG, 28–31 May, 1985.

Faiz, A., Weaver, C., Sinha, K., Walsh, M. and Carbajo, J. 1992 *Air Pollution from Motor Vehicles*, World Bank, Washington, DC and UNEP Industry and Environment Office, Paris.

FEAM 1994 *Questionnaire response: Air Quality Monitoring and Assessment Capabilities questionnaire*, Fundacão Estadual do Medio Ambiente, Belo Horizonte, Minas Gerais.

IUAPPA 1991 *Clean Air Around the World*, 2nd Edition, Loveday Murley (Ed.), International Union of Air Pollution Prevention Association, Brighton.

Liu, B. W. Y., de Morais, F. M. B. and da Silveira, I. L. 1992 *Situacão da monitoracão da qualidade do ar na Região Metropolitana de Belo Horizonte*, presented at II Congresso Latino-Americano de Ecologia and I Congresso de Ecologia do Brasil, 6–11 December, 1992, Caxumbu, Minas Gerais, Brazil.

Tolentino, J. A. 1989 *Monitoracão da qualidade do ar na Região Metropolitana de Belo Horizonte/RMBH Belo Horizonte*, CETEC.

WHO 1979 *Sulfur Oxides and Suspended Particulate Matter*, Environmental Health Criteria 8, World Health Organization, Geneva.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

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

8

Birmingham

Statistical Summary

Country: UK
Estimated population 1990 (millions): 3.02
Projected population 2000 (millions): 3.10
Map reference: 52°30'N, 1°50'W
Area (km²): 500
Altitude (m): 183–300
Climate: Maritime
Average temperature range (C): 3–15.5

Situational Analysis

Birmingham is the UK's second largest city. It is located in central England and is part of an urban agglomeration which comprises the "Midlands". Historically this area was considered the manufacturing centre of the UK. The economic recession of the early 1980s had a devastating effect on these manufacturing industries. Between 1978 and 1989 there was a 62 per cent decline in metal, mineral and chemical manufacturing employment, 44 per cent in metals and vehicles, and 30 per cent in construction and other manufacturing (BCC, 1991). During this same period finance and business employment in Birmingham increased by 54 per cent.

The major part of air pollution emissions in the city is from mobile sources. Birmingham acts as a central focus of the UK's road network; no part of the city is more than six miles from a motorway, with five motorways converging in or on the city boundaries and with radial routes connecting these to the city centre (Figure 8.1). Unleaded petrol is now widely used in vehicles and airborne lead concentrations (averaging 0.21 $\mu g\ m^{-3}$ in 1992) are well below WHO guidelines (0.5-1.0 $\mu g\ m^{-3}$) (WHO, 1987). The introduction of compulsory catalytic converters on all new petrol-engine cars is projected to reduce emissions of nitrogen oxides and particulates during the next 10 years; despite the expected growth in traffic volume. There is currently some concern that this improvement in air quality will be at least partially offset by the increased market penetration of diesel engine cars; currently about 20 per cent of cars in the UK (QUARG, 1993). Fifty-seven per cent of commuters in Birmingham travel to work by car compared with 13 per cent by train. The rail network comprises 160 km of track, half of which is electrified and half running diesel locomotives.

The main legislation controlling pollution in the UK is the Environmental Protection Act. Under this act polluting industries in the UK are classified as Part A or B processes depending on their size and the nature of their emissions. In Birmingham there are five sites registered under Part A (larger emitters): four combustion processes and an incinerator. There are 191 Part B registered plants: 42 per cent involving printing or coating processes of some kind, 61 per cent of which are located in inner city wards of Birmingham. There are no major power generation facilities in Birmingham; electricity being supplied through the national grid. There are also no large petrochemical plants, refineries, smelting or iron and steel production.

Domestic heating is generally required between October and April and predominantly uses natural gas because Birmingham is a smoke-control area. Domestic coal burning, historically significant, is no longer permitted; consequently, levels of sulphur dioxide (SO_2) and smoke have fallen to low levels (Figure 8.2). Monitoring for nitrogen dioxide (NO_2) has only taken place since 1986 and results indicate

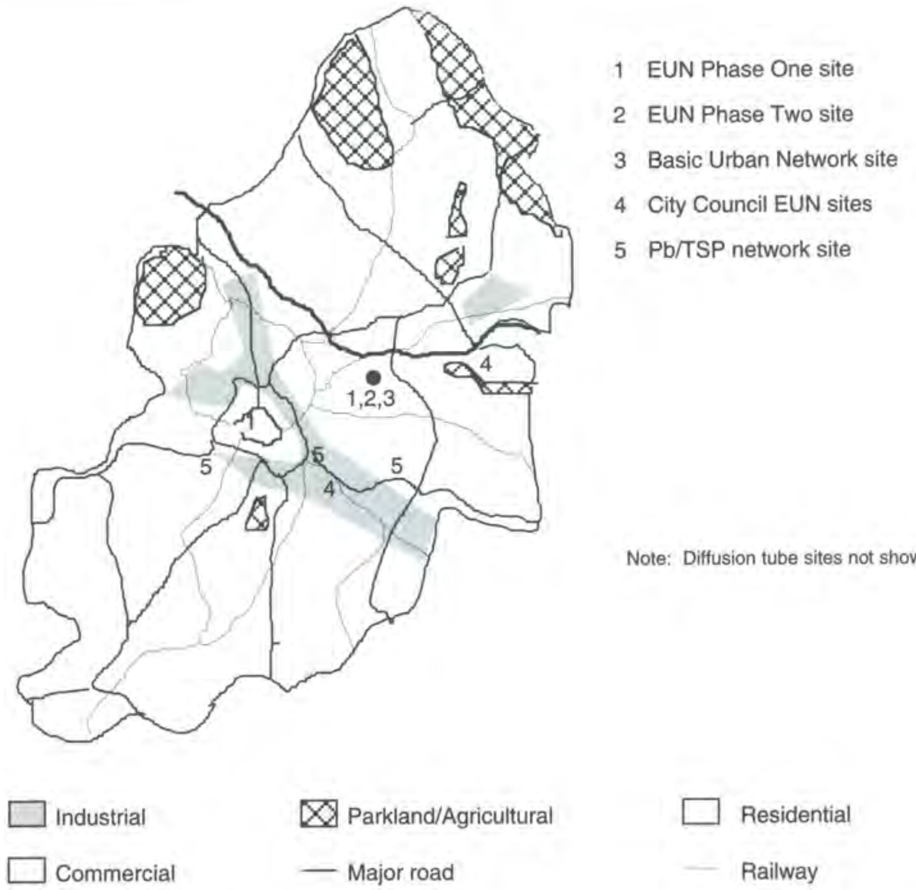


Figure 8.1 Sketch map of land use and monitoring sites in Birmingham

Source: BCC, 1991

an approximately flat trend as industrial emissions have fallen, but those from motor vehicles have increased.

Air quality in Birmingham is generally good, or very good, as defined by the UK Department of the Environment (Table 8.1) (WSL, 1994). From April 1992 to April 1993 exceedances of WHO guidelines were rare (Table 8.2). One such event occurred during an air pollution episode in December 1992 when concentrations of SO_2, NO_2 and particulate matter became especially elevated. The daily mean concentrations through this episode for particulate matter less than 10 µm (PM_{10}), SO_2 and NO_2 as measured by the Enhanced Urban Air Network site in central Birmingham are shown in Figure 8.3. Chronic effect WHO guidelines for sulphur dioxide and black smoke and lead are not approached in Birmingham.

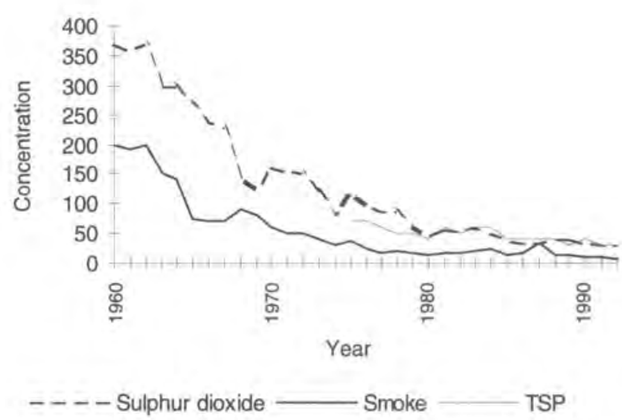


Figure 8.2 Annual mean sulphur dioxide and smoke concentrations, 1960–1992

Source: BCC, 1993

Table 8.1 UK and BCC air quality bands (μm-3)

Band	DoE NO_2	BCC NO_2	DoE SO_2	BCC SO_2	DoE O_3	BCC O_3
Very good	<95	<48	<160	<82	<100	<44
Good	95–190	49–143	160–330	83–250	100–180	45–134
Mediocre	–	144–191	–	251–332		135–180
Poor	191–574	192–574	331–1,064	333–1,064	181–360	181–360
Very poor	>574	>574	>1,064	>1,064	>360	>360

Source: WSL, 1994; BCC; 1991

Table 8.2 Exceedances of WHO acute air quality health guidelines in Birmingham, April 1992–93 as measured at the EUN monitoring station – Centenary Square

Pollutant	Time weighted averaging period	Guideline	Days in which exceedence occurred
Nitrogen dioxide	1 hour	400 $\mu g\ m^{-3}$	0(1)
	24 hours	150 $\mu g\ m^{-3}$	0(1)
Sulphur dioxide	1 hour	350 $\mu g\ m^{-3}$	4
	24 hours	125 $\mu g\ m^{-3}$ (2)	1
Carbon monoxide	15 minutes	100 $mg\ m^{-3}$	Not known(3)
	30 minutes	60 $mg\ m^{-3}$	Not known(3)
	1 hour	30 $mg\ m^{-3}$	0
	8 hours	10 $mg\ m^{-3}$	0
Ozone	1 hour	150–200 $\mu g\ m^{-3}$	2
	8 hours	100–120 $\mu g\ m^{-3}$	2
PM_{10}	24 hours	70 $\mu g\ m^{-3}$ (4)	4

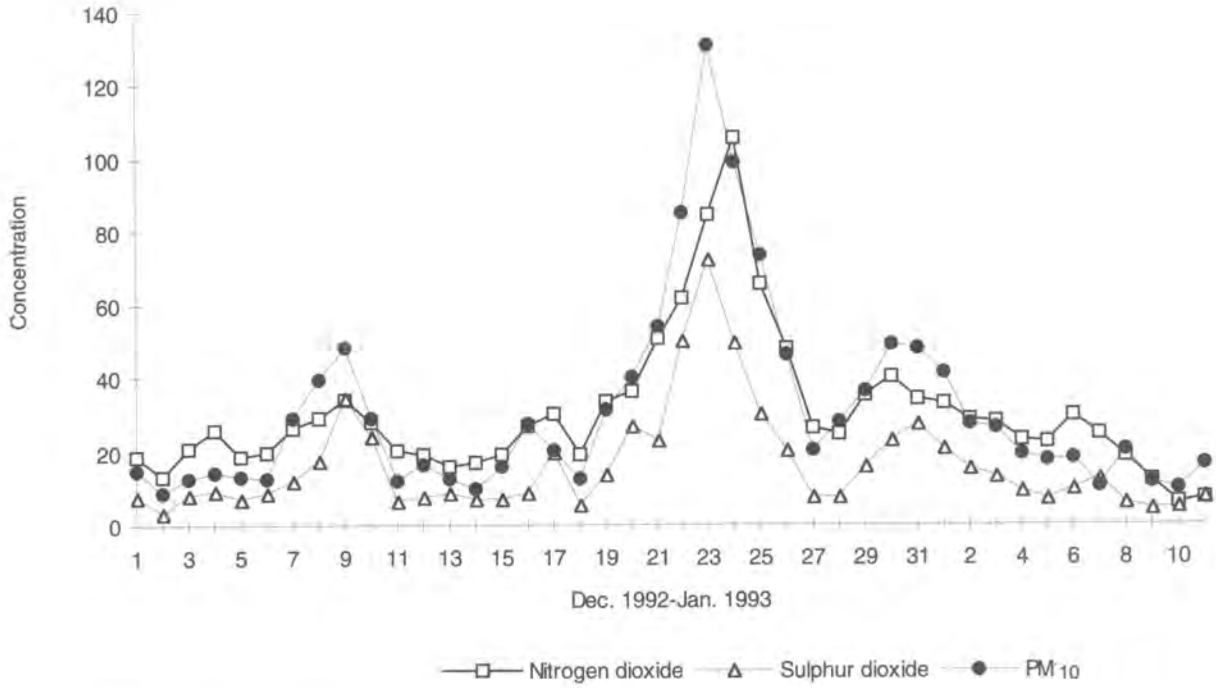
(1) Data from the December 1992 episode exceeded WHO guidelines but were removed during the data validation process owing to an inefficient molybdenum converter on the analyser identified during subsequent site audit.

(2) Combined smoke guideline.

(3) Unavailable as shortest averaging time for which data are available is 1 hour.

(4) Guideline is for thoracic particles, to which PM_{10} is approximately equivalent and is a combined standard with SO_2.

Source: WSL, 1994



Units: NO_2 and SO_2 (ppb), PM_{10} (µg m^{-3}).
Note: NO_2 data were subsequently unratified owing to an inefficient molybdenum converter – NO_2 concentrations were therefore likely to be higher than those shown.

Figure 8.3 Air quality during a pollution episode in December 1992 as monitored by the EUN site at Centenary Square, Birmingham

Source: Walters *et al.*, in press

Monitoring Networks

Air quality monitoring in Birmingham is conducted on behalf of the UK Department of the Environment (DOE) and the Birmingham City Council (BCC) Environmental Services Department. There are five networks in operation: The Enhanced Urban and Basic Urban Networks which are national networks, and three networks operated by the city council: the Diffusion Tube Network (which also includes some sites which are part of the National Diffusion Tube Survey), the City Council Enhanced Urban Network and the TSP and Pb monitoring network (see Table 8.3 and Figure 8.1). The BCC Environmental Services Department is responsible for the day-to-day operation of all sites in the city (BCC, 1994a).

The Enhanced Urban Network

The Enhanced Urban Network (EUN) is a relatively new national network, operated on behalf of the UK DOE, and designed to provide continuous on-line data of background urban pollutant concentrations (sites not directly influenced by adjacent point or line sources). It is operated principally to provide public information. Data are collected continuously; 15-minute averages are determined and collated as hourly mean values on the EUN data base. There is currently a "Phase One" EUN site located in the city centre at Centenary Square monitoring: nitrogen oxides (NO, NO_2 and NO_x) by chemiluminescence; SO_2 by fluorescence; ozone (O_3) by UV photometry; carbon monoxide (CO) by infra-red absorption and PM_{10} by Tapered Element Oscillating Microbalance (TEOM). A second EUN site

Table 8.3 Monitoring networks in Birmingham

Network	Organizations responsible	Period of operation	Network objectives	Sites
Enhanced Urban	UK DOE	1992–present	Monitoring of background urban air; compliance with guidelines; issuing of forecasting and warning alerts	2
Basic Urban	Birmingham City Council, Environmental Services Department (operated as part of a national network)	1962–present	Monitoring at urban centres and industrial sites; compliance with guidelines; source determination	2
City Council Enhanced Urban	Birmingham City Council, Environmental Services Department	1992–present	Monitoring of background urban air; compliance with guidelines; issuing of forecasting and warning alerts	3
TSP and airborne metals	Birmingham City Council, Environmental Services Department	1975–present	Monitoring of trends and spatial distribution	3
Diffusion Tube	Birmingham City Council, Environmental Services Department	1987–present	Monitoring of trends and spatial distribution at roadside and background urban sites	20

Source: BCC, 1994a

is located in Washwood Heath, a mixed residential and industrial suburb about 5 km from the city centre, measuring hourly concentrations of 28 different hydrocarbon species ("Phase 2" EUN pollutants) including benzene and 1,3-butadiene, in addition to hourly concentrations of the "Phase One" pollutants.

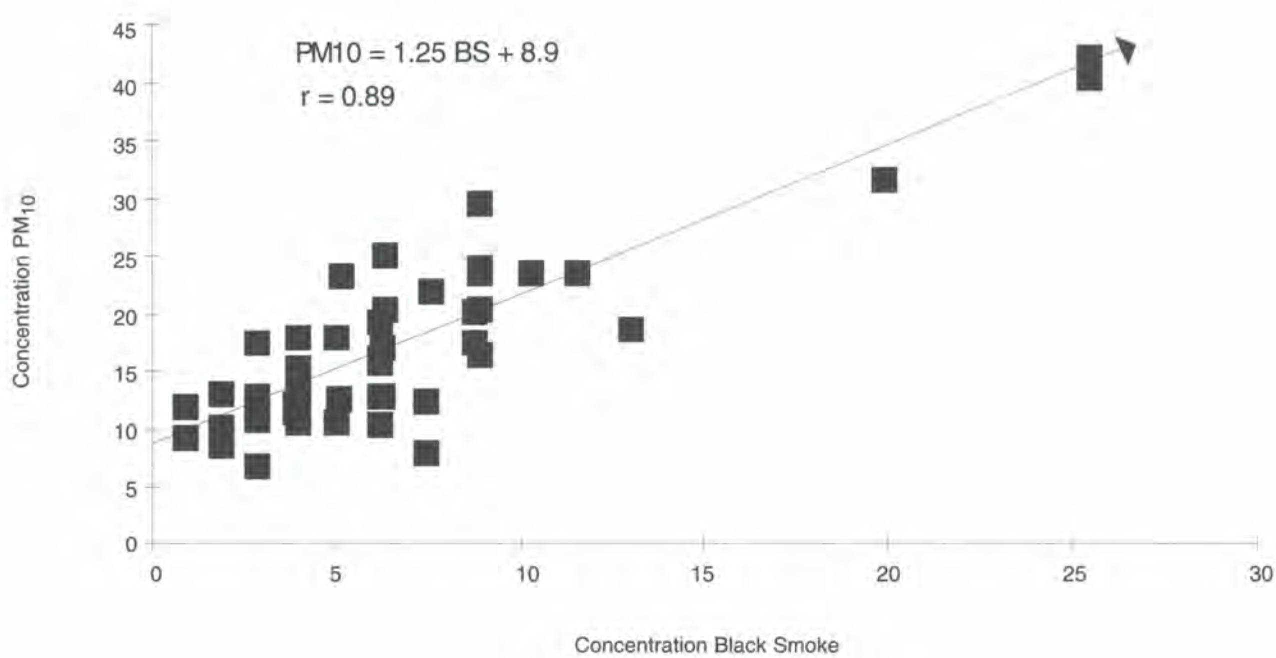
The Basic Urban Network

The Basic Urban Network consists of two sites designed to measure long-term trends in SO_2 and particulate concentrations at city centre and industrial sites through the provision of daily average values. Sulphur dioxide measurements are made by the Net Acid technique and particulates are measured by British Black Smoke which measures the soiling capacity of the air upon a filter. The method for black smoke compares the darkness of a filter, through which air has been drawn, with a standard curve established at the time of the method's introduction in the 1960s which relates particulate concentration to reflectance. Since the calibration was first performed the composition of particulate matter in the UK has altered considerably. The soiling capacity of the air in urban areas is now mostly caused by diesel emissions rather than domestic coal burning and, consequently, the calibration of darkness to mass of particulates has altered. One of the basic urban monitoring sites is co-located with the EUN site in Washwood Heath, enabling comparison of particulate matter measurements made for black smoke and PM_{10} (Figure 8.4). The figure clearly demonstrates a strong daily correlation between measurements made by the two techniques and shows the error which now exists in the standard curve used to relate particulate concentration to reflectance in the black smoke method.

Basic urban sites are reviewed every five years to ensure that the character of the sites has not changed appreciably. The number of sites in this network, located in Birmingham, have been reduced from 15 to 2 as levels of urban SO_2 have fallen to low levels and black smoke measurements have become obsolete as a measure of particulate concentration.

City Council Monitoring Networks

Birmingham City Council conducts a considerable amount of air quality monitoring; providing additional information on air quality to that supplied by the national monitoring networks. Monitoring is conducted primarily to assess the extent of public and environmental health problems in the city; there is no legal requirement upon the council to conduct measurements. The monitoring conducted specifically by Birmingham City Council is broadly divided into three networks: the City Council Enhanced Urban Network, the Nitrogen Dioxide Diffusion Tube Network and the TSP and Airborne Metals Network.



Note: Winter ratios differ and the data set is quite small – the relationship derived is, therefore, an example only.
r = regressive co-efficient.

Figure 8.4 Comparison of particulate concentrations by the EUN TEOM system and Basic Urban Network black smoke methodologies, Summer 1993

Source: BCC, 1993

The City Council Enhanced Urban Network has two permanent sites: one adjacent to a major arterial road measuring CO and NO, NO_2 and NO_x and another close to a motorway passing through the city measuring NO, NO_2, NO_x, SO_2, PM_{10} and $PM_{2.5}$. The co-located PM_{10} and $PM_{2.5}$ monitors are intended to provide continuous information about the size fraction of particles in the city (at present, in the UK, there is considerable interest in the size fractions of particles and their relationship with respiratory health). One of these instruments is fitted with an Automatic Cartridge Calibration System (ACCU) which enables particles in the bypass flow to be collected on a filter and analysed. This was not previously possible with the TEOM system. The council also operates a mobile air quality monitoring unit comprising of continuous analysers for SO_2, NO_2, NO, NO_x, O_3 and PM_{10}; together with meteorological sensors for temperature, humidity, wind speed and wind direction. The mobile unit is used for short study periods to identify areas in which air quality problems exist.

The Nitrogen Dioxide Diffusion Tube Network is used to determine the spatial distribution of NO_2 across the city and to determine concentration trends. Palmes Tubes are used with a monthly sampling period; analysis is performed by colorimetry using the Saltzman technique. Monitors are located at background and near-road sites; predominantly in residential areas. The near-road sites are used to identify areas in which there is concern regarding the levels of NO_2. All sites are reviewed annually. Some sites in the diffusion tube network are co-located with continuous instruments to provide an inter-comparison of techniques.

The City Council also operates three sites which monitor for TSP and airborne metals (particularly Pb) on a weekly basis, using an intermediate flow rate. The number of sites in this network has been recently reduced owing to falling ambient Pb concentrations resulting from the increased and increasing use of unleaded petrol.

Other monitoring

Other monitoring is carried out for research purposes on an ad-hoc basis. These have included monitoring by the city council using a Differential Optical Absorption Spectrometry (DOAS) instrument and measurements of less frequently monitored species including polynuclear aromatic hydrocarbons (PAHs), aerosol strong acidity and nitrous acid by the University of Birmingham. Epidemiological studies have also been conducted by the University of Birmingham in collaboration with a local hospital on the effects of pollution upon respiratory health in Birmingham.

Quality assurance and control

The quality assurance and control procedures (QA/QC) used in Birmingham vary between the different monitoring networks but are generally of a very high standard – particularly the national monitoring sites which undergo vigorous data checking; including site auditing conducted by independent bodies. All the networks undergo regular weekly calibration checks and data validation following prescribed procedures; site locations are checked periodically to ensure instrument siting remains adequate to meet monitoring objectives.

The practice of co-locating different monitoring instruments is extensively applied in Birmingham and provides important inter-comparison data from different measurement techniques and networks. In the Basic Urban network, black-smoke monitors and those using the net-acid method of measuring SO_2 are co-located at the EUN site in Washwood Heath which also measures PM_{10} and SO_2 using state-of-the-art instruments. A further example of a regular inter-comparison exercise conducted to continue a long historical data set is the co-location of diffusion tubes (used to measure spatial distribution of NO_2) with a continuous analyzer by the EUN in Centenary Square; this methodology also enables validation of the less sophisticated technique.

Data analysis and reporting

Techniques of data analysis and reporting vary between the national and city council-operated monitoring networks; depending on the individual network objectives. Data assessments of national networks are conducted predominantly by the National Environmental Technology Centre and findings are published in reports and annual summaries (WSL, 1994). Data from the EUN are used principally for public information and are disseminated through the media during periods of poor air quality. They are available at all times on CEEFAX – a television text information service. Episodes of poor air quality are also predicted by the Meteorological Office using EUN data and are now used to control emissions from some large point sources during unfavourable meteorological conditions for dispersion.

Public understanding of air quality has been enhanced by the introduction of an air quality classifications banding system by the UK Department of the Environment and Birmingham City Council. The difference between the bandings is a result of the council believing five bands provide a more coherent picture than the four used by the UK Department of the Environment; examination of Table 8.1 demonstrates that they are very similar.

The Department of the Environment air quality bands can be accessed via a national telephone line and provide up-to-date information on air quality in different parts of the UK. The service includes advice on appropriate behaviour when air quality is in either the "poor" or the "very poor" band. This information is especially useful for members of vulnerable groups such as asthmatics.

Information from city council-operated monitoring sites is not as widely disseminated as that from the EUN; although a state of the environment report for the city was produced in 1991 and data are available in the public library on request in internal council documents. A summary of the data assessments and reporting undertaken by the different monitoring networks operating is shown in Table 8.4.

Emissions Inventories

No emissions inventory has been conducted to date in Birmingham; one is planned for 1994–95. This will be extensive: covering not only the area within the city boundary, but also the surrounding residential/industrial areas of Wolverhampton, Dudley and Sandwell. The inventory will include both fixed and mobile emissions sources for a number of air pollutants.

An emissions inventory calculated on a 20 km^2 basis for the whole of the UK (Eggleston et al., 1992) for NO_x and SO_2 can be used as a first approximation for

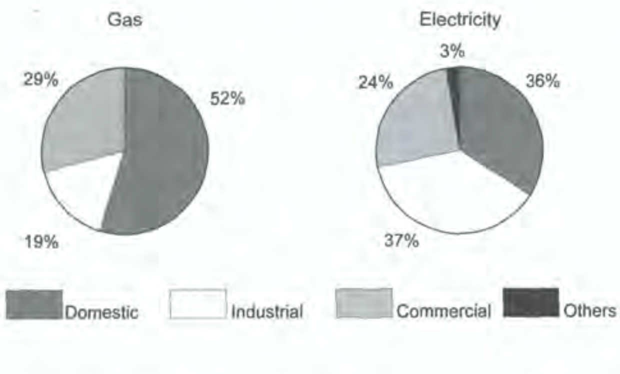
Table 8.4 Data assessment and reporting in the monitoring networks operating in Birmingham

	EUN	Basic	Council EUN	Diffusion tube	TSP/Pb
Data processed by computer	+	+	+	+	+
Inter-comparisons between networks carried out	+	+	+	+	–
On-line data acquisition	+	–	+	–	–
Long-term trends analysed	–	+	+	+	+
Temporal variations examined	+	+	+	-	+
Spatial distributions determined	–	–	+	+	+
Exceedences of air quality standards recorded	+	+	+	–	+
Modelling carried out using the data	+	–	–	–	–
Annual data reports published	+	+	–	–	–
Data freely available	+	+	+	+	+
On-line data availability	+	–	–	–	–

Source: BCC, 1994a

estimation of emissions of these gases in Birmingham (the boundaries of the 20 km squares do not correspond precisely with those of the city). Using these figures, about 34,200 t of NO_2 were emitted from the vicinity of the city in 1989; with emissions per 20 km^2 grid within the city ranging between 6,024 t and 10,518 t. Emissions of SO_2 for Birmingham in 1989 were estimated at 14,699 t, with emissions ranging between 1,653 t and 7,082 t (per 20 km^2). These values are typical of urban air emissions in the UK. Emissions within the city are predominantly from mobile sources and engineering/manufacturing plants. There have been no major power generating facilities in the city since the early 1980s and demand is met predominantly by coal-burning power stations at least 40 miles to the north-east of the city (supplied through the national grid). Electricity consumption has grown overall by 20 per cent during the last decade; but it has remained relatively level during the past three years owing to a combination of mild winters and economic recession. Natural gas consumption is predominantly by domestic consumers for heating of individual houses and cooking. Sales of electricity and gas to different sectors are shown in Figure 8.5.

There are no readily available estimates of solid and liquid fuel consumption in Birmingham. An *ad hoc* survey by the BCC Engineers' Department estimated a total of 416 million litres sold in 1991–92 (BCC, 1993). Birmingham is a smoke control area and therefore domestic coal burning is negligible.



Gas sales ending March 1991 for Birmingham; electricity supplies ending 1993 for the Midlands.

Figure 8.5 Sectoral electricity and gas sales in the Midlands area

Sources: British Gas, 1991; Midland Electricity Board, 1993

Mobile sources, in particular motor vehicles, constitute the most important source of urban air pollution emissions. Approximately 68,400 people travel into Birmingham daily by car and there is extensive congestion across the city during peak periods. Between 1980 and 1989, daily flows into the city increased by 25 per cent. Since 1985 there has been a 10 per cent rise in traffic outside of peak periods causing "peak spreading".

There are no estimates of the contribution of vehicle emissions in Birmingham to air quality and it is not appropriate to extrapolate findings from the London emissions inventory. London has a somewhat different commuting pattern to other UK cities, with a higher proportion of journeys being made by public transport and diesel taxis, and with slower average traffic speeds.

Estimates of emissions in Birmingham are poorly known but will be considerably better identified after an inventory is conducted in 1994–95. The addition of this component to Birmingham's monitoring capability will be important for planning considerations in the future.

Air Quality Management

Air quality management in the UK is predominantly the responsibility of national government and emissions have traditionally been controlled through the use of non-statutory emissions standards implemented through a pollution inspectorate. European Union (EU) regulations introduced since 1980 have added a second dimension to these controls with the adoption of air quality standards for health protection; implemented through the *UK Air Quality Standards Regulations*. There are currently directives for SO_2 and suspended particulates/smoke, NO_2 and, recently, O_3. The Directives comprise non-mandatory guide values and mandatory limit values. The Ozone Directive also incorporates public information and warning levels which it is intended will be introduced for the other Directive pollutants in the future. The European Commission's Fifth Action Programme *Towards Sustainability* contains a commitment to review air quality directives before 1995, including expanding the range of pollutants for which guide and limit values are set. The programme also contains a commitment to harmonize monitoring procedures. There is no EC Directive site for NO_2 in Birmingham, the closest being in Walsall, about 15 km away. This is because the UK Department of the Environment considers that Birmingham would be unlikely to exceed the Directive on the basis of previous measurements.

Emissions from stationary sources in the UK are currently controlled by the Environmental Protection Act (1990) (EPA). Smoke emissions are predominantly controlled by the Clean Air Act (1993), introduced to consolidate a number of other acts. The Clean Air Act controls emissions of smoke and dust, predominantly to prevent statutory nuisance, including the implementation of "Smoke-free zones" and legislation on the maximum sulphur content of different fuels and of lead in petrol (currently 0.15 g l^{-1}).

The EPA operates the principle of Integrated Pollution Control (IPC) by which it is recognized that a reduction in the release of a pollutant to one medium may have implications for another and that the Best Practicable Environmental Option (BPEO) should be applied. The EPA assigned responsibility for controlling emissions from potentially major sources (Part A processes) to Her Majesty's Inspectorate of Pollution (HMIP); smaller sources of emissions (Part B processes) are the responsibility of local government: in the case of Birmingham the responsibility of the City Council Environmental Services Department. Details of the different industrial processes registered in Birmingham under Part B of the EPA are given in Figure 8.6. Emissions are controlled on the principle of Best Available Techniques Not Entailing Excessive Cost (BATNEEC). Public registers of processes under their control are held by the relevant responsible authorities which charge fees in order to recover their costs.

Local authorities are provided with General, Process and Technical Guidance Notes covering each of the Part B process sectors as an aid in setting conditions for authorizations. These provide details of what constitutes BATNEEC for each category of process; including details of emissions limits and controls, monitoring, sampling and the measurement of emissions. In granting an authorization the local authority must consider whether the process will preclude compliance with UK and EU air quality regulations and standards and adhere to other relevant legislation (such as the Clean Air Act). Comments from members of the public and the ability of the applicant to meet the terms of the authorization are also important. Local authorities are required to institute a programme of site inspections and monitoring and to carry out reviews every four years; they can also issue abatement notices to prevent further breaches of the authorization. Failure to obtain or implement the terms of an authorization carries the penalty of an unlimited fine and up to two years imprisonment.

Between April 1992 and March 1993 there were a total of 1,294 calls for assistance to the BCC Environmental Services Department relating to air quality. Calls regarding industrial or commercial premises are usually investigated within two working days; those regarding domestic houses within five working days. Informal methods and persuasion by Environmental Health Officers meant that no abatement orders were served during this period and there was only one prosecution (under the Clean Air Act) relating to dark smoke emissions. There were two prosecutions under Part A of the act by HMIP in Birmingham regarding failure to comply with smoke and dust emissions controls; for one of which a £1,000 fine was levied, and another with regard to radioactive substances, for which the fine was £51,000.

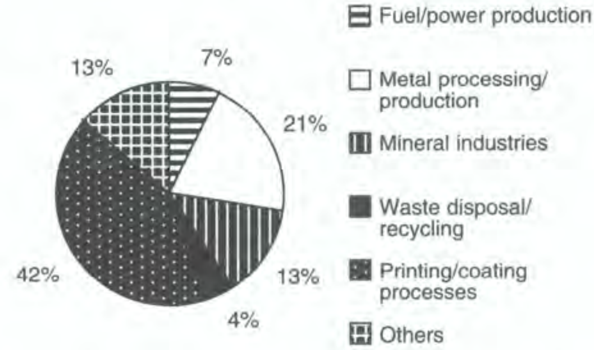


Figure 8.6 Proportion of different industrial processes registered under Part B of the Environmental Protection Act in Birmingham

Source: BCC, 1991

Emissions from mobile sources in the UK are controlled by EC regulations. Current regulations on passenger vehicles were implemented by *Directive 91/441/EEC* (Table 8.5) and have been mandatory on all new cars since the beginning of 1992 (except those with direct injection diesel engines which have until 1995 to meet the requirements). To meet the standards, all new petrol-engine cars require fitting with three-way catalytic converters and diesel engines with state-of-the-art emissions reduction technology. New proposals seeking to make these measures mandatory for all new models from 1996 and new registrations from 1997 have also been proposed. These apply different standards to petrol and diesel vehicles and make no differentiation between type approval and conformity of production (see Table 8.5 and footnotes). Fiscal incentives may be offered to encourage manufacturers to implement the tighter regulations before they become mandatory. A further tightening of emissions will be proposed in mid-1994; to be implemented by the year 2000 taking account of EC air quality targets, technological advances and improvements in fuel quality.

Emissions limits are set by the EC for light and heavy commercial vehicles. Light commercial vehicles are controlled under *Directive 93/59/EEC* which comes into force for all new vehicles in October 1994. Vehicles are classified in three categories depending upon their mass. Petrol-engine vehicles are required to fit three-way catalytic converters and carbon canisters to meet emissions limits; diesel vehicles require engine modifications or two-way catalytic converters. A reduction of these limits is proposed for new vehicles from 1996. Emissions from heavy-duty vehicles, over 3.5 tonnes, have been limited since 1972 and gradually tightened since that time. Current limits were set by *Directive 91/542/EEC* which acts in two stages becoming effective for all new vehicles in October 1993 and 1996 respectively. The Directive introduces a mass-based standard for particulate emissions, replacing the visibility criteria originally used and matches the strict US 1994 diesel standard. The limits will require an improvement in diesel fuel quality to reduce the sulphur content (in order to reduce emissions of sulphate aerosol) to 0.2 per cent, and later to 0.05 per cent by mass.

Table 8.5 EC light duty vehicles emissions limits – current and prospective

	Emissions limit g km^{-1}		
Standard – 91/441/EEC	**CO**	**$HC+NO_x$**	**Particulates**
Type approval (1)	2.72	0.97	0.14
Conformity of production (2)	3.16	1.13	0.18
Standard – COM(92)572			
Petrol engines	2.2	0.5	(3)
Diesel engines – indirect injection	1.0	0.7	0.08
Diesel engines – direct injection (4)	1.0	0.9	0.10

(1) Standard imposed on new models.
(2) Standard imposed on all new registrations.
(3) Emissions of particulates for petrol-engine vehicles are considered negligible.
(4) Limit until 30/9/99; HC+NOx is total hydrocarbons plus total nitrogen oxides.

Source: NSCA, 1994

Emissions from existing, as distinct from new, vehicles are controlled by the EC Roadworthiness Directive. These include emissions limits which in the UK are checked annually in the MOT test which all vehicles must pass in order to be driven. There is some concern that the emissions regulations are flouted by unscrupulous vehicle inspectors who issue MOT certificates to unroadworthy vehicles and who also tune a car's engine to ensure that it passes the test and then re-tune it to provide greater power; abuse of these regulations is, however, not common. There are further EC Directives on petrol storage and distribution; designed to limit VOC emissions.

Beyond the national air quality emissions limits and standards which apply throughout the UK (with the exception of some in Northern Ireland), Birmingham City Council has made a strong commitment to environmental protection through its own actions. The Green Action Plan initiated by BCC recognizes the important role local government has in changing public attitudes and institutional structures in addressing environmental problems, including air quality. It has four components:

- The Environment in Birmingham: a State of the Environment report for Birmingham providing base-line information about environmental issues of concern, including air quality.
- Policy Impact Assessment: addresses all those council activities which potentially harm the environment and the means of limiting their impact.
- Strategy for the Environment: the council's strategic plan for protecting the environment which has identified 14 areas for "Immediate Action" and details managerial and organizational tools necessary for their success.
- Corporate Action Plan: provides a summary of the environmental actions the departments are taking to fulfil the requirements of the strategy.

An Environmental Forum with members from the public and private voluntary and academic organizations has also been established as part of the sub-committee of the council. It seeks to act as a forum for the exchange of ideas, to identify issues of concern and to act as a watchdog to monitor the progress of the City and Council. In the future it is intended that the Green Action Plan will be developed through the establishment of performance targets for council departments in meeting environmental objectives; with annual reviews being undertaken and reports produced (including an annual air quality report). Birmingham City Council is also involved in environmental management through participating in the piloting of British Standard (BS) 7750, which attempts to formalize the key elements of an environmental management system; it also co-operates with a number of private sector and statutory organizations in the Midlands in environmental management and provides support for environmental education and awareness.

Comment

In general, Birmingham has very good air quality management capabilities: with an extensive monitoring network, established air quality regulations and comprehensive emissions control legislation. At present, however, no emissions inventory exists for the city and surrounding industrial/residential areas; this will be rectified in 1994–95 when a planned inventory will be conducted.

The existence of both national network and council-operated sites in the city provide a good balance of local and national air quality monitoring. The continuing development of these monitoring networks demonstrates a genuine commitment to air quality management and the data generated from both the national and local networks are of a high standard. A considerable volume of data is now being generated and it is important that the maximum possible use be made of this information and that its distribution be as wide as possible.

Although there is considerable monitoring within the Birmingham City Council boundaries, less monitoring takes place within the surrounding metropolitan districts and an expansion in monitoring in these areas to provide a more comprehensive picture of the spatial distribution across the whole agglomeration would be useful. Currently, in Birmingham, there are no national kerbside or EC Directive nitrogen dioxide monitoring sites. This situation is likely to change in the foreseeable future with a proposed expansion in the number of sites in the EC NO_2 Directive monitoring network. This is an important development in air quality monitoring in Birmingham.

The Green Plan initiated by the council is an important development in generating greater environmental awareness and protection. As was the Policy Impact Assessment conducted by the council in 1989; which sought to ensured that all the council's activities are as environmentally friendly as possible.

Air quality in Birmingham has improved greatly over the last 30 years, through effective emissions control legislation and changes in the industrial structure of the city. Birmingham City Council is actively encouraging the greater use of public transport; necessary if the projected increases in traffic volumes are not to halt or reverse the trend in improving air quality. Poor air quality in Birmingham is now an episodic phenomenon and, with more sophisticated modelling, it is increasingly possible to predict such events. Future developments of an air quality management strategy could target the reduction of emissions during these periods. Sizable contributions to total emissions of particulate matter and NO_2 in the city are probably generated by motorway traffic passing through Birmingham on national routes (BCC, 1994b). Local policies to reduce the emissions from motorway traffic in Birmingham would therefore need to consider the implications for the UK road network. Air quality management strategies for Birmingham are required to alleviate the severity of air pollution episodes. These will, however, be a need to balance the health considerations for residents with the need to maintain vehicle movement along one of the UK's principal road arteries.

Summary

- There is an extensive air quality monitoring network in Birmingham, with less comprehensive monitoring taking place in the surrounding metropolitan areas.
- No emissions inventory currently exists, although one is planned for the near future.
- Comprehensive national emissions control regulations and air quality standards exist.
- Air quality is generally good, with episodic events which can exceed WHO guidelines.
- The major source of emissions is from mobile sources with vehicle numbers projected to grow considerably in the future. Reducing emissions from motor vehicles is therefore sure to remain a priority of both national and local government.

References

BCC 1991 *The Environment in Birmingham*, Environmental Policy Unit, Environmental Services Department, Birmingham City Council, Birmingham.

BCC 1993 Personal communication, Environmental Services Department; Birmingham City Council, Birmingham.

BCC 1994a Personal communication, Birmingham City Council, Birmingham.

BCC 1994b Personal communication, Birmingham City Council, Birmingham.

British Gas 1991 Annual Report, British Gas, London.

Eggleston, S., Hackman, M. P., Heyes, C. A., Irwin, J. G., Timmis, R. J. and Williams, M. L. 1992 Trends in urban air pollution in the UK during recent decades, *Atmospheric Environment* **26B**, Vol. 2, 227–239.

Midland Electricity Board 1993 Annual Report, Midland Electricity Board, London.

NSCA 1994 *Pollution Handbook*, L. Murley (Ed.), National Society for Clean Air and Environmental Protection, Brighton.

QUARG 1993 *Diesel Vehicle Emissions and Urban Air Quality*, Second Report of the Quality of Urban Air Review Group, Birmingham.

Walters, S., Ayres, J., Archer, G. T. and Miles, J. In press. Effect of an Air Pollution Episode on A Panel of Severe Asthmatics in Birmingham, Birmingham.

WHO 1979 *Sulfur Oxides and Suspended Particulate Matter,* Environmental Health Criteria 8, World Health Organization, Geneva.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

WSL 1994 *Air Pollution in the UK 1992/93*, Air Monitoring Group, Warren Spring Laboratory, Stevenage.

9

Ekaterinburg and St Petersburg

Statistical Summary

Ekaterinburg
Country: Russian Federation
Estimated population 1990 (millions): 1.38
Projected population 2000 (millions): 1.51
Map reference: 56°52'N, 60°5'E
Area (km²): 430
Altitude (m): 286
Climate: Continental
Average temperature range (C): -14.6 to 17.8
Annual mean precipitation (mm): 439

St Petersburg
Country: Russian Federation
Estimated population 1990 (millions): 5.05
Projected population 2000 (millions): 5.39
Map reference: 59°55'N, 30°25'E
Area (km²): 604
Altitude (m): 70
Climate: Sea continental
Average temperature range (C): -7.9 to 18.4
Annual mean precipitation (mm): 585

This chapter combines information on two major cities in the Russian Federation: St Petersburg in the North-west Region and Ekaterinburg in the Ural Region. Both of these cities represent important population and industrial agglomerations (see Figure 9.1). These cities experience quite different air quality problems but have very similar air quality management capabilities and strategies because these are centrally coordinated at the Federal level. This chapter provides an outline of the air quality management capabilities operating throughout the Federation and compares and contrasts the experiences of these two cities.

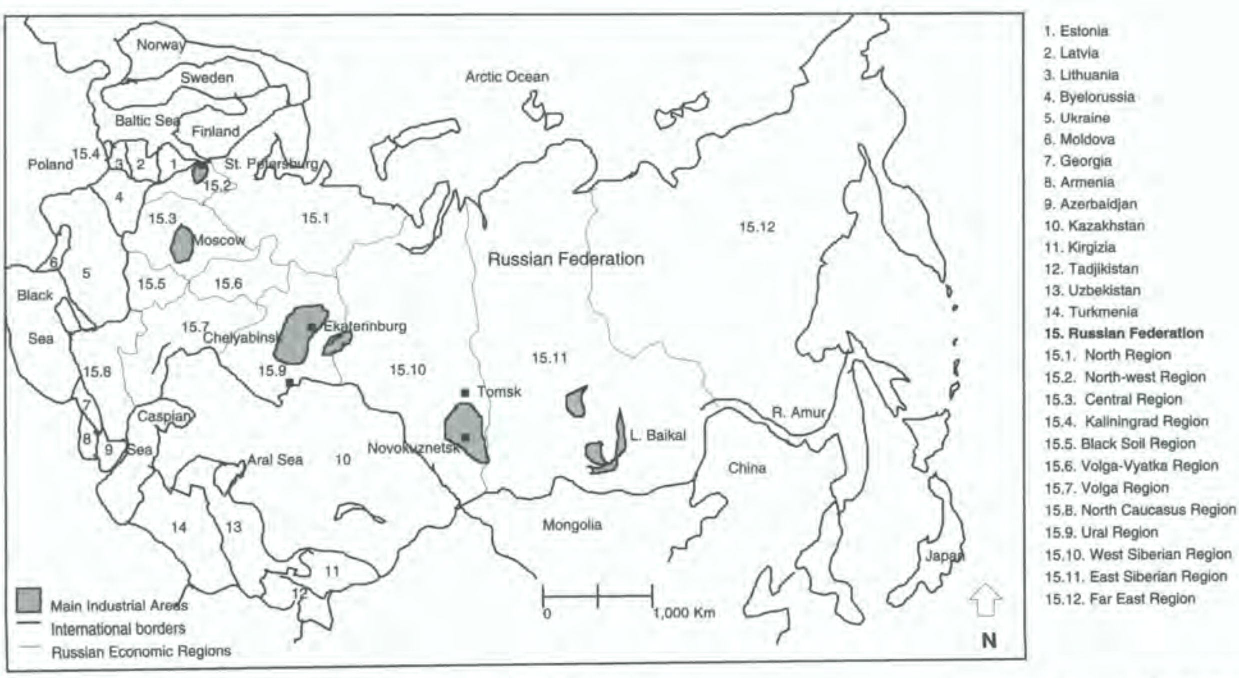


Figure 9.1 Sketch map of the Russian Federation

Source: Mnatsakanian, 1992

Situational Analysis – St Petersburg

St Petersburg, the second largest city in the Russian Federation, generally experiences good climatic conditions for rapid pollution dispersion. The city is located on an open coastline with strong sea breezes. Temperature inversions develop infrequently; generally during spring or autumn when their potential effects are ameliorated by heavy precipitation. St Petersburg is a highly industrialised city with significant industrial emissions. It also experiences substantial emissions from mobile sources: contributing about 61 per cent of total emissions (Mnatsakanian, 1992). The principle emissions sources are: three gas burning power stations, road traffic, building construction, and chemical and other heavy industries. During the last five years total city emissions have decreased by approximately 4 per cent. However, concentrations of dust, carbon monoxide (CO) and nitrogen dioxide (NO_2) have all risen in the most heavily polluted areas of the city.

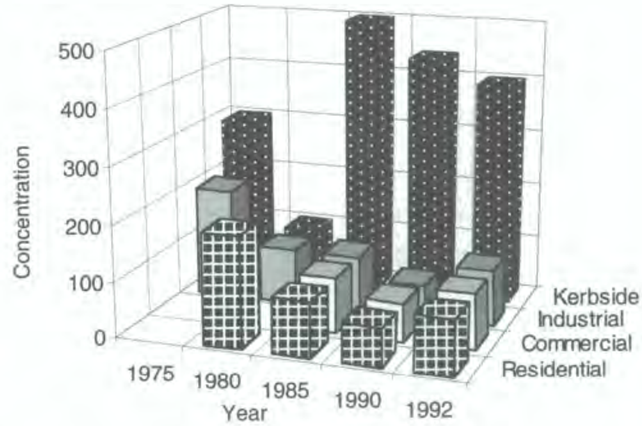


Figure 9.2 St Petersburg annual mean dust concentrations, 1975–1992 (µg m^{-3})

Source: MGO, 1994

Ambient monitoring shows that, in most parts of the city, dust concentrations are currently about 100 µg m^{-3} - this is above the WHO Guideline range of 60 to 90 µg m^{-3} for total suspended particulates (TSP) (WHO, 1979) (see Figure 9.2). Concentrations at kerbside locations are even higher; demonstrating the important contribution of motor vehicles to city air quality.

Table 9.1 shows maximum recorded concentrations for a number of pollutants at different locations in the city. Dust concentrations in particular are extremely high. Sulphur dioxide (SO_2) levels, however, are low: maximum reported SO_2 concentrations have never exceeded the short-term Maximum Permitted Concentration (MPC) or the WHO 24-hour guideline range (WHO,

Table 9.1 NO_2, SO_2, dust, CO and Pb maximum concentrations for 1992 at four sites in St Petersburg (µg m^{-3})

Compound	Maximum concentrations (µg m^{-3})				
	Residential	Commercial	Industrial	Kerbside	MPC[a]
NO_2	660	330	330	450	85
SO_2	24	–	84	120	500
Dust	1,500	1,300	1,900	5,800	500
CO	7,000	25,000	7,000	12,000	5,000
Pb[b]	–	–	–	0.02	0.03

(a) Short-term maximum permissible concentration for NO_2, SO_2, dust and CO and long-term MPC for Pb.
(b) Monthly average concentration.

Source: MGO, 1994

1979). Mean concentrations for 1992 were generally below 8 µg m^{-3}. These low SO_2 concentrations are surprising in view of the high levels of SO_2 emitted (an estimated 84,000 tonnes in 1988). A large proportion of SO_2 emissions do, however, originate from tall-stacks and as a result they are unlikely to significantly affect the city. The maximum short-term concentrations for NO_2, dust and CO, shown in Table 9.1, are significantly above MPCs at all sites. Unfortunately, no data are available on the frequency of the exceedances of the standard. This would provide important additional information on the extent of St Petersburg's air quality problems. Levels of toxic air pollutants also present a problem: for example formaldehyde, ammonia (NH_3) and benzo[a]pyrene (BaP) concentrations are high throughout the year. Elevated concentrations of ethyl benzene, hydrogen chloride, acetone and phenol are also found in specific areas of the city and can be attributed to emissions from nearby industrial sources.

Situational Analysis – Ekaterinburg

Ekaterinburg is located in the highly industrialized southern Ural Region (Figure 9.1). This regional industrial area now covers approximately 400 x 175 km and includes the cities of Nizny Tagil, Ekaterinburg and Chelyabinsk; with a combined population of over 3 million. These industrial activity produce substantial emissions which are ineffectively dispersed owing to unfavourable meteorological conditions. During the winter, temperature inversions and calm periods occur frequently (45–60 and 14–19 per cent of the time respectively). In the summer, temperature inversions often occur at night but generally break down following sunrise. Ekaterinburg also acts as a heat island with city centre temperatures generally being about 11–12C higher than the surrounding area; this temperature gradient occurs throughout the year. During winter and early spring the daytime heat island effect contributes to an increase in air pollution in the city centre. In summer this heat island tends to disperse more readily.

Poor pollution dispersion during winter is exacerbated by increased emissions from domestic and district heating. In summer, dry conditions produce significant weathering of soils in the surrounding agricultural areas and thus increase resuspended dust concentrations. Furthermore, traffic emissions in the sunny summer months produce photochemical smogs. The predominant south-westerly winds also bring pollutants from the industrial cities of Revda and Polevskoy to Ekaterinburg. The location and meteorology of Ekaterinburg combine to produce extremely unfavourable conditions for the maintenance of good air quality.

Over 8 million tonnes of dust, SO_2, CO, oxides of nitrogen (NO_x) and hydrocarbons (HCs) are released annually into the atmosphere in the Ural Region. Nevertheless, monitored annual mean concentrations for most compounds in Ekaterinburg are generally below WHO guidelines; although NO_2 and lead (Pb) come close to, or even exceed, their national long-term MPC's (40 and 0.03 µg m^{-3} respectively); owing, in part, to the rigorous nature of these particular standards. Figure 9.3 shows annual NO_2 concentrations from 1975 to the present; it demonstrates significantly elevated kerbside concentrations and a reversal in the previously declining (1990 - 1992) NO_2 concentrations at non-kerbside locations. As reported for St Petersburg, SO_2 concentrations in Ekaterinburg are lower than expected; 1992 annual mean concentrations being below 10 µg m^{-3} at all sites (MGO, 1994). Annual mean concentrations for dust are within national and WHO guidelines.

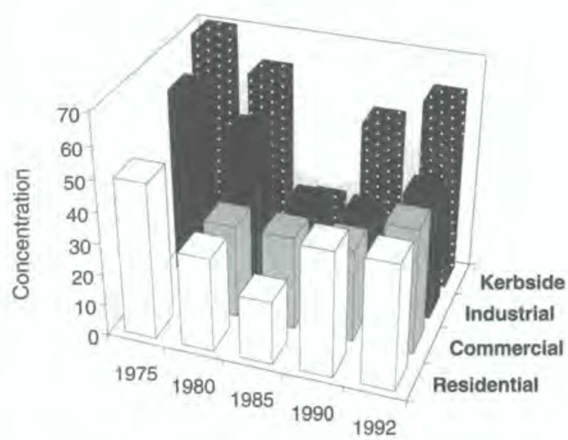


Figure 9.3 Annual mean NO_2 concentrations at four sites in Ekaterinburg, 1975–1992 (µg m^{-3})

Source: MGO, 1994

Table 9.2 NO_2, SO_2, dust, CO and Pb maximum concentrations for 1992 at four sites in Ekaterinburg (µg m^{-3})

Compound	Residential	Commercial	Industrial	Kerbside	MPC[(a)]
NO_2	410	520	750	460	85
SO_2	154	311	76	254	500
Dust	300	1,100	1,200	1,300	500
CO	18,000	5,000	9,000	16,000	5,000
Pb[(b)]	0.06	0.06	0.51	0.15	0.03

(a) Short-term maximum permissible concentration for NO_2, SO_2, dust and CO and long-term MPC for Pb.

(b) Monthly average concentration.

Source: MGO, 1994

Table 9.2 presents maximum monthly concentrations for Pb in 1992 as well as maximum concentrations of NO_2, SO_2, dust and CO at four sites. Short-term MPCs are exceeded at most sites, especially for NO_2 and dust. Carbon monoxide concentrations exceed national air quality standards, but are within the WHO guidelines.

Ekaterinburg also experiences high concentrations of a number of toxic compounds. Annual mean concentrations in excess of 4 ng m^{-3} for BaP and 6 µg m^{-3} for formaldehyde have been reported at some sites; exceeding the long-term MPCs by factors of four and two respectively. Concentrations of these and other toxic compounds including styrene, ethyl benzene, toluene, hydrogen chloride and phenol also exceed short-term MPCs: particularly in western and central parts of the city which are the most polluted (Mnatsakanian, 1992 and Bezuglaya et al., 1991). The principal sources of these compounds are believed to be metal and petrochemical industries, railway transport and power-generating facilities. A variety of fuels are also used for electricity production and by industry including coal, oil and gas; wood is still used in some homes.

Monitoring Networks

Air pollution monitoring and data assessment in the Russian Federation are centrally coordinated by the State Committee for Hydrometeorology and Environmental Monitoring. This has overall responsibility for all pollution monitoring. The enforcement of environmental protection regulations and pollution research and development are the responsibility of the Ministry for Environmental Protection and Natural Resources. The national monitoring network was established in the mid-1960s and is the direct responsibility of the State Service of Observations of the Environment; part of the State Committee for Hydrometeorology and Environmental Monitoring. Guidance on methodology is provided by the A.I. Voeikov Main Geophysical Observatory (MGO) in the Methodology and Assessment Research Centre located in St Petersburg. The MGO is responsible for a number of activities including: the co-ordination and management of the national monitoring network; monitoring methodology development; data handling; co-ordination of the national data base; and the preparation of reports on air quality.

The current national network of the Russian Federation has 666 permanent monitoring stations (Bezuglaya et al., 1991). No accurate data are available regarding the number of temporary sites. This programme monitors the principal air pollutants: dust, NO_2, SO_2 and CO; as well as more than 20 other pollutants specific to various districts and cities, for example: HCs, BaP, formaldehyde, phenols, NH_3, sulphuric acid, and heavy metals including Pb. The number of sampling sites in a city or region is determined by a number of factors such as: population density, the size of city, the number of roads and industries, and the importance of tourism. Each station has instruments for sampling air and aerosols on filter and for making meteorological observations including wind speed, temperature and weather conditions (Guidance on Air Quality Monitoring, 1991).

St Petersburg currently has 11 monitoring stations and Ekaterinburg has 8. The sampling site locations are shown in figure 9.4a and 9.4b. These monitoring stations have been operational since 1965 and are managed by the Vjunov A. N. and Sotoboev J. S. Monitoring Environmental Centres in St Petersburg and Ekaterinburg respectively (PMEC and EMEC). Monitoring seeks to determine spatial and temporal variation in pollution levels and to predict and monitor hazardous levels of pollution; and for public information (MGO, 1994). Both networks have industrial, commercial, residential and kerbside sampling sites. This site classification is, however, relative since residential districts in Russian cities are often located in close proximity to industrial enterprises and highways.

Monitoring at all stations is conducted following a set of guidelines, established in 1991, to ensure comparability of data between sampling sites throughout the Russian Federation (Guidance on Air Quality Monitoring, 1991). Samplers should be located at a distance of 1.5–3.5 m above ground level. Air and dust samples should be taken 3 to 4 times daily at 01:00, 07:00, 13:00 and 19:00 hours local time and should sample for a period of 20 minutes. During pollution

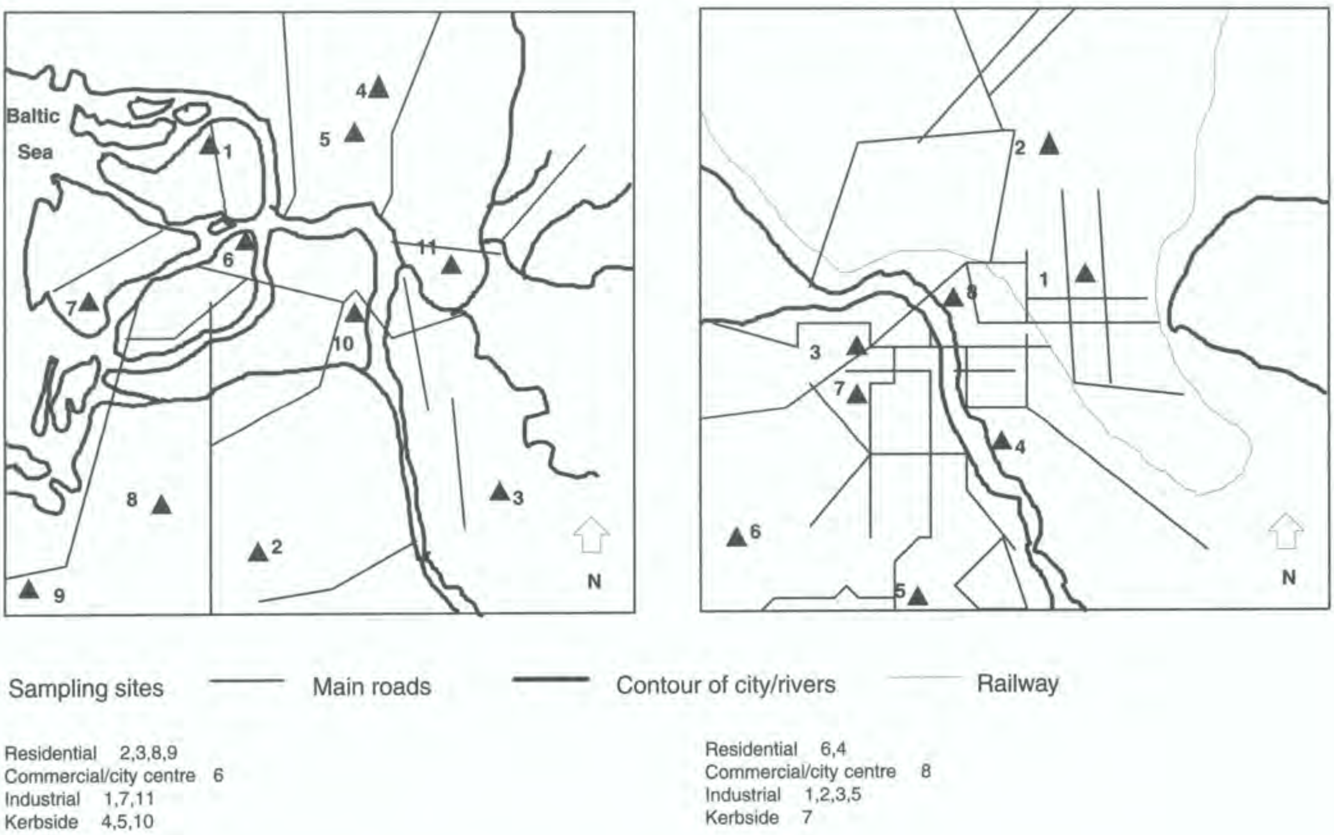


Figure 9.4 Sketch maps of St Petersburg and Ekaterinburg

Source: MGO, 1994

Table 9.3 St Petersburg and Ekaterinburg Air Quality Monitoring Networks

Pollutant	Sampling method	Analytical method	Sampling period/ frequency	No. sites 1992	
				St Petersburg	Ekaterinburg
NO_2	Sorption tubes	Colorimetric	20 minutes, 3–4 times daily	11	8
SO_2	Sorption tubes	West-Gaeke	20 minutes, 3–4 times daily	6	8
Dust	Low volume	Gravimetric	20 minutes, 3–4 times daily	10	8
CO	Active	Electrochemical	20 minutes, 3–4 times daily	11	8
Pb	Low volume – dust	AAS	20 minutes, 3–4 times daily, bulked monthly	1	7

Source: MGO, 1994

episodes, monitoring should be increased to take samples every three hours. All sites should also take measurements of wind direction, temperature and other meteorological conditions. Monitoring is not conducted at weekends and bank holidays. These directives are necessary given the absence of automatic gas analysers. Active sampling methodologies are used for NO_2, SO_2, dust, CO and Pb (Table 9.3). Currently, there is no national programme for monitoring ozone (O_3). Nitrogen dioxide and SO_2 are sampled using sorption tubes with film chemisorbent; laboratory-based photometric methods of analysis are used to determine concentrations. Dust is analysed gravimetrically, using low volume air samplers. Lead samples are bulked over a one-month period and analysed using Atomic Absorption Spectrophotometry (AAS).

The Main Geophysical Observatory (MGO) carries out all quality assurance and quality control (QA/QC). The number of sampling sites, analytical methodologies, duration and frequency of sampling and QC/QA are laid down in legislation (Guidance on Air Quality Monitoring, 1991). Good comparability of data between cities and regions is therefore possible. These standard methodologies were established in 1986 by the USSR Standards for Atmospheric Pollution, Regulation of Air Control in Cities. Calibrations of instruments are performed using standard solutions and gas standards and inter-comparisons conducted between monitoring stations. All data are validated and the laboratories that carry out the analyses (PMEC in St Petersburg and EMEC in Ekaterinburg) are in the process of obtaining an accreditation certificate from the MGO. Sampling sites are reviewed every five years to ensure that site locations remain appropriate (MGO, 1994). No comparisons have been made between the Russian procedures using very short sampling periods and the more conventional 24-hour or continuous monitoring methods used by networks in other countries. Uncertainty therefore exists over the accuracy of these methods (WHO/UNEP, 1991).

Daily averages (based on the four 20-minute sampling periods in a 24-hour period), monthly and annual mean concentrations and percentiles are determined for NO_2, SO_2, dust, CO and Pb for all monitoring stations. Twenty-minute maximum concentrations are also calculated for NO_2, SO_2, dust and CO. Data are processed with computers and annual reports are prepared on the state of air pollution in the cities of the Russian Federation (Bezuglaya, 1991). These reports present information on the general state of the atmosphere in the main cities and regions of the Russian Federation and include exceedances of the maximum permissible pollutant levels, spatial distribution for some pollutants and meteorological conditions. Until recently, although data were published at regular intervals, very few copies were actually printed and were therefore not available to the general public. Information on the level of air pollution in cities is also

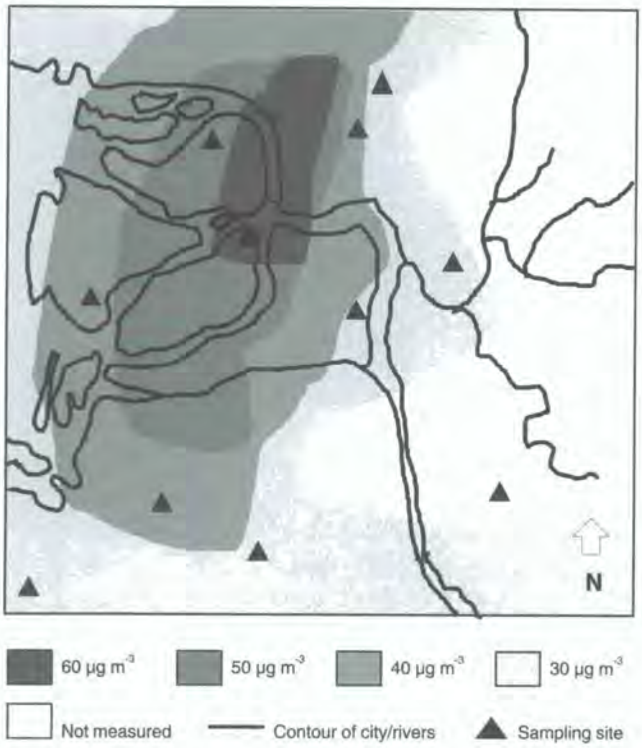


Figure 9.5 Spatial distribution of NO_2 concentrations in the city of St Petersburg for the period 1984–1988 (µg m^{-3})

Source: Bezuglaya et al., 1991

available in the local press and announced on radio and television. Modelling of the data is carried out to provide a general picture of the spatial distribution and potentially harmful levels of certain pollutants within a city (see Figure 9.5). Data are also used in conjunction with meteorological information to determine relationships between these variables.

Emissions Inventories

As with monitoring, emissions inventories are produced and collated by the federal government. Inventories are compiled for large and/or industrial cities and are published on a regular basis. Indeed, information is published on emissions released throughout the Russian Federation: for each economic region and individual city. These emissions estimates include stationary and mobile sources of pollution; they are calculated from emission measurements, fuel consumption statistics and other indirect methods of assessment. Inventories are also used to calculate the spatial distribution of pollutants and to determine Maximum Permissible Emissions (MPEs). Modelling is conducted according to the Russian Federal Guideline Technique for calculating the concentrations of air pollutants emitted from all industrial enterprises (MGO, 1994).

The estimated contributions of major source categories, for the whole Federation in 1989, are presented in Figure 9.6. In 1989, a total of 54.7 million tonnes of pollutants were emitted of which over half were from industrial sources and one quarter from motor vehicles (Mnatsakanian, 1992). Emissions of dust, SO_2, CO and NO_x from energy production and metallurgical processes contribute very significantly to overall national emissions (Table 9.4). Between 1980 and 1989 total emissions decreased by 10 per cent.

St Petersburg produces the second highest mass of urban emissions in the Russian Federation, after Moscow, with a total of 608,300 tonnes of air pollution (Mnatsakanian, 1992). It also accounts for two-thirds of total emissions from the North West region. Within St Petersburg, motor vehicles account for 61 per cent of total emissions of which over 50 per cent of this is CO.

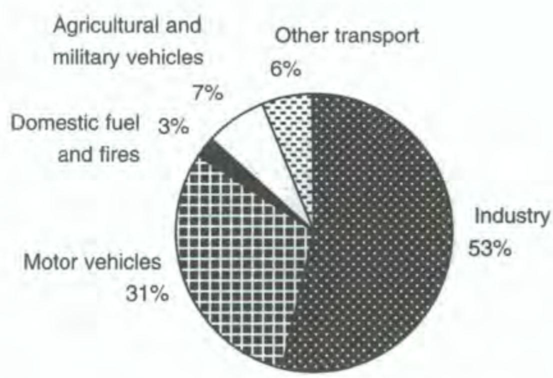


Figure 9.6 Emission sources for the Russian Federation in 1989

Source: Berlyand, 1990; Mnatsakanian, 1992

Table 9.4 Percentage contribution by energy and metallurgy production towards the total emissions produced by industry in the Russian Federation, 1989

Industry	Dust	SO_2	CO	NO_x
Metallurgy	25	49	46	–
Energy production	48	38	–	57

Source: Mnatsakanian, 1992

Emissions in the Ural region totalled over 8.6 million tonnes in 1988; of which Ekaterinburg contributed 175,200 tonnes. Mobile sources of emissions within Ekaterinburg accounted for 50 per cent of total emissions; CO emissions accounted for 65 percent of the total (see Figure 9.7). Emissions of toxic compounds accounted for 0.2 per cent of emissions (Berlyand, 1990). As in the North-west Region, dust and SO_2 are the main pollutants from stationary sources in the Ural Region.

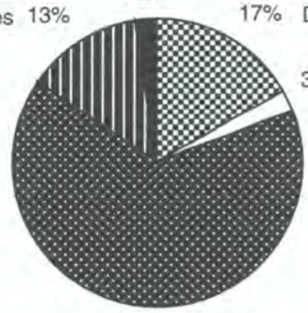


Figure 9.7 Percentage contribution of major pollutants to emissions in Ekaterinburg

Source: Mnatsakanian, 1992

Air Quality Management

Air quality management in the Russian Federation is based on the 1981 *Protection of Atmospheric Air Act*. To comply with this law the *Procedure for Standardizing Industrial Emissions into the Atmosphere* was developed in 1981; this procedure set Maximum Permissible Emission (MPE) standards for each urban source of pollution. These Maximum Permissible Emission (MPE) standards are set taking into account all other emission sources in populated areas in order that the MPE from a particular source will not create concentrations in excess of the ambient air standard. MPE standards are subject to enforcement and companies pay for the right to emit pollutants into the atmosphere.

In 1991, the Russian Federation law on *Protection of the Natural Environment* was passed. This new law covers MPEs and sets new emission charges for 207 substances from stationary sources. For SO_2 the charge was set at R66 per tonne emitted and for NO_2 at R82.5 per tonne emitted (UN, 1993). Furthermore, if the MPE set by this regulation is exceeded additional fines are imposed of R316 per tonne of SO_2 and R395 per tonne of NO_2. Companies are inspected every few years. Following the introduction of this regulation factory emission control technologies are being progressively introduced and cleaner fuels more widely used.

Throughout the Russian Federation air quality is assessed using Maximum Permissible Emission standards and concentrations measured over 20-minute sampling periods. Short-term MPCs, for concentrations measured for 20 minutes of exposure, and long-term MPCs, calculating exposure for 24 hours or longer, have been established for more than 400 pollutants. In accordance with these standards, the air in a city is considered clean if pollutant concentrations do not exceed the MPC. The air quality standards for various compounds are summarized in Table 9.4. Short-term MPCs for NO_2 and CO are much stricter than the WHO guideline values for 1 hour and 30 minutes respectively; the short-term standard set for O_3 is within the WHO 1-hourly concentration range. No short-term guidelines (i.e., less than 24-hour averages) have been set by WHO for either dust or SO_2. Regarding long-term MPCs, the standard for dust is within the WHO 24-hourly range, although it is less

Table 9.5 Maximum permissible concentrations and World Health Organization guidelines (µg m^{-3})

Pollutant	Short-term MPC (20 minutes)	WHO (1-hour)	Long-term MPC	WHO (24-hour)	WHO (yearly)
Dust	500	–	150	150–230	60–90
SO_2	500	500[b]	50	100–150	40–60
NO_2	85	400	40	150	–
CO	5,000	30,000	3,000	100,000[a]	–
O_3	160	150–200	30	–	–
Pb	–	–	0.03	–	0.5–1.0
NH_3	200	–	40	–	–
BaP	–	–	0.001	–	–
Formaldehyde	35	–	3	–	–
Phenols	10	–	3	–	–

WHO 1979 Guidelines are quoted as these are not for combined SO_2/particulate matter.
– No air quality standard for this compound.

(a) 15 minutes.
(b) 10 minutes.

Source: WHO, 1979, 1987; Mnatsakanian, 1992; MGO, 1994

stringent than the WHO yearly guideline range. The SO_2 standard is more stringent than the WHO 24-hourly range, but comparable with the WHO yearly average. Finally, the long-term MPC for Pb is much stricter than the WHO guideline range for this compound (see Table 9.5).

Atmospheric Pollution Indices (APIs) are calculated for all cities in the Russian Federation in order to quantify and rank them according to their air pollution problems. For each particular city, the five substances considered the greatest pollution problems contribute towards the API score. It is not, however, clear whether extra resources and/or financial support are given to those cities with the highest API. In 1988 there were 68 cities with high API scores. Ekaterinburg is included on this list owing to high levels of BaP, formaldehyde, nitric oxide (NO), NO_2 and NH_3; these are emitted by the ferrous metallurgy and the petrochemical industries and railroad transport. Although St Petersburg was the 14th largest source of air pollutants and the 2nd largest source of motor vehicle emissions in 1988 it is not on this priority list because the compounds emitted in this city are dispersed more readily. In 1989 it was still included in the list of 99 most polluted cities in the Russian Federation (Izrael and Rovinsky, 1991).

No controls or regulations currently exist to reduce or restrict domestic air pollution sources. Emission standards do, however, exist for motor vehicles, although not for heavy goods vehicles. Vehicles exceeding emission standards are illegal to drive. Vehicle exhaust emissions are not checked on a regular basis but police carry out spot checks to ensure compliance. Low compression engines are the most common and most of the petrol sold has a high sulphur content and low octane number (72 and 76). In recent years, higher octane petrol (93 and 95) is increasingly used as more private cars appear on the roads. Badly adjusted and old diesel engines common for trucks and buses. These factors, together with the rapid increase in car ownership in recent years, add to the pollution problems in large cities.

To try and reduce emissions from mobile sources, new regulations have been introduced. The sulphur content for diesel fuels has been limited to from 0.2–0.5 per cent for various engine types (UN, 1993) and, in 1991, fuel taxes were introduced on diesel, leaded petrol and unleaded petrol. This tax is reduced by 25 per cent when engines are equipped with exhaust gas cleaning devices. There is also a plan to extend this system of taxation to other types of fuels such as liquefied and compressed natural gas and kerosene; increasing the levy is also planned (UN, 1993).

Annual emissions have decreased significantly in recent years; both as a result of the greater use of emission control technologies and a decline in manufacturing production. However, MPCs are still frequently exceeded in St Petersburg, Ekaterinburg and many other cities in the Russian Federation. Although the State Committee for Hydrometeorology has the power to fine and even close down polluting factories and to compel local authorities to conform with the set standards, pollution control is still at a relatively early stage of development. There are, for example, insufficient resources to ensure compliance with standards. Regional and local environmental protection funds are being set up to provide subsidies and credits to firms either producing environmental equipment or are engaged in construction, re-equipping or repairs for environmental purposes (UN, 1993).

In St Petersburg a new programme seeks to improve the air quality of the city by the year 2005. This programme includes: the reconstruction of boilers in power plants to include, for example, new technologies for reducing NO_x emissions; the modernization of industrial installations; and, the closure of the most polluting enterprises. Changes in the financial rules have also been suggested in order to encourage enterprises to spend their own money on environmental protection; rather than being dependent on funding from the central budget. Vehicle emissions account for 59 per cent of all the pollution in the city; proposals have been made to alleviate these, together with congestion, by building a ring road to divert traffic from the city centre.

Work is also under way to improve the air pollution situation in Ekaterinburg. This includes plans to modernize the electrofurnaces in the main metallurgical factory; initiated in 1988. Furthermore, more than 2,000 air purifiers have been installed in city industries of which 22 per cent are now ineffective; this is an area in which improvements are planned.

Comment

Air quality management capabilities appear to be well-developed within the Russian Federation; these include: considerable, quality assured, ambient air quality monitoring in all major cities; city, region and national emissions inventories; air quality standards and emissions limits; and, increasingly better access to environmental data.

From the information on which this brief summary is based it would appear that poor air quality is not a serious problem in St Petersburg or Ekaterinburg. The monitoring methodologies adopted in the Russian Federation are, however, significantly different to those used in most other countries. Studies to determine the effectiveness of, and relationship between, the short sampling periods used in the Russian Federation and measurements obtained using state-of-the-art continuous analysers would be extremely useful. Such studies may help explain why, for example, the recorded sulphur dioxide concentrations reported for Ekaterinburg and St Petersburg are particularly low despite there being substantial amounts of SO_2 emitted. This anomaly could be explained by the fact that SO_2 is mainly released from high stacks situated in the outskirts of these cities and thereby emissions are dispersed over long distances. Furthermore, that boiler houses in the centre of these cities generally use gas and therefore do not make large contributions to total urban SO_2 emissions (Bezuglaya, 1994).

Until recently annual reports on ambient air quality in Russian Federation cities and regions were only available to researchers, specialists and state establishments because very few copies were produced. Since 1987, however, information has become more widely available and data are published annually, lists of priority cities are compiled on a regular basis and information on air quality is reported through the local press, television and radio.

Air quality standards are widely used throughout the Russian Federation; as is an air pollution index grading cities according to the severity of their air pollution problems and hence their need for air quality management. In recent years there have been a number of measures adopted to reduce emissions. This study would suggest that strong emphasis needs to be placed on ensuring that existing emission abatement equipment operates effectively through regular maintenance and repairs. In St Petersburg, 26 per cent of all industries and 34 per cent of all power generation systems are currently using obsolete scrubbing equipment that clearly needs to be replaced. Another important possible measure to reduce emissions would be to more closely control the burning conditions of fuels in domestic furnaces and in heating boilers. In the longer-term, it would also be desirable to locate, and even relocate, industrial developments away from residential areas in order to reduce public exposure to air pollution; especially industries emitting large amounts of dangerous and toxic compounds. Finally, to help counter adverse air quality effects that may accompany the anticipated increase in vehicle numbers in future years, it would be useful to implement strategies to: modernise old diesel buses and trucks, refit and better maintain existing public transport vehicles and introduce stricter regulations controlling all vehicle emissions.

Summary

- In Ekaterinburg air quality problems are exacerbated by highly unfavourable dispersion characteristics; the climate and topography of St Petersburg, on the other hand, generally enable rapid dispersion of pollution.

- Ekaterinburg and St Petersburg have comprehensive monitoring networks which form part of a larger, centrally coordinated national network which has been operational since 1965. Samples are taken four times daily for a period of 20 minutes each using active analytical methods. Ozone is not currently monitored.

- Air quality standards: Maximum Permitted Concentrations are mandatory but are frequently exceeded in both St Petersburg and Ekaterinburg.

- Emissions inventories are conducted on a city, regional and national scale and are used to set Maximum Permitted Emissions for industries. Maximum Permitted Emissions are mandatory; however, these are frequently exceeded in both St Petersburg and Ekaterinburg.

- The Russian Federation has established a number of programmes and strategies to improve air quality in both cities and more are planned for future years.

References

Berlyand, M. E. (Ed.) 1990 Annual Report of the State of Air Pollution and Harmful Pollutant Emissions to the Atmosphere of Cities and Industrial Centres of the Soviet Union. Harmful Pollutant Emissions, Main Geophysical Observatory, Leningrad. (In Russian).

Bezuglaya, E. (Ed.) 1991 *Annual Report of the State of Air Pollution in Cities and Industrial Centres – 1990*, State Committee on Hydrometeorology, St Petersburg. (In Russian).

Bezuglaya, E., Rastorgueva, G. and Smirnova, I. 1991 *The Breathing of an Industrial City*, Gidrometeoizdat, Leningrad. (In Russian).

Bezuglaya, E. 1994 Personal communication, State Committee on Hydrometeorology, St Petersburg.

Gidrometeoizdat 1991 *Guidance on Air Quality Monitoring*, Gidrometeoizdat, Leningrad. (In Russian).

Izrael, Yu. A. and Rovinsky, F. Ya. (Eds) 1991 Review of the State of the Natural Environment in the USSR (1988-1989 Observational Materials), USSR State Committee for Hydrometeorology, Moscow.

MGO 1994 Questionnaire response: Air Quality Monitoring Capabilities Questionnaire, Main Geophysical Observatory, St Petersburg.

Mnatsakanian, R. A. 1992 *Environmental Legacy of the Former Soviet Republics*, Centre for Human Ecology, Institute of Ecology and Resource Management, University of Edinburgh.

UN 1993 The State of Transboundary Air Pollution 1992 Update, Air Pollution Studies Number 9, United Nations, New York.

WHO 1979 *Sulfur Oxides and Suspended Particulate Matter*, Environmental Health Criteria 8, World Health Organization, Geneva.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

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

10

Hong Kong

Statistical Summary

Country: Hong Kong (a UK territory until 1997)
Estimated population 1990 (millions): 5.9
Projected population 2000 (millions): 6.5
Map reference: 22°19'N, 114°10'E
Area (km^2): 1,077
Altitude (m): sea level to 957
Climate: Sub-tropical
Average temperature range (C): 0–36.1
Annual mean precipitation (mm): 2,214

Situational Analysis

The territory of Hong Kong is situated on the south coast of China; it comprises of the Hong Kong and Lantau islands, Kowloon Peninsula, New Territories and a number of small islands. The total land area of Hong Kong is 1,077 km^2, but the urban agglomeration is concentrated in a 151 km^2 area (UNEP/WHO, 1993); much of the territory is hilly. The city currently has a population density of approximately 37,000 inhabitants per km^2; this is one of the highest in the world.

Hong Kong is a major commercial centre; industrial activities include the manufacture of consumer goods, such as toys, textiles and electronics, shipbuilding, cement manufacturing, steel and food processing (EPD, 1994). A large proportion of the city's production is for export. The harbour and main airport, both situated within the city centre, are important sources of urban air pollution. There are currently four major coal and oil burning power-generation plants on the island. The main fuel used for domestic heating and cooking is town gas, followed by electricity and fuel oil (EPD, 1994). No area-servicing central heating systems have been developed in Hong Kong. In the summer months, notably July and August, there is great demand for air conditioning and as a consequence, energy consumption increases during this period (UNEP/WHO, 1993).

Elevated concentrations of total suspended particulate matter including respirable particulate matter (PM_{10}) constitute the principal air pollution problem in Hong Kong. These problems are exacerbated by past siting of industrial and residential buildings and by the hilly terrain and narrow, pollution trapping streets. The Hong Kong Air Quality Objectives (AQO) for particulate matter are being exceeded at many locations in the city. Rigorous controls on sulphur dioxide (SO_2) emissions, described in the following section entitled Air Quality Management, have significantly reduced ambient concentrations to well below AQOs.

The growth in motor vehicle numbers (Table 10.1) and congestion within the Island's many street canyons cause concentrations of nitrogen dioxide (NO_2) to rise above AQO's at some sites, especially those with kerbside locations. Carbon monoxide (CO) and ozone (O_3) concentrations are generally within the maximum AQO values. However, occasional O_3 values can exceed the WHO guideline of 150–200 $\mu g\ m^{-3}$. For example, in Central/Western – a commercial/residential site – the 1-hour maxima values for 1991 and 1993 were 201 and 220 $\mu g\ m^{-3}$ respectively. Trends in pollutant concentrations at one site are shown in Figure 10.1 and compliance with AQOs at different sites in Table 10.2. The growth in motor vehicle numbers is expected to increase at a very rapid rate during the next decade, despite the city having an excellent public transport network which includes ferries, trains, metros, trams and buses (EPD, 1994).

Table 10.1 Number of motor vehicles registered in the city in 1980, 1990 and predicted numbers for the year 2000

	1980	1990	2000 (predicted)
Passenger vehicles	225,545	253,786	–
Lorries	58,801	130,270	207,000
Buses	10,459	14,711	24,000
Government vehicles	4,590	6,640	–

– Data not available.

Source: EPD, 1994

Monitoring Networks

The principal objectives of air quality monitoring in Hong Kong are:

- To provide information concerning attainment of AQOs within each of the 10 air quality zones which have been established in the territory;
- To provide public information;
- To measure spatial and temporal pollution concentration variations.

There is a substantial monitoring network in Hong Kong; including both fixed sites and a mobile laboratory. Other short-term monitoring projects are also carried out where and when they are considered appropriate. Permanent monitoring sites are shown in Figure 10.2, which also shows main roads, industrial and commercial/city centre areas within the territory.

Hong Kong Air Quality Monitoring Network

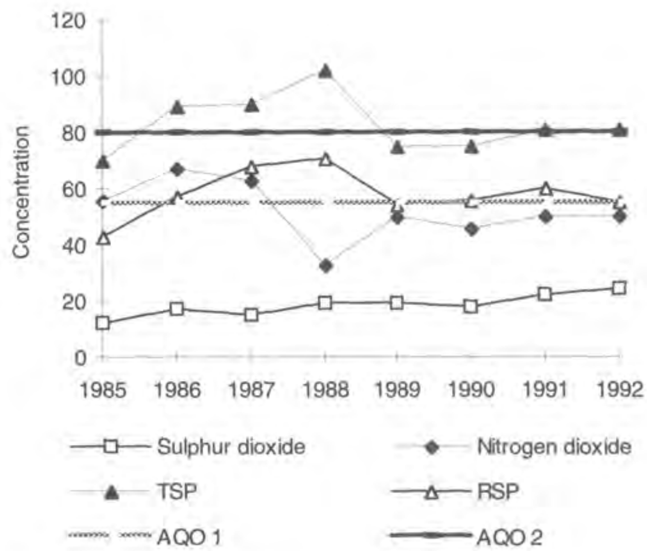
The Hong Kong Air Quality Monitoring Network is one of the permanent monitoring network in the territory and it is operated by the Environmental Protection Department (EPD). The network has been operational since 1983 and includes nine monitoring stations; eight for ambient air measurements and one kerbside station adjacent to a busy main road. Of the eight stations monitoring ambient air, three are located in industrial areas and five in commercial/city centre and new development areas. These stations are located between 17 and 25m above the ground, on the roofs of buildings, and are intended to represent typical levels

Table 10.2 Compliance with the AQOs at different air sampling sites in Hong Kong for 1992

District	NO_2	TSP		RSP	
	24 hours	24 hours	1 year	24 hours	1 year
1. Central/Western	–	–	no	–	no
2. Kwun Tong	no	no	no	–	no
3. Mong Kok	no	no	no	–	no
4. Sham Shui Po	–	no	no	–	no
5. Kwai Chung	–	–	no	–	–
6. Tsuen Wan	–	no	no	–	no
7. Sha Tin	–	no	no	–	–
8. Tai Po	–	no	no	–	–
Standard	300	260	80(a)	180	55

– means compliance with AQO at the site.
no means non-compliance with AQO at that site.
(a) not to be exceeded more than three times per year.

Source: EPD, 1993



TSP: Total suspended particulate matter/suspended particulate matter.
RSP: Respirable particulate matter.
AQO 1: Air Quality Objective for sulphur dioxide, nitrogen dioxide and TSP.
AQO 2: Air Quality Objective for respirable particulate matter.

Figure 10.1 SO_2, NO_2 and particle concentrations (μg m^{-3}) at a city centre/commercial site (Central/Western) in Hong Kong since 1985

Source: EPD, 1990, 1991b, 1993

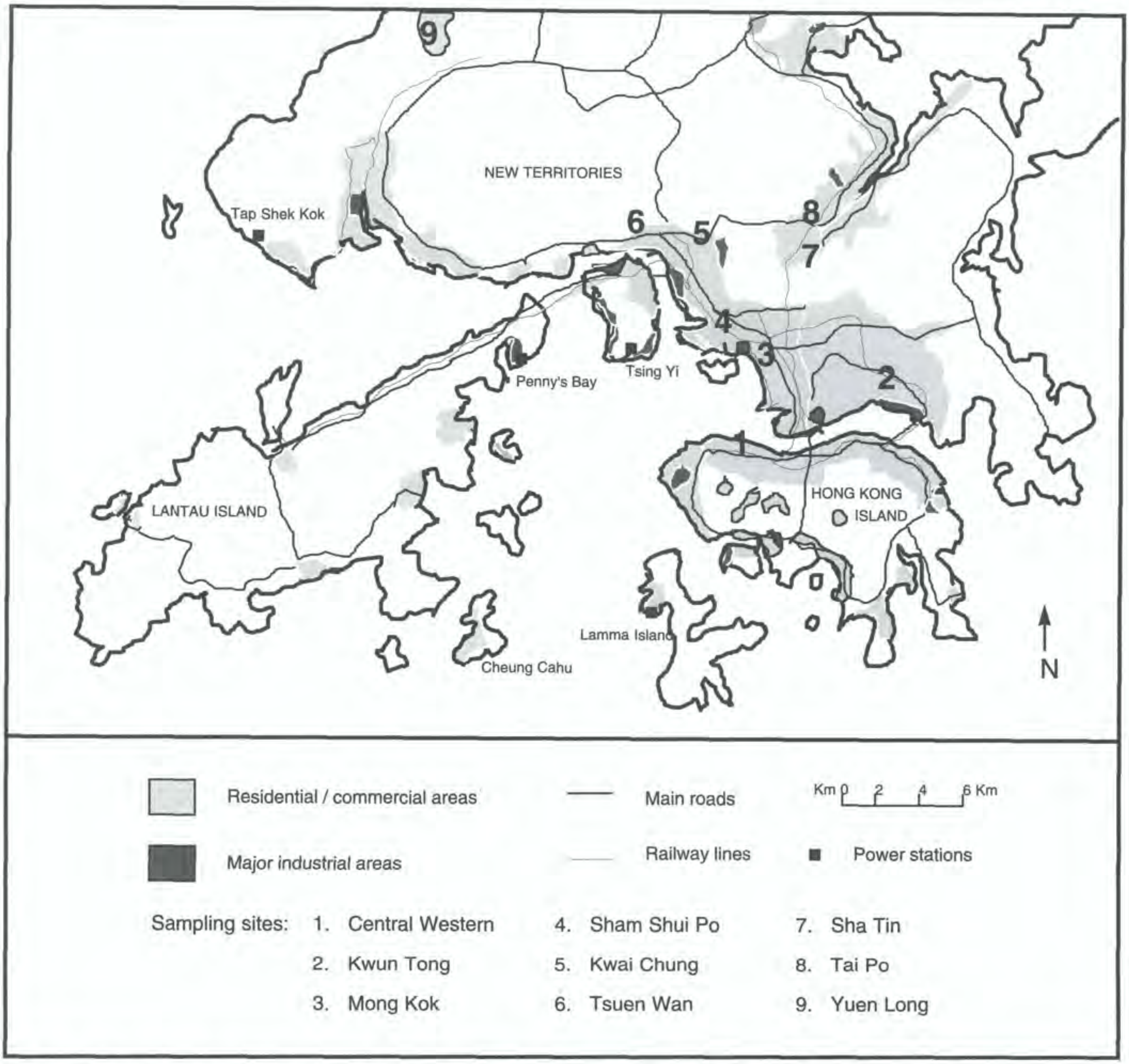


Figure 10.2 Sketch map of Hong Kong showing sampling sites, main roads and railway lines, residential/commercial areas and major industrial areas

Source: EPD, 1994

of exposure to the general population. The roadside site is situated 2 m above ground level and is primarily used to monitor urban air quality at street level, where traffic is dense.

The number of sampling stations and the pollutants monitored have increased over the years. Table 10.3 summarizes the analytical methods, sampling frequencies and number of sites measuring for each pollutant. Each site is equipped with continuous automatic gaseous analysers as well as meteorological instruments to measure wind speed, wind direction, temperature and solar radiation (to assist with subsequent validation and assessment of the measurements) (EPD, 1994). The stations also sample particulate matter in air with the use of discrete high volume samplers.

Table 10.3 Hong Kong Air Quality Monitoring Network

Pollutant	Analytical method	Sampling period/ Frequency	Number of sites
NO_2	Chemiluminescence	Continuous	9
SO_2	Fluorescence	Continuous	7
TSP and RSP	Gravimetric/TEOM	24 hours–1 day in 6	9
O_3	UV light absorption	Continuous	3
CO	Non-dispersive infrared	Continuous	2
Pb	AA Spectrometry	24 hours–1 day in 6	9

Source: EPD, 1994

Total suspended particulates, respirable suspended particulates (RSP) and lead (Pb) are measured on a 24-hour basis, typically on a six-day sampling cycle. Currently, six sites, Yuen Long, Kwun Tong, Central/Western, Sha Tin, Tsuen Wan and Kwai Chung, have been continuously monitoring. Carbon monoxide has only been monitored since 1991.

Mobile laboratories

Hong Kong's EPD also operates a Mobile Air Quality Monitoring Laboratory designed to conduct short-term investigations of local air quality (EPD, 1991/1993). It is fitted with continuous analysers of the major gaseous air pollutants, with particulate samplers to measure TSP and RSP in ambient air, and with meteorological instruments. The mobile laboratory is placed for short periods of time in different areas/districts where there is no fixed monitoring equipment. For example, in 1992 the mobile laboratory was deployed at Chai Wan (see Figure 10.2) for four months to determine the concentrations of the major pollutants in that area (EPD, 1993). As these were subsequently found to be within the Air Quality Objectives for Hong Kong the mobile monitoring unit moved on.

Hong Kong also has a Mobile Stack Emission Monitoring Laboratory which monitors gaseous and particulate emissions from major fuel combustion plants (EPD, 1993). The EPD commissioned this mobile laboratory in 1990 to ensure compliance with imposed emission limits for specified processes. During 1992 the mobile laboratory carried out seven source measurements in major air-polluting plants, including power stations and incineration, asphalt and sewage treatment plants.

Short-term monitoring studies

The EPD, in collaboration with the Consumer Council, conducted a study in 1992 monitoring the CO concentrations in 39 underground car parks in Hong Kong in order to determine the health effects on individuals using these car parks (EPD, 1993). Based on results collected over a two-and-a-half month period it was determined that nearly 50 per cent of measurements were higher than the guideline value given by WHO for a 15-minute average time exposure (100 mg m^{-3}). From these findings it was then estimated that 75 per cent of Hong Kong's car park workers would be exposed to unacceptably high levels of CO. Ventilation in these car parks was found to be inadequate; follow-up monitoring and amelioration recommendations were to be proposed by the EPD after consultation with appropriate bodies.

Another short-term study was conducted over a four-month period in 1991–92, aimed at assessing the impact of vehicle emissions on pedestrians (EPD, 1993). Total suspended particulates, Pb, CO and NO_2 concentrations were monitored, and found to be generally within the AQOs established for these compounds, with the exception of TSP which frequently exceeded the AQOs. A follow-up study is planned.

A territory-wide NO_2 concentrations survey, using passive diffusive tube samplers, was conducted along major roads over a two-month period in late 1991 (EPD, 1993). Results confirmed that NO_2 is a serious problem at kerbsides in Hong Kong. A follow-up study was carried out in late 1992 to investigate the contributing factors governing NO_2 levels at roadsides.

Monitoring for other air contaminants

Toxic air contaminants, including six toxic chemicals (arsenic, beryllium, cadmium, chromium, lead and mercury), benzo[a]pyrene, polychlorinated biphenyls and nine other volatile organic compounds are regularly monitored at three stations in the city covering both residential and industrial sites (EPD, 1993). A radon survey in a number of buildings was undertaken in December 1992.

Quality assurance and data reporting

The data quality assurance and control procedures conducted by the Hong Kong Air Quality Monitoring Network are constantly revised and assessed. A quality assurance team was set up in 1990, by the EPD, with the aim of achieving conformity with internationally recognized quality assurance practices ensuring data accuracy and precision. Currently, calibration audits have been performed for SO_2, NO_2, O_3, CO, TSP and RSP at all ambient air quality monitoring stations. The quality assurance system involves keeping a track record of all procedures, ensuring that calibrations match authoritative reference standards and conducting site audit checks. The Hong Kong Laboratory Accreditation Scheme (HOKLAS) has accredited the Air Services Laboratory (ASL), which operates and maintains the air quality monitoring network, for the measurement of ambient concentrations of SO_2, NO_2, O_3, CO, TSP and RSP. Network sites are reviewed on an "as-need basis" to ensure they remain suitable (EPD, 1994).

Quality control is conducted in the laboratory, in the field and during data processing. The EPD laboratory is responsible for analyser maintenance and the calibration of working gases used in field operations. All analysers are calibrated prior to being used in the field and after maintenance. Calibration gases used are either the quality of standard reference material (SRM) or else traceable to SRM. In the field, SO_2 analysers perform daily span and zero checks. Flow calibration of gas calibrators is performed regularly, as is the flow rate of hi-volume samplers for particulate monitoring.

Data from the continuous instruments are sent back to a main computer at the EPD, for further processing and compilation, through an on-line public data communication network. Questionable data are first screened and flagged for investigation before being further processed. Data collected are divided into hourly, daily, monthly and annual measurements. A valid hourly mean requires at least 67 per cent of valid five-minute data, while daily means require at least 16 hours of 67 per cent valid data. All validated hourly means are used to calculate monthly and annual averages.

Data are published annually by the EPD and are available to the general public (EPD, 1991a, 1991b and 1993). Currently, the daily monitoring data for SO_2, NO_2, O_3, CO, TSP and RSP are used to calculate the Air Pollution Index (API), a single number ranging in value from 0 to 500. An index between 0 and 100 represents good or moderate air quality, and shows that no individual Hong Kong Air Quality Objective (HKAQO) is exceeded. An index over 100 indicates that one or more individual HKAQOs are being exceeded at one or more of the monitoring stations. The API for each day, and the forecast API for the following day are released to the information media. This assists the public in understanding air quality and is useful for susceptible groups, such as those with heart or respiratory illness, who might wish to consider taking precautionary measures when necessary.

Emissions Inventories

Emission inventories have been compiled to determine emissions caused by vehicles, major industries and other sources of pollution; and, to estimate Hong Kong's contribution towards the total, global emission of greenhouse gases. Data, although not published, are available on request from the EPD (EPD, 1994). Information obtained from such inventories are used for territory development planning, policy formulation, and the control of emissions from vehicles and major industries. Emissions inventories for stationary and mobile sources of pollutants have been calculated; these include: oxides of nitrogen (NO_x), SO_2, PM, CO, carbon dioxide (CO_2), hydrocarbons, non-methane and

Table 10.4 Hong Kong pollutant emissions, 1995

	SO_2	NO_x	CO	Particulates
Sources				
Electricity	104757	64097	3520	3733
Fuel consumption & vehicles	23899	54582	192130	7386
Others	2486	18012	13000	1501
Total	131142	136691	208650	12620

Source: EPD, 1996

methane volatile organic compounds (VOCs). These are estimated using actual measurements as well as transport data, fuel consumption data for stationary sources and the relevant emissions factors (EPD, 1994). Questionnaires are also sent to relevant factories and organizations for the estimation of local emission inventory.

Fossil-fuel fired power stations and vehicles are the major sources of SO_2 and NO_x in Hong Kong (Table 10.4). In 1995, an estimated 131,000 tonnes of SO_2 and 136,000 tonnes of NO_x were emitted into the atmosphere in Hong Kong (EPD, 1996). Sulphur dioxide mainly came from the combustion of sulphur-containing fossil fuels; major emission sources being power-generating plants and liquid fuel use by industrial and commercial sectors. Releases of SO_2 and NO_x from other contributors, including incinerators, aircraft and cement work, remained close to 1991 levels (EPD, 1996).

A total of 12,620 tonnes of particulate matter were emitted in 1995, of which industrial fuel combustion and emissions from vehicles were the principal sources in industrial areas. Dense traffic and intensive construction activities account for high levels in residential and commercial areas. Overall, 58 per cent of total particulate matter emissions were attributed to industrial fuel consumption and vehicle emissions, primarily diesel combustion, and 30 per cent of the total was attributed to power station emissions. Incinerators and cement works contributed towards the remainder. An estimated 163,000 tonnes of CO were released into the atmosphere in 1991, 85 per cent of which was attributed to mobile combustion sources.

A greenhouse gases emissions inventory has been compiled, and consideration is being given to see to what extent Hong Kong could reduce greenhouse gas emissions.

Air Quality Management

Air quality management in Hong Kong is based upon the attainment of Air Quality Objectives by each of the territory's 10 Air Quality Zones. Attainment is sought through the introduction of control initiatives, and where necessary, developments of legislation to deal with specific air pollution problems. The HKAQOs are shown in Table 10.5.

The *Air Pollution Control Ordinance* (APCO) is the principal piece of air pollution control legislation in Hong Kong and is the enabling act for a host of other regulations and ordinances. The EPD is responsible for enforcing this environmental legislation, as well as for formulating and presenting policy proposals to the Government , monitoring environmental quality, advising on the environmental aspects of new industrial

Table 10.5 Hong Kong air quality objectives

	Concentration (micrograms per m^3) (i)			
	Averaging time			
Pollutant	1 hour (ii)	24 hours (iii)	1 year (iv)	Other
SO_2	800	350	80	
TSP		260	80	
RSP (v)		180	55	
NO_2	300	150	80	
CO	30,000			10,000 (8 hours) (iii)
O_3 (vi)	240			
Pb				1.5 (3 months) (iv)

(i) Measured at 25 C and 1 atm.
(ii) Not to be exceeded more than three times per year.
(iii) Not to be exceeded more than once per year.
(iv) Arithmetic means.
(v) Respirable suspended particles (10 micrometres or less)
(vi) Photochemical oxidants are determined by measurement of ozone only.

Source: EPD, 1996

plans and other developments, and providing a centralized complaints and enquiries handling service. The EPD also uses the collected data to evaluate the effectiveness of current air pollution control programmes. The processed data are also used to answer questions from legislative bodies, researchers and the general public.

Apart from the APCOs, Hong Kong enacted the Ozone Layer Protection Ordinances (OLPO) in 1989 to take up the challenge as a party to the Montreal Protocol. Under the OLPO, the consumption of the CFCs and halons is strictly controlled through an import/export registration and licensing system. This, together with a quota system administered by the EPD, has proved to be very effective in keeping consumption of various ozone depleting substances in Hong Kong well within the limits set by the phase-out programme of the Montreal Protocol.

In 1992, there were around 13,000 businesses in Hong Kong discharging air pollutants, of which 141 conducted activities emitting significant amounts of air pollution through what are classified as 'specified processes'. These include: power stations, incinerators, petrochemical works, cement, ceramic, electricity and gas works and mineral plants. Specified processes are strictly licensed; however, 69 per cent of these plants were already operating in 1987 when the licensing procedures were introduced meaning that they are currently exempt. This status is being reviewed and a staged programme of removing the exemptions granted to these plants is in progress. The licensing of specified processes require plants to use the best practicable means of pollution control. For example, the new coal-fired power station in Lamma Island (see Figure 10.2) was licensed in 1990 with a prerequisite that flue gas desulphurization and sulphur trioxide injection systems were installed to reduce SO_2 and particulate emissions into the atmosphere. A person who conducts a specific process without a valid licence or exemption can be heavily fined.

Emissions from furnace, oven and chimneys for non-specified processes are controlled through a prior approval system; whereby, a certificate of approval must be obtained before installation or alteration of any such equipment. Before granting an approval, the EPD studies the existing air quality of the relevant area and, if necessary, using an air quality model, examines the

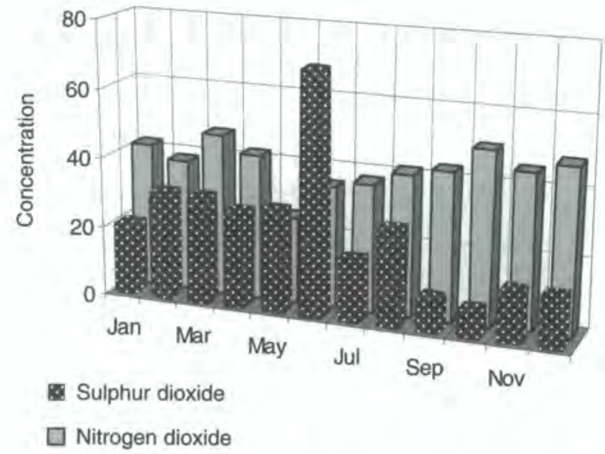


Figure 10.3 SO_2 and NO_2 concentrations in 1990 at an industrial site (Kwun Tong) ($\mu g\ m^{-3}$)

Source: EPD, 1991a

potential effects of the additional emissions upon surrounding businesses and residents.

Industrial pollution problems are of considerable concern in Hong Kong as there is a high density of chimneys, built on multi-storey industrial buildings, in close proximity to residential buildings. To reduce exposure to the general population, the permitted darkness of smoke from such chimneys was lowered in September 1990 (down to Ringelmann shade 1);

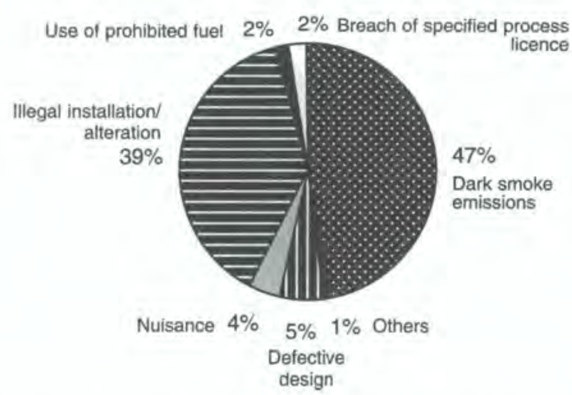


Figure 10.4 Air pollution prosecutions upon industrial premises

Source EPD, 1993

requiring owners of fuel burning appliances to maintain higher standards of operation and maintenance in order to minimize smoke emissions.

In addition to controls upon individual processes, *Fuel Restriction Regulations* were implemented in July 1990 which apply to virtually all non-domestic fuel users. These regulations require fuel oils and solid fuels to have a sulphur content below 0.5 and 1 per cent by weight respectively (EPD, 1991a). Breaching this regulation can make owners liable to fines (of up to HK$20,000) and imprisonment for six months. In addition, a daily fine (not exceeding HK$5,000) can also be imposed for part or the whole of each day during which the offence continues. The introduction of this regulation prohibited the use of high sulphur heavy fuel oil and led to an immediate reduction of SO_2 emissions. Following the implementation of this regulation there was a substantial reduction of SO_2 concentrations in ambient air (EPD, 1991a). Nitrogen dioxide concentrations over that same period remained constant (Figure 10.3).

Industrial emissions controls are rigorously enforced. In 1992, EPD inspectors made 8,432 visits to plants and responded to 1,570 complaints (EPA, 1993). EPD officers offer advice and where necessary issue legal notices which, if ignored, result in legal action. In 1992 such advice was given to 1,445 premises, legal notices served upon 112, and 302 prosecutions initiated. Emissions monitoring is conducted using the EPD's mobile unit. Air pollution prosecution statistics are shown in Figure 10.4.

Mobile emissions sources are a major source of air pollution in Hong Kong which the *Air Pollution Control (Amendment) Ordinance* of 1991 was introduced to address. From January 1992 all newly registered petrol vehicles were required to comply with stringent emission standards. Petrol vehicles would have to use unleaded petrol and be equipped with catalytic converters. In order to comply, all filling stations now stock unleaded petrol, which in the middle of 1996 accounted for 80 per cent of all sales. The tailpipe emissions of these new petrol vehicles have been reduced by 80 to 90 per cent; airborne lead levels are also now significantly below the AQO limits and are no longer a problem. In April 1995, stringent emission standards were also introduced to control the emissions of larger vehicles (EPD, 1996).

Table 10.6 Vehicle smoke control programme enforcement statistics

	1993	1994	1995
Smoky vehicle reports received	66,705	67,551	51,635
Smoky vehicles tested	43,428	44,103	34,935
Warning letters issued	3,516	3,336	3,750
Vehicle licences cancelled	1,689	1,571	1,030

Source: EPD, 1996

Another measure aimed at reducing vehicle emissions involves the use of accredited 'spotters' to identify vehicles emitting excessive smoke (EPD, 1993). These are then required to be examined at vehicle emission testing centres. In 1995, the department received about 52,000 smoke reports and tested 35,000 vehicles. Of the vehicles tested, approximately 3 per cent had their vehicle license cancelled because of multiple failure or non-attendance at the testing centre. The number of vehicles called for testing increased rapidly after this control programme was first introduced in 1988 (EPD, 1993), and has stabilised in recent years (Table 10.6). Roadside surveys, conducted to determine whether this programme is effective, found fewer excessively smoky vehicles (particularly taxis and buses) on the road as a result of this programme. This programme has also contributed towards increasing public awareness of smoke problems, especially among diesel vehicle owners (EPD, 1993).

Hong Kong has a high proportion of diesel vehicles and a number of plans designed to combat the pollution from these vehicles have been proposed. These include:-

- Improving the quality of diesel fuel and thereby the development of diesel engine technology in order to comply with more stringent diesel emission standards.

- Reducing reliance on diesel-driven taxis and public light buses by requiring these to operate on unleaded petrol to reduce urban particulate emissions. A pilot study has indicated that forcing these

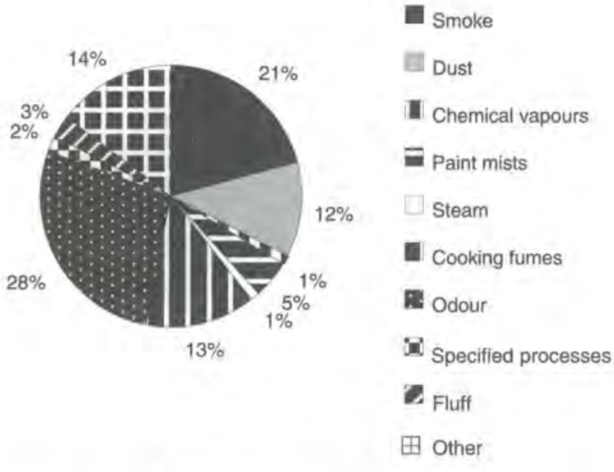


Figure 10.5 Air pollution complaints for 1992

Source: EPD, 1993

vehicles to use unleaded petrol is the most effective way of reducing levels of urban particulates; this is also one of the very few options available to ameliorate this growing problem.

- Encouraging the use of petrol engines in all small vehicles.
- Studying flow-through technology with the intention of finding suitable catalysts for old buses. If the trial is successful, older buses might be required to be retrofitted with flow-through catalysts;
- The introduction of vehicle inspection and maintenance programmes and increasing the penalties imposed for smoky vehicles.

A telephone hotline has been established for the general public to lodge complaints and make enquiries regarding environmental pollution matters (EPD, 1993). The hotline provides a strong focal point for communication between the EPD and the general public; it also raises public awareness of environmental issues and harness the support of the community for environmental protection. Pollution complaints have been divided into six categories: air, noise, liquid waste, solid waste, water and miscellaneous. In 1992, 47 per cent of all complaints made were on air pollution matters; a total of 2,774 environmental complaints were registered representing an increase of about 8 per cent from the previous year. Figure 10.5 shows the nature of the complaints made concerning air pollution. Complaints concerning vehicle emissions accounted for approximately half of the total, with commercial and industrial, restaurants and textile factories as other major complaint sources. A total of 43 per cent of the complaints were satisfactorily resolved; the rest were still awaiting the implementation of remedial measures by the end of the year.

Comment

Hong Kong has significant air quality management capabilities. The monitoring network is particularly well established, with good quality assurance and control procedures; the range of pollutants monitored could be expanded. Furthermore, particulate monitoring is, at present, conducted on a one day in six rota and authorities should perhaps consider whether, in view of the existing exceedances of AQOs for particulate matter, greater emphasis could be placed on measuring this pollutant. Similarly, there is one fixed kerbside monitoring site with CO measurement. The EPD plans to expand the network to fourteen with two more kerbside monitoring stations. In general, however, the range of data assessments, modelling and access to air quality information available through publications and the media are all excellent. There is also a detailed emissions inventory linked with air quality monitoring data in an air quality model and used to assess planning proposals and establish emissions controls upon industrial sources across the territory. Moreover, emissions controls are rigorously enforced through a substantial emissions monitoring and inspection programme ensuring that industrial and vehicular emissions limits are attained.

Air quality management in Hong Kong makes good use of Air Quality Objectives, which must be attained throughout each of the 10 Air Quality Zones comprising the territory. Emissions controls within each of these zones take into account existing emissions sources and enable the development of rational, cost-effective emission abatement. Hong Kong undoubtedly needs very careful and sophisticated management of its air quality owing to the close proximity of residential and industrial areas. Emissions controls have been progressively introduced since 1980 and are contributing to improving air quality, although levels of PM_{10} and NO_2 – particularly in street canyons – remain high. Nevertheless, despite the substantial industrial activities and numbers of motor vehicles, Hong Kong has, in recent years, managed to attain generally acceptable air quality, based upon its own objectives. The growth in motor vehicle emissions in the future, however, represents a continuing challenge for the EPD. The development of further public transport is an important factor in the future air quality equation and the Hong Kong public will need to be further encouraged to use these facilities and other clean forms of transport. Diesel emissions are a particular problem and are currently being targeted by the EPD.

Hong Kong clearly has a good understanding of air pollution problems and makes good use of this understanding for planning and development purposes.

Summary

- There is a comprehensive monitoring network in Hong Kong covering commercial/city centre, industrial locations and new development areas. The network includes fixed sites to measure ambient pollution levels and mobile laboratories which monitor emissions from major air polluting plants.

- Emission inventories are produced annually to include SO_2, NO_x, particulates, CO, hydrocarbons, VOCs and CO_2.

- Hong Kong has a set of Air Quality Objectives (AQOs) and emission controls. Specified processes and major industrial sources of atmospheric pollution are kept under tight control to ensure compliance with legislation.

- In general SO_2 and Pb concentrations have improved in recent years following the introduction of stringent regulations to reduce emissions. Current ambient air concentrations are within the established AQOs.

- Nitrogen dioxide and particulates still remain problems of concern and levels could deteriorate if action is not taken to further control vehicle emissions or use.

References

EPD 1990 *Air Quality in Hong Kong: Results from the Air Quality Monitoring Network 1986–1988*, Environmental Protection Department, Hong Kong.

EPD 1991a *Environment Hong Kong 1991: A review of 1990*, Environmental Protection Department, Hong Kong.

EPD 1991b *Air Quality in Hong Kong: Results from the Air Quality Monitoring Network 1991*, Environmental Protection Department, Hong Kong.

EPD 1993 *Environment Hong Kong 1993: A review of 1992, Environmental Protection Department, Hong Kong.*

EPD 1994 Questionnaire response: air quality monitoring and assessment capabilities questionnaire, Environmental Protection Department, Hong Kong.

EPD 1995 *Environment Hong Kong 1995: A review of 1994, Environmental Protection Department, Hong Kong.*

EPD 1996 Personal communications.

UNEP/WHO 1993 *City Air Quality Trends (GEMS/Air Data), Vol. 2*, WHO PEP/93.26, UNEP GEMS.93.A.2. United Nations Environment Programme, Nairobi.

11

Hyderabad and Madras

Statistical Summary

Hyderabad
Country: India
Estimated population 1990 (millions): 4.13
Projected population 2000 (millions): 6.69
Map reference: 17°22'N, 78°26'E
Area (km²): 217
Altitude (m): 545
Climate: Tropical
Average temperature range (C): 9.9–31.9
Annual mean precipitation (mm): 764

Madras
Country: India
Estimated population 1990 (millions): 5.28
Projected population 2000 (millions): 6.57
Map reference: 13°05'N, 80°18'E
Area (km²): 128
Altitude (m): 16
Climate: Tropical
Average temperature range (C): 10–40.3
Annual mean precipitation (mm): 1,215

This chapter is based on information available at the time of carrying out the original assessments. It is recognised that some of the data used and quoted here are relatively old. Nevertheless, this study provides a baseline upon which any further improvements can be assessed, and serves well as an example of similar air pollution situations that could occur in other developing cities.

Situational Analysis

India currently has the world's second largest urban population: 216 million in 1990 (UNDESD, 1993). There are 23 cities in India with populations of more than one million people and numbers are projected to grow substantially throughout the next decade (CSE, 1985). Urbanisation has been accompanied by considerable environmental degradation, including air pollution.

The National Environmental Engineering Research Institute, (NEERI) coordinates an air quality monitoring network with sites in all India's major cities (Figure 11.1). Air quality issues in India's cities, as with those in other countries, demonstrate certain national characteristics; this study has, therefore, chosen to examine the cities of Hyderabad and Madras in one chapter to enable their respective monitoring capabilities and management approaches to be compared and contrasted. Three principal sources of air pollution: vehicle, industrial and domestic, all contribute significantly to air pollution in both Hyderabad and Madras.

Vehicle generated air pollution

Vehicle emissions constitute a growing problem in India's cities and are predominantly caused by poorly maintained diesel lorries and buses using relatively low grade fuel. There is also a very high proportion of two- and three-wheeled vehicles with two-stroke engines with disproportionately high emissions for their engine size. In 1990, there were 2.06 million passenger cars and 1.61 million commercial vehicles in India; an increase from 0.9 and 1.12 million in 1981, respectively (UNEP, 1993). These figures do not, however, include two- and three-wheeler vehicles; which, in 1978 (the most recent year for which data are available), accounted for over 50 per cent of the total of 80,000 vehicles registered in the city of Madras (CSE, 1982). Although no emission estimates have been made for Hyderabad or Madras, it has been estimated that, for the cities of Bombay and Delhi, 70 per cent of total CO emissions, 50 per cent of hydrocarbons and 30/40 per cent of suspended particulate matter (SPM) can be attributed to vehicle emissions (CSE, 1985).

Figure 11.1 Cities participating in the NEERI AQMN

Source: NEERI, 1994a

Domestic emissions from firewood burning

Domestic emissions, primarily from cooking, are another important source of air pollution in Hyderabad and Madras. The use of traditional fuels, such as coal, wood and biomass, is still widespread; contributing to raised concentrations of a number of pollutants, especially SPM and benzo[a]pyrene (BaP). Firewood provides 50 per cent of the cooking energy in India's cities: a 1981 study in Hyderabad estimated that the city consumed approximately 150,000 tonnes of wood per year (CSE, 1985). Wood burnt in Hyderabad comes from throughout the state of Andhra Pradesh; 95 per cent of which is transported into the city on trucks (with the remainder on bullock carts). The use of wood for domestic consumption, therefore, in addition to the pollutants produced by its' combustion, also influences road congestion and vehicle emissions. There are over 470 wood selling outlets in metropolitan Hyderabad with as many as 97 per cent of these outlets in north and south Hyderabad – the poorer parts of the city (CSE, 1985). Wood burning is further discussed in the Air Quality Management Section.

Industrial emissions in Hyderabad and Madras

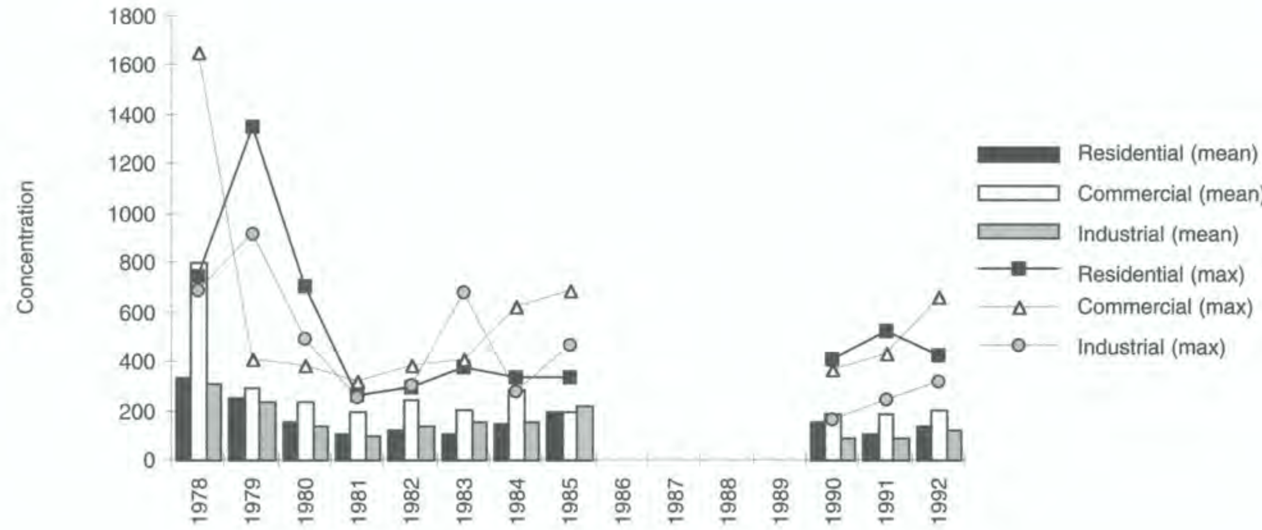
Small industries and businesses such as restaurants, bakeries, soap makers and crematoriums also burn wood as fuel; contributing to pollution in commercial and city centre areas. The main sources of energy for larger industries in Hyderabad and Madras include electricity, coal, natural gas and kerosene. Electricity is mostly generated by thermal power stations, predominantly coal-powered; producing approximately 65 per cent of the nation's power supply. In 1980, there were over 75 major plants in the country; one of which is situated in Madras, supplying a large proportion of the city's electricity needs (CSE, 1985). Indian coal has a low sulphur content (less than 1 per cent) but a very high ash content (30 per cent or more) making fly ash a major problem (DTI, 1982).

In both cities there is an absence of effective industrial zoning; increasing public exposure to industrial pollutants. Hyderabad is one of the major industrial growth centres in India; with engineering, chemical and other auxiliary industries located in industrial estates surrounding the city. These industries produce a large proportion of the air pollution in the area. Madras also has a rapidly growing industrial sector which includes refineries, fertilizer production, thermal power plants, organic chemicals, dyes and pigments and pharmaceutical industries. Most of the industries in Madras are located in the northern part of the city.

Air Quality in Hyderabad

Hyderabad is the capital of Andhara Pradesh and the most important inland city in the south-central part of India. The city has a moderate climate throughout the year, with increased wind speeds (>5 km/hr) and high rainfall, aiding pollution dispersion, during the monsoon period (June to September).

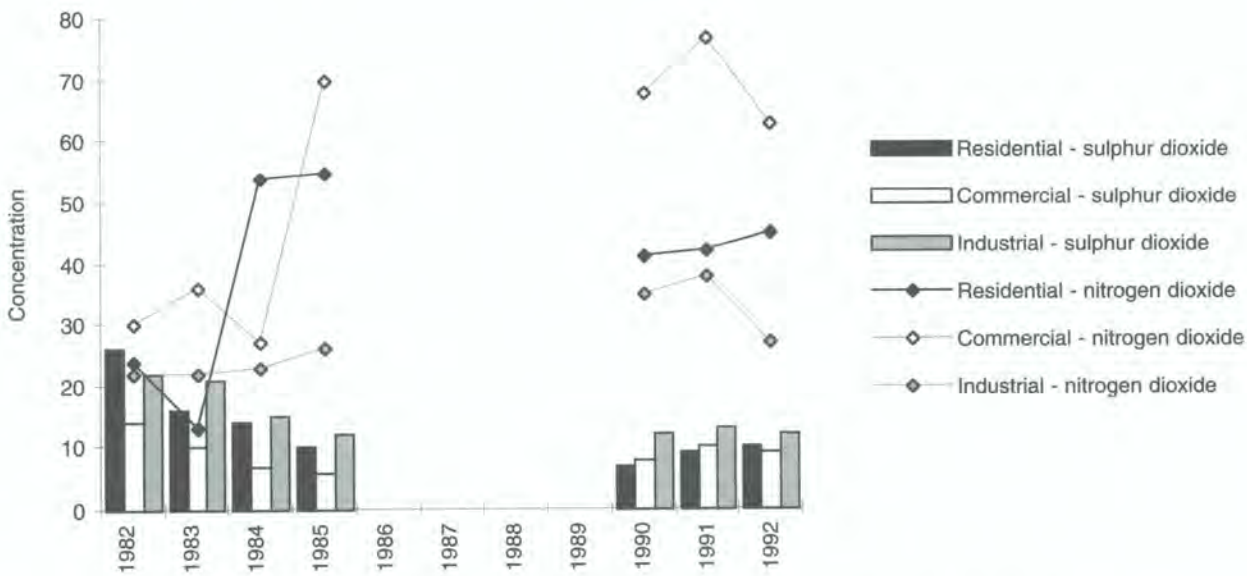
Annual trends for suspended particulate matter for the three sampling sites in Hyderabad are presented in Figure 11.2. This figure shows that SPM concentrations are generally higher at the commercial site than those at the industrial and residential sampling locations. Between 1978 and 1981, there was a general decline in concentrations at all sites and since then levels have remained constant: annual mean levels varying between approximately 100 and 250 μg m^{-3} at all locations. In recent years (1991 onwards), levels



Monitoring was conducted in 1986 and 1987 but information is not available; no measurements were taken during 1988 and 1989; 1992 values refer to an 8-hourly sampling period instead of 24 hours.

Figure 11.2 SPM annual mean trends and annual daily maximum concentrations at three sites in Hyderabad (µg m^{-3})

Sources: NEERI, 1980, 1983, 1988, 1991, 1994a, 1994c



Monitoring was conducted in 1986 and 1987 but information is not available; no measurements were taken during 1988 and 1989.

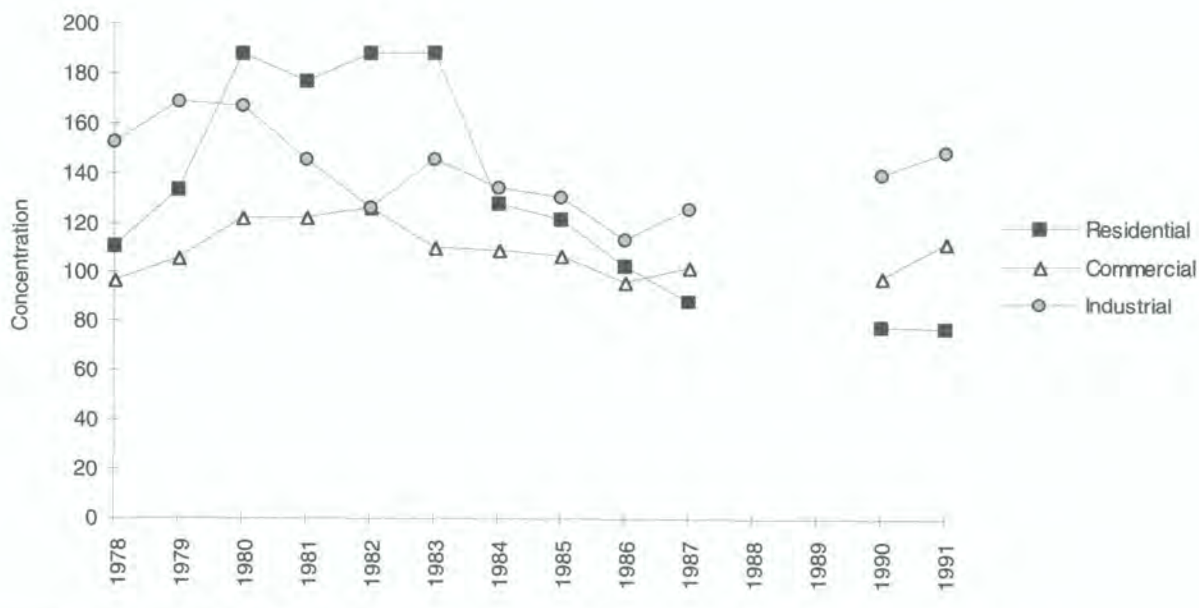
Figure 11.3 SO_2 annual mean and NO_2 98th percentile trends at three sites in Hyderabad (µg m^{-3})

Sources: NEERI, 1980, 1983, 1988, 1991, 1994a, 1994c in the commercial district have exceeded the proposed national air quality standard of 200 µg m^{-3}. Maximum 24-hourly SPM concentrations remain within the proposed standard. However, both annual averages and 24-hourly maximum concentrations for SPM exceed WHO guideline values at all sites (WHO, 1987). Particulate matter less than 10 µm has been measured since March 1991. Monthly averages ranged from 23–115 µg m^{-3} in 1991, and from 23–137 µg m^{-3} in 1992 (NEERI, 1994a). Maximum concentrations of 773 µg m^{-3} were recorded in February 1992. The overall lead content of particulate matter is below the WHO guideline and the national standard and does not represent a risk to health; although no measurements have been made at kerbside locations where concentrations would be appreciably higher.

Figure 11.3 presents sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) concentrations at all sites in Hyderabad from 1982 onwards. Data are based on four-hourly mean values averaged over the whole year. Sulphur dioxide concentrations show a steady decline at all sites from 1982 to 1985, followed by a very slight increase from 1990 onwards. Both compounds are below the Central Pollution Control Board (CPCB) standards and WHO guidelines.

Air quality in Madras

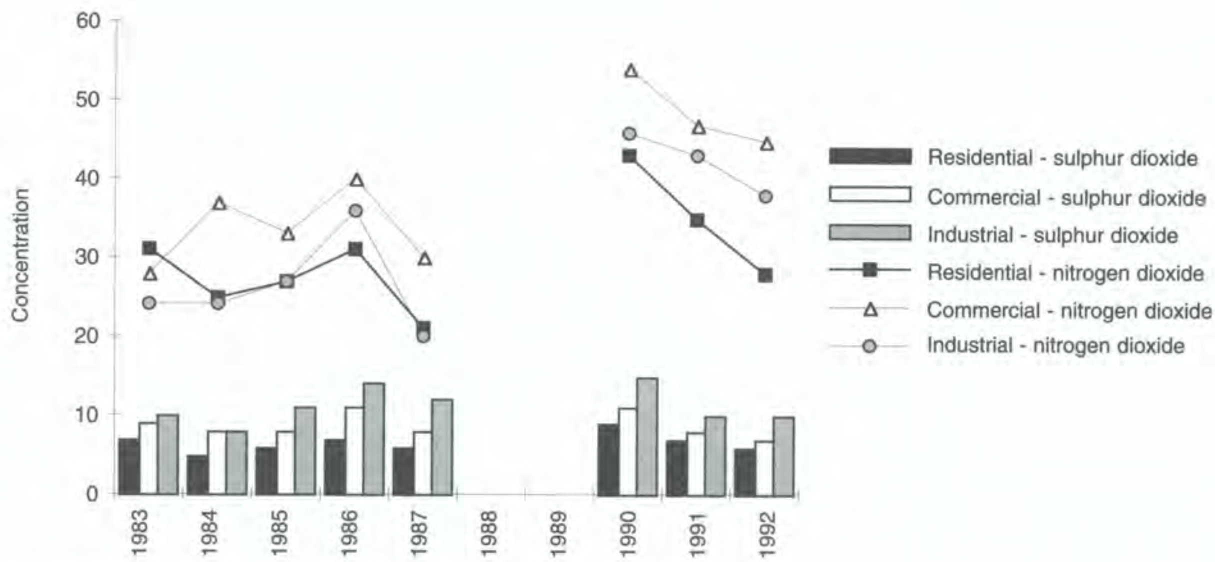
Madras is the fourth largest city in India and is situated on the east coast in the state of Tamil Nadu. The climate is more conducive to pollution dispersion than it is in Hyderabad owing to its coastal location and higher wind speeds; pollution concentrations are generally lower. Suspended particulate matter concentrations in Madras are shown in Figure 11.4. Concentrations have decreased since 1979 at the industrial site and since 1983 at residential sites. This has been attributed to a change towards the use of cleaner domestic fuels and the imposition of tighter control measures on emissions from the large thermal power station in the city. Concentrations at the commercial site have fluctuated around 100 µg m^{-3} since 1978. However, a slight upward trend has been reported at the commercial and industrial locations between 1990 and 1991. Monthly average levels for particulate matter less than 10 µm (PM_{10}) ranged from 24 to 151 µg m^{-3} in 1991 and 1992, with a maximum



No measurements were taken during 1988 and 1989.

Figure 11.4 Annual mean SPM trends at three sites in Madras (µg m^{-3})

Sources: NEERI, 1980, 1983, 1988, 1991, 1994a, 1994c



No measurements were taken during 1988 and 1989.

Figure 11.5 SO_2 annual mean and NO_2 98th percentile trends at three sites in Madras (μg m^{-3})

Sources: NEERI, 1980, 1983, 1988, 1991, 1994a, 1994c

8-hourly measurement of 687 μg m^{-3} in October 1992. Urban SO_2 and NO_2 (Figure 11.5) appear to have increased significantly between 1987 and 1990, when no monitoring was being conducted, but have subsequently declined in recent years. Seasonal extremes of climatic and wind conditions do not occur in Madras and therefore ambient levels of these pollutants do not follow the typical seasonal pollution build-up pattern found in Hyderabad, with lower concentrations during the monsoon season.

Lead concentrations in Madras, as in Hyderabad, are below WHO guidelines. However, average seasonal concentrations for BaP are generally higher than the 10 ng m^{-3} levels recommended by the CPCB for total SPM; they were reported as being as high as 42 ng m^{-3} (in the PM_{10} fraction) for the city of Madras during the winter of 1989/90. There are no set WHO guidelines for BaP as this compound is a suspected carcinogen and, therefore, no safe threshold value exists (WHO, 1987). However, the German Federal Environment Agency has proposed an annual guideline limit of 10 ng m^{-3} for BaP (Baek et al., 1992) which is the same as that recommended by India. The declining trend in BaP concentrations observed in London over the past few decades has been attributed to a reduction in coal burning (Baek et al., 1992). From these examples, we can infer that the high BaP concentrations reported in Hyderabad and Madras possibly result from coal and wood burning during cooking, rather than from vehicle emissions.

Monitoring Networks

Monitoring networks in Hyderabad and Madras form part of the National Air Quality Monitoring Network (NAQMN), operated since 1978 by NEERI. The national network covers 10 urban agglomerations (Figure 11.1), each having at least three sampling sites (in residential, commercial and industrial locations). Monitoring objectives include: identifying pollution trends; assessing the environmental impact of industrialization and urbanization; and, assessing the success of pollution abatement strategies. The information obtained is available to public health authorities and to city planners. This way data from the air monitoring programme can be used to form the basis for future air pollution management strategies.

The NAQMN programme has undergone two separate phases of development. Phase I, coordinated by NEERI, undertook studies from 1978 to 1987 to determine concentrations and trends of SO_2, oxides of nitrogen (NO_x) and SPM in 10 Indian cities and to define the main air quality problems in large urban agglomerations. The 10 cities were selected on the basis that they represent major regional growth centres, have high rates of industrialization and urbanization, and cover a wide range of geographic and climatic characteristics. Each of the chosen cities has a research laboratory (NEERI Zonal Centres) supporting the work of the programme. During 1988 and 1989 monitoring was stopped but the sites were re-opened in 1990 when Phase II was initiated. This phase, coordinated by NEERI in collaboration with the CPCB, goes beyond the scope of phase 1 to include the analysis of additional air pollutants, mainly hydrogen sulphite (H_2S), fluorine (F), ammonia (NH_3), lead (Pb) and polynuclear aromatic hydrocarbons (PAHs). Monitoring for particulates has been extended to include the size ranges of <10 μm (PM_{10}) and 10–100 μm (SPM). This phase of monitoring will continue indefinitely and forms an important part of the national integrated air pollution management strategy.

In 1984, the CPCB initiated its own monitoring network: the National Ambient Air Quality Monitoring (NAAQM) programme. This followed the introduction of the *Air (Prevention and Control of Pollution) Act 1981*, which gave the CPCB the responsibility for improving air quality and preventing, controlling and abating air pollution throughout India (CPCB, 1990a). Since 1984, this network has expanded from 7 stations to cover 220 locations in 19 states by 1990. The NAAQM monitors SO_2, NO_2 and SPM, and covers large cities as well as smaller towns and rural areas, with five sampling sites in Madras (three in industrial, one in residential and one in commercial locations). These sites have been operational since 1987.

Sampling methodologies and data capture are summarized in Table 11.1. All the sampling and analytical methods chosen are relatively low-cost and easy to set up; the equipment is designed and manufactured in India (by NEERI) ensuring that it is adaptable to local conditions. Methodologies for Phase I and II have remained basically the same, allowing for comparability of data. During Phase I of the programme, SO_2 and SPM samples were collected every tenth day, thus maintaining a sampling frequency of three times a

Table 11.1 Sampling methodology

Pollutant	Sampling method	Analytical method	Sampling period (hours)	Data capture Hyderabad (%)	Data capture Madras (%)
NO_2	Bubbler	Colorimetric: Jacob-Hochheiser	4	65	88
SO_2	Bubbler	West-Gaeke	4	65	88
SPM and PM_{10}	High Vol.	Gravimetric	8 or 24	95	75
Pb	High Vol.	AAS	8 or 24	–	–
NH_3	Bubbler	Nesselar Reagent	4	–	42
H_2S	Bubbler	Methylene Blue	4	–	47
PAHs	High Vol.	GC-FID	8 or 24	–	–

– Information not available.

Source: NEERI, 1994a

month. Since then samples have been taken approximately twice a week; yielding data for eight to ten random sampling days per month. The sampling duration for gaseous pollutants (NO_2, SO_2, NH_3 and H_2S) is four hours and for particulates (SPM and Pb) it is either eight or 24 hours depending on local circumstances. No monitoring is currently conducted for ozone (O_3) or CO.

Sulphur dioxide samples are collected on a 4-hourly batch basis for a continuous period of 24 hours by bubbling air through a tetrachloromercurate solution. Nitrogen dioxide is collected alongside SO_2 using the arsenite gas bubbler method. Concentrations are then determined colorimetrically with standard solutions. Suspended particulate matter and PM_{10} are also sampled in parallel with SO_2 and NO_2 over eight- or 24-hour periods using high volume (Hi Vol.) sampling techniques. A two stage size dust fractionator, designed and developed by NEERI, has been introduced into the sampling programme specifically for the collection of PM_{10} particles. Concentrations of particulates deposited in both filters are determined gravimetrically. Lead concentrations are determined from the SPM fraction using Atomic Absorption Spectrophotometry (AAS).

Polynuclear aromatic hydrocarbons have also been routinely monitored since 1990 when they were first incorporated into the AQMN programme. Polynuclear aromatic hydrocarbons are measured in the PM_{10} fractions collected at all sites in both cities. Twelve circles of 1 cm diameter each are punched from the filters and PAHs are then extracted from these by Soxhlet or ultrasonic extraction methods using cyclo-hexane. Polynuclear aromatic hydrocarbons are then analysed using Gas Chromatography with a Flame Ionization Detector (GC-FID). Five PAHs are analysed: fluoranthene, pyrene, benzo[a]anthracene, benzo[b]fluoranthene and BaP. In this assessment, data are presented only for the carcinogenic BaP. Meteorological data are collected from local observatories in all cities and are processed into wind roses using computer graphics; these are presented on a monthly and yearly basis.

There are three NAQMN sampling sites in Hyderabad and Madras, representing maximum activity zones for residential, commercial/city centre and industrial locations. Figure 11.6 shows the sampling sites in these two cities.

Quality assurance and data reporting

NAQMN quality assurance and data reporting are conducted centrally, by NEERI, and procedures are currently being developed to improve the reliability of the monitoring data produced. There is an internally standardized quality assurance programme (QAP) followed by all the laboratories taking part in the national network in order to ensure that good quality data are generated by all participating laboratories (NEERI, 1994b). Sampling sites are reviewed every five years to ensure that site locations remain adequate. Each city centre laboratory takes full responsibility for ensuring that the correct QAP is followed. As part of the QAP, two training courses for staff working at each participating laboratory have been organized in recent years.

During sampling, hourly observations are recorded at each site by the operator. High-volume samplers are calibrated and best fit calibration curves are produced at the central laboratory (NEERI in Nagpur) before dispatching the equipment to all of the cities. Top loading calibration units are also provided for subsequent field flow rate calibration checks. A similar procedure is followed for monitors of gaseous pollutants; although for these, spiked samples are also provided in order to establish precision and accuracy during sampling, and for calibration curve verification. Information recorded at the monitoring site includes the pressure drop used for flow rate calculations for gaseous and dust monitoring measured on an hourly and four-hourly basis respectively (NEERI, 1994b). Once a 24-hour sampling cycle has been completed, samples are taken to the laboratory for analysis following prescribed analytical procedures (summarized in Table 11.1).

Data are recorded in modified versions of Storage and Retrieval of Aerodynamic Data (SAROAD) formats as part of the national air quality management plan. The SAROAD computer programme was designed to suit local data handling needs. All ambient air quality information supplied by the active monitoring sites in the NAQMN are incorporated into this database. Information is stored in the data base by each participating city and sent to NEERI for final compilation and report preparation.

Reports are prepared through PC-based data analysis generating monthly, seasonal and annual mean concen-

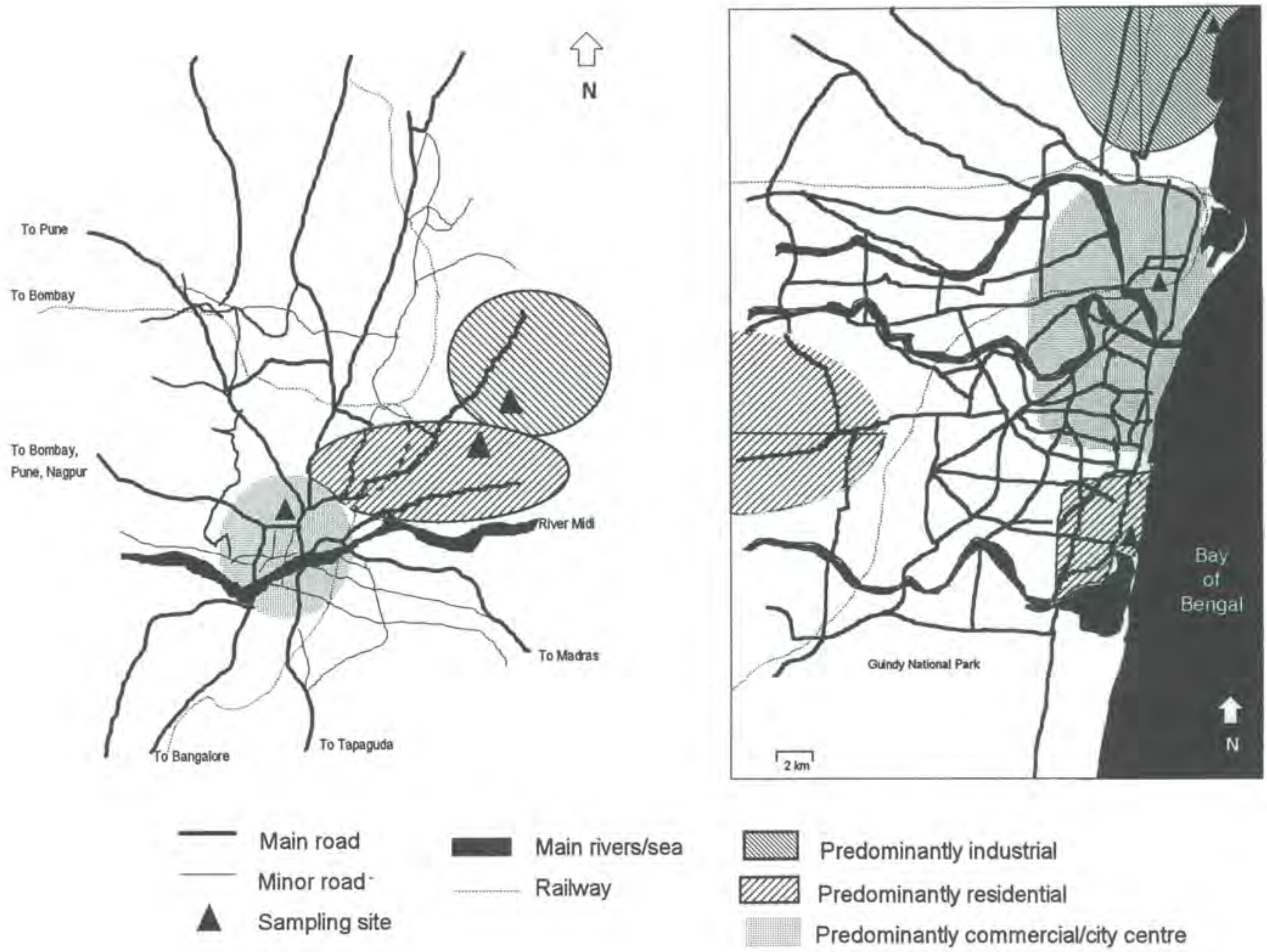


Figure 11.6 Monitoring sites in Hyderabad and Madras

Source: NEERI, 1994a

trations, maximum concentrations and percentiles. Pollution levels at each station are presented in the form of summary tables, computer printouts and in graphical form. Data summaries for the NAQMN have been produced on a biennial basis and, to date, six reports have been published (NEERI, 1980, 1983, 1988, 1991, 1994c). Data are available in internal bulletins produced by either NEERI in Nagpur or CPCB in Delhi, in scientific journals and through the media. Two state of the environment reports have also been published for 1982 and 1984/1985 (CSE, 1982, 1985); and the CPCB has also published two reports (CPCB, 1990a, 1990b) summarizing NAAQM network data for 1987 and 1989. Information from this network is not presented in this assessment as its results do not differ significantly from those reported by the NAQMN. The NAQMN has also been operational for a longer period of time and therefore provides longer trends data. Data are used in conjunction with meteorological information to determine possible correlations. Modelling is not carried out to predict spatial air pollution distribution because there are only a few sampling stations in each city. However, the three sampling sites chosen (i.e., residential, commercial and industrial activity zones) are used to obtain representative concentrations of the various pollutants for these three areas.

Although the QAP exists, quality assurance procedures are not carried out by an independent body; neither laboratory in Hyderabad or Madras has an accreditation certificate. However, both laboratories are recognized by the CPCB and are also covered under centralized review checks by NEERI at Nagpur. So far only three of the cities that take part in the NAQMN (Bombay, Calcutta and Delhi) have taken part in this review programme (NEERI, 1994b).

Emissions Inventories

Emissions inventories have not been produced for either Hyderabad or Madras although estimates are available for other Indian cities (Bombay and Delhi). Data from these cities, however, cannot be directly extrapolated to other cities as the source profile is different.

Air Quality Management

In 1981, the *Air (Prevention and Control of Pollution) Act* came into force and now forms the basis for controlling air pollution in India. This act gives the CPCB powers to lay down air quality standards and to prevent, control or abate air pollution in areas which exceed these standards (CPCB, 1990a). Air pollution standards and regulations are issued and enforced by central government. Different standards have been set for different geographical areas: industrial and mixed use, residential and rural zones (which also include commercial/city centre sites) and sensitive areas which include hill stations, national parks and monuments. These standards were established in 1982 and are summarized in Table 11.2. Under existing regulations, 95 per cent of the time, air concentrations should be within the prescribed limits given in the above mentioned table. These standards are based on measurements taken over 12 months of a year with a frequency of not less than once a week with a sampling time of eight hours for any sample, following the analytical procedures specified by CPCB (CPCB, 1990a).

Some of the air quality standards are under review and new limits have been proposed for SO_2, NO_2 and SPM (CPCB, 1990a). These new limits correspond to hourly, daily and annual average values (Table 11.3) and are based on levels that will ensure public health is protected, after allowing for an adequate margin of safety. They also represent levels that are not to be exceeded. Existing regulations (Table 11.2) are based on eight-hourly sampling intervals which do not always coincide with the actual monitoring sampling period for some of compounds. The biennial reports produced by NEERI are generally in the form of four-hourly, daily or annual average concentrations; with the exception of SPM which is sometimes reported as eight-hourly values. Based on the data presented in the reports published by NEERI it is often difficult to make comparisons with eight-hourly standards. For this reason, comparisons in this assessment have generally been made with the proposed standards, summarized in Table 11.3, although no information is available of the likelihood of these proposed standards being approved.

Table 11.2 Air quality standards in India

	Eight-hourly concentration (μg m^{-3})				
Site	SPM	SO_2	NO_2	CO	Pb
Industrial and mixed use zones	500	120	120	5,000	1.0
Residential, rural and commercial/ city centre	200	80	80	2,000	1.0
Sensitive areas	100	30	30	1,000	0.5

Source: NEERI, 1994a

Table 11.3 Proposed national ambient air quality standards for SO_2, NO_2 and SPM

Pollutant	Site	Indian time-weighted average ($\mu g\ m^{-3}$)			WHO guidelines ($\mu g\ m^{-3}$)[c]		
		1 hour	24 hours	Annual [a]	1 hour	24 hours	Annual
SPM	R and I	–	400 (800) [b]	200 (400) [b]	–	150–230	60–90
	S	–	200	100			
SO_2	R and I	655	130	80	350	100–150	40–60
	S	–	30	30			
NO_2	R and I	470	200	100	400	150	–
	S	–	30	30			

I = industrial and mixed use zones; R = residential, rural and commercial/city centre and S = sensitive areas.

(a) Annual arithmetic mean of a minimum of 104 measurements in a year taken twice a week, 24-hourly at uniform intervals.

(b) No more than 2 per cent of the total number of observations in a year should exceed the figures presented in brackets.

(c) Note that WHO guidelines do not make a distinction between different exposure zones.

Source: CSE, 1985 and WHO, 1987

The carbon monoxide standards (Table 11.2) are more stringent than those established by WHO (10 mg m^{-3} for 8-hourly averages). Although WHO guidelines for Pb are not directly comparable with the Indian standards for this compound, as they are not based on the same average time of exposure, they are within the range established by WHO. WHO has no eight-hourly guidelines for SPM, SO_2 or NO_2 and therefore the figures shown in Table 11.2 are not directly comparable with their guidelines. However, it is possible to make comparisons with the proposed standards summarized in Table 11.3. The proposed standards for these three compounds are fairly lenient compared with WHO guidelines, with the exception of the standards set for sensitive areas which are similar and in some cases stricter (SO_2 and NO_2) (see Table 11.3). It should be noted, however, that WHO Guidelines do not make a distinction between different exposure zones and were intended for use in Europe. The more lenient standards may have been set for practical reasons, to be achievable by national control measures, equipment already manufactured in India (DTI, 1982), and to take account of the high dust resuspension from deserts.

National regulations exist to control emissions from industry and large power generation plants. Companies are inspected annually to ensure compliance; they are also required to keep records and summary reports of emissions and to provide these to the responsible authority when requested. Exceedances, by degree, can lead to warnings, fines and even plant closures. National strategic plans for reducing emissions from industry include: the greater use of available control techniques; the substitution of fuels; and, process optimization. No specific information is currently available regarding strategic plans to reduce industrial emissions in Hyderabad or Madras. The effectiveness of national, industrial emissions control capabilities has been demonstrated in certain sensitive areas. The most well known example being the targeted reduction of emissions of SO_2 in Agra, following concern over the corrosive effects that ambient concentrations might have on the Taj Mahal. Following extensive assessments, emissions from main industrial sources were appreciably reduced, lowering SO_2 concentrations near the Taj Mahal by 75 per cent (CSE, 1985).

To control emissions from large thermal plants in populated areas, stacks have been equipped with scrubbers and mechanical dust collectors. Fly ash from power stations, such as that in Madras, is mixed with water and dumped off the coast. While this has reduced SPM emissions, the heavy metals present in fly ash are likely to have negative effects on the marine environment; they may accumulate in fish, in this major fishing ground (CSE, 1989). All modern stations and most old ones have been fitted with mechanical dust collectors which have operating efficiencies of about 70 per cent. Electrostatic precipitators which can perform with up to 99 per cent efficiency have not been introduced extensively owing to their high costs. Where these have been fitted, they are often poorly maintained, thereby reducing their efficiency (CSE, 1982). Sulphur dioxide contamination is also a problem. In Madras, for example, refineries process crude oil with a high sulphur content, resulting in high emissions into the atmosphere. Small industries are also a problem as they use inefficient furnaces and boilers and low chimney stacks. Emissions from such industries are made worse as coal supplies are unpredictable and often wood, rice husk and other biomass materials are burned. At present it is difficult to bring emissions from small companies under control owing to resource problems and limited knowledge of the contribution made by these industries towards total emissions.

Traffic is becoming an increasingly important source of air pollution in cities like Hyderabad and Madras; where the over-used transport infrastructure is heavily dependent upon motor vehicles. This problem has been exacerbated by the rapid expansion of the city limits, resulting in increased travel distances (CSE, 1982). The number of trips per person has also substantially increased; for example, in Madras, growing bus fleets kept pace with population growth between 1961 and 1978 (CSE, 1982), however, during that period commuting habits changed resulting in a doubling of the number of trips per capita. Thus it has not been possible to prevent overcrowding of buses and trains. Rising urban incomes, for sections of the population, has resulted in a considerable growth in the number of private vehicles, particularly two- and three-wheelers and cars. Bicycle use, which has always been an important means of transport in Hyderabad and Madras, has been declining in recent years; although they still account for a large proportion of journeys travelled (an estimated 60–75 per cent of total traffic in Hyderabad in 1980) (CSE, 1982). The increase in vehicle numbers, combined with inadequate roads and traffic planning has inevitably lead to increased congestion. With relatively high emissions per vehicle, owing to the age and poor maintenance of many of the cars, buses and HGVs, vehicle emissions make a considerable impact upon urban air quality despite the relatively low rate of vehicle ownership per thousand population.

National exhaust emissions regulations exist for motor vehicles and heavy goods vehicles which are meant to be checked every six months. Smoke intensity should not exceed 65–75 on the Hartridge scale for heavy diesel vehicles and CO and hydrocarbon emissions from petrol-driven vehicles should not exceed 3 per cent and 100 ppm, respectively. No information is, however, available on the number of vehicles that are checked or that comply with these standards. Petrol, that has a low octane rating, raising emissions and exceeding emission standards, does not lead to a penalty (NEERI, 1994a). Vehicle owners, therefore, currently have no incentives for tuning and maintaining their vehicles. However, the introduction of fines is currently being proposed and may lead to greater compliance with vehicle emission standards in the future (NEERI, 1994a).

Few studies have so far been carried out on urban energy consumption in India (CSE, 1985). Those that have been conducted reveal a growing dependence, especially of the urban poor, on firewood and biomass; particularly cow dung. Over five million tonnes of cow dung (32 kg per person per year) is burnt every year in urban India (CSE, 1985). A reasonable proportion of city supply comes from cattle in the cities themselves, with surrounding villages making up the shortfall. The government is attempting to reduce dependence on biomass fuels and reduce indoor exposure to air pollutants through encouraging the use of cleaner stoves; however, to date, progress has been slow (CSE, 1982, 1985). Emissions of SPM can be reduced by as much as 60 per cent, CO by 86 per cent, through the simple introduction of more fuel-efficient stoves equipped with a ventilation chimney. Supplies of cleaner fuels, mainly kerosene, coal and LPG, are available but only the most affluent are currently using them. These cleaner fuels are currently more expensive than firewood, but stoves using them are much more efficient (40 per cent for kerosene compared with

3–7 per cent for firewood). This makes kerosene cooking appreciably cheaper than wood after the initial purchase of the stove has been made. In slum areas, the high initial cost of investing in a more expensive stove, lack of adequate housing and the risk of having the cooking stove stolen, mean that people living in these areas continue using firewood. The traditional use of firewood hinders the introduction of the new equipment.

Comment

India has substantial and competing demands upon the funds available to invest in urban air quality management. Many of the problems associated with air quality management are made more severe by rapid urbanisation; the populations of both Hyderabad and Madras are projected to exceed 6.5 million inhabitants by the year 2000. Of the two cities studied here, Hyderabad is likely to be more severely affected by the pressures brought to bear on air quality by urban development because it does not experience the same favourable dispersion characteristics. It is also growing more rapidly.

The Government of India has a number of policies aimed at addressing urban air quality problems. The national monitoring network produces regular quality assured data and cities are attempting to control emissions from major industrial and power-generating facilities, particularly in sensitive areas. Quality assured air quality data is also well reported in various publications. Unfortunately, little information is available regarding air quality management strategies followed in Hyderabad and Madras. In larger cities than Hyderabad and Madras emissions inventories have also been compiled. Clearly, in terms of developing air quality management plans for Hyderabad and Madras, monitoring for other pollutants, particularly O_3 and CO, would provide useful information as would establishing kerbside monitoring sites. NEERI has included the measuring of O_3 and CO as part of its future workplan; for when funding becomes available. As monitoring of these pollutants usually involves the use of expensive continuous instruments, NEERI could investigate the use of passive sampling; appropriately cost-effective these could supplement work currently undertaken. Plans also exist to conduct emissions inventories for more of India's cities. The government is also trying to encourage use of cleaner fuels, improved stoves and better ventilation to reduce domestic emissions. However, the projected population increase will work against these efforts and could lead to greater demands for firewood and biomass.

Adequate quality-assured monitoring exists in Hyderabad and Madras enabling a preliminary assessment of their air quality. The production of a simple emissions inventory would now be an important air quality management development in these cities. Emissions estimates could then be incorporated into future development plans for these cities.

Summary

- India has a national air quality monitoring network which covering 10 major cities, including Hyderabad and Madras. Part of this network, these two cities each have three monitoring stations situated in a residential, commercial and industrial area. Sulphur dioxide, NO_2, SPM and Pb have been monitored since 1978. Particulate matter less than 10 µm and other variables, including PAHs, have been monitored since 1990.

- No emissions estimates have been produced for either Hyderabad or Madras, although estimates have been conducted for other larger Indian cities.

- Sulphur dioxide, NO_2 and Pb concentrations are generally below the national and WHO standard/guideline values. Suspended particulate matter levels, however, often exceed the national air quality standards in both cities. Benzo[a]pyrene concentrations are also high, generally above the national standard of 10 ng m^{-3}.

- There are seasonal variations in the concentrations of some of these compounds in Hyderabad; levels being lower in the winter and monsoon periods. Madras, being a coastal city, has more effective, climatic air pollution dispersion – levels of most compounds generally being lower than in Hyderabad.

References

Associated Octel Company Limited 1990 Worldwide survey of motor gasoline quality, 1989, Associated Octel Co. Lmt, London.

Baek, S. O., Goldstone, M. E., Kirk, P.W.W., Lester, J. N. and Perry, R. 1992 Concentrations of particulate and gaseous aromatic hydrocarbons in London air following a reduction in the lead content of petrol in the United Kingdom, *Sci. Total Environ.* **111**, 169–199.

CPCB 1990a *Ambient Air Quality Status of Some Cities/Towns in India*, Central Pollution Control Board, Delhi.

CPCB 1990b *National Ambient Air Quality Statistics of India*, Central Pollution Control Board, Delhi.

CSE 1982 *The State of India's Environment 1982: A Citizens' Report*, Centre for Science and Environment, New Delhi.

CSE 1985 *The State of India's Environment 1984–85, The Second Citizens' Report*, Centre for Science and Environment, New Delhi.

CSE 1989 The environmental problems associated with India's major cities, *Environment and Urbanization* **1**, 7–15.

DTI 1982 Reports from Overseas Posts No 12. Air Pollution, Part 4. Department of Trade and Industry, London.

NEERI 1980 *Air Quality in Selected Cities in India 1978–1979*, National Environmental Engineering Research Institute, Nagpur.

NEERI 1983 *Air Quality in Selected Cities in India 1980–1981*, National Environmental Engineering Research Institute, Nagpur.

NEERI 1988 *Air Quality Status in Ten Cities: India 1982–1985*, National Environmental Engineering Research Institute, Nagpur.

NEERI 1991 *Air Quality Status 1990*, National Environmental Engineering Research Institute, Nagpur.

NEERI 1994a Questionnaire response: Air quality monitoring and assessment capabilities questionnaire, National Environmental Engineering Research Institute, Nagpur.

NEERI 1994b *Audits of GEMS/Air Monitoring Stations, South-east Asia Region*, Vol. 1, National Environmental Engineering Research Institute, Kampur.

NEERI 1994c *Air Quality Status 1991 and 1992*, National Environmental Engineering Research Institute, Nagpur.

UNDESD 1993 *World Urbanization Prospects: the 1992 Revision*, Department for Economic and Social Development (Population Division), United Nations, New York.

UNEP 1993 *United Nations Environment Programme Environmental Data Report 1993–94*, Blackwell Publishers, Oxford.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

12

Johannesburg - Soweto

Statistical Summary

Country: South Africa
Estimated population 1990 (millions): 3.60*
Projected population 2000 (millions): 4.51*
Map reference: 26°15'S, 28°W
Area (km²): 148,600*

Altitude (m): 1,700
Climate: Temperate grassland
Average temperature range (C): 4–26
Annual mean precipitation (mm): 811

* including adjacent townships

Situational Analysis

Johannesburg is located in South Africa's highveld, in the Transvaal. The climate is mild but extremely unfavourable for air pollution dispersion owing to the highly stable anti-cyclones which persist in the region, particularly during winter. This results in strong ground-level radiation inversions which trap pollutants emitted at low levels. The high altitude, with about 20 per cent less oxygen than is present at sea-level, also reduces combustion efficiency, causing greater smoke production. The city and surrounding area, therefore, have a natural tendency towards poor air quality.

The Witwatersrand area has substantial gold reserves with many mines to the south of the city. There are also substantial coal deposits in the eastern Transvaal, 60 km to the east of the city. Johannesburg has consequently developed a major industrial sector which expanded rapidly following the international trade embargo imposed in the 1960s. There are four industrial areas located within the current Johannesburg municipal area, including several large chemical plants. Vereeniging, Vanderbilpark and Sasolburg are important industrial towns that form a complex 45 km to the south of the city centre. It includes the ISCOR steel mill, SASOL (which manufacture synthetic fuels and chemicals), the NATREF refinery, and Portland cement factory. Industry uses a combination of town gas, hard coal and electricity to meet their fuel needs. Electricity is provided through a national grid and there are two coal-burning power stations in the vicinity of Johannesburg. The mining industry has created enormous deposits of mine tailings – crushed rock from gold workings forming sand dumps or slime dams. These deposits generate substantial amounts of wind-blown dust resulting in elevated concentrations of particulate matter. Dust control programmes through the grassing of sand dumps have been undertaken since the 1960s. Reprocessing of old mine tailings using new technology is also undertaken if it is considered to be economically viable.

During the period of apartheid, the black workforce was predominantly housed in townships surrounding Johannesburg, such as Soweto (see Figure 12.1). Large areas of the townships are not electrified; furthermore, the relatively high cost of electricity discourages its use in other areas. Most township residents rely on solid fuel - coal and wood - for space heating and cooking. As a consequence, domestic emissions of smoke and sulphur dioxide (SO_2) in the Witwatersrand area are substantial and, as they are primarily emitted at a few metres above ground-level, give rise to large concentrations of pollutants.

Air quality in the Johannesburg Municipal Authority

Air quality monitoring has been conducted in both the Johannesburg Municipal Authority and Greater Soweto township. The most recent data available to this study, for the Johannesburg Municipal Authority area are shown in Table 12.1. Measured concentrations in the

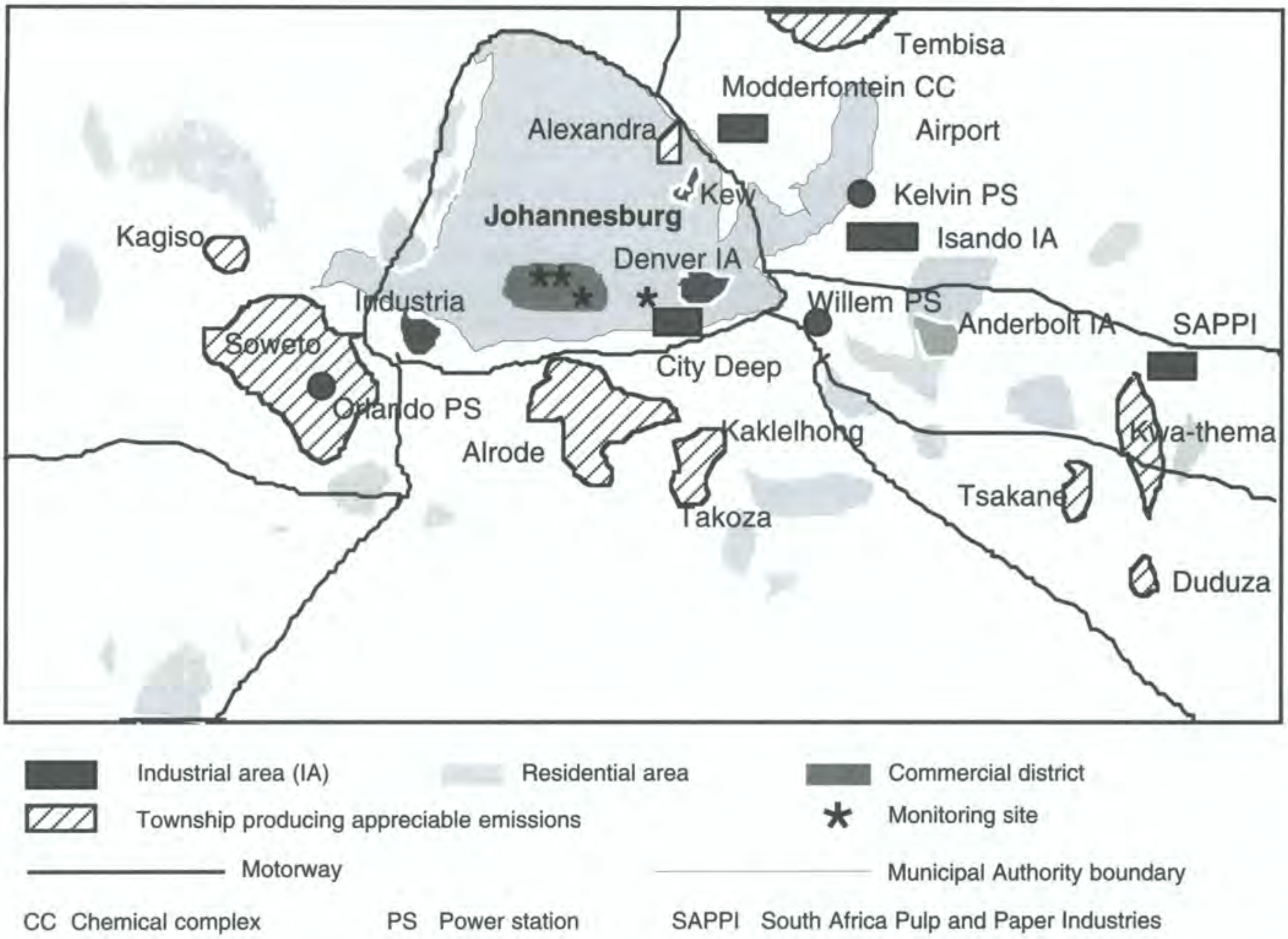


Figure 12.1 Sketch map of the Johannesburg area

Source: AA, undated; Johannesburg City Council, 1994

city are not high and are generally below WHO European Guidelines; with the exception of the maximum hourly carbon monoxide (CO) concentration (WHO guideline equivalent to 38.5 ppm). Kerbside maximum total suspended particulate (TSP) concentrations are also quite high, indicating the importance of motor vehicles as a source of TSP; probably both through exhaust emissions and resuspended dust. Regular SO_2 monitoring has only begun recently; however, during a three month study in 1990, the maximum of 24-hour concentrations measured was only 30 ppb; overall concentrations ranged between 6 and 16 ppb on most days.

The determination of trends is difficult owing to discontinuities in the monitoring programme. However, between 1982 and 1992, there appeared to be an increase in summer (September to April) concentrations of nitric oxide (NO); no trend is discernible for the winter months. During this period overall ozone (O_3) concentrations increased at the residential site by 1.5–2.0 ppb a^{-1}; the city centre site shows a similar rate in winter and the summer shows a flat trend (Khrom, 1992).

Table 12.1 Air quality monitoring data in Johannesburg from 1991

	Residential site (1991/92)		Commercial site (1993)		Kerbside site (1993)	
	Annual mean	Maximum (hourly)	Annual mean	Maximum (hourly)	Annual mean	Maximum (hourly)
NO_2	16	84	26	99	–	–
TSP	–	–	26[(a)]	90[(a)]	68[(a)]	235[(a)]
CO	–	–	1.6[(b)]	33[(b)]	–	–
O_3	58	109	21	84	–	–
Pb	–	–	0.53[(a),(c)]	0.80[(a),(c)]	–	–
NMHC	83	365	149	2,055	–	–

Units ppb.

(a) $\mu g\ m^{-3}$.

(b) ppm.

(c) monthly average.

Source: City of Johannesburg, 1994

Air quality in Soweto

Air quality data for the Soweto township are shown in Table 12.2. The values demonstrate concentrations of gaseous pollutants to be below WHO Guidelines, but also demonstrate levels of particulate matter to be significantly elevated (City of Johannesburg, 1995; du Plessis, 1995).

The size distribution of the particulate matter is shown in Figure 12.2. Although the TSP concentration is high, the proportion of the fine particulate matter fraction is only between 10 and 25 per cent of PM_{15} (the monitored fraction). Consequently, health impacts are not likely to be as significant as a reading of the TSP measurements would suggest. There are statistically significant variations between the concentration of the course fraction; the highest concentrations being observed at the lowest elevation sites and in the informal shanty areas such as Soweto: where population densities are highest and coal burning significant (Sithole et al., 1994).

Table 12.2 Air quality monitoring data in Soweto – Dhlamini

	October 1990–April 1991		1992	
	Annual mean	Maximum (hourly)	Annual mean	Maximum (hourly)
SO_2	23	117	18	113
NO_x	50	336	62	349
NO	30	–	–	–
NO_2	20	–	–	–
O_3	20	120	22	64
$PM_{10/2.5}$	115[(a),(b)]	213[(a),(b)]	95[(a),(c)]	746[(a),(c)]

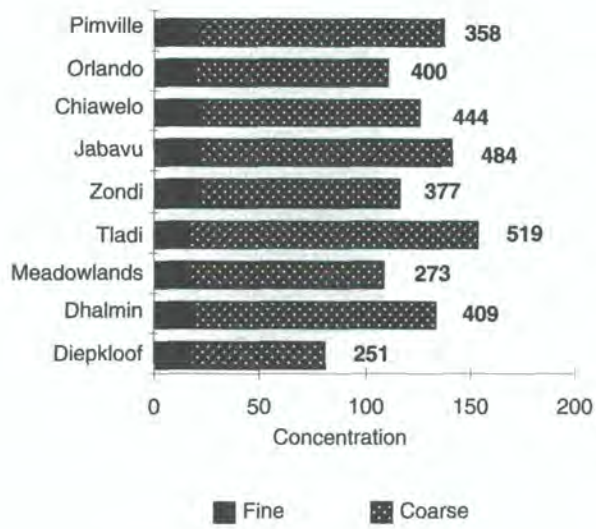
Units ppb.

(a) $\mu g\ m^{-3}$.

(b) PM_{10}.

(c) $PM_{2.5}$.

Source: Johannesburg City Council, 1995; du Plessis, 1995



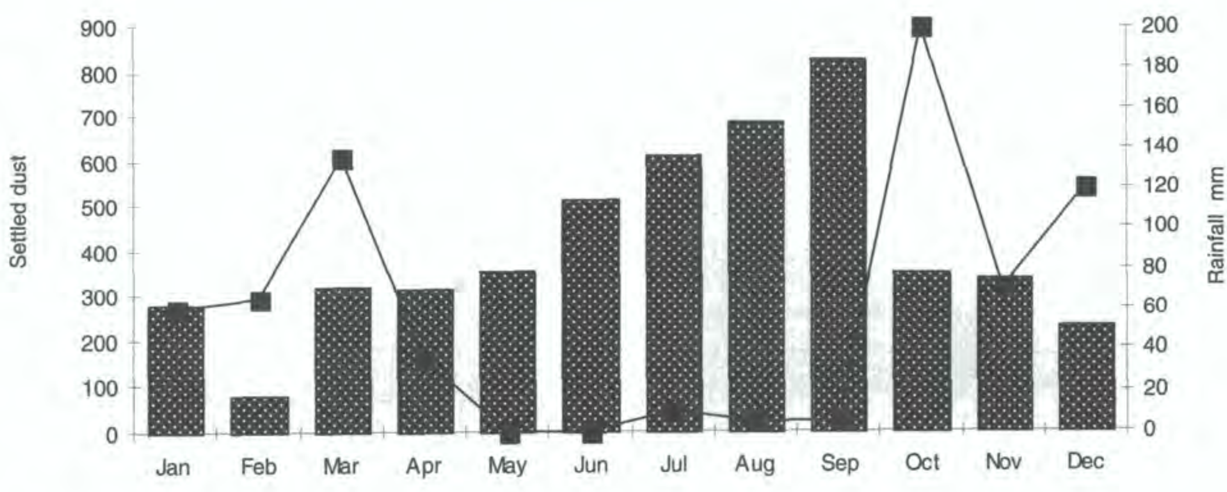
15 > Coarse > 2.5 µm.
Fine < 2.5 µm.
The numbers signify the maximum 24-hour concentration at each site in 1993.

Figure 12.2 Annual mean particulate matter concentrations at nine sites in Soweto, 1993 (µg m^{-3})

Source: Sithole et al., 1994

There are significant seasonal variations in the coarse and settled dust fractions, although not in the fine fraction particulate matter. Monthly settled dust flux for 1993 is shown in Figure 12.3 and demonstrates a close inverse relationship between dust and rainfall. The highest levels are observed in August and September at the end of the dry season when wind-blown dust levels increase. The dry season also corresponds with the winter heating period during which emissions of smoke are also likely to rise; and with the onset of particularly unfavourable dispersion conditions. It is difficult to ascertain the relative importance of the different factors influencing particulate matter concentration throughout the year (Sithole et al., 1994).

X-ray analysis of selected samples of the particulate matter for elemental composition and qualitative source apportionment indicates that, in addition to coal burning and wind-blown dust, other important sources of particulate matter are: indiscriminate garbage burning (producing nickel, copper, zinc and lead); motor vehicles (lead); secondary production of sulphate (from transboundary movement of SO_2); and biomass burning. Excess levels of iron and calcium were also detected, although the sources are at present unidentified (Sithole et al., 1994).



Data averaged over five sites.

Figure 12.3 Monthly mean settled dust (mg d m^{-2}) and rainfall, Soweto, 1993

Source: Sithole et al., 1994

Monitoring Networks

Johannesburg Municipal Authority

Ambient air quality monitoring in the Johannesburg Municipal Authority area is currently conducted by the Health, Housing and Urbanization Directorate of the Johannesburg City Council. In the central commercial district there are three sites (City Hall, Newtown and Fordsburg), with a further site at South Hills – a residential suburb in the south of the city. A summary of the measurements made recently are shown in Table 12.3 and the location of the sites is shown in Figure 12.1. An additional monitoring site, about 20 km to the north of the city, was located at the Northern Sewage works in 1984 to measure the background pollution concentrations for oxides of nitrogen (NO_x), O_3 and hydrocarbons. The site was closed, however, in 1989 owing to a lack of serviceable equipment and also because the local pollution generated by the sewage works affected the readings of background concentrations.

Table 12.3 Ambient air quality monitoring in Johannesburg

Site	Measured	Measurement frequency	Began operation	Closed operation
City Hall	NO_2, NO, NO_x	Hourly	June 1982	March 1994
	O_3	Hourly		
	Methane and non-methane hydrocarbons	Hourly		
	CO	Hourly		
	Black smoke	Daily		
Newtown	NO_2, NO, NO_x	Hourly	1995	Current
	O_3	Hourly	1995	Current
	Methane and non-methane hydrocarbons	Hourly	April 1996	Current
	CO	Hourly	1995	Current
	Meteorological parameters	Various	1992	Current
Fordsburg	TSP	Weekly	Feb 1994	Current
	SO_2	Weekly	Feb 1994	Current
	Black smoke	Daily	1952	Current
Municipal Destructor	TSP (a)	Weekly	June 1994	Current
	SO_2	Weekly	June 1994	Current
South Hills	NO_2, NO, NO_x	Hourly	July 1984	Current
	O_3	Hourly		
	Methane and non-methane hydrocarbons	Hourly	July 1984	December 1991
	TSP(a)	Weekly	Mar 1994	Current
	SO_2	Weekly	Mar 1994	Current
	Meteorological parameters	Hourly	July 1984	Current

(a) Including measurements of Pb, Hg, Cd, Ni, Mn, Cr, Cu, Zn, Polyaromatic hydrocarbons including benzo-a-pyrene (1994 only), inorganic anions (sulphate, nitrate, nitrite and chloride).

Source: Johannesburg City Council, 1994

Monitoring is conducted to measure compliance with national air quality standards and to determine temporal variations. Continuous monitors are calibrated using standard gas mixtures, and regular flow checks are performed on all instruments; however, the data are not formally validated. Site audits are conducted at regular intervals by an independent body and the site locations are inspected every 10 years to ensure that they are still appropriate. In 1993, good data capture was achieved for most measured parameters (in excess of 90 per cent).

The data produced are assessed for a variety of purposes including determining trends, checking compliance with standards and for meteorological modelling. The data are published in internal bulletins, scientific journals and five-yearly data reports.

Soweto

An air quality monitoring network was first established in Greater Soweto in a co-operative programme between the Greater Soweto Health Department, National Association for Clean Air (Soweto Branch), Eskom Technology, Research and Investigations and the University of Witwatersrand. The network was established to address the health effects of air pollution and specifically to collect exposure data for the Birth-to-Ten Epidemiological Study – aimed at assessing the influences of urbanization on the growth of a selected population of children (Sithole et al., 1994). The monitoring network operated from December 1991 to March 1994, but is currently suspended.

The network comprised one automatic monitoring station at Dhlamini operated by Eskom and consisted of: a fluorescent SO_2 monitor, chemiluminescence NO, NO_2 and NO_x analyser, O_3 UV photometry instrument, and meteorological instruments – anemometer, thermometer, nephelometer to measure light scattering, and a humidity probe. Dhlamini was selected as the site as it was anticipated to be the location at which the highest concentrations of pollution would be detected in Soweto, being located at the bottom of the Klip Valley (Sithole et al., 1991). There are also nine particulate monitoring sites (including one at Dhlamini), mostly located at local health clinics. These sites were selected to provide good coverage of Greater Soweto, providing sites with a mixture of elevations, domestic energy resources and socio-economic status. The sites are shown in Table 12.4. Sampling was conducted using stacked filter samplers with an inlet providing a PM_{15} cut-off and a $PM_{2.5}$ cut-off between the two filters. The sampling schedule was one day in six for 24 hours, midnight to midnight, using a timer and dry gas meter to determine the volume of air. Particulate monitoring was the responsibility of the Soweto Environmental Health Department and quality assurance and elemental analysis of the filters performed by the Schonland Research Centre, University of Witwatersrand (Sithole et al., 1994).

Table 12.4 Particulate matter monitoring sites in Soweto

Site	Elevation	Energy resources	Socio-economic status
Dhlamini	Low	Coal only	Lower
Jabavu	Medium	Mixed	Lower
Zondi	High	Mixed	Middle
Tladi	Low	Mixed	Middle
Chiawelo	Low	Mixed	Lower
Meadowlands	Medium	Mixed	Middle
Pimville	Medium	Electricity	Upper
Orlando	High	Mixed	Lower
Diepkloof	High	Electricity	Upper

Source: Sithole et al., 1994

As part of the Birth-to-Ten study, indoor air quality monitoring has also taken place in Soweto; however, no details of the measurements are available. Data from monitoring in Soweto have been presented at conferences and published in conference proceedings and a number of papers have been produced. The data have been collected for an epidemiological study and will be used to research the relationship between urbanization and health. The programme is currently suspended, but it is hoped that monitoring will commence again in 1995.

Emissions Inventories

No emissions inventory has been compiled for Johannesburg, although a national inventory was conducted in 1985 and more recently in 1993 – the results from which are currently being compiled.

Air Quality Management

Air quality management in Johannesburg and throughout South Africa is based upon the Atmospheric Pollution Prevention Act of 1965 (IUAPPA, 1991). The Act is divided into five sections; the first of which established the Air Pollution Advisory Committee to advise ministers on all aspects of air pollution abatement. The remaining four sections of the act specify controls upon scheduled processes, smoke, dust and vehicles respectively.

Industry in South Africa operates under the principle of Best Practicable Means (BPM), and industries are categorized as either scheduled or non-scheduled, depending upon the nature of the process. For scheduled processes, limits are set and controls are imposed such that "if the limits are not exceeded then it is presumed that best practical means are being complied with" (Government of South Africa, 1965). The limits established are based upon Threshold Limit Values (TLVs) so that under normal operating conditions the ground level concentration of the pollutant at any point around the plant should not exceed the TLV/50, unless the pollutant is carcinogenic or accumulative in which case the ratio TLV/100 is used. Stack emissions guidelines have also been adopted for different processes and pollutants. Table 12.5 shows the air quality guidelines for some more common pollutants. Scheduled processes are provided with a registration certificate by the Chief Officer Air Pollution Control appointed by the Air Pollution Advisory Committee. The registration certificate enables the plant to operate and can be withdrawn if it is considered that the BPM is not being met, thus closing the operation. An appeals procedure is laid down in the event of such circumstances. Companies are inspected annually to ensure they continue to meet the provisions of the authorization.

Control of smoke is covered under part three of the Act and requires local authorities to impose one of three levels of smoke control. The Johannesburg Municipal Authority employs the most rigorous of these levels – a smoke-control zone – to prohibit emissions of smoke from any location (including domestic dwellings) such that the smoke obscures light to greater than 20 per cent. The township authorities have

Table 12.5 South African air quality standards (μg m^{-3})

Pollutant	Annual mean	Daily maximum	Hourly maximum
TSP	150	350 (120[b])	–
Black smoke	100 (50)	250 (125[b])	–
SO_2	80 (50)	265 (125[c])	780 (350)
NO_2	90	180 (150)	360 (400)
O_3	20	100 (100–120[d])	240 (150–200)
Pb	2.5[a] (0.5–1.0)	–	–

WHO Guidelines are shown in parenthesis for comparison.

(a) Monthly mean.

(b) Combined guideline with SO_2.

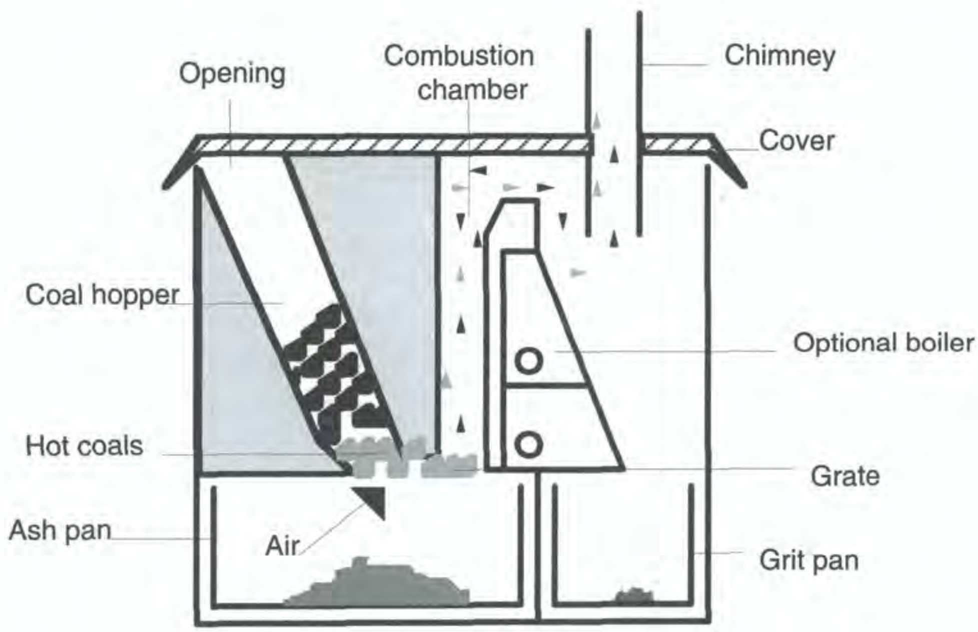
(c) Combined guideline with smoke.

(d) 8 hours.

Source: Johannesburg City Council, 1994; WHO, 1987 not adopted the provisions of the Atmospheric Pollution Prevention Act and therefore do not operate a smoke control area (Johannesburg City Council, 1995). All new stoves for domestic use are supposed to comply with national standards in force since 1982. However, the introduction of smokeless (or, more accurately, low-smoke stoves) is quite slow owing to the long life of existing stoves. The Box below describes the operation of one of the many designs of such stoves.

Control of dust is specified under section four of the Act and is intended to control emissions from sand and sludge dumps composed of mine tailings. In the past, dust has presented a major problem in the residential areas surrounding these waste deposits. However, the establishment of dust-control areas, analogous to the smoke-control areas, has resulted in the extensive planned vegetation of many of these dumps helping to alleviate the problem. In mines about to be closed down, sufficient funds must be allocated to prevent pollution from abandoned workings; thus making owners responsible for preventing future environmental damage. As a local measure to reduce dust concentrations, Johannesburg City Council has recently fitted a bag filter system to the stack of its Kelvin power station to reduce fly-ash emissions.

The smokeless stove



Wood and paper are placed on the grate through the opening and ignited, the cover being left off until the burning wood is incandescent. The hopper is filled with coal, the cover is replaced and the ash pan is pulled out slightly to allow the introduction of primary air. The coal combusts and the gases are burnt in the combustion chamber, with recirculation ensuring complete combustion before being emitted through the chimney. The grit pan collects the fly ash that falls back in the chimney and is emptied as required.

Emissions from motor vehicles are covered under section five of the Act. Only smoke from diesel vehicles is currently subject to control, and standards vary depending upon altitude. Notices can be served on vehicle owners requiring servicing and subsequent re-testing; but few municipal authorities actually enforce these regulations (South Africa, 1993). The Johannesburg Municipal Authority, however, requires strict adherence to the regulations, inspecting vehicles regularly and prosecuting owners who do not comply with notices to rectify excessive emissions (Johannesburg City Council, 1994). To reduce vehicle emissions unleaded petrol will be available in South Africa from October 1995; enabling the voluntary introduction of cars with catalytic converters – at present there are no formal plans for these to be mandatory for new cars.

The Atmospheric Pollution Prevention Act was 25 years old in 1990 and, in order to ensure its provisions are still adequate for South Africa's needs, a committee was formed in 1990 to recommend revisions and to bring forward a "Clean Air Act". It has been proposed that air pollution should be combined with soil and water pollution to ensure that integrated environmental management will be undertaken, particularly for new developments. There is also to be a more unified system of control and more qualified staff by including health inspectors and some other disciplines into pollution control (following suitable training). It has been recommended that control of dust from mines will pass to the Government mining engineer and those of vehicles to the traffic control authorities – with the exception of future exhaust emission standards which are to be set by the Ministry of Health. The extent to which these recommendations have been adopted and are now being introduced is unclear.

Comment

Currently there is a significant difference between the air quality management capabilities of the City of Johannesburg and the surrounding townships such as Soweto – the largest township. Air quality in the City of Johannesburg is generally good with only occasional breaches of WHO Guidelines. In Soweto the predominant use of solid fuels for domestic heating and cooking cause high concentrations of smoke, whilst the closer vicinity to mine waste and presence of unpaved and unvegitated areas combine to cause high concentrations of dust. The monitored fraction of particulate matter (PM_{15}) does not equate with any health standards but levels are substantially above the TSP standard set by the WHO (WHO, 1987). Only between 10 and 25 per cent of the PM_{15} is, however, smaller than $PM_{2.5}$ and the majority of particles are not, therefore, readily deposited in the lungs. In 1993, the average concentration of fine particulate matter ranged between 16 and 22 $\mu g\ m^{-3}$ at the nine sites at which it is monitored in Soweto and this level of fine particulates is unlikely to have significant health effects.

Assessing the likely health effects of ambient air in the townships is extremely difficult – typical of many arid areas with large amounts of wind-blown dust. Furthermore, the very high exposures of particulate matter experienced indoors – particularly by women and young children – compound these assessment problems. The Birth-to-Ten Epidemiological Study in Soweto is designed to address these problems and it is, therefore, unfortunate that monitoring in Soweto is at present discontinued. While the monitoring programme in Soweto was originally started to provide data for the Birth-to-Ten Study the restarting of measurements would be useful from an holistic air quality management perspective.

Although the regulations controlling air quality date from 1965, they have, nevertheless, successfully maintained acceptable levels of pollution in the city centre. The proposed revisions to the act and introduction of the new Clean Air Act should help to provide an administrative framework in which good air quality can be maintained. At present it is probably unrealistic for such controls to be introduced uniformly in all areas. However, if improvements in township air quality are to occur, reducing the contribution made by domestic fuel burning will be required; the existing legislative structure of smoke controls operated in South Africa could provide a mechanism to achieve this. The electrification of the townships has been made a priority for the new government and should help to reduce emissions of smoke. Township residents will, however, require incentives and support to switch to using this cleaner fuel owing to its present high cost and the strong tradition of using solid fuels. These factors are likely to make the greater use of electricity a slow process.

If future economic development is not to be bought at a high cost to the environment, strict controls on emissions will have to be maintained. The meteorology and topography of Johannesburg result in poor pollution dispersion characteristics. The city is, therefore, susceptible to episodes of poor air quality and consequently any significant increase in emissions could have potentially serious consequences for air quality and respiratory health. There is currently no emissions inventory for Johannesburg, although one has been produced recently for South Africa. Information concerning the emissions trends would a valuable air quality management tool; enabling the identification of sources of emissions and, where necessary, the development and implementation of focused emissions control plans.

Summary

- Air quality in the city is generally very good at present, although there are very few sulphur dioxide measurements. Trends in air quality are difficult to identify owing to the irregular nature of the measurements. In Soweto, levels of particulate matter are high; however, much of this matter is not inhaled owing to its course size fraction.
- Limited air quality monitoring currently takes place in the area of Municipal Johannesburg. In Soweto monitoring is at present discontinued, although useful information was being produced until 1994.
- The predominant source of emissions in Soweto are domestic coal and wood burning; in the city of Johannesburg this source is less important.
- An emissions inventory has been compiled for South Africa, but not for Johannesburg.
- Air quality has been successfully managed in South Africa since 1965 by the Atmospheric Pollution Prevention Act – this is currently being updated and will be replaced by a Clean Air Act. Air quality management in the townships is not as well developed.

References

AA Undated AA Travel Services, Southern Transvaal, Johannesburg.

du Plessis, P. J. 1995 Personal communication, Technology Group, ESKOM, Cleveland.

Government of South Africa 1965 Pollution Prevention Act, Government of South Africa, Pretoria.

IUAPPA 1991 *Clean Air Around the World 1991*, International Union of Air Pollution Prevention Associations, L. Murley (Ed.), Brighton.

Johannesburg City Council 1994 Personal communication, Health Housing and Urbanization Department, Johannesburg City Council, Johannesburg.

Johannesburg City Council 1995 Personal communication, Health Housing and Urbanization Department, Johannesburg City Council, Johannesburg.

Krohm, J. 1992 *10 Years of Photo-chemical Smog Monitoring,* Health Housing and Urbanization Department, Johannesburg City Council, Johannesburg.

Sithole, J. S., Turner, C. R., Lynch, E., Rorich, R., Annegarn, H. J. 1991 National Association of Clean Air, Annual Conference, 14–15 November 1991, Durban.

Sithole, J. S., Lethlage, D., Mphati, D., Annegarn, H. J., Malahlela, J. Q., Kneen, M. A., Hlapolosa, H.P.S. 1994 Air quality in Soweto: two years of particulate monitoring, National Association of Clean Air Annual Conference, 24–25 November 1994, Cape Town.

South Africa 1993 *Official South Africa Yearbook 1993*, South Africa Press, Pretoria.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization Regional Office for Europe, Copenhagen.

13

Katowice

Statistical Summary

Country: Poland
Estimated population 1990 (millions): 3.56
Projected population 2000 (millions): 3.88
Map reference: 50°15'N; 19°00'E
Area (km²): 6,650
Altitude (m): 200 to 400
Climate: Mixed continental marine
Average Temperature Range (C): -3 to 17
Annual Mean Precipitation (mm): 717

Situational Analysis

Katowice Voivodship (province), also known as Upper Silesia, is situated in southern Poland and is the most populous region of the country. The area suffers from severe environmental degradation; caused by the substantial mining and heavy industries located throughout the region. In 1983, the central part of the Katowice Voivodship, including the whole Katowice agglomeration, was declared an Ecologically Endangered Region. There are another 26 ecologically endangered regions in Poland, 5 of which are adjacent to the Upper Silesia Ecologically Endangered Region (Main Statistical Office, 1992).

Since the introduction of free market economics in the late 1980s, the traditional economy of the region has suffered a serious downturn. Many of the older, more polluting industrial plants have, or are being, closed down. This, combined with the introduction of better emissions controls, has resulted in a 22 per cent decline in emissions of oxides of nitrogen (NO_x) and a 41 per cent fall in emissions of particulate matter from 1988 to 1992. Air quality in city centres has also improved over the last five years with a 44 per cent reduction in nitrogen dioxide (NO_2) concentrations and a 30 per cent decline in sulphur dioxide (SO_2) (Main Statistical Office, 1993). High coal consumption by industry and by domestic consumers is the cause of substantial SO_2 emissions; especially in winter. The Silurian coal used contains between 0.7–1.3 per cent sulphur with maximum of 3.5 per cent in coal from the Jaworzno region. In 1993, the Polish standards for total particulate matter (Table 13.7) were exceeded in all of the cities comprising the Katowice agglomeration (see Figure 13.1); short-term guidelines for SO_2 were also exceeded in all of these cities in 1993, often by a factor of three or four (Katowice Voivodship Office, 1993).

Detailed knowledge of emissions from mobile sources are not known. However, between 1990 and 1993, there was a 12 per cent increase in the number of motor vehicles in Poland (mostly through mass importation of second-hand cars from Western Europe). Vehicle emissions, therefore, appear to constitute an increasingly significant source of urban air pollution (Main Statistical Office, 1993). The rapid growth in vehicle numbers has now been checked by the introduction of a prohibitive tax on the import of cars older than four years. The road network is dense, but heavy transit traffic generally passes through the major urban centres. Most cars use leaded petrol, the lead content of which has recently been halved to 0.15 g l^{-1}. Concentrations of lead fall within the WHO guideline range (0.5–1.0 $\mu g\ m^{-3}$) with the exception of those measured in Tarnowskie Gory, where two zinc smelting plants exist: the 1993 mean annual concentration was 1.63 $\mu g\ m^{-3}$. Consumption of petrol and diesel are now approximately equal with the consumption of diesel having fallen by 13 per cent since 1980. Although the concentration of NO_2 has declined significantly in recent years, the WHO 24-hour guideline (150 $\mu g\ m^{-3}$) is exceeded in the Voivodship.

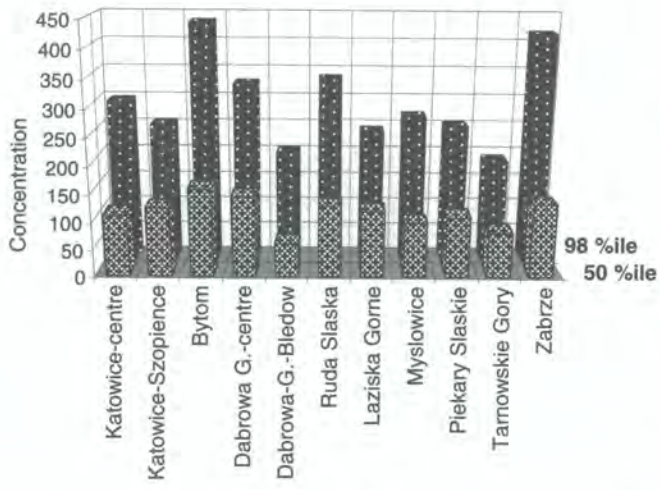


Figure 13.1 98th and 50th percentile concentrations of PM_{10} (µg m^{-3}) in the Katowice agglomeration, 1993

Source: Voivodship Sanitary and Epidemiology Station in Katowice, 1994

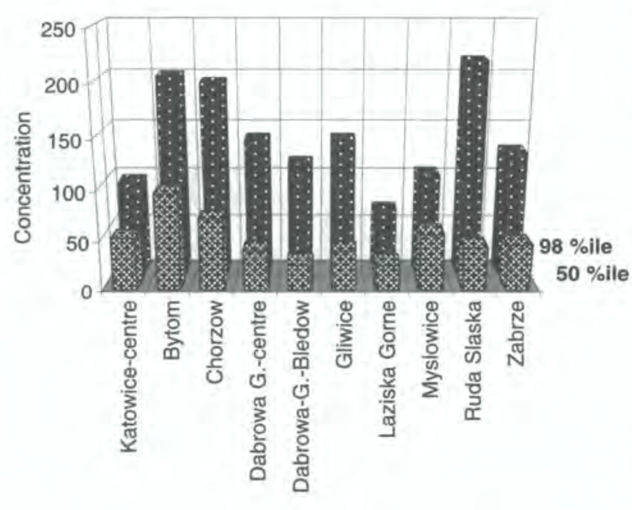


Figure 13.2 98th and 50th percentile concentrations of NO_2 (µg m^{-3}) in the Katowice agglomeration, 1993

Source: Voivodship Sanitary and Epidemiology Station in Katowice, 1994

However, there is a considerable variation in spatial distribution between the cities (see Figure 13.2).

A range of public transport options exist within the Voivodship. The rail network in Katowice is one of the most dense in the world and is the major means of transporting raw materials and products between the mines, industrial plants and markets. Passenger trains in this region are slow owing to widespread mining subsidence beneath tracks. There is also an extensive bus and tram network.

Monitoring Networks

Air pollution in the Katowice agglomeration has been recognized as a serious problem since the 1950s. The first measurements of air pollutant concentrations were made in 1958. As a result of the adoption of the first Clean Air Act in Poland in 1966, regular air pollution monitoring networks were established at the beginning of the 1970s . During the last 25 years, monitoring capabilities in the Katowice Voivodship have developed with regard to both spatial coverage and the range of substances measured. Recently, an automated monitoring network has been established to complement those employing passive and active sampling.

The three networks shown in Table 13.1 have been recently combined and named the "Regional Air Pollution Monitoring System in the Upper Silesia Agglomeration". Locations of sampling sites and monitoring stations are shown in Figure 13.3 (Voivodship Sanitary and Epidemiology Station in Katowice, 1994). The new combined monitoring network is a component of the World Bank Programme: the "Strategy of the Environmental Management in the Upper Silesia Region". It is intended that further components will be incorporated to enable rational air pollution control, specifically:

- Emission measurements using mobile laboratories;
- Air quality modelling for supporting decision makers with information regarding the cost and effectiveness of air pollution abatement;
- Establishment of criteria and procedures for smog alarm episodes.

Table 13.1 Air quality monitoring networks in the Katowice agglomeration

Network Name	Organizations responsible	Period of operation	Network objectives	Sites
Passive sampling	Voivodship Sanitary and Epidemiology Station in Katowice	1970–present	Monitoring of compliance with standards, sources, spatial distribution and trends	740
Active sampling	Voivodship Sanitary and Epidemiology Station in Katowice	1970–present	Monitoring of compliance with standards, temporal and long-term trends and spatial distribution	35
Automated	1. Centre for Investigation and Control of the Environment in Katowice (co-ordinator) 2. Voivodship Sanitary and Epidemiology Station in Katowice 3. Institute of Meteorology and Water Management in Katowice	1993–present	Monitoring of compliance with standards, issuing of alarm warnings and air pollution forecasting, source identification	10

Source: Cimander, 1994

Passive Sampling Monitoring Network

The principal objective of the passive sampling network (details of which are summarized in Table 13.2) is to accurately determine the spatial distribution of pollutants. The passive sampling methods used cannot directly give results in concentration units, but in mass of the pollutant per unit of collecting surface area per month. Results from passive sampling measurements are correlated with active sampling manual measurements and the correlation and regression factors are then used for estimation of annual average concentrations at all sites where passive sampling measurements are carried out. The existing network is based on a uniform grid of 2 km squares covering the whole country, produced by Institute of Cartography in Warsaw in 1968. The measuring points were located at corners of the squares and, if required, in the middle of the squares (see Figure 13.3). Data capture for dustfall is about 80 per cent.

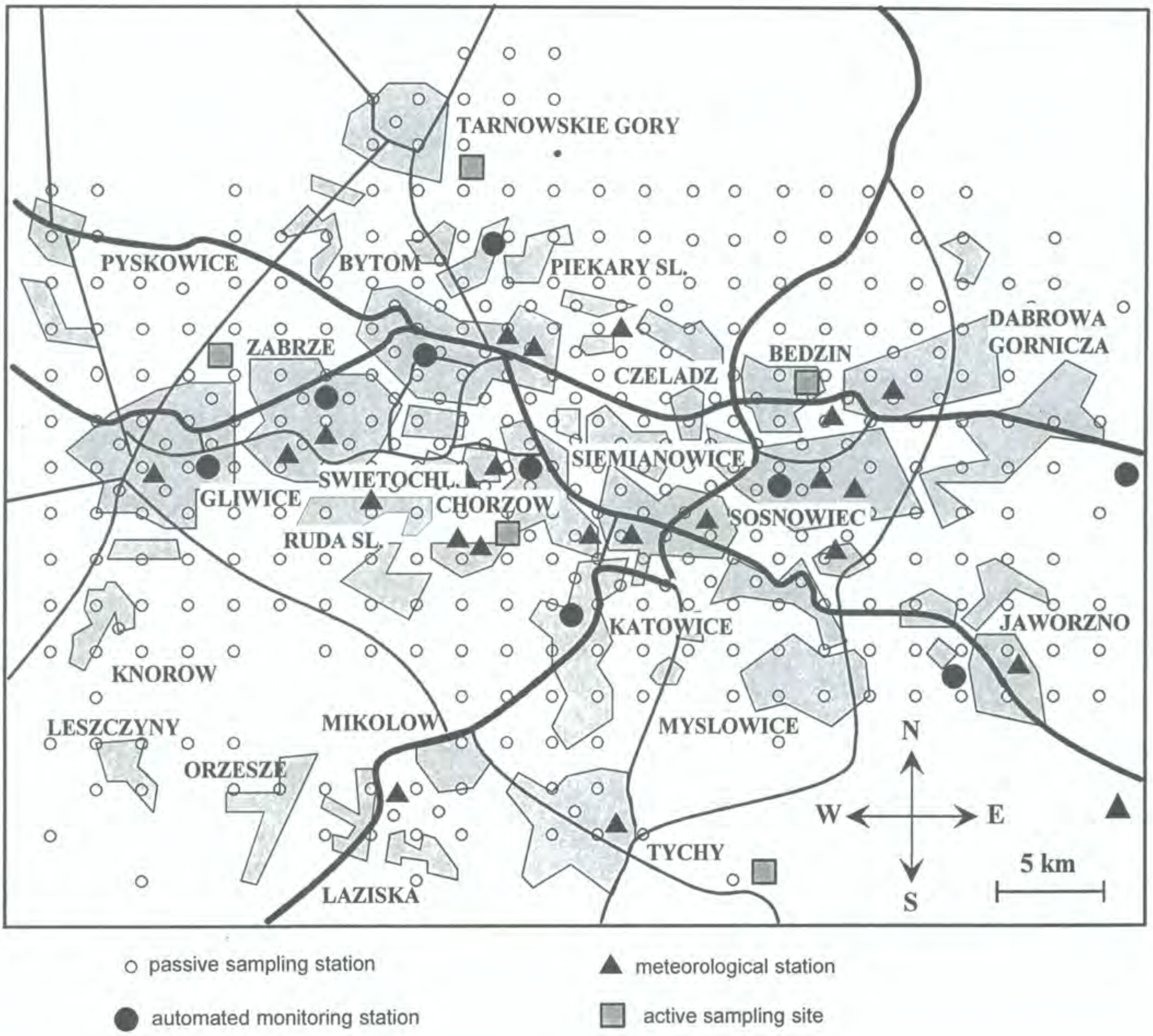
An example of the types of maps showing the spatial distribution of pollutants is shown in Figure 13.4.

Active Sampling Network

This network does not have the extensive spatial coverage of the passive sampling network, but it does enable investigation of temporal trends in pollutant concentrations and covers a wider range of pollutant species. The basic unit of time resolution is 24 hours; further calculations are performed to obtain parameters of log normal distribution of pollutants and to enable the generation of summary statistics; for example, percentiles, maximum, and air quality standard exceedances.

The sampling protocol involves taking 24-hour samples 8 times per month on randomly chosen days; enabling the network to operate with relatively limited personnel and equipment resources. Established sampling and analytical methods are used, making the data directly comparable with those from other countries. Similar procedures are used by equivalent organizations in other Voivodships throughout Poland.

Figure 13.3 Sampling sites of three monitoring networks in the Katowice agglomeration



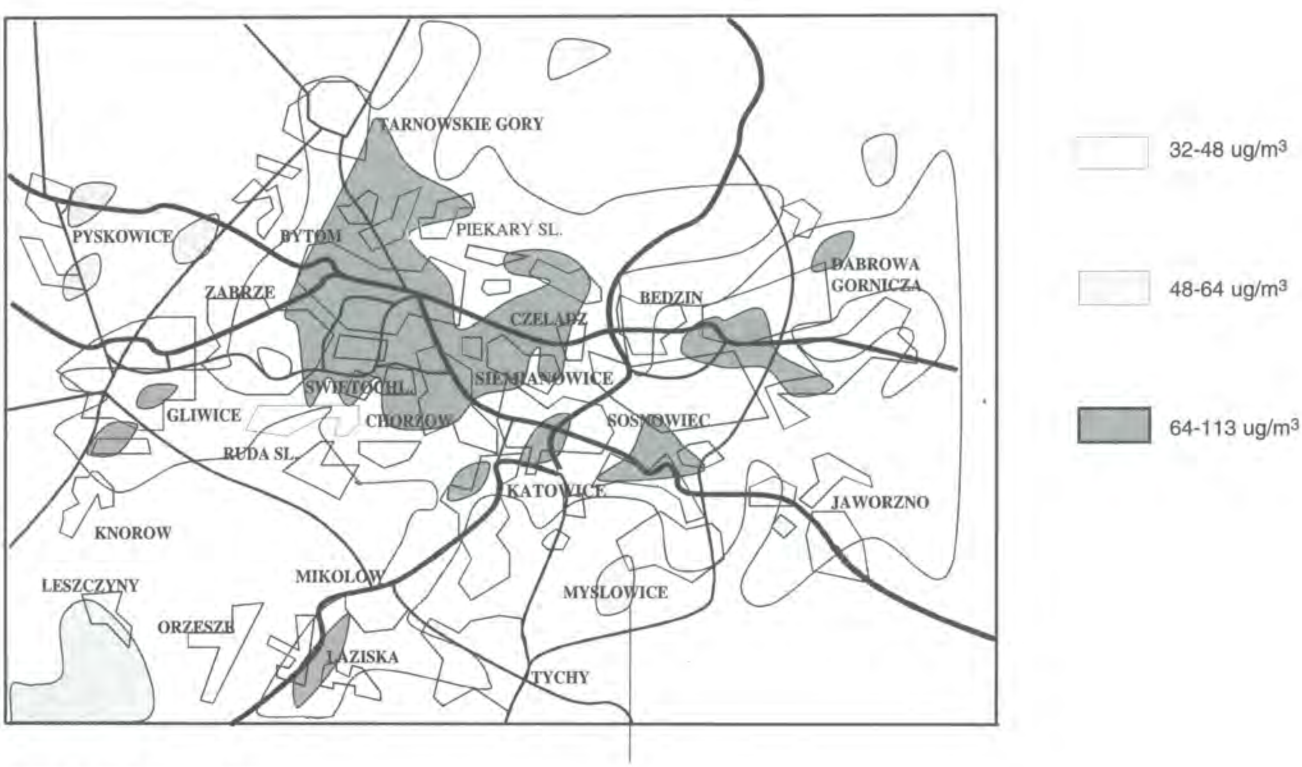
Source: Voivodship Sanitary and Epidemiology Station, Katowice, 1994

In addition to the priority pollutants monitored at 23 sites (listed in Table 13.3), many other pollutant species are routinely investigated. There are 26 sampling sites for fluorine, ammonia, formaldehyde and phenol; and, 5 sites for carbon monoxide (CO), carbon dioxide (CO2) and aliphatic hydrocarbons. Particular attention is given to polyaromatic hydrocarbons, concentrations of which significantly exceed Polish air quality standards. With the establishment of a new, automated network, an extensive inter-comparison exercise has been taken to compare results obtained using manual methods and automated monitors.

Table 13.2 Passive sampling network in the Katowice Voivodship

Pollutant	Analytical method	Sampling period/ Frequency	Number of sites
Nitrogen dioxide	Colorimetry, Saltzman	1 month/12 per year	228
Sulphur dioxide	Nephelometry	1 month/12 per year	228
Dust fall	Gravimetric	1 month/12 per year	740
Metals in dustfall (Pb, Cd, Zn, Cu, Cr, Ni, Mn, Fe, Co)	Atomic Absorption Spectrometry	1 year/monthly samples are collected	740

Source: Cimander, 1994



Annual average concentrations.

Figure 13.4 Spatial distribution of SO_2 in the Katowice agglomeration, 1990

Source: Voivodship Sanitary and Epidemiology Station, Katowice, 1994

Table 13.3 Active sampling network in the Katowice agglomeration

Pollutant	Sampling method	Analytical method	Sampling period/ Frequency
PM_{10}	High Volume	Gravimetric	24 hour / 8 per month
Nitrogen dioxide	Bubbler	Colorimetry, Saltzman	24 hour / 8 per month
Sulphur dioxide	Bubbler	Colorimetry, West-Gaeke	24 hour / 8 per month
Metals in PM_{10} (Pb, Mn, Fe, Zn and Cu)	High Volume	Atomic Absorption Spectrometry	24 hour / 8 per month
Metals in PM_{10} (Cd, Cr, Co and Ni)	High Volume	Atomic Absorption Spectrometry	2 weeks / daily samples are collected
Polyaromatic hydrocarbons (15 compounds)	High Volume	Column liquid chromatography/UV or GC/ECD	1 month / daily samples are collected

Source: Cimander, 1994

Automated network

The automated network is based on 10 air quality monitoring stations and 5 meteorological stations. Their locations are shown in Figure 13.3. Eight stations are situated within the Katowice agglomeration; one is advanced to the west (beyond the range of the map) and one to the east. These two stations are used in evaluating pollutant transport across the city. Meteorological stations measure temperature, humidity, wind velocity and direction and solar radiation intensity. The central meteorological station in Katowice is also capable of measuring temperature inversions using a SODAR instrument and a correlation spectrophotometer. Data are transferred to the data acquisition centre; four additional terminals are provided to the organizations responsible for running the network. Compounds measured and analytical methods used are summarized in Table 13.4.

The automated network has added new dimensions to the existing manual monitoring networks: fine time resolution and on-line measurements are now carried out in many places simultaneously. These kind of data will enable analyses of air pollution situations with respect to various emission patterns and meteorological factors.

Table 13.4 Automated network in the Katowice agglomeration

Pollutant	Analytical method	Number of sites
PM_{10}	TEOM	10
Nitrogen dioxide and nitric oxide	Chemiluminescence	10
Sulphur dioxide	Fluorescence	10
Carbon monoxide	Gas filter correlation	8
Ozone	UV absorption	3
Aliphatic hydrocarbons	Flame Ionization	3

Source: Cimander, 1994

Quality assurance and data reporting

Calibration exercises are the responsibility of one laboratory: the Voivodship Sanitary and Epidemiology Station in Katowice. Table 13.5 summarizes quality assurance measures and ways in which the data are reported by the particular networks.

Table 13.5 Quality assurance and reporting in the Katowice agglomeration air quality networks

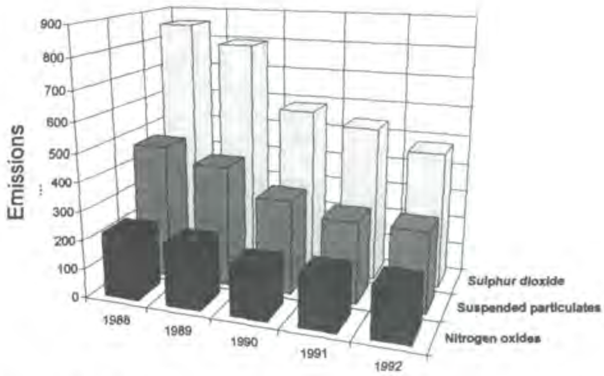
	Passive network	Active network	Automated network
Calibration using standard solutions	+	+	-
Calibration using gas standards	-	-	+
Inter comparisons between networks carried out	-	+	+
Data validated	+	+	+
Data processed by computer	+	+	+
On-line data acquisition	-	-	+
Long-term trends analysed	+	+	+
Temporal variations examined	-	+	+
Spatial distributions determined	+	+	+
Exceedences of air quality standards recorded	+	+	+
Modelling carried out using the data	-	-	+
Data reports published	+	+	+
Data freely available	+	+	+

Source: Cimander, 1994

Emissions inventories

Emissions data are available for the Katowice Voivodship, the Katowice Ecologically Endangered Region and some 300 major cites in Poland; including almost all the cities of the Katowice agglomeration and for all sources of pollution except for those from mobile sources. The basis for calculation are data on emissions from stationary industrial sources. It is estimated that 60–70 per cent of total emissions of air pollutants come from these sources.

There has been a marked decline in industrial emissions since 1988 (see Figure 13.5) both within the Katowice Ecologically Endangered Region and the whole Katowice Voivodship, the former showing the greater relative decline. This trend is due to a fall in overall production and the introduction of more efficient cleaning technologies, as shown in Table 13.6.



Emissions from stationary sources: industry, power plants, municipal sources (motor vehicles are not included).

Figure 13.5 Emissions in Katowice Voivodship, 1988–1992

Source: Voivodship Sanitary and Epidemiology Station in Katowice, 1994

It is believed that during winter, up to 80 per cent of air pollution in the city centres of the Katowice agglomeration result from the burning of hard coal in domestic stoves and in local boiler houses; these are termed "low-level emissions". The compilation of accurate emissions estimates for this source is complicated because recent changes in the distribution system of coal makes it difficult to determine the amount of fuel burnt in this way. However, it is estimated that 2.5 million t a^{-1} of coal is combusted in domestic stoves. Total emissions of air pollutants from low-level sources, in 1993, for the whole Katowice Voivodship have been estimated at: 50,000 t a^{-1} of particulates, 40,000 t a^{-1} of SO_2, 3,500–4,000 t a^{-1} of NO_x, 350,000 t a^{-1} of CO, 1,500 t a^{-1} of soot, and significant amounts of polyaromatic hydrocarbons.

Coal combustion is also the most significant source of heavy metals in ambient air; these include zinc, cadmium, chromium, copper, nickel, mercury and arsenic. Ambient lead has been regarded as one of the most serious problems in the Katowice province; especially in areas surrounding zinc and lead metallurgy plants (Tarnowskie Gory, Katowice-Szopienice, Miasteczko Slaskie). In the 1970s, annual average concentrations of lead in Katowice-Szopienice exceeded 20 µg m^{-3}. Other important sources of heavy metals in air are iron and steel production and road transport (see Figure 13.6).

Estimates of emissions from mobile sources are not available. However, there has been a substantial growth in the number of motor vehicles in recent years.

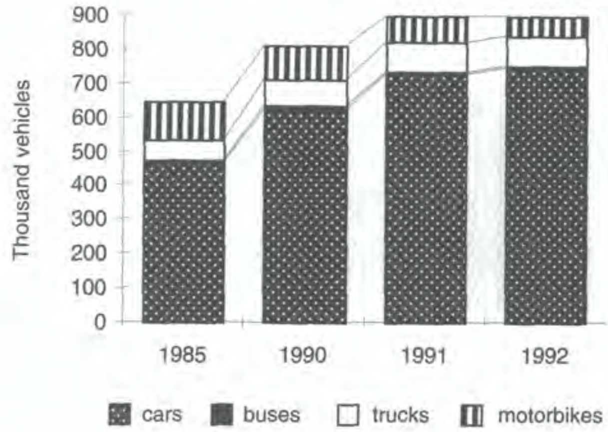


Figure 13.6 Number of motor vehicles

Source: Main Statistical Office, 1993

Table 13.6 Percentages of industrial pollutants retained by facilities in the Katowice Voivodship

Pollutant/Year	1983	1988	1990	1992
Particulate matter	92.6	95.0	95.3	97.0
Sulphur dioxide	5.6	13.8	16.1	21.0
Nitrogen oxides (as NO_2)	–	–	0.4	0.2

Only significant industrial sources of pollution are included.

Source: Voivodship Sanitary and Epidemiology Station in Katowice, 1994

Air Quality Management

Within the Katowice Ecologically Endangered Region and the Katowice Voivodship a number of policies are currently in force to control levels of air pollution with the ultimate intention of attaining Polish Air Quality Standards. Within the Katowice Ecologically Endangered Region it is no longer possible to establish new enterprises or to develop existing ones which could significantly pollute the environment.

Polish Air Quality Standards refer separately to "general areas" (which include urban areas), "industrial areas" and "special areas" (such as national parks). Maximum permissible concentrations are expressed as: annual means, 98 percentiles of 24-hour concentrations and 99.8 percentiles of 30-minute concentrations (Table 13.7). Maximum permissible dustfall values are also determined at: 200 g m-2 $year^{-1}$ for total dustfall, 0.1 g m^{-2} $year^{-1}$ for lead and 0.01 g m^{-2} $year^{-1}$ for cadmium. Polish standards with regard to Pb and CO are below equivalent WHO European guidelines.

Within the Voivodship there are currently 280 Category A enterprises which are required to maintain emissions within stipulated limits established by the local

Table 13.7 Polish standards of air quality in general areas (µg m^{-3})

Pollutant	Annual arithmetic mean	98th percentile of 24-hour means	99.8 percentile of 30-minute means
Total suspended particulates	50	120	250
Sulphur dioxide	32	200	600
Nitrogen dioxide	50	150	500
Carbon monoxide	120	1,000	5,000
Ozone	–	30	100
Lead	0.2	1.0	3.5
Benzo[*a*]pyrene	0.001	0.005	0.02

Source: Main Statistical Office, 1993

Voivodship Office. These emissions are then charged according to a tariff issued by the Ministry for Protection of the Environment, Natural Resources and Forestry. Inventorization of industrial emissions is the responsibility of the State Inspectorate for Protection of the Environment (SIPE). The actual levels of emissions are based on measurements made predominantly by the enterprises themselves or by commercial laboratories and these are then submitted to the Voivodship Office and inspected by the local branch of SIPE (Siadek, 1994). If these are found to be unsatisfactory, independent measurements are then performed and fines for exceedances can be issued; although owing to limited resources for conducting appropriate measurements these measures are infrequently applied. Smaller enterprises are classified as Category B; only some of which have formal emissions limits set owing to the lack of personnel in SIPE and in the Voivodship Office. The fee for releasing of air pollutants is quite substantial and certain enterprises, such as coal mines and the large Katowice Steel Works, for social and political reasons, are allowed to pay at a discounted rate to enable them to continue operation. In 1991, the total amount of fees paid by enterprises in the Katowice Voivodship for polluting the air was approximately US$40 million. A quarter of that money was spent on the construction and modernization of air protection facilities. Most of local fees go to the National Environmental Fund which redistributes the money throughout the country.

Reduction of low level emissions produced from domestic and small industrial processes is recognized as a priority issue. In the past, house owners have been encouraged to switch fuels for heating from hard coal to natural gas. However, recent changes in the price of these fuels has made the use of natural gas very expensive. Local authorities are, therefore, seeking other solutions including the use of hot water area heating from power plants and industries. This would both reduce low-level domestic emissions and improve the efficiency of power-generating plants. Another plan is to extract and utilise coalbed methane, of which deposits are estimated to be 300 to 320 billion m3. So far only a small part of these reserves have been used.

The problem of lead emissions has been partially solved with the modernization or closure of the most polluting, non-ferrous metallurgy plants. As a result, annual average concentrations of Pb in Katowice-Szopienice have fallen to 0.65 µg m^{-3} in 1992 and to 1.63 µg m^{-3} in Tarnowskie Gory in 1993 (at present this is the most polluted location in the Katowice agglomeration with regard to Pb concentrations). Emissions of Pb from road transport have also been lowered as unleaded petrol is now used in many cars. From the beginning of 1995, all new passenger cars with petrol engines have had to be equipped with a catalyst (except for cars that have engines smaller than 700 cc, which have to comply by a deadline of July 1997).

Emissions of SO_2 are also being reduced through the construction of two installations for the desulphurization of flue gases (FGD) in two major power plants: in Jaworzno and in Rybnik. All power plants and industries are encouraged, by high fees for SO_2 and fly ash emissions, to use coal with a low sulphur and ash content. Coal cleaning technologies are also increasingly being applied to reduce emissions from coal in a more cost-effective manner than flue gas desulphurization.

Comment

Katowice already has many of the monitoring capabilities required by decision makers to formulate and implement a rational air pollution control strategy; although the means to ensure that this strategy is enforced are less developed.

The air quality measurement capabilities of the Katowice Voivodship are excellent, with extensive passive and active monitoring networks supporting the information available from the new state-of-the-art automatic network. The passive sampling network has the enormous potential to determine the detailed spatial distribution of pollutants in the Katowice Voivodship. However, the current siting criterion, using a fixed grid, limits this potential. A new approach in the location of sampling sites has been recently suggested by the State Inspection for Environmental Protection. It has suggested using the approach adopted by the US Environmental Protection Agency which takes into account, among other things, site topography and distance from sources of pollution. A revision of existing site locations with respect to these criteria would greatly improve the comparability of data obtained at different locations and would enable maps of the spatial distribution of air pollutants to be produced with much greater confidence and accuracy. Passive samplers which measure concentrations directly are also now readily available, and their use would be an improvement on the existing methodology.

Historically, the manual monitoring network was established to monitor air pollutants produced by large industrial sources. Subsequent changes in the emissions pattern in the Voivodship, with industrial sources decreasing and emissions from motor vehicles rapidly increasing, means that the location of sites in the active sampling network needs to be reassessed. For example, there is a need to revise the existing network to increase the proportion of traffic-oriented sites. The adjusted network could also develop more sophisticated siting criterion to fully take into account the very complex structure of the Katowice agglomeration with industrial and residential areas mixed together over large areas. It is, however, important , if changes do take place in either methodology or siting, that existing techniques be retained at some sites at which a long time series of measurements exist.

With the access to the newest technology and equipment for calibration purposes made available by the introduction of the automated network, a more sophisticated method for calibration of manual monitoring methods, such as the use of gas standards, could be considered. An audit system of accreditation of laboratories according to the ISO-9002 standard has recently been introduced. This is a progressive development, and the laboratories which have been conducting air quality measurements in the Katowice Voivodship are encouraged to obtain such accreditation. Links with air quality systems in Krakow, Opole, Wroclaw, Legnica and other cities in the southern part of Poland could also be established to investigate long range transport of air pollutants; and to make the maximum use of the considerable high quality data produced by these networks.

Emissions inventories providing information on the sources of air pollution in Katowice are not as developed as the monitoring network; they represent an aspect of decision facilitating information which could be further developed, particularly quantifying emissions from mobile sources. The growth in the number of motor vehicles and the decline in industrial productivity is resulting in mobile sources of emissions becoming an increasingly important sector and this should be reflected in the development of the city's monitoring capabilities.

Although a regulatory system exists to ensure that excessive emissions are not produced by industrial processes and that polluters pay, there have been criticisms of the system whereby the moneys raised from pollution fees in Katowice are distributed across Poland, rather than being spent in the Voivodship. Furthermore, checks upon the emissions data supplied by industrial processes are still quite limited; perhaps more could be done to improve the validation of inventory returns. In the medium and long-term it will also be necessary to phase out the exemptions granted to certain industrial enterprises permitting a lower level of pollution fee to be paid.

Summary

- An extensive and well organized monitoring network exists in the Katowice Voivodship incorporating passive, active and automated sites – some with long uninterrupted sampling histories.
- An emissions inventory exists for point sources only.
- The principal air pollution problems in the Voivodship are winter smoke and SO_2 concentrations which are particularly elevated due to domestic coal consumption.
- Well regulated emission controls exist in Katowice but are hindered by a lack of resources, particularly for emissions monitoring.

References

Siadek, B. 1994 Personal communication, Voivodship Sanitary and Epidemiology Station in Katowice, Katowice.

Hlawiczka, S. 1994 *Quantitative Assessment of Heavy Metals Emission in Poland.* Proc. EMEP Workshop on European Monitoring, Modelling and Assessment of Heavy Metals and Persistent Organic Pollutants, Beekbergen, The Netherlands, 3–5 May 1994.

Katowice Voivodship Office 1993 *Bulletin on the Air Quality in Katowice Agglomeration*, Katowice Voivodship Office, Katowice.

Main Statistical Office 1990 *Report on the State, Threats to and Protection of the Environment 1990*, Main Statistical Office, Warsaw.

Main Statistical Office 1993 *Protection of the Environment 1993*, Main Statistical Office, Warsaw.

Main Statistical Office 1993 *Statistical Yearbook 1993*, Main Statistical Office, Warsaw.

Main Statistical Office 1992 *Ecologically endangered regions in Poland in 1982 and 1990*, Main Statistical Office, Warsaw

Voivodship Sanitary and Epidemiology Station in Katowice 1994 *Pollution of the Atmosphere*, Voivodship Sanitary and Epidemiology Station in Katowice, Katowice.

14

Kiev

Statistical Summary

Country: Ukraine
Estimated population 1990 (millions): 2.64
Projected population 2000 (millions): 3.08
Map reference: 50°30'N, 30°30'E
Area (km²): 834
Altitude (m): 167
Climate: Mild summer continental
Average temperature range (C): -6 to 20
Annual mean precipitation (mm): 610

Situational Analysis

Kiev is the capital city of the Ukraine. The Ukraine is located to the north of the Black Sea bordering Poland, Slovakia, Hungary, Romania, Belarus and the Russian Federation (see Figure 14.1 in the chapter on Ekaterinburg and St Petersburg). The Ukraine occupies 2.8 per cent of the land area and contains 18 per cent of the population and 17 per cent of the industrial production of the former USSR; including 50 per cent of the iron ore, 30 per cent of the steel and 25 per cent of the coal production (Mnatsakanian, 1992). Ukraine is an industrialized country with many of the environmental problems, including air pollution, that often accompany industrialisation. Most heavy industry is located in the east of the country; in the Donetsk-Pridneprovskiy region, notably the Donbass and Krivoy Rog areas. In addition to being the largest city in the Ukraine, Kiev also has a high concentration of industrial facilities. Levels of air pollution in Kiev, although not the most severe in the country, are nevertheless, appreciable; and the population exposed to them is relatively large.

In Kiev, measured concentrations of nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter and lead (Pb) are generally below WHO Guidelines (Table 14.1) (WHO, 1987). However, the confidence with which air quality data can be considered is uncertain: this is discussed later in the Comment section. The Kiev authorities, and others, consider the most serious pollutants in the city to be toxic substances produced by industry, including: benzo-a-pyrene, phenol, carbon disulphide, ammonia, zinc, hydrogen sulphide and hydrochloric acid (Bezuglaya, 1991; State Hydrometeorological Committee of the Ukraine, 1995). Monitoring of these compounds shows concentrations in excess of national air quality standards.

Trends in air quality have remained relatively static since 1975. The exception to this is SO_2 which has shown a marked decline. Trends for a residential and an industrial site are shown in Table 14.2. The trend in pollutant concentrations is explained by the depression experienced by industrial production in recent years (State Hydrometeorological Committee of the Ukraine, 1995).

In addition to the important industrial sources of air pollution it is estimated that mobile sources contribute as much as 71 per cent of total anthropogenic emissions of Kiev (Bezuglaya et al., 1991). There is also, undoubtedly a significant contribution to air pollution from domestic, winter heating emissions.

Monitoring Networks

Ambient air quality monitoring in the Ukraine is the responsibility of the State Hydrometeorological Committee and the Ministry of Health. Emissions monitoring is conducted by the Ministry of Environmental Protection; measuring 65 pollutants. In the Ukraine, the Hydrometeorology Committee has 173

Table 14.1 Annual and maximum air pollutant concentrations in Kiev, 1993 (μg m^{-3}) and WHO and national air quality standards for comparison

Site/Pollutant	NO_2	SO_2	TSP	Pb
Residential	60 (190)	29 (143)	100 (300)	0.020
Commercial/City centre	80 (200)	38 (194)	100 (300)	0.09
Industrial	80 (230)	38 (151)	100 (400)	0.04
Kerbside	90 (260)	38 (150)	200 (700)	0.38
WHO guideline	400[(a)]	50[(d)], 500[(b)]	120[(c)]	0.5–1.0[(e)]
National air quality standard	60 (500)	40 (85)	150 (500)	0.3

Values in parentheses are maximum 20-minute values.
Site descriptions are very general, throughout Kiev industrial facilities occur widely within residential areas.

(a) 1 hour.
(b) 10 minutes.
(c) 24 hours.
(d) Annual.
(e) 3 months.

Source: State Hydrometeorological Committee of Ukraine, 1994

Table 14.2 Trends in annual mean ambient air quality, 1975–1990 (μg m^{-3})

Residential	**1975**	**1980**	**1985**	**1990**
NO_2	50	30	40	60
SO_2	80	80	40	14
TSP	100	200	100	100
CO	12,000	17,000	5,000	9,000
Industrial				
NO_2	80	50	60	70
SO_2	120	70	40	15
TSP	300	300	200	200
CO	15,000	18,000	10,000	11,000

Source: State Hydrometeorological Committee of Ukraine, 1994 fixed monitoring sites monitoring 37 different compounds; it also has mobile equipment used for monitoring at specific industrial facilities and power plants. The Ministry of Health has 54 fixed sites including mobile equipment for taking measurements at point sources or at locations of particular concern. The Ministry of Health also has an epidemiology unit which includes within its operating brief the effects of air pollution. The State Hydrometeorological Committee of the Ukraine has a total of 16 fixed monitoring sites in Kiev. The study of NO_2 is monitored with an active bubbler system using the Greiss calorimetric method; samples are taken for 20 minutes, four times per day at 0100, 0700, 1300 and 1900 hours (as was the practice in the former USSR – see chapter on Ekaterinburg and St Petersburg for more details). Sulphur dioxide is monitored using a similar protocol: employing the West-Gaeke method using sodium tetrachloromercurate. Total suspended particulates (TSP) are measured using a high-volume sampler sampling for 20 minutes at 0700 and 1900 hours. Carbon monoxide (CO) is monitored continuously and Pb is monitored using a high-volume sampler for one hour per day and bulked over one month. Data capture of about 90 per cent is reported. The monitoring site locations are shown in Figure 14.1.

Data quality is assured by conducting all procedures according to a specified common methodology with regular laboratory inspections and the independent auditing of sites. Data are also validated to ensure reliability. Annual, six-monthly and monthly mean values are reported; as are maximum annual values. It would appear from the data reported that NO_2 is measured to the nearest 10 $\mu g\ m^{-3}$, TSP to the nearest 100 $\mu g\ m^{-3}$, and the continuous CO analyser with a precision of 1 $mg\ m^{-3}$ (see Tables 14.1 and 14.2). Calibrations using standard solutions and gas mixtures are reported to take place regularly and sites are reviewed annually.

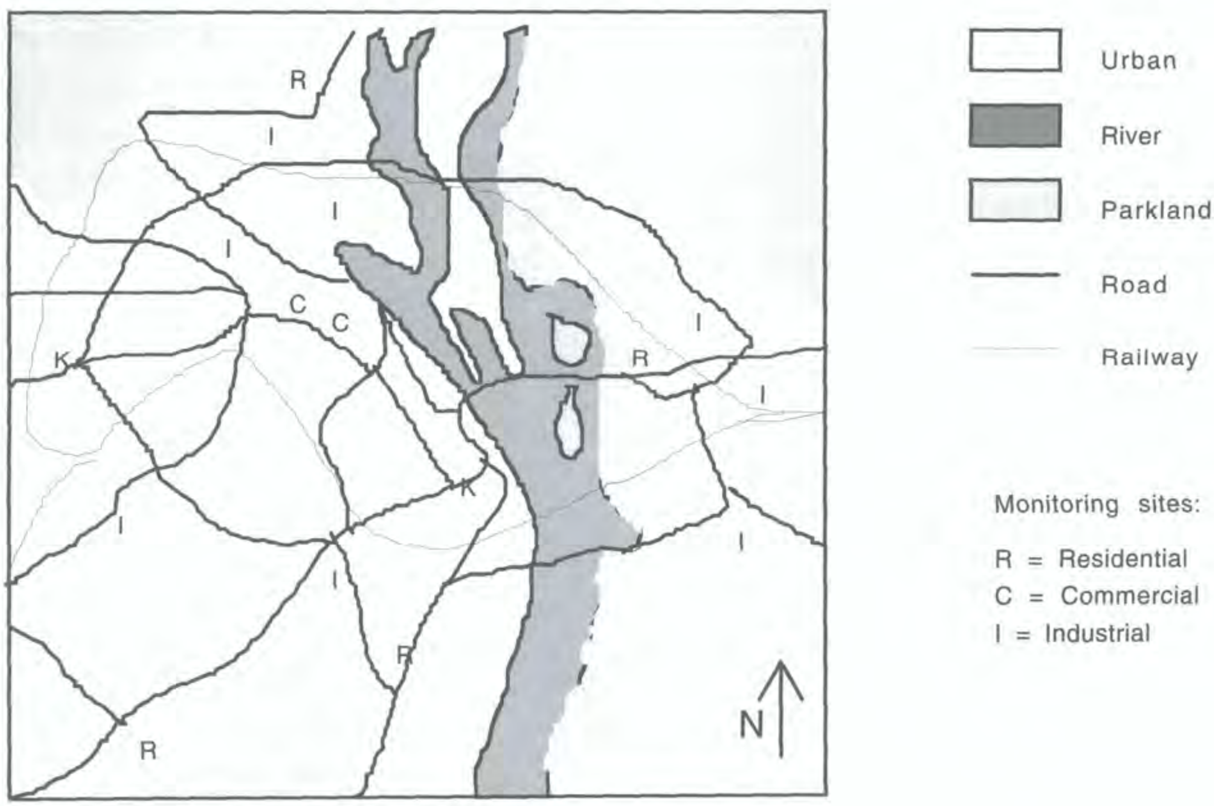


Figure 14.1 Sketch map of Kiev

Source: Bezuglaya, 1991

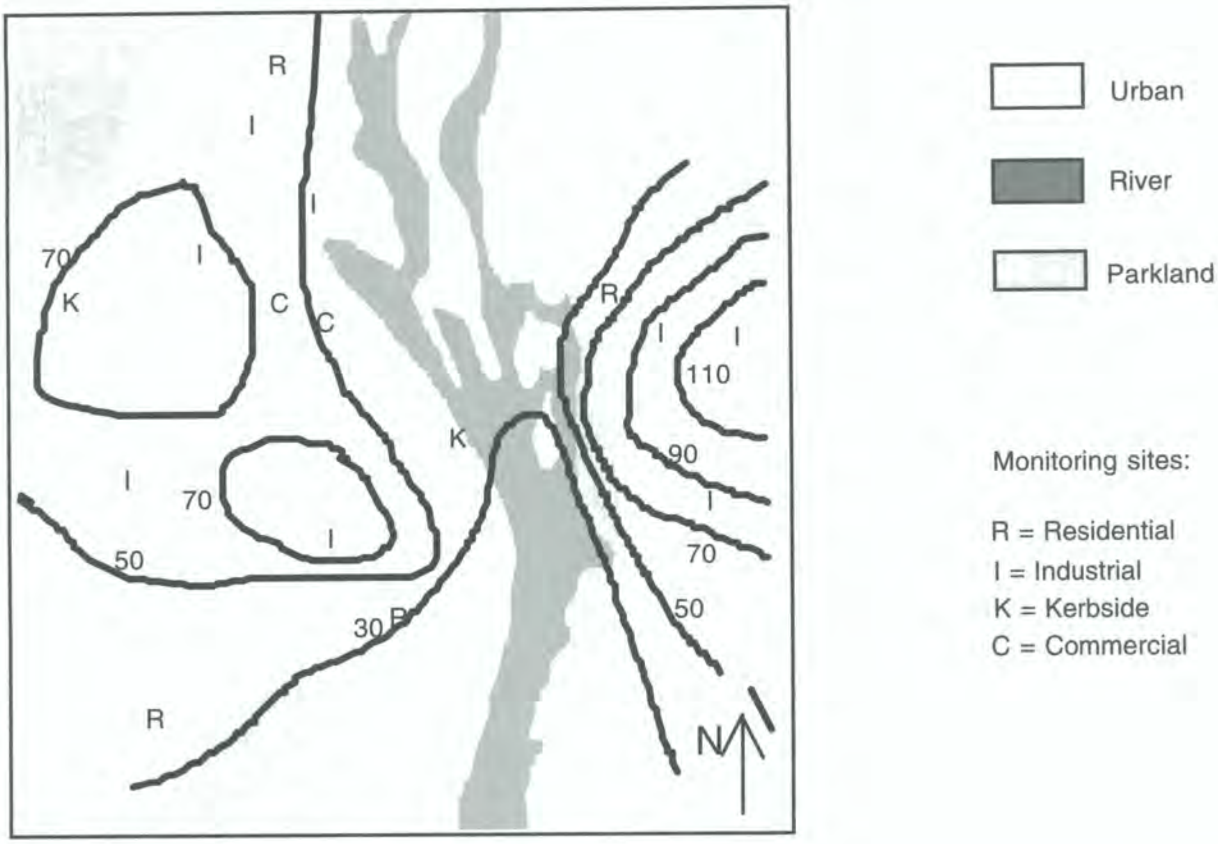


Figure 14.2 Nitrogen dioxide isopleths for Kiev, 1984–88

Source: Bezuglaya, 1991

Data are processed manually and reported in publications of the Ukraine Hydrometeorological Committee; these are readily available. The spatial distribution of pollution in the city has been determined: an example of which is shown in Figure 14.2 (more recent information is available from the State Hydrometeorological Committee of the Ukraine but has not yet been published). Figure 14.2 shows elevated concentrations in the eastern, more industrial parts of the city. Air quality data are also combined with meteorological variables to determine relationships.

Emissions Inventories

Relatively detailed emissions inventories exist for the period when the Ukraine was part of the former Soviet Union; more recent inventories are currently being compiled by the State Hydrometeorological Committee. Emissions records are compiled by each individual industrial facility for all harmful substances emitted, including details of stack operating conditions. These figures are then used to produce maximum permissible emissions levels in order to ensure acceptable air quality is maintained in the vicinity of each plant. Mobile source emissions estimates are produced for all categories of vehicle.

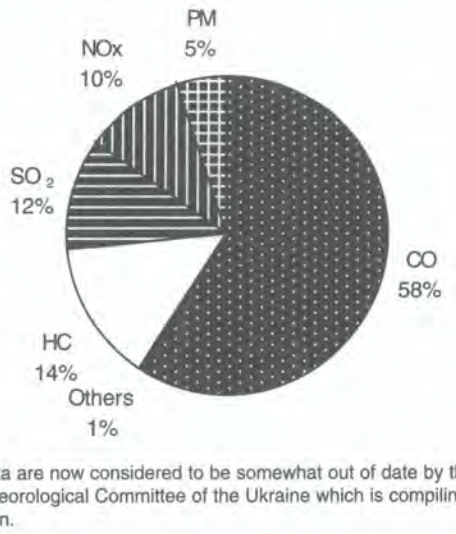
In 1988, total emissions of air pollutants for Kiev were estimated at 327,000 tonnes (Bezuglaya, 1991; Bezuglaya et al., 1991). The main reason given for this high estimate, when compared with cities of a similar size, is that of inefficient production techniques (State Hydrometeorological Committee of the Ukraine, 1995). It has also been estimated that only 27 per cent of all pollutants produced are retained. Sixty per cent of power generation, chemical and coal production facilities and 80 per cent of petrochemical industries have no emissions control equipment. Of those industrial facilities with pollution abatement technologies, 21 per cent perform below their anticipated abatement level; almost half were more than 10 years old in 1987 (Mnatsakanian, 1992). A breakdown of the composition of total emissions is shown in Figure 14.3.

Air Quality Management

Air quality in the Ukraine is the responsibility of four government ministries which co-ordinate their activities to develop air quality management strategies:

1. The Ministry of Environmental Protection is responsible for controlling industrial emissions and ensuring that emissions limits are not exceeded. This is achieved for Kiev through the City Committee for Nature Protection. This body is also responsible for the compilation of emissions inventories.

2. The Ministry of Health conducts monitoring and is responsible for assessing the health implications of pollution.



These data are now considered to be somewhat out of date by the State Hydrometeorological Committee of the Ukraine which is compiling new information.

Figure 14.3 Emissions of air pollutants in Kiev, 1988

Source: Bezuglaya et al., 1991

3. The Committee for Hydrometeorology also conducts monitoring and assessment of air quality. They also determine the relationship between air quality and meteorological variables.

4. The State Car Inspectorate is responsible for controlling emissions from motor vehicles; this is achieved through an inspection every two years on all vehicles, including an emissions check.

The Ukraine inherited certain administrative structures from in the former Soviet Union; where air quality monitoring, emissions inventories and controls were conducted in a uniform manner across the country. Air quality management in Kiev is, therefore, also based upon the system reported in the previous chapter on St Petersburg and Ekaterinburg. Administrative responsibilities have subsequently evolved although the procedures and regulations remain broadly similar. Emissions limits, seeking to ensure that acceptable air quality is maintained, are established for all harmful emissions from each individual plant (in combination, for those which react synergenically). These are formulated using information on local dispersion conditions and other local emissions sources. More general information relating to past air quality management strategies adopted in the Ukraine can be found in the Ekaterinburg and St Petersburg chapter.

Comment

From the monitoring data for Kiev it would appear that air quality problems are restricted to those of exposure to certain toxic compounds, particularly BaP. The reported concentrations of NO_2, SO_2 and TSP are below WHO Guidelines. Reported values are, however, somewhat surprising and could be expected to be higher in view of the extent of heavy industry, prevailing production techniques and the limited availability of emissions control equipment. More conclusively, perhaps, from the actual emissions reported for the city. The monitoring procedures adopted in the Ukraine are the same as were applied throughout the former Soviet Union and are not internationally standard. In this regard, sampling periods are short (generally 20 minutes four times per day) and, using the analytical procedures reported, samples must be approaching the limit of detection for normal urban ambient concentrations. In a report on Moscow, similar reservations were expressed and it was suggested that quality assurance and control audits should be performed to test the current monitoring methodology against internationally accepted (ISO) methods (WHO/UNEP, 1992). This recommendation would also appear to be relevant to Kiev, and to the Ukraine as a whole.

Most of the components of an effective air quality management strategy are in place in Kiev. Monitoring is conducted (accepting the reservations explained above); emissions inventories have been compiled and are being updated; and, emissions standards are applied to both mobile and stationary sources with procedures to effect compliance.

It is, however, important that the information available to decision makers is of known quality and adequate for its intended use. Existing experience and structures provide good foundations for effective air quality management.

Summary

- Air quality in Kiev is surprisingly good in view of industry and emissions controls.
- There is substantial monitoring of ambient air quality in Kiev. However, there is some uncertainty over the monitoring methodologies and quality assurance and control procedures operated; the confidence which can be placed in reported air quality data is therefore unknown.
- Emissions inventories have been conducted, although compilation procedures and methods of inventory validation are not known.
- Air quality standards (generally below those of similar WHO guidelines) have been established as have emissions limits.

References

Bezuglaya, E. (Ed.) 1991 *Annual Report of the State of Air Pollution in Cities and Industrial Centres – 1990*, State Committee on Hydrometeorology, St Petersburg (in Russian).

Bezuglaya, E., Rastorgueva, G. and Smirmova, I. 1991 *Annual Report on the State of Air Pollution and Harmful Pollutant Emissions to the Atmosphere of Cities and Industrial Centres of Russia*, Main Geographical Observatory, St Petersburg (in Russian).

Mnatsakanian, R. A. 1992 *Environmental Legacy of the Former Soviet Republics*, Centre for Human Ecology, University of Edinburgh, Edinburgh.

Lipinskij, V. 1994 Personal communication, State Hydrometeorological Committee of Ukraine, Kiev.

State Hydrometeorolgical Committee of the Ukraine 1995 Personal communication, State Hydrometeorolgical Committee of the Ukraine, Kiev.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

WHO/UNEP 1992 *Urban Air Pollution in Megacities of the World*, World Health Organization, United Nations Environment Programme, Blackwell, Oxford.

15

Lagos

Statistical Summary

Country: Nigeria
Estimated population 1990 (millions): 7.74
Projected population 2000 (millions): 13.5
Map reference: 3°30'E, 14°0'N
Area (km²): 3,200
Altitude (m): approx 1
Climate: Tropical rain forest
Average temperature range (C): 26–27.5
Annual mean precipitation (mm): 0

Situational Analysis

Located in south-west Nigeria, Lagos is the former capital city of Nigeria and the most populous city in Africa. It has one of the fastest growing populations in the world, currently about 5.5 per cent per annum; by the year 2000 Lagos is projected to be the eighth largest urban agglomeration in the world (UN, 1992). Lagos is sited on a coastal plain with a series of lagoons and creeks (which characterise over one-fifth of the land area of the Lagos Municipality). The city consists of three large islands adjacent to the mainland: Lagos, Ikoyi and Victoria, (see Figure 15.1). Some of the land has been reclaimed and all is just above sea level. Lagos experiences a tropical rain forest climate with a wet season between about April and November and a dry season from December to March. The annual mean temperature is 27C with very little seasonal variation.

Lagos is the largest manufacturing centre in Nigeria with most of the industry located in industrial estates on the mainland. The most important industries and industrial estates in which they are located are shown

Table 15.1 Industry in Lagos

Ikeja	Ikorodu	Ilupeju	Apapa	Mushin
Aluminium smelting	Textiles	Printing	Metal products	Textiles
Enamelware		Paint manufacture	Vehicle assembly	Printing
Asbestos		Textiles	Food and beverages	Light engineering
Furniture			Plastics	
Fabricated metal products			Building materials	
Building materials			Glass	
Glass				

Source: Iloeje, 1981

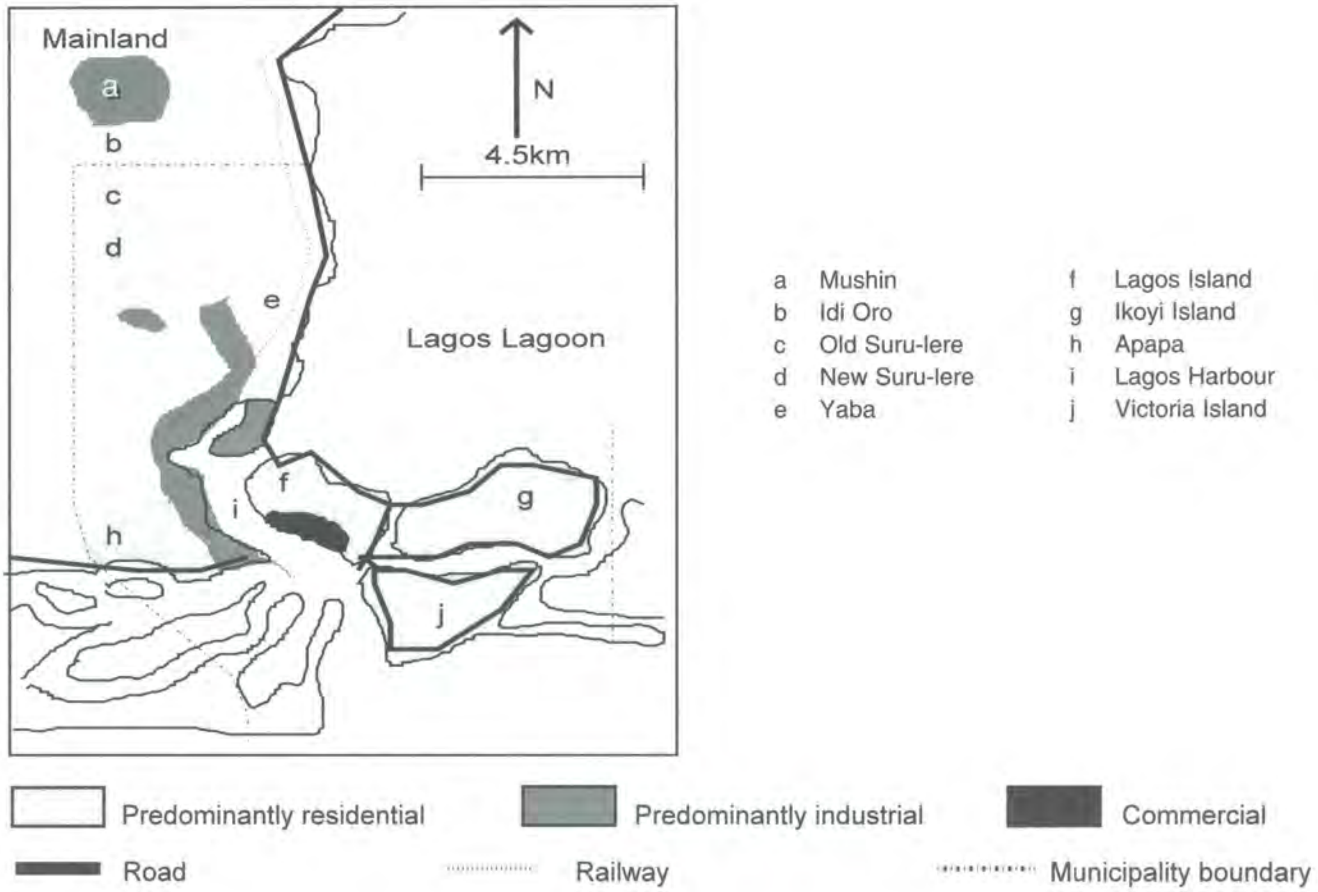


Figure 15.1 Sketch map of Lagos Municipality – land use and transport infrastructure

Source: Iloeje, 1981

in Table 15.1. Electricity is generated by a large diesel burning power station at Iddo; the other important source of industrial energy is hard coal. A variety of fuels are used for domestic cooking, including natural gas – the most widely used fuel - electricity, hard coal, wood and kerosene/fuel oil.

There has been very little air quality monitoring in Lagos and there are no monitoring networks collecting data on a daily basis. However, the Environmental Research group in the Physics Department at the University of Ile-Ife monitored total suspended particulates (TSP) and lead levels at residential, industrial and kerbside sites in 1991; their results are shown in Table 15.2 (Oluwole, 1994). The concentrations recorded imply that, from the high kerbside values, and from the relatively small difference between residential and industrial areas, road traffic is a serious source of pollution (although these results must be considered as tentative because relatively few sites were used and few samples taken). The lead content of petrol in Lagos is among the highest in the world (Ndiokwere, 1984), (0.74 g l^{-1} compared with 0.15 g l^{-1} in the European Union) and unleaded petrol is not available. A study examining the elemental characterization of roadside dust in Lagos found a positive correlation between lead and other vehicular emission-related elements with traffic density (Ogunsola, in press). Traffic congestion is a major problem in Lagos, the road building programme in the city has not matched the growth in numbers of cars, buses and motorcycles.

Table 15.2 Annual mean and daily maximum TSP and lead concentrations monitored in Lagos, 1991 compared with WHO Guidelines (µg m^{-3})

Site	TSP	Lead
Residential	269 (379)	5.16 (17.1)
Industrial	302 (900)	5.47 (18.23)
Kerbside	728 (1,903)	20.8 (47.0)
WHO	120 (24 hours)	0.5 to 1.0 (12 months)

Figures in brackets are maximum values.

Source: Oluwole, 1994; WHO, 1987

The suggestion that TSP and lead levels in Lagos are at levels detrimental to the health of residents is supported by additional research. This research examined blood lead levels in traffic wardens from Lagos, Ile-Ife (a sparsely populated town) and a control group (Ogunsola, in press). Mean blood lead in the Lagos wardens was 18.1+/- 6.4 µg dl^{-1} compared with 10.2 +/- 2.7 µg dl^{-1} in the Ile-Ife wardens and 12.9 +/- 7.0 µg dl^{-1} in the control group (there is no significant difference between blood lead levels of these latter two groups). The WHO European Guidelines suggest that blood lead levels should be below 10 µg dl^{-1} for the population as an average. Although the traffic wardens group is not representative of the population as a whole, it indicates that this population sub-group is exposed to high, health-damaging lead levels.

Monitoring Networks

There is no routine monitoring of air quality conducted in Lagos, only individual research projects which have measured levels of TSP and the composition of the particulate matter (Ogunsola et al., 1993). Details of these studies have been published in international science journals.

Emissions Inventories

There are no emissions estimates for Lagos or Nigeria as a whole.

Air Quality Management

Legislative framework

The formation of the Federal Environmental Protection Agency (FEPA) together with the publication of the *National Policy on the Environment* in 1989 has led to the initiation of a number of developments in air quality management throughout Nigeria. The National Policy states in its introduction the need for "*sustainable development based on proper management of the environment in order to meet the needs of present and future generations*"; and that "*development is a national priority but actions designed to meet essential needs must be reconciled with environmental issues which had been hitherto neglected or not given sufficient attention*".

The document goes on to outline a series of policy goals, including:

- to secure for all Nigerians a quality of environment adequate for their health and well-being;
- to raise public awareness and promote understanding of the essential linkages between environment and development and encourage individual and community participation in environmental improvement and efforts;
- to conserve and use the environment and natural resources for the benefit of present and future generations.

Source: FEPA, 1989

It is proposed that these and other objectives will be met by implementing a number of strategies: the establishment of standards and monitoring capability for the evaluation of environmental change; public dissemination of relevant environmental data; and, environmental assessment of proposed activities which may affect the environment or use of natural resources. For air quality in particular a series of more detailed plans were presented:

1. The designation and mapping of National Air Control Zones (ACZ).

2. Setting of air quality objectives for each ACZ.
3. Establishment of ambient air quality standards and monitoring networks.
4. The setting of emissions standards.
5. Licensing and regulation of major industrial polluters and monitoring of emissions.
6. The establishment of guidelines for pollution abatement.
7. The setting of stringent standards for automobile exhaust emissions and those from energy generating plant.
8. The control of acid rain.
9. Regional co-operation to minimize transboundary air pollution across international boundaries.

A number of these plans were addressed in the 1991 *Guidelines and Standards for Environmental Pollution Control Nigeria* (FEPA, 1991) which set emission and ambient air quality standards. The introduction of this document further developed the themes of the National Policy statement and recognized that industrial pollution cannot be abated and halted if an appropriate legal framework does not exist. It recognized that standards are ideally based on nationally generated environmental baseline data but that this is not yet practicable for Nigeria and therefore standards have been based upon those operated in Germany, India, Japan, UK, USA, Brazil, Canada, Singapore, Turkey, Poland and Russia. Likewise, guidelines have either been adopted from elsewhere, if appropriate, or else modified to suit conditions in Nigeria.

Industrial pollution abatement

Industrial emissions limits, which must not be exceeded, have been established for 37 different pollutants (shown in Table 15.3). These limits are, in general, a range of values set in order to take account of the size and nature of the source. Emissions limits for particulate matter are classified depending upon the nature of the process and are also given as a range of values. Overall, emissions limits in Nigeria are broadly similar to those adopted in developed countries.

All industries must have emissions monitoring capabilities, or assign responsibility to a consultant/contractor approved by the FEPA. This presented small-scale operators with problems arising from the cost of implementing this requirement; consequently, during the consultation process preceding the publication of the final policy document FEPA agreed that groups of contiguous industries could borrow or jointly sustain on-site pollution units so long as compliance with FEPA Guidelines was maintained. Records must be kept by emitters of all discharges which are logged with regional FEPA offices monthly. Accidental discharges must be reported within 24 hours and contingency plans must have been developed by the operator to deal with such unplanned releases. Environmental auditing of existing industry and Environmental Impact Assessments of new industries and development projects are now mandatory under this legislation.

During the formulation process described above there was criticism of the proposed standards; it was said that they were imported, inappropriate and irrelevant to the Nigerian situation. FEPA countered these criticisms by explaining that the values had been based on a wide number of studies of the physiochemical characteristics of effluents and experiences in other developing countries, such as India. The consultation process was conducted over a period of six weeks in 1990 and a variety of responses obtained. These have been published and some of the comments incorporated into the revised final document.

In addition to their statutory duties, FEPA also holds regular seminars and workshops for workers in industry to educate them about the effects of pollution and abatement and monitoring methodologies.

Air quality standards

These prescribe guidelines for safe levels of specific substances in the air tolerable to humans, aquatic organisms and vegetation. There are two sets of values: *Nigerian Ambient Air Quality Standards* for conventional pollutants (shown in Table 15.4) and *Tolerance Limits for Ambient Air Pollutants* which give the permitted levels of 74 specific substances in the air. The averaging times used refer to acute exposure; no chronic exposure, ambient air quality standards have been set. The standards which have been set are discussed further in the Comment section.

Table 15.3 Emissions limits for specific pollutants from stationary sources

Substance	mg m^{-3}
Acid gases	200–9,000
Aldehydes	20
Ammonia	3 kg hr^{-1}
Antimony	20–100
Arsenic	20–100
Benzene	24 kg hr^{-1}
Beryllium	0.1
Cadmium	1.0–40
Carbon	50–250
Carbon dioxide	10 per cent by vol.
Carbon disulphide	100–500
Chlorine	3.0–200
Copper	20
Formaldehyde	0.5 kg hr^{-1}
Fluorine	1.0–100
Fluorine compounds	20–50
Heavy metals (total)	10
Hydrocarbon	50
Hydrochloric acid	100
Hydrofluoric acid	100
Hydrogen Fluoride	1.0230
Hydrogen sulphide	5–150
Lead	10–100
Manganese	0.1 kg hr^{-1}
Mercury	1.0–250
Nickel	20
Nickel carbonyl	0.5
Nitric acid	500–4,000
Nitrogen oxides	350–1,000
Organic compounds	50
Particulates	50–5,000[a]
Sulphur dioxide	30–3,000
Sulphuric acid	5.0–1,000
Sulphur trioxide	100–200
Sulphur trioxide and sulphuric acid mist	0.8 kg ton^{-1} (acid)
Vinyl chloride	10–200 ppm

(a) Particulate emissions limits are based upon the type of process.

Source: FEPA, 1991

Air quality can be monitored by any standard method recognized by the US Environmental Protection Agency, UK Department of the Environment and European Union. It is intended that FEPA will adopt standard methods for Nigeria in the future.

Comment

The absence of any regular monitoring and emissions data makes it very difficult to assess the extent of the seriousness of air pollution in Lagos. The research that has been conducted suggests that high concentrations of traffic-derived pollutants may be having an adverse effect upon the health of Lagos residents – but much more information is required to determine this with confidence.

The *National Policy on the Environment* proposed to address environmental concerns through the setting of policy goals and objectives, part of which were met with the publication of *Guidelines and Standards for*

Table 15.4 Nigerian Ambient Air Quality and Tolerance Standard (μg m^{-3})

Pollutant	Limit (Daily mean of hourly values unless stated)	Long-term Tolerance Limit (24 hours)	Short-term Tolerance limit (30 minutes)	WHO European Guideline (24 hours unless stated)
Particulates	250 and 600[(a)]	–	–	120
SO_2	26 and 260[(a)]	50	500	125 and 350[(i)]
Non-methane hydrocarbons	160[(b)]	–	–	–
CO	11.4 mg m^{-3}[(d)] and 22.8[(d),(e)]	1 mg m^{-3}	5 mg m^{-3}	60[(e)] and 10[(f)] mg m^{-3}
NO_2	75–113	85	85	150 and 400[(i)]
Photochemical oxidant	0.06 ppm[(e)] (118)[(g)]	80[(h)] and 100[(c)]	100[(h)] and 200[(c)]	150–200[(c)] and 100–120[(c),(e)]
Lead	–	5	2	0.5–1.0[(j)]

(a) Concentration not to be exceeded more than once a year.
(b) Daily average of 3 hourly values.
(c) Ozone standard.
(d) Unit given in legislation is μg m^{-3} which is incorrect for ppm equivalent stated.
(e) 8 hours.
(f) 30 minute limit.
(g) Using conversion factor for ozone at 25C.
(h) Oxidant standard.
(i) 1 hour value.
(j) Annual value.

Source: FEPA, 1991

Environmental Pollution Control, Nigeria in 1991. The setting of standards for emissions and ambient air quality is an important component of an integrated air quality management strategy. The approach adopted by FEPA in establishing these limits – assessing the standards used in other countries and modifying them to Nigeria's needs – recognizes the limited resources available to the country and makes use of the experience of other nations.

In air quality management the setting of air quality standards should go hand in hand with the implementation of strategies to encourage and monitor compliance and penalize exceedances. In Nigeria, inspections of sources occur irregularly owing to limited resources and it is therefore difficult to enforce the emissions limits which have been set. Since there is no monitoring of ambient air routinely conducted in Lagos, compliance with air quality guidelines cannot be measured, although a commitment to establish monitoring networks was made in the *National Policy on the Environment* document in 1989.

The ambient air quality standards which have been adopted contain some anomalies. The particulates standard does not specify the type of measurement to be used – smoke, total suspended particulates (TSP) or particulate matter less than 10 μm (PM_{10}). The daily carbon monoxide (CO) *Ambient Air Quality Standard* is broadly similar to the European WHO 8-hour Guideline value, but 1-day *tolerance limit* is an order of magnitude lower than this and *short-term* (30 minute) *tolerance limit* is half the *Ambient Air Quality Standard*. The nitrogen dioxide (NO_2) ambient air quality standard is below the WHO value (which incorporates a safety margin for sensitive individuals) and *tolerance limits* are also below the WHO guideline and are the same for 30-minute and 24-hour exposure – this does not recognize the enhanced effects upon respiratory health which occur with longer exposures. The photochemical oxidant standard is unclear as to whether it is total oxidant or ozone alone which is monitored and the values are also below comparable WHO ones. There are no standards for long-term exposure to pollutants likely to produce chronic health effects; the 30-minute *short-term tolerance limit* for lead is a good example, particularly as the 24-hour standard is higher than the 30-minute lead standard. There are also no standards to limit exposure to carcinogenic substances such as benzene and polynuclear aromatic hydrocarbons (PAHs).

The emissions limits similarly set standards for a wide number of pollutants for which there is no emissions monitoring capability. There are also some notable omissions – no standard for CO and no indication of the particulate matter measurement to be used. The emissions limits for specific pollutants are also very broad thus leaving the possibility of widely differing levels of emissions being permitted from similar processes. It is not clear from the legislation how the emission limit applied to a particular process has been established.

Emissions limits for mobile sources were not included in the *Guidelines and Standards for Environmental Pollution Control* although there are plans by the FEPA to introduce controls. It is particularly important that the legislation when presented provides the means to enforce the standard through a mandatory, enforced vehicle inspection programme.

The *Guidelines and Standards for Environmental Pollution Control, Nigeria* contain a section on industrial processes and the types of pollutant emanating from them. Pollutants are classified as aerosol, gas or vapour, but it is not clear from the document whether this is intended to be a comprehensive list which indicates the pollutants industrial processes should monitor for, or if it is intended for reference purposes only. There are a number of notable anomalies and omissions in this table, not least of which are the absence of NO_2 and CO as pollutants from combustion processes, and lead and hydrocarbons from automotive engines; the distinction between petroleum operation and petroleum refining is also not clear.

Nigeria has made a significant commitment to managing its environment in a sustainable manner and has recognized that the issue of air pollution has received insufficient attention in the past. It has attempted to rectify this situation through the development of emissions limits and air quality standards, but these mandatory values cannot be used as part of an integrated air quality management strategy as no monitoring is being conducted and no emissions data is available.

This chapter has highlighted some of the problems of the air quality management strategies adopted to control air pollution in Lagos. There is recognition in Nigeria of the problems of air pollution and the first steps have been taken to address these problems.

Summary

- There is no routine monitoring of air pollution conducted in Lagos and no emissions inventory has been conducted.

- Monitoring as part of research at the university indicates high levels of lead and particulate pollution and raised blood lead levels amongst exposed groups.
- Mandatory ambient air quality standards have been set for acute effects of pollution only, some of which are below WHO European Guidelines.

- Mandatory emissions limits exist for industrial sources which are broadly similar to those in developed countries although the extent of compliance with these is uncertain.

References

FEPA 1989 *National Policy on the Environment*, Federal Environmental Protection Agency, Lagos.

FEPA 1991 *Guidelines and Standards for Environmental Pollution Control*, Federal Environmental Protection Agency, Lagos.

Iloeje, N. P. 1981 *A New Geography of Nigeria*, Longman Press, Lagos.

Ndiokwere, C. L. 1984 A study of heavy metal pollution from motor vehicle emissions and its effect on roadside soil, vegetation and crops in Nigeria, Environmental Pollution (Series B), 7, 35.

Ogunsola, O. J., Asubiojo, O. I., Durosinmi, M. A., Fatusi, A. O. and Ruck, W. *Environmental Impact of Vehicular Traffic in Nigeria – Health Aspects*. In press.

Ogunsola, O. J., Oluwole, A. F., Asubiojo, O. I., Oleniyi, H. B., Akeredolu, A. F., Akanle, O. A., Spyrou, N. M., Ward, N. I. and Ruck, W. *Traffic Pollution; Preliminary Elemental Characterization of Roadside Dust in Lagos, Nigeria*. In press.

Ogunsola, O. J., Oluwole, A. F., Obioh, I. B., Asubiojo, O. I., Akeredolu, F. A., Akanle, O. A. and Spyrou, N. M. 1993 Analysis of suspended air particles along some motorways in Nigeria by PIXE and EDXRF, *Nuclear Instruments and Methods in Physics Research*, **B79**, 404–407.

Oluwole, A. F. 1994 Personal communication.

UN 1992 *World Urbanization Prospects*, United Nations, New York.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

16

Lahore

Statistical Summary

Country: Pakistan
Estimated population 1990 (millions): 3.78
Projected population 2000 (millions): 5.39
Map reference: 31°20'N, 74°20'E
Area (km²): 1,706
Altitude (m): 208–213
Climate: Semi-arid
Average temperature range (C): 12–33
Annual mean precipitation (mm): 490

Situational Analysis

Lahore is the second largest city in Pakistan and is located in the east of the country. It experiences a semi-arid climate with large seasonal variations (LUDP, 1990). The daily minimum temperature falls to an average of 5C in the winter from December to February and domestic space heating during this period is provided by natural gas (in which the country is self sufficient), kerosene and wood burning. Summer temperatures are much hotter, rising to a mean daily maximum of 41C in June, accompanying the monsoon. The wind direction is predominantly from the north-west; wind speeds are lowest in the winter and peak during the dry season generating dust storms.

Since 1950 the population of Lahore has been effectively doubling approximately every 20 years; this has led to a dramatic increase in the size of the city, encroachment into surrounding agricultural lands, and, serious environmental and social problems. The high demand for work has encouraged successive governments to broaden the traditionally agrarian economy and to develop an industrial manufacturing sector. Industry in Lahore is dispersed across the city, with a concentration 20 km to the south of the city centre in the Kot Lakhpat industrial area covering an area of about 6 km^2 (Figure 16.1). In Kot Lakhpat there are a number of different industries which are major local sources of pollution, these include: steel and paper mills, stone crushing works, pharmaceuticals and textile factories, and a large railway engineering works and sidings. This industrial area is surrounded by a mixed residential and light industrial zone. Natural gas and electricity are the predominant fuels used by industry, with some use of coal burning and liquid petroleum gas (LPG). Electricity is provided from the Pakistan national grid, 51 per cent of which is generated from thermal (gas and fuel oil) power stations. There is one gas-fired power station located in Lahore.

Motor vehicles are an increasingly important source of pollution in Lahore. Congestion is a serious problem in some parts of the city and reliance upon old, poorly maintained vehicles with inefficient combustion produces very high emissions per vehicle. It has been estimated that the average Pakistani vehicle emits 20 times as much hydrocarbons, 25 times as much carbon monoxide (CO) and 3.6 times as much nitrogen oxides (NO_x) per km as an equivalent US vehicle (IUCN Pakistan, 1993). The presence of many small two-stroke motor cycles and rickshaws with disproportionately high emissions relative to their engine size – especially of particulate matter – exacerbates the problem.

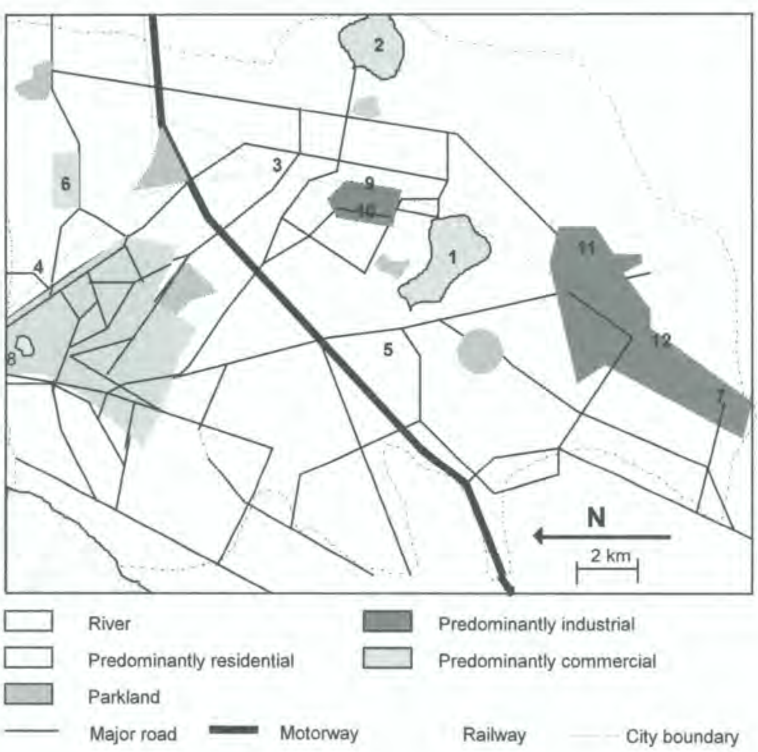
The most serious air quality problem in Lahore is associated with the high level of particulate matter. At a city centre monitoring site the concentration of total suspended particulates (TSP) averaged 439 $\mu g\ m^{-3}$ in 1992–93, whilst at industrial and semi-rural sites the concentrations averaged 536 and 838 $\mu g\ m^{-3}$ respectively (IPHER, 1994a). The raised rural concentrations are accounted for by particularly high values during the dry season and the possible influence of ploughing and harvesting. There may also be a contribution from brick kilns which burn a combination of wood (sawdust), coal, furnace oil and tyres. These statistics are significantly above WHO guidelines (WHO, 1987). Furthermore, a significant proportion of the TSP, particularly during the summer, is likely to result from wind-blown and resuspended dust. Research is currently being undertaken to determine the proportion of TSP which is respirable and its composition.

In 1992–93 the mean lead concentrations in the city of 3.38 $\mu g\ m^{-3}$ (IUCN Pakistan, 1993) were also significantly above the WHO guideline of 0.5 to 1 $\mu g\ m^{-3}$. This results predominantly from the high lead content of petrol at 1.5 to 2.0 $g\ l^{-1}$. Measurements for NO_2 made at different locations, in the year July 1992/3 (Table 16.1), show significantly elevated roadside concentrations – particularly at road junctions. In residential areas, concentrations are considerably lower and are at levels unlikely to contribute towards severe respiratory health problems.

Table 16.1 NO_2 concentrations July 1992/3

Site Classification	Average concentration (ppb)
Road junction on city major roads	43–48
Roadside – commercial area	35–41
Roadside – industrial area	25–29
Residential area	13–14
Rural area	11

Source: IPHER, 1994b



1 Walton Airport
2 Lahore Airport
3 Railway station
4 Railway station
5 Punjab University
6 University of Engineering and Technology (City site)
7 Industrial site
8 Old City
9 Pharmaceutical industry
10 Beverages industry
11 Paper industries
12 Iron and steel plant

Figure 16.1 Sketch map of Lahore

Source: Pakistan Tourism Development Corporation, 1988

Recent measurements of carbon monoxide have ranged between 9 and 350 mg m^{-3} (WHO 1-hour guideline 30 mg m^{-3}) (IUCN Pakistan, 1993) of which 96 per cent is estimated to be generated by motor vehicles. Carbon monoxide data from sites located at urban background locations are, however, generally below WHO Guidelines (IPHER, 1994b). Ozone concentrations can also become significantly elevated, particularly during summer. Measurements made between April and June 1993, at six sites between 1000 and 1600 hours, averaged between 56 and 75 ppb (IPHER, 1994b). Although it is difficult to compare the data available with WHO guidelines, it is likely that exceedances of the 8-hour guideline do occur. Concentrations of sulphur dioxide are low, the 24-hour maximum concentration in 1993 being below 10 ppb.

Monitoring Networks

Monitoring in Lahore has been conducted on an ad hoc basis since the GEMS/Air monitoring sites ceased to be operational in 1989 owing to equipment failure. Prior to this GEMS/Air had operated a site since 1977 in a residential area measuring sulphur dioxide and suspended particulate matter. Data are available through the GEMS/Air data base, although they are now somewhat out-of-date (WHO, 1985). Non-GEMS/Air monitoring equipment is also available in Lahore, however, it is frequently under-utilized owing to inadequate supplies of consumables, spare parts and trained staff.

The Punjab Environmental Protection Agency has recently acquired a mobile air quality monitoring laboratory with which it has been making measurements throughout the Lahore area. The unit is equipped with continuous monitoring instruments to measure nitrogen oxides (NO, NO_2 and NO_x), SO_2, O_3 and TSP; in addition to meteorological instruments for wind speed and direction, relative humidity, temperature, barometric pressure and solar radiation.

Further air quality monitoring has been conducted as part of joint academic research contracts between universities in Europe and Pakistan. These include a study measuring the concentration of particulate matter, its composition and size fractionation, at city centre, industrial and semi-rural sites. The study has provided detailed information about particulate matter in Lahore, including the concentration of metallic species. The results of this study have been fully validated, the instruments calibrated regularly and inter-comparison of results between the different participating laboratories conducted. The data are therefore likely to be reliable and the results will be published in a scientific journal. Other research has been conducted on ozone and related damage to crops.

Emissions Inventories

Emissions inventories have been conducted in the past using fuel consumption statistics and emissions factors to determine the emissions of different pollutants. The most recent available year for which an inventory has been conducted is 1985, shown in Figure 16.2 and Table 16.2.

Air Quality Management

The effectiveness of air quality management in Pakistan has been limited in the past by the absence of quantitative emissions limits for which controls could be implemented. However, the introduction of *Statutory Notification 742(I)/93* (Gazette of Pakistan, 1993) in 1993, setting national air quality emissions standards for a range of pollutants from industrial sources and motor vehicle exhaust as well as noise (Table 16.3), has helped to rectify this problem. The Notification provides the necessary legislation for the *Pakistan Environmental Protection Ordinance* of 1983 to be effectively implemented and provides a means by which the Environmental Protection Agency can effectively regulate emissions.

In the past, with the absence of statutory standards, the Punjab EPA attempted to reduce emissions through consultations with industry. It is difficult to quantify the effectiveness of such an approach as current emissions are not known, but the good relationship which has been generated between industry and regulator should assist the effective operation of the new legislation. Other non-regulatory measures have also been adopted to lower emissions and to reduce the impact of pollution upon the environment and population. For example, there is now much greater zoning of provincial industry to avoid the siting of new heavy

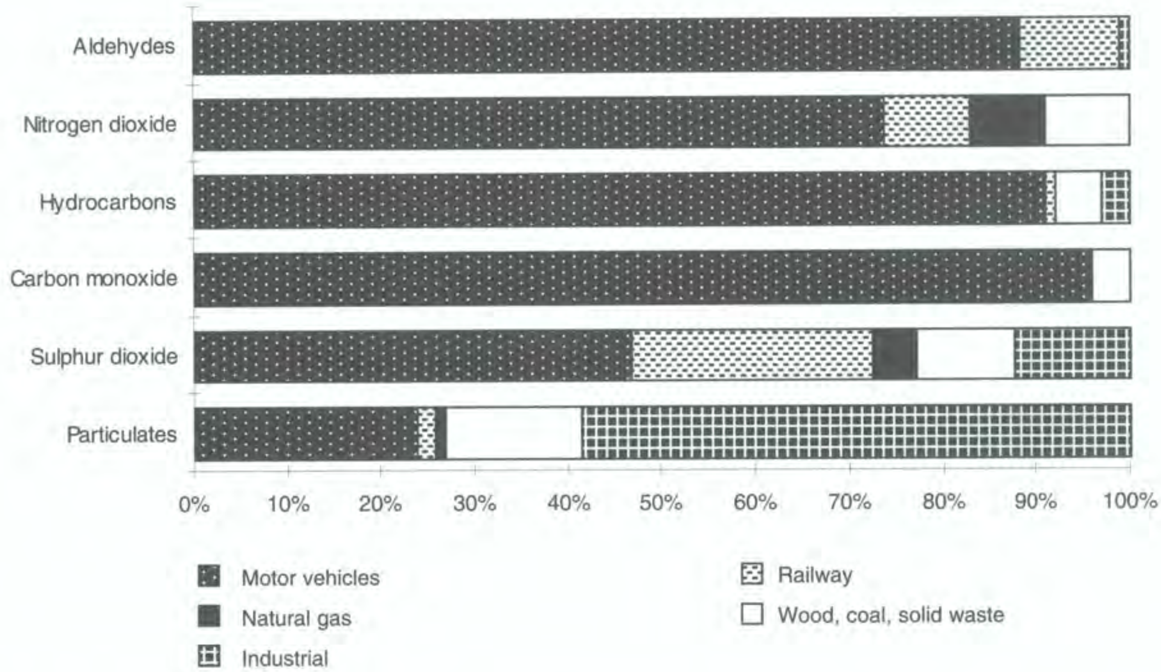


Figure 16.2 Annual proportion of emissions from different sources in Lahore, 1985

Source: IUCN Pakistan, 1993

Table 16.2 Annual emissions of air pollutants, Lahore, 1985 (tonnes)

	Motor vehicles	Railway	Natural gas	Wood, coal, solid waste	Industrial units	Total
Particulates	2,014	171	54	1,119	4,406	**7,764**
SO_2	1,377	756	5	302	358	**2,798**
NO_2	14,565	1,878	1,553	3,424	162	**21,582**
CO	123,054	657	193	4,622	285	**128,811**
Hydrocarbons	29,536	447	51	1,569	1,010	**32,613**
Aldehydes	209	26	–	–	1	**235**

Source: IUCN Pakistan, 1993

Table 16.3 National air quality emissions standards – motor vehicles

Pollutant	Measurement method	Standard
Smoke	At a distance of 6 m	40 per cent obscurence or Ringleman scale 2
Carbon monoxide	Idling, NADIR detection at a distance of 6 m	4.5 per cent (new vehicles) 6.5 per cent (used vehicles)

Source: IUCN Pakistan, 1993

industry in urban centres; plans to fit emissions control equipment on the largest emitters have also been developed, although how quickly and extensively they can be implemented will depend upon the availability of capital. A government agency, ENERCON, has been providing expertise on the tuning of boilers and vehicles to improve their efficiency, although this is currently a limited service. The National Conservation Strategy (IUCN Pakistan, 1993), published by the government in 1993, identifies a number of different approaches, including economic tools, by which emissions of different pollutants could be reduced. There is also a recognition that the under-pricing of gas and electricity in the past has led to its inefficient use; with the combined effects of non-renewable resource depletion and the generation of excessive emissions. The National Conservation Strategy also recognizes the potential of pricing and duties in encouraging the use of lead-free petrol, ethanol and electric or gas vehicles to reduce emissions from mobile sources.

Comment

The air quality data available for Lahore indicates that levels of TSP and lead are significantly above WHO Guidelines and that measures of NO_2, CO and O_3 also exceed guidelines at some locations. The acquisition of a mobile air quality monitoring unit by the Punjab EPA has significantly improved air quality measurement capability. However, during the unit's first year of operation it was located at a wide variety of sites; this has made it difficult, at the data evaluation stage, to paint a coherent, overall picture of the air quality in Lahore. A WHO consultant visited Lahore in 1990 to assist in the preliminary investigation into air pollution problems, to help to plan a strategy for rapid evaluation of these problems and to provide advice on air pollution monitoring methodologies (Commins, 1990). One of the recommendations from this visit was the development of a coordinated monitoring programme. Having completed preliminary air quality investigations the Punjab EPA should now consider how the mobile air quality monitoring unit can be used most effectively in a coordinated monitoring programme. The responsible authorities may also wish to consider the WHO report findings, to assess whether they are still relevant and, if so, how they can be implemented.

The introduction of statutory emissions limits should assist the Punjab EPA to further its work with industry to control emissions. These limits will not, however, be totally effective until a coordinated emissions monitoring and enforcement programme is operative. Without supporting the new legislation with the resources required to implement emissions controls the capacity of the EPA to conduct its mandate is limited.

Motor vehicles represent a major source of emissions in Lahore; now that new regulations are in place, a vehicle inspection and maintenance programme with the necessary enforcement powers is needed. The emissions standards adopted for new vehicles in Pakistan are equivalent to the *1987 EC standards* which impose the strictest emissions limits possible without the fitting of catalytic converters and which require the widespread use of lead-free petrol. Unfortunately, lead-free petrol is not yet available. Overall, however, this is a significant development; the impact of which will be long-term, owing to the lifetime of vehicles in Pakistan, and will require routine vehicle inspection to ensure that new vehicles remain in good running order. Furthermore, if the number and use of the highly polluting vehicles currently found in Lahore are to be reduced, without creating undue transport problems, it will be necessary to explore alternative modes of mass transport; for example, a relatively clean, viable mass transit system. Effective vehicular emissions control is necessary if the progress made in limiting industrial emissions is not to be diminished.

Air quality data can be used much more effectively, to develop rational air quality management strategies, when used in combination with emissions data identifying the most serious sources of pollution. Past emissions inventories provide invaluable information and demonstrate that the skills required to conduct such inventories exist in Lahore. A new survey, updating information from the 1985 inventory, would provide important information about trends in emissions within the city and enable the more effective planning and management of emissions.

There are currently, no set ambient air quality standards in Pakistan; WHO guidelines are being used to determine the level of acceptable air quality. In the intermediate term, the development of realistic ambient air quality standards for Pakistan will assist in the evaluation of acceptable air quality and significantly enhance the effectiveness of the air quality management strategies which are presently being implemented. These standards should not only consider the health and environmental consequences of pollution, but be realistic in terms of what can be achieved. Once established, they can be strengthened over time so as to become more stringent.

Summary

- There is considerable evidence of policy and political awareness of air pollution issues in Lahore.
- There is no coordinated monitoring of air quality in Lahore; measurements being made by ad hoc research projects at a large number of sites.
- Concentrations of particulate matter significantly exceed WHO guidelines, as do those of lead owing to the high additive content of the petrol. Adjacent to major roads and in heavily congested parts of the city, vehicle-generated pollutants are also likely to exceed WHO guidelines.
- Air quality management policies are being developed: emissions standards have recently been introduced; effective enforcement is the next step.
- There are no Pakistan-specific ambient air quality standards or guidelines; WHO European Guidelines currently being used.

References

Commins, B. 1990 *Air Pollution in Pakistan*, WHO-EMRO/REP-2564Q.

Gazette of Pakistan 1993 *Statutory Notification 742(I)/93*, 29 August 1993, Islamabad.

IPHER 1994a *Physico-chemical Characterization and Source Apportionment of Atmospheric Suspended Particulate Matter in Pakistan*, 3rd annual report, Institute of Public Health Engineering and Research, University of Engineering and Technology, Lahore.

IPHER 1994b Personal communication, Institute of Public Health Engineering and Research, University of Engineering and Technology, Lahore.

IUCN Pakistan 1993 *The Pakistan National Conservation Strategy*, The World Conservation Union, Karachi.

LUDP 1990 *LUDP Solid Waste Disposal Plan for Lahore 1990*, Lahore Urban Development Plan, Lahore.

Pakistan Tourism Development Corporation 1988 Map of Lahore.

WHO 1979 *Sulfur Oxides and Suspended Particulate Matter*, Environmental Health Criteria 8, World Health Organization, Geneva.

WHO 1985 *Urban Air Pollution 1973–1980*, World Health Organization, Geneva.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

17

Nairobi

Statistical Summary

Country: Kenya
Estimated population 1990 (millions): 1.52
Projected population 2000 (millions): 2.75
Map reference: 1°15'S, 36°45'E
Area (km²): 684

Altitude (m): 1,600–1,700
Climate: Savannah
Average temperature range (C): 6.8–29.4
Annual mean precipitation (mm): 879

Situational Analysis

Nairobi is currently the third fastest growing city in the world after Guadaloupe, Mexico and Maputo (UN, 1992). The population of Nairobi currently is growing at a rate of about 6.12 per cent per annum (see Figure 17.1), whilst that of Kenya as a whole is increasing at 3.35 per cent per annum. Although small relative to many developed and developing countries, Nairobi's industrial sector is also growing very rapidly.

It is extremely difficult to determine how the levels of air pollution in Nairobi have changed with the expansion of the city as there is little monitoring data – only total suspended particulates (TSP) and sulphur dioxide (SO_2) measurements having been made in the past 15 years. The TSP data (Table 17.1), however, suggest that air quality is deteriorating – especially in the industrial areas and commercial city centre.

A major study by the University of Nairobi at 11 sites (see Figure 17.2) (Karue et al., 1992) found that TSP was composed of a large proportion of soil dust particles; subsequent research (Gatebe and Kinyua, 1994) noted that TSP concentrations increase with wind speed. This is contrary to the experience in many cities where high concentrations of particulate matter are associated with stagnant air conditions and low dispersion of pollution, suggesting that a significant proportion of TSP is wind-generated through the resuspension of dust. Nairobi is surrounded by dry savannah, parts of which has been heavily deforested; there are also

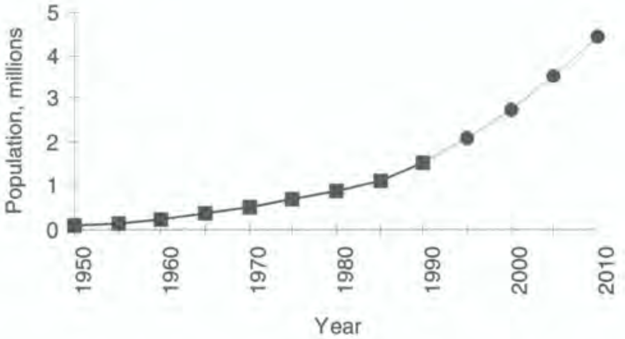


Figure 17.1 Nairobi population trend, 1950–2010

Source: UN, 1992

Table 17.1 Trends in TSP concentration (µg m^{-3})

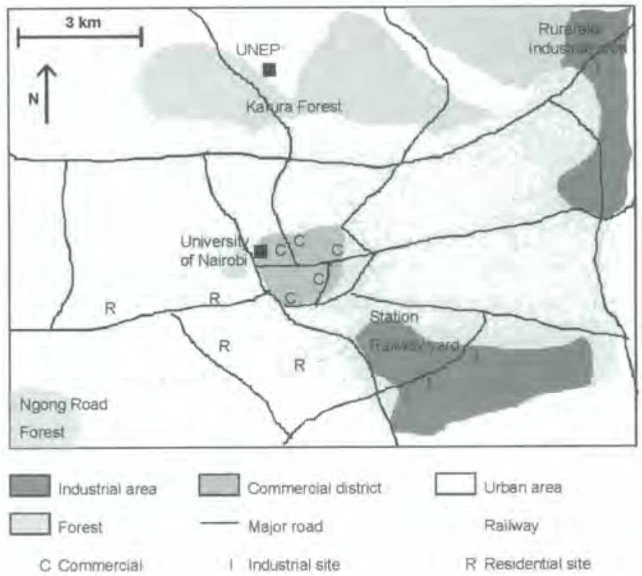
Site classification	1978–79	1982	1991
Residential	89	80–103	70–98
Commercial	72	–	165–319
Industrial	80	252	383–398
Kerbside	–	–	300–572[a]

[a] Measurements conducted in 1990.

Sources: UNEP, 1987; Gatebe, 1990; Karue et al., 1992; Ministry of Labour, 1994 considerable construction activities within the city. The necessary conditions for production of significant amounts of wind-blown dust therefore exist. Many roads in Nairobi are not tarmacked and the dry climate for much of the year allows large amounts of dust to collect on road surfaces. Concentrations of TSP in Nairobi have been shown to be strongly correlated with total daily traffic flow on nearby roads (Karue et al., 1992). It is, therefore, clear that motor vehicles are an important source of TSP, both through exhaust emissions, particularly black smoke from heavy goods vehicles, and resuspension of dust caused by vehicle movement. The relative contributions of these sources to TSP emissions are unknown, but both are undoubtedly significant.

The lead content of TSP has also been measured (Karue et al., 1992; Kinyua et al., 1994) and concentrations were found to be highest in the city centre; ranging between 0.40 and 1.3 $\mu g\ m^{-3}$. Although this is within the WHO Guideline range of 0.5–1.5 $\mu g\ m^{-3}$ (WHO, 1987), it is relatively high in relation to the number of vehicles in Nairobi. The lead content of petrol, which is 0.40 $g\ l^{-1}$, is approximately three times greater than that permitted in most developed countries.

There has been a significant increase in road vehicles in Kenya, and specifically in Nairobi, during the past decade. Detailed statistics for Nairobi are not readily available; estimates for the proportion of Kenyan vehicles registered in Nairobi vary between 40 and 67 per cent (Ministry of Labour, 1994; Karuga, 1993). From this, estimates of vehicle numbers in the city have been made and are shown in Table 17.2. The numbers of vehicles are not large in comparison with cities of a similar size with a greater per capita Gross National Product (GNP), but they are increasing rapidly. Furthermore, the age and state of repair of many of the vehicles result in substantial emissions per vehicle. Of particular concern is the growth in "Matatus" mini-buses, frequently diesel powered, many with engines tuned for maximum power, emitting large quantities of black smoke and particulates. The importance of motor vehicles as direct and indirect sources of TSP, and the growth in the number of motor vehicles, suggest that air quality is likely to deteriorate further in the future. However, the rate of increase in the registration of new vehicles has been declining in recent years owing to economic difficulties.



Note: Sites refer to the study conducted by Karue et al., 1992.

Figure 17.2 Sketch map of Nairobi

Source: Tourist Maps of Kenya Ltd, 1992

Domestic fuel consumers in Nairobi predominantly use kerosene and charcoal for cooking, both of which are relatively clean fuels; with no heating season (average temperatures only dropping to a minimum of about 7 C) pollution from domestic sources is less likely to

Table 17.2 Estimated vehicles in Nairobi, 1980 and 1988

Vehicle type	1980	1988
Passenger	8,000–114,000	88,000–147,400
Lorries	10,000–16,750	12,000–20,100
Buses	2,300–3,900	4,200–7,000
Other	7,000–11,700	8,600–14,400

Based on the estimates that 40 and 67 per cent of all Kenyan vehicles are registered in Nairobi.

Source: Ministry of Labour, 1994; Karuga, 1993 contribute significantly to total emissions. Nairobi has no heavy industry and no local electricity generating plants and, therefore, does not have appreciable problems from large point source emitters. The most important industrial activities in the city are food and drink manufacturing and textiles; neither of which are usually associated with large emissions of air pollutants. The most widely used industrial fuels in the city are hydro-generated electricity and kerosene/fuel oil, all of which produce relatively low emissions. The high concentrations of TSP in industrial areas are, therefore, likely to result from the combination of greater numbers of HGVs in these areas which cause considerable dust resuspension and frequently emit large amounts of black smoke in addition to the direct emissions by industrial processes many of which are undocumented.

Monitoring Networks

No regular monitoring has taken place in Nairobi since 1977–78, although research on air pollution continues at the University of Nairobi.

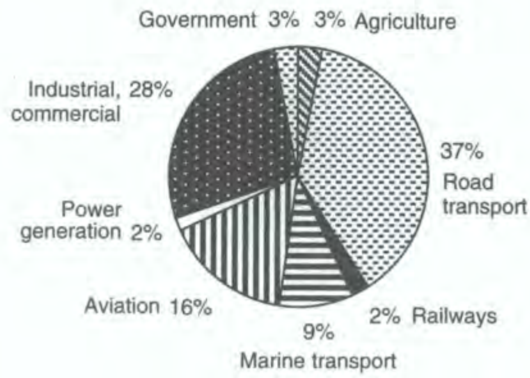


Figure 17.4 Kenyan petroleum sales by consumer category, 1989

Source: Republic of Kenya, 1990a

Emissions Inventories

No emissions inventory has been conducted for Nairobi and emissions estimates do not appear to be available. Data is generated for Kenyan petroleum supply and trends (shown in Figure 17.3) and these demonstrate

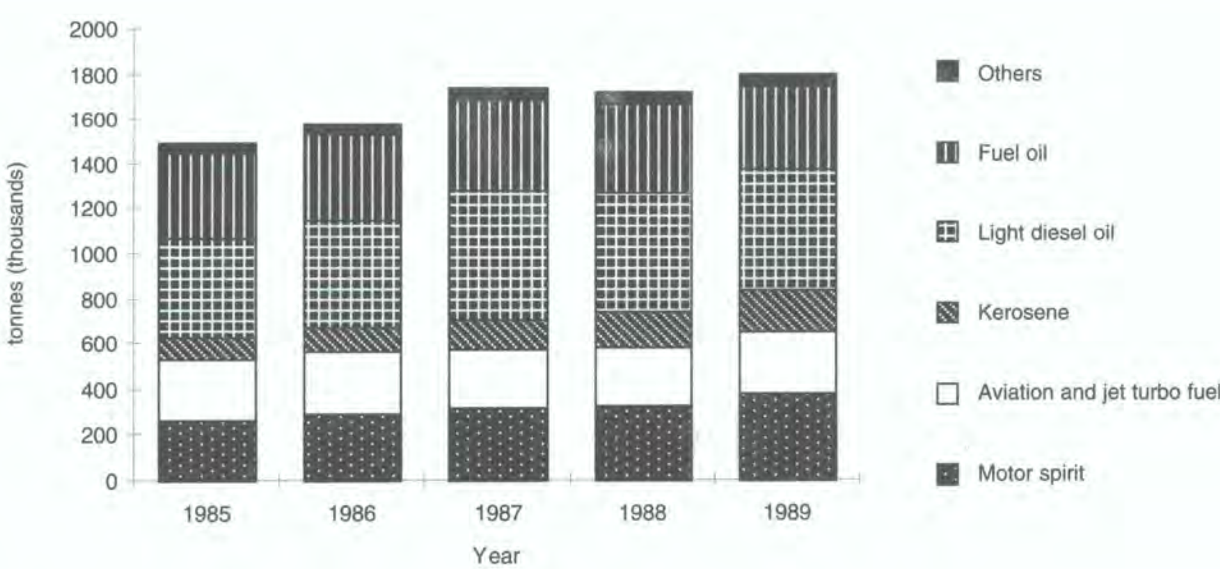


Figure 17.3 Kenyan petroleum supply, 1985–89

Source: CBS, 1990

a growth in demand for petroleum products and, in particular, light diesel which is predominantly used in both light and heavy goods vehicles and buses. Figure 17.4 shows that the largest proportion of petroleum sales (37 per cent) are accounted for by road transport vehicles.

Air Quality Management

There is very little in the way of formal legislation or policy with which to manage air quality either in Kenya in general, or in Nairobi specifically. New legislation has been drafted by an inter-ministerial committee and is awaiting discussion in parliament after which, if accepted, it will become law. There is currently no publicly available timetable for this process nor details of what the legislation will include.

There are no set air quality standards in Kenya, nor are there formal emissions limits for stationary or mobile sources. Section 17 of the Factories (Amendment) Act 1990 requires that no "dusts, fumes, gases or impurities shall be allowed to enter the atmosphere without undergoing appropriate treatment" (Republic of Kenya, 1990). There is, however, no systematic procedure for investigating emissions and companies are not required to keep records. But, if the regulations within the Factories Act are breached, the legislation allows for the temporary closure of the facility until the problem is rectified. There is no indication within the legislation when a breach is deemed to have occurred.

Emissions from motor vehicles are treated in a similar manner to those from stationary sources. There are no formal emissions limits although vehicles can be declared unfit to drive owing to their emissions and their drivers fined – although it is not clear how excessive emissions are defined.

Comment

Nairobi demonstrates very limited air quality monitoring and management capabilities. The few monitoring and emissions data which do exist indicate that TSP concentrations are probably above WHO Guidelines (120 $\mu g\ m^{-3}$ daily mean) (WHO, 1987) in industrial and commercial city centre areas; these could possibly cause adverse health effects. Dust particles produced by soil erosion in deforested surrounding areas and by the on-going construction in Nairobi are likely add to the TSP background originating from normal dry-season conditions. The very limited air quality information presently available for Nairobi makes it extremely difficult to determine whether there is currently a need to develop air quality management strategies and emissions controls, or at what point in the future these may become necessary.

Table 17.1 shows no significant trend in TSP concentrations in residential areas and during sampling periods (which correspond to working hours) traffic flows in these areas are very low (Karue et al., 1992). This suggests that in areas where traffic flows have not risen appreciably during sampling that TSP concentrations have not increased significantly either. The contribution of resuspended road dust to TSP emissions could be significantly reduced by increased, regular street sweeping. A pilot study to determine the impact of road sweeping on local TSP concentrations would provide very valuable information on a possible cheap solution to the elevated TSP concentrations.

The concentration of lead in ambient air is currently within WHO Guidelines but the growth in motor vehicles in Nairobi is likely to result in exceedances of guidelines at some locations in the future. The permitted lead content of petrol in Kenya is currently relatively high (0.4 $g\ l^{-1}$) and the relevant authorities could give consideration to reducing this figure as the number of petrol driven vehicles grows. This could ensure that adverse health effects from excessive lead exposure do not occur.

The information upon which the draft air quality management legislation can be based is extremely limited. Without collecting data on ambient air quality levels it is extremely difficult to propose air quality standards appropriate to the area which could then act as good management tools. Without information on the sources and levels of emissions in the city it is impossible to construct equitable emissions limits to ensure the most cost-effective use of resources in controlling emissions. Without an administrative framework to ensure that the air quality standards and emissions limits adopted are enforced, any air quality management strategies adopted will have only a marginal effect upon the levels of air pollution. The new proposed air quality legislation in Kenya presents an opportunity for the Government to take very positive steps to control air pollution in Nairobi and other major cities in Kenya for the next decade.

Summary

- Nairobi is the third fastest growing city in the world with a current population growth rate of 6.12 per cent per annum.
- There has been no emissions inventory constructed for Nairobi and air quality monitoring has not been routinely conducted since 1978, although some studies of TSP continue to be conducted.
- There are no emissions limits currently imposed upon mobile or stationary sources of pollution in Kenya.
- New air quality legislation is currently being considered by parliament.

References

CBS 1990 *Economic Survey*, Central Bureau of Statistics, Ministry of Planning and National Development, Republic of Kenya, Nairobi.

Gatebe, C. K. 1990 Survey of Particulate Air Pollutants in Nairobi City Centre using an Optical Dust Sampler, MSc Thesis, Department of Meteorology, University of Nairobi, Nairobi.

Gatebe, C. K. and Kinyua, A. M. 1994 TSP matter in air of some urban areas in Kenya – a review, *International Journal of BioChemiPhysics* **3**(1), 8–11.

Karue, J., Kinyua, A. M. and El-Busaidy, A. H. S. 1992 Measured components in TSP matter in a Kenyan urban area, *Atmospheric Environment* **26(B**4), 505–511.

Karuga, J. G. 1993 *Actions towards a better Nairobi*, Report and recommendations of the Nairobi City Convention, 27–29 July 1993, Nairobi.

Kinyua, A. M., Gatebe, C. K., Mangala, M. J., Njau, L. N., Kwach, R. and Mukolwe, E. A. 1994 Urban air pollution monitoring using energy dispersive X-ray fluorescence analysis, Second National Workshop of Meteorological Research Applications and Services, Nairobi, 5–9 December 1994.

Ministry of Labour 1994 Personal communication, Directorate of Occupational and Safety Services, Ministry of Labour, Nairobi.

Republic of Kenya 1990 *Kenya Gazette*, Supplement No. 31 (Acts No. 1), Republic of Kenya, Nairobi.

Tourist Maps of Kenya Ltd 1992 A map of Greater Nairobi with street index, 1992, Tourist Maps of Kenya Ltd, Nairobi.

UN 1992 *World Urbanization Prospects*, United Nations, New York.

UNEP 1987 *Kenya National State of the Environment Report 2*, United Nations Environment Programme, Nairobi.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

18

Pusan

Statistical Summary

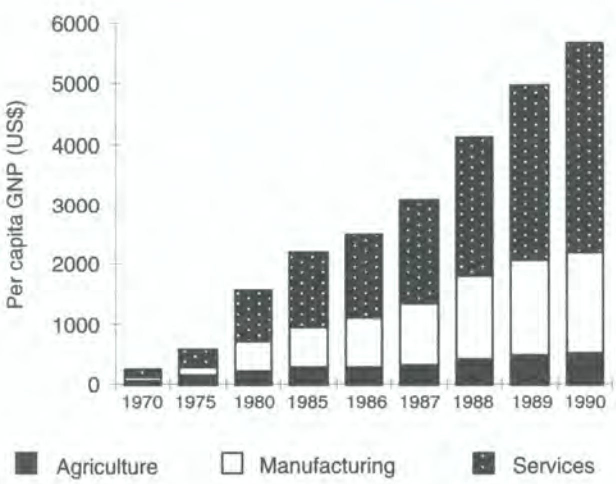
Country: Republic of Korea
Estimated population 1990 (millions): 3.88
Projected population 2000 (millions): 4.46
Map reference: 35°N, 129°E
Area (km²): 529

Altitude (m): 70
Climate: Humid sub-tropical
Average temperature range (C): -8 to 33
Annual mean precipitation (mm): 1,380

Situational Analysis

Pusan is located on the south-eastern tip of the Korean Peninsula and is the second largest city in the Republic of Korea. Surrounded by the Yellow Sea and inland by mountains, Pusan has a temperate climate with hot, wet summers (about half the annual rainfall occurring during the July monsoon) and dry, cool winters. The wind direction is predominantly from the west with an average annual surface speed of about 3 m s^{-1}.

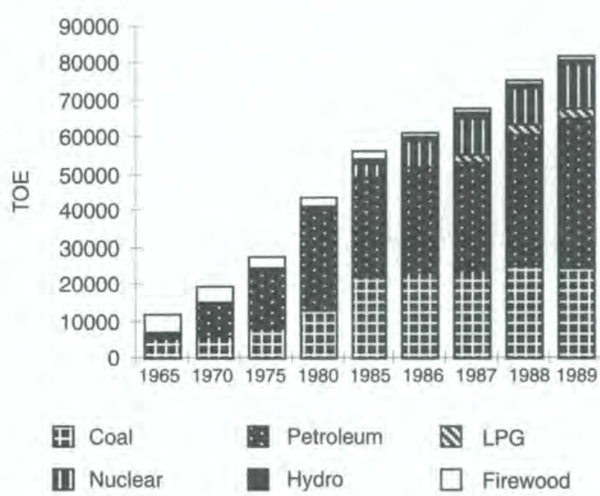
Korea has undergone a huge, eightfold increase in Gross National Product (GNP) during the past 25 years. Rapid economic growth has been achieved by the total restructuring of the economy (as shown in Figure 18.1). There has been extensive, rapid industrialization and urbanization which have significantly impacted on the Korean environment; including urban air quality. The evolution of the Korean economy from a predominantly agrarian one to that of a newly industrialized country is illustrated clearly in Figure 18.2. This



Agriculture includes forestry and fishery; Manufacturing includes mining; Services are social overhead services and others.

Figure 18.1 Korean per capita GNP, 1970–90

Source: Ministry of the Environment, 1992



TOE = Tonnes of oil equivalent; LPG = Liquid petroleum gas.

Figure 18.2 Trends in primary energy consumption by fuel type

Source: Ministry of the Environment, 1992

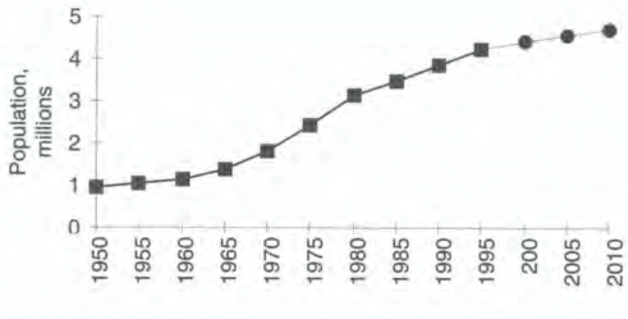


Figure 18.3 Urbanization of Pusan, 1950–2010

Source: UN, 1992

Accompanying the major industrialization of the Korean economy there has been extensive urbanization, particularly of Seoul and, to a lesser but significant extent, of Pusan (Figure 18.3). The urbanization of Pusan has included the development of transport infrastructure, including a metro service and an extensive road and rail network. There has been substantial growth in car ownership and in the number of buses and lorries (projected to continue throughout the next five years); see Figure 18.4, along with the fuel consumption statistics in Figure 18.2.

shows the structure of primary energy consumption by fuel type and shows how this has increased substantially since 1960. The type of fuels used has also changed; from predominantly wood fuel to petroleum. In recent years, the rate of growth of the Korean economy has diminished through a combination of factors including the slow-down in the world economy and rising labour costs. Nevertheless, as a result of the economic successes of the past 30 years, manufacturing and services now account for approximately 30'and 60'per cent of Korean GNP respectively.

The main sources of air pollution are oil burning industries (particularly metal processing) and electricity generating facilities in and around the city. There are also appreciable emissions of particulate matter and sulphur dioxide (SO_2) through the burning of anthracite briquettes for domestic space heating, although the domestic use of natural gas and of kerosene is becoming increasingly common. Emissions controls have been progressively implemented during the past 10 years and consequently levels of pollution are declining (see Figure 18.5). The concentration of different pollutants monitored at a residential, city centre and industrial site in Pusan in 1993 are shown in Table 18.1 and compared against Korean Air Quality Standards

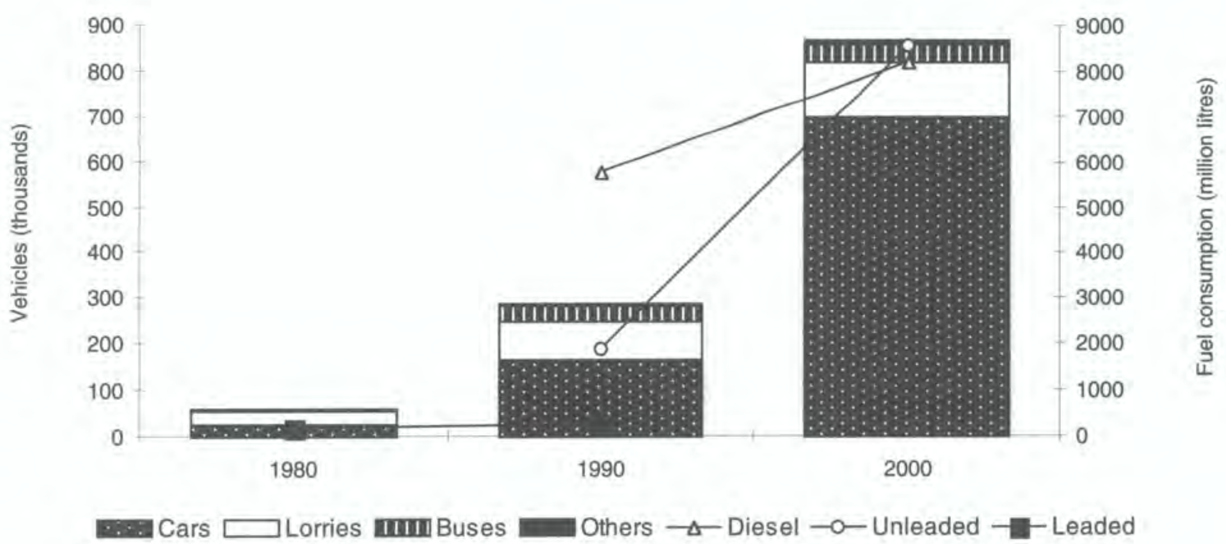
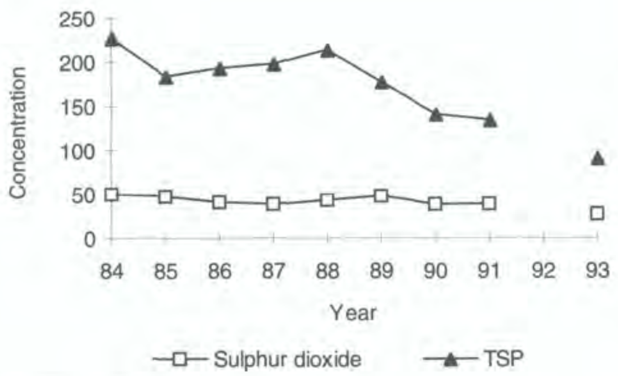


Figure 18.4 The growth in vehicle numbers and fuel consumption in Pusan

Source: Ministry of the Environment, 1991



Data for 1992 have not been made available.

Figure 18.5 Trends in Annual mean TSP (µg m^{-3}) and SO_2 (ppb), Pusan 1984–93

Source: Ministry of the Environment, 1991

and WHO European Guidelines (WHO, 1987). This shows that Korean air quality standards for daily total suspended particulates (TSP) and 8-hour ozone (O_3) are exceeded in Pusan, and that the O_3 standard is below that of the equivalent WHO Guideline range. The annual mean concentration of TSP in some parts of the city is close to the WHO 24-hour guideline value and hence exceedances of this guideline occur very regularly. Annual mean and daily SO_2 concentrations also exceed relevant WHO Guideline values. This suggests there are likely to be some health implications, particularly among vulnerable groups, due to exposure to these pollutants. Traffic-related pollutants in Pusan are all below the WHO Guidelines, although O_3 is almost within the range.

Monitoring Networks

Air quality monitoring in Korea is conducted by the Ministry of the Environment via its six Regional Offices, one of which is located in Pusan. Pusan has a network of seven air quality monitoring stations, some of which are located at sites which have been operating for as long as 20 years. The network is now fully automated and supplies data averaged over one hour periods to a central control centre. The stations are located across the city in residential, commercial and city centre sites and industrial areas and monitor pollution levels and exceedances of air quality standards. It is also intended that the network will provide advance warning of periods of poor air quality through measurement and meteorological modelling and will therefore enable implementation of emergency air quality control procedures during pollution episodes.

Table 18.1 Annual mean and maximum concentrations of air pollutants in Pusan 1993, compared with Korean and WHO European air quality guidelines

Pollutant	Residential	Commercial	Industrial	Korean standards	WHO guideline$^{(a)}$
TSP (µg m^{-3})	106, (513)$^{(c)}$	61, (250)$^{(c)}$	109, (595)$^{(c)}$	150, 300$^{(c)}$	120$^{(c)}$
SO_2	27, (103)$^{(c)}$	28, (75)$^{(c)}$	29, (86)$^{(c)}$	30, 140$^{(c)}$, 250$^{(b)}$	19, 47$^{(c)}$, 132$^{(b)}$
NO_2	30, (103)$^{(b)}$	34, (132)$^{(b)}$	15, (51) $^{(c)}$	50, 80$^{(c)}$, 150$^{(b)}$	81$^{(c)}$, 209$^{(b)}$
CO (ppm)	(5.1)$^{(d)}$	(4.3)$^{(d)}$	(4.3)$^{(d)}$	9$^{(d)}$, 25$^{(b)}$	8.6$^{(d)}$, 26$^{(b)}$
O_3	(74)$^{(b)}$	(74)$^{(b)}$	(71)$^{(b)}$	100$^{(b)}$ and 60$^{(d)}$	75-100$^{(b)}$, 50-60$^{(d)}$

ppb unless stated. Values in brackets are the maximum observed, those without parenthesis are annual mean values.

(a) Using conversion factors at 20°C, 1 atm for comparison.
(b) 1 hour.
(c) 24 hours.
(d) 8 hours.
(e) Annual mean.

Source: Murley, 1991

Nitrogen dioxide (NO_2) is monitored by chemiluminescence, SO_2 by fluorescence, O_3 by spectrophotometry, carbon monoxide (CO) by non-dispersive infra-red, hydrocarbons by gas chromatography and TSP using ß-radiation. Hourly average concentrations are logged and data capture in excess of 95 per cent is usually achieved by each monitor. A wide variety of statistical procedures are performed upon the data, including the production of percentile values and modelling with meteorological variables using data collected from mini-meteorological stations co-located at each of the sites. Acid deposition is also measured at a number of city sites. The data are published in internal bulletins, including an annual summary review, and daily concentrations are circulated to the public through the media and electronic display boards in the city centre. Calibration of the continuous instruments is performed regularly using standard gas mixtures from cylinders. The data are critically assessed and site audits performed by an independent body before the data are ratified. There is also an active sampling network for SO_2 in the city with 20 sites.

Emissions in Pusan are measured by a stack monitoring network with sites concentrated in areas which do not meet national air quality standards. The network collects emissions data on TSP, SO_2, NO_2, hydrogen chloride (HCl), hydrogen fluoride (HF), ammonia (NH_3) and O_3 for large industrial emitters. The stack monitoring network was first established at the Ulsan Industrial Complex in Pusan and is therefore extensively developed across the city.

Emissions Inventories

Pusan has created an emissions inventory for pollutants originating from motor vehicles for NO_2, SO_2, particulate matter and CO. The inventory is based upon fuel consumption statistics in the city and has been published in an internal Ministry of the Environment publication. Emissions estimates also exist for Pusan and other major centres in Korea for a range of pollutants including CO and SO_2 (see Figure 18.6) (Ministry of the Environment, 1991). This shows that the scale of emissions of SO_2 (predominantly produced through combustion of oil and coal) and CO (from motor vehicles) in Pusan approximately correlates, in relation to the size of the city, with other Korean urban areas.

The relative contributions of different sources of pollutants for Korea are shown in Figure 18.7 (Ministry of the Environment, 1991). This demonstrates that a surprisingly large contribution to total CO emissions comes from domestic sources; predominantly generated by the burning of anthracite briquettes. Emissions from individual vehicles in Korea are strictly controlled and this reduces the proportion of CO emitted from petrol engine cars. Emissions of pollutants by fuel type have also been calculated relative to the amount of energy produced (Rhee, 1990).

Air Quality Management

The evolution of environmental management and legislation in Korea

In the Korean National Report to UNCED in 1992 (Ministry of the Environment, 1992), the Minister of the Environment commented that although Korea's export-led economic growth had successfully created the basis for economic prosperity it has resulted in "*the deterioration of environmental conditions*". This, he went on to say, called for the "*modification of Korea's prevailing economic development policy*". The establishment of a more environmentally-aware approach to economic development has been implemented progressively in Korea.

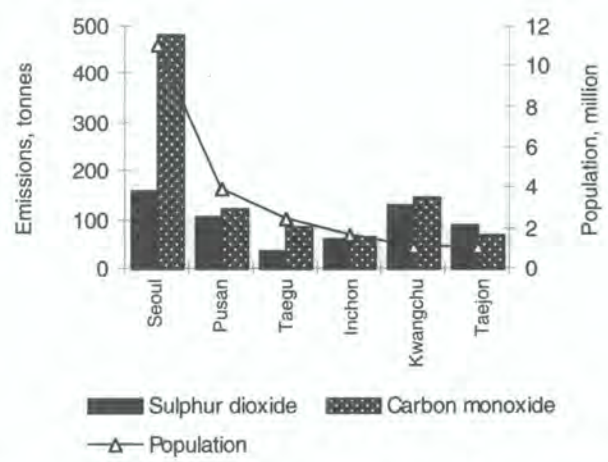


Figure 18.6 Emissions of SO_2 and CO in Korean cities, 1989

Source: Ministry of the Environment, 1991

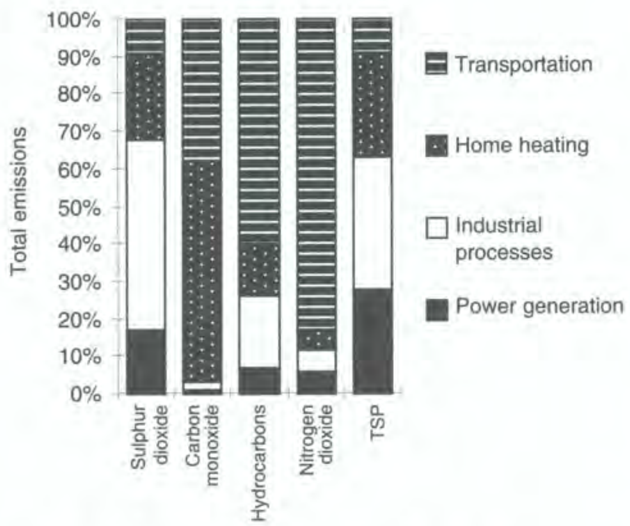


Figure 18.7 Relative emissions source contributions, Korea 1989

Source: Ministry of the Environment, 1991

The first controls on emissions of pollution were enacted during the fourth Five Year Plan (1977–1981), during which the Environment Administration (EA), with responsibility for environmental management, was established as a vice-ministry within the Ministry of Public Health and Social Affairs. The EA had relatively limited powers but introduced a series of new environmental legislation to strengthen existing laws. The new statutes included an additional article in the National Constitution protecting people's environmental rights and the Environmental Preservation Law (EPL) of 1977. This act saw subsequently amendments and remained the central environmental legislation throughout the 1980s.

During the period of the fifth Five Year Plan (1982–1986) environmental conservation was included for the first time as an official goal of national economic development. During this period the administration of the EA was significantly strengthened, culminating in the establishment of six Regional Environmental Offices (REOs) and of semi-governmental agencies such as the Korean Environmental Management Corporation. The EA and supporting agencies initiated a number of air quality management strategies including the use of unleaded petrol, production of low emission vehicles and construction of desulphurization plants at major oil refineries. Throughout the late 1980's public concern about air pollution grew rapidly into an important political issue, and strategies for reducing emissions were tightened and expanded.

In 1990 the vice-ministry of the EA was elevated to the full Ministry of the Environment (MOE). The MOE has four major bureaus – one of which, the Air Quality Management bureau, is responsible for air pollution and is divided into four divisions: Air Quality Planning, Air Pollution Control, Automotive Pollution Control and Noise and Vibration Control. The MOE has its own research programme undertaken by the National Institute of Environmental Research and also has a Central Environmental Disputes Co-ordination Commission which is empowered to settle claims concerning damage from environmental pollution through mediation. The establishment of the MOE was followed by new environmental legislation, in 1991, with six new environmental statutes more capable of rapidly responding to the changing nature of Korea's environmental problems. This produced three tiers of environmental legislation in Korea:

1. Article 35 of the Constitution.

2. The Basic Law for National Environmental Policy (BLNEP) which established: national air quality standards (which are shown in Table 18.1); the responsibilities of citizens, industry and government for pollution control; areas with particular environmental problems and special counter-measures to reduce emissions; and the requirement for Environmental Impact Assessment for various major development projects.

3. Six sectoral laws – that with relevance to air pollution being the Air Quality Control Law (AQCL) which requires mandatory continuous monitoring of air pollutants and stipulates procedures for the authorization of emissions of air pollutants from sources, including emissions limits.

Under the AQCL, before the construction of any new facility, permission must be obtained from the REOs. For major developments (private or public) or those in certain areas (such as those which do not meet national air quality standards) environmental impact assessment must be conducted to ensure environmental considerations are included in development plans and that potential impacts are minimized. Once in operation, facilities must meet statutory emissions limits. Exceedance of emissions limits results in fines under the Emission Charge System, the amount of the penalty being dependent upon how much the emission concentration was exceeded and for how long the exceedance occurred. Since 1992 the MOE has also operated the Environmental Improvement Charge System in order to raise funds for the Pollution Control Fund. This fund provides low-interest long-term loans for investors in pollution control facilities and operators of public environmental facilities. This charge system is levied against facilities which fall into certain specific categories.

Regional Air Quality Management

In addition to the national air quality management structures and legislation operating in Korea, there are regional strategies to address specific local problems. The BLNEP and AQCL define one special city (Seoul), five supervisory cities (including Pusan) and nine provinces which are responsible for air quality within their district and which are encouraged to establish administrative plans, introduce legislation and enforce national laws to control air quality. In areas which have, or may have, air quality poorer than national ambient air quality standards, *special countermeasure areas* are assigned in which emissions from industry are controlled on the basis of the total amounts of pollution emitted, rather than stipulating emissions limits from individual sources.

Control of sulphur dioxide

Sulphur dioxide is one of the most prevalent and serious air pollutants in Pusan, and in Korea in general. The government has lowered the sulphur content of fuels used by industry in order to meet its objective of lowering annual mean SO_2 concentrations to below 30 ppb in the near future. The sulphur content of Bunker-C (B-C) fuel oil, which is extensively used in Korea, has been progressively reduced to 1.6 per cent, with plans to lower this further to 1.0 per cent by 1995 when installation of desulphurization facilities in oil refineries will be complete. Similarly, the sulphur content of light-duty oil is currently 0.4 per cent and will be lowered to 0.2 per cent. In addition to this the more widespread use of cleaner fuels such as liquid petroleum gas (LPG) is being encouraged; it is even a requirement for some uses, in certain areas. By the year 2000 it is intended that all heating requirements in Korea will be met by LPG.

The growth in projected energy demand for the next 40 years is from 128.9 million TOE (tonnes of oil equivalent) in 1990 to 928.7 million TOE in 2030; with fossil fuels contributing about 80 per cent of this demand, as they do currently. This projected level of growth will require extensive pollution control/energy conservation policies if the gains made in reducing emissions of pollution per kilowatt energy consumed are not to be offset by the growth in total energy consumption. These measures are being progressively implemented and include the expansion of district heating systems, encouragement of combined heat and power systems in industrial parks and the requirement for energy impact statements from large energy-using facilities.

Control of TSP

High concentrations of particulate matter is the most serious air pollution problem in Pusan. Total suspended particulates (TSP) is particularly difficult to reduce; however, a number of different strategies have been adopted to reduce the problem and these include:

- Substitution of coal and B-C oil by use of cleaner fuels;
- Strengthening regulations against emissions of dust from industry, particularly steel, cement and coal factories, and from construction and demolition sites;
- Increasing use of street sweeping equipment including vacuum sweeping systems;
- Installation of stack monitoring instruments in primary sources of TSP;
- Relocation of those industries producing high concentrations of TSP away from residential areas.

Control of motor vehicle emissions

Motor vehicles represent a major source of pollution in Korea, particularly in major urban centres such as Pusan. Emissions standards for all types of vehicles, both new and in-service, are shown in Tables 18.2 and 18.3 (Murley, 1991). Vehicles undergo inspections at least every two years and are subject to mandatory maintenance orders with the possibility of fines if there are exceedances of emissions limits. Random roadside checks are also conducted by Regional Environmental Offices (REOs) and the number of inspection teams has recently been expanded from 80 to 200.

Diesel-engine vehicles in Korea make up a disproportionately large proportion of road vehicles, when compared with other countries, and represent a major

Table 18.2 Emissions standards for new vehicles

Type of vehicle	Model year	Test procedure	CO	NO_x	HC	PM	Smoke (%)
Small car (P)[a]	1987	CVS-75	8.0	1.5	2.1 (4.0)	–	–
	2000	CVS-75	2.11	0.62	0.25 (2.0)	–	–
Passenger car (P)	1987	CVS-75	2.11	0.62	0.25 (2.0)	–	–
	2000	CVS-75	2.11	0.25	0.16 (2.0)	–	–
Passenger car (D)	1993	CVS-75	2.11	1.25	0.25	0.25	–
	1996	CVS-75	2.11	0.62	0.25	0.12	–
	2000	CVS-75	2.11	0.62	0.25	0.05	–
Light duty (P)	1987	CVS-75	6.21	1.43	0.5 (2.0)	–	–
	2000	CVS-75	2.11 or 6.21[b]	0.62 or 1.43[b]	0.25 (2.0) or 0.5 (2.0)[b]	–	–
Light duty (D)	1993	6Mode	980[c]	750[c] or 350[c],[d]	670[c]	–	40
	1996	CVS-75	6.21	1.43	0.5	0.31	–
	2000	CVS-75	2.11 or 6.21[b]	0.62 or 1.43[b]	0.25 or 0.5[b]	0.05 or 0.16[b]	–
Heavy duty (P)	1991	G-13Mode	33.5[e]	11.4[e]	1.3[e]	–	–
	2000	G-13Mode	33.5[e]	5.5[e]	1.3[e]	–	–
Heavy duty (D)	1993	6Mode	980[c]	750[c] or 350[c],[d]	670[c]	–	40
	1996	D-13Mode	4.9[e]	11.0[e]	1.2[e]	0.9[e]	40
	2000	D-13Mode	4.9[e]	6.0[e]	1.2[e]	0.25[e] or 0.1[e],[f]	25

Units g km^{-1} unless otherwise stated (P) gasoline or LPG engines (D) diesel engine

(a) < 800 cc.

(b) Light duty truck except with a loaded weight of < 1.5 ton or passenger car capable of seating 15 persons or less.

(c) ppm.

(d) Direct injection/indirect injection.

(e) (g kWh^{-1}).

(f) City bus.

Source: Murley, 1991

Table 18.3 Emissions standards for in-service vehicles

Type of vehicle	Month and year of registration	CO (%)	HC (ppm)	Smoke (%)
Gasoline and LPG	1979–June 1984	4.5	–	–
	July 1984–July 1987	4.5	1,200	–
	August 1987–present	4.5 or 1.2 [(a),(b)]	1,200 or 220 [(a)] or 400 [(b)]	–
Diesel	1979–1990	–	–	50
	1991–present	–		40

(a) New model gasoline car.

(b) New model LPG car; CO/HC idling measured by NDIR; smoke-free acceleration opacity measurement.

Source: Murley, 1991

source of emissions of pollutants. Diesel exhaust contains greater emissions of SO_2, TSP and NO_2 than petrol-engine cars with catalytic converters (which have been compulsory on all new vehicles since 1987). A number of different approaches are being used to address this problem, including the development of a low emissions diesel engine, improved after treatment devices such as particle traps, and the use of cleaner fuels such as LPG and gasoline (Ministry of the Environment, 1993b). There are also plans to convert bus fleets in major centres such as Pusan to the use of compressed natural gas (CNG). The ultimate intention of the Korean authorities remains the development of clean cars powered by electricity, hydrogen or a similar fuel; this is likely to be a long-term solution.

Comment

Korea has made enormous improvements in its air quality management capabilities during the past 10 years. The government has a number of different strategies to alleviate air quality problems in urban areas, including Seoul and Pusan, and has created a downward trend in annual mean concentrations. Improving air quality indicates the success of the air quality management approaches adopted. Emissions limits from industrial and mobile sources are being progressively tightened. However, the high projected growth in energy consumption suggests that managing urban air quality will remain problematic. The setting of more stringent emissions limits should help drive this process forward, but there is a need for greater private sector investment in equipment and training to support government initiatives and ensure continued improvements in urban air quality.

Emissions control strategies are wide ranging, address many basic problems, and appear to be effectively enforced. The adoption of local air quality management strategies in areas in which Korean Air Quality Standards are exceeded is a particularly progressive policy. National strategies will never be able to solve every local problem due to the wide range of parameters affecting air quality in a given area, such as the size and nature of emissions, topographical features affecting dispersion, the vicinity of major roads and residential areas and so forth. The introduction of local strategies, such as total emission limits and Environmental Impact Assessments, which include consideration of all sources in the area, enable air quality management to be conducted on a local level and therefore more effectively tackle hot-spots which develop. Knowledge of the spatial distribution of pollutants within Pusan and other urban areas could be enhanced by the use of passive samplers to identify local areas of raised concentration and could be a useful addition to the monitoring programme. Identification of areas which need additional local air quality management strategies is based upon exceedances of Korean air quality standards. The levels set are therefore important in ensuring the measures which are adopted are as cost-effective and appropriate as possible. Korean air quality standards for traffic-derived pollutants are similar to European WHO Guidelines (WHO, 1987). For SO_2 and TSP the Korean values are two to three times those of the WHO. This reflects air pollution realities in Korea and is appropriate to the country's current situation. It must, however, be recognized that since WHO guidelines are based upon the lowest-observed-adverse-effect level with a protection factor, exceedance of Korean TSP and SO_2 standards represents a more serious potential health effect than for other pollutants. Ideally, it should be the intention of the Korean authorities to improve air quality with respect to these pollutants, ultimately leading to the tightening of Korean air quality standards for particulate matter and SO_2.

The absence of detailed emissions inventories for Pusan makes evaluating the scale of emissions from the different sources in the city difficult. When setting emissions limits, it is therefore difficult to ensure an equitable distribution of costs between polluters. An emissions inventory for stationary sources in Pusan would complement that which has been conducted for mobile ones. The results of both of these emissions inventories could then be incorporated, using dispersion modelling software, in order to make better predictions of the effects of proposed emissions.

Summary

- Korea has undergone rapid industrialization and urbanization during the last 30 years which have resulted in significant environmental degradation. Policies are now being implemented to rectify this degradation.
- Pusan experiences concentrations of TSP and SO_2 likely to have health impacts; in general, these concentrations result from the widespread burning of fossil fuels by industry.
- Emissions have been controlled by stringent emissions limits and adoption of cleaner fuels, particularly in areas exceeding Korean air quality standards.
- Concentrations of traffic-derived pollutants are currently at acceptable WHO levels. However, the projected increase in vehicle numbers could produce problems in the future.
- Pusan has a good monitoring programme and some emissions inventory data.
- The projected energy consumption figures for Korea during the next 40 years suggest that with continuing economic growth, emissions from all sources will need to be even more tightly controlled if acceptable air quality is to be maintained.

References

Ministry of the Environment 1991 *Korean Environmental Yearbook*, 1990, Ministry of the Environment, Seoul.

Ministry of the Environment 1992 *National Report of the Republic of Korea to UNCED 1992*, Ministry of the Environment, Seoul.

Ministry of the Environment 1993a *Environmental Protection in Korea*, Ministry of the Environment, Seoul.

Ministry of the Environment 1993b *Environmental News* **1**, Ministry of the Environment, Seoul.

Ministry of the Environment 1994 Questionnaire response: Air quality monitoring and assessment capabilities questionnaire, Ministry of the Environment, Seoul.

Murley, L. (Ed.) 1991 *Clean Air Around the World*, International Union of Air Pollution Prevention Associations, Brighton.

Rhee, D-G. 1990 Environmental Protection in Korea, Workshop on energy efficiency and environmental protection institutions in east and south-east Asia, Seoul.

UN 1992 *World Urbanization Prospects*, United Nations, New York.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

19

Quito

Statistical Summary

Country: Ecuador
Estimated population 1990 (millions): 1.4
Projected population 2000 (millions): 2.1
Map reference: 78°29'N, 00°28'E
Area (km^2): 60

Altitude (m): 2,800
Climate: Mountainous Equatorial
Average Temperature Range (C): 10–28
Annual Mean Precipitation (mm): 1,140

Situational Analysis

Quito is the capital and second largest city in Ecuador. Quito is situated in a narrow valley 44 km long and 7 km wide (at its broadest point) at an altitude of 2,800m; it is surrounded, to the west and south, by mountains as high as 4,794m. The topography and micro-meteorology of the area surrounding the city is therefore extremely complex. The city has an daily mean temperature range from 10 to 28C; the mild temperature owing to the high altitude at which the city is located. There is a rainy season (from December to May) when there are strong downpours during the early afternoon; annual precipitation is approximately 1,600 mm in the south of the city and 800 mm in the north. The hot, dry season runs from June to September, during which the average temperature increases and there are stronger winds. During the rest of the year wind conditions are calm (i.e., <0.5 m/s) and there is a high frequency of temperature inversions; presently there are no accurate measurements of the extent and duration of these inversions.

Rural to urban migration has contributed to a population growth rate in Quito of 2.2 per cent (INEC, 1990); 48 per cent of the population of Ecuador now live in either Guayaquil or Quito. Urban environmental degradation is a growing problem within these major cities.

Industries in Quito include the manufacture of food, drinks, tobacco and textiles; metal industries include iron, steel and non-ferrous metals and manufacture of machinery. The province of Pichincha, in which Quito is located, produces 34 per cent of the total national industrial product (Suarez Torres et al., 1992). Industry is predominantly located in the south of the city (Figure 19.1), with some industrial activities in the north. Most urban pollution has been caused by the construction industry and, more recently, by motor vehicles; the number of which is increasing. There are approximately 120,000 vehicles registered in the city; 51 per cent of them are over 10 years old and 83 per cent are over 5 years old. There has been a significant increase in vehicle numbers and kilometres driven; emissions per vehicle are high owing to inadequate maintenance. Problems are particularly acute in the city centre where narrow streets and poor wind dispersion facilitate the accumulation of air pollutants. All vehicles are imported and are designed to use a higher octane petrol (see Table 19.2) than that produced by the refineries in Ecuador. A high concentration of lead is added to domestically refined petrol to increase its octane number; unleaded petrol is not generally available. Maximum lead (Pb) concentrations in petrol are shown in Table 19.1.

Concern over lead levels has resulted in a number of studies being conducted to determine the extent of the problem. Monitoring at 32 locations throughout Quito over a five-month period showed that the average lead concentration in ambient air was 0.67 $\mu g\ m^{-3}$, with a range of 0.05–7.6 $\mu g\ m^{-3}$ (IEOS, 1992). Ninety-two per cent of the sampling sites found concentrations which complied with the national air standard of

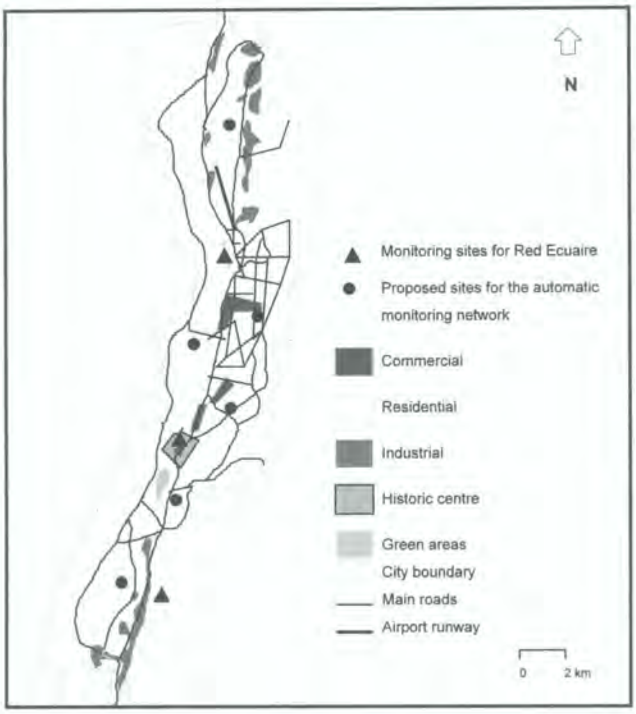


Figure 19.1 Sketch map of Quito

Source: DCCA/ACCA, 1993

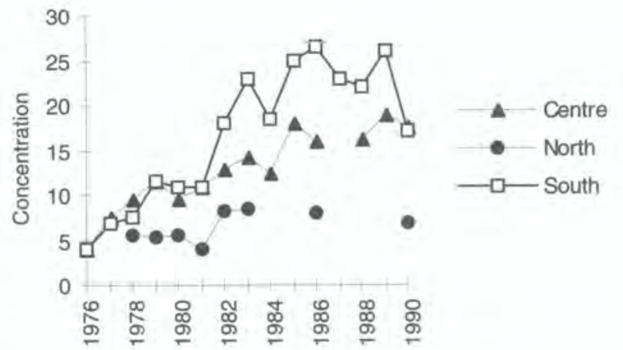


Figure 19.2 SO_2 annual mean trends, 1976–1990 ($\mu g\ m^{-3}$)

Source: Vasquez and Polo Yepez, 1992

1.5 $\mu g\ m^{-3}$. Higher concentrations were measured near main roads and especially at sites located near the entrance of road tunnels. Overall, ambient concentrations of lead, with the exception of heavily exposed sites, do not appear to represent a serious problem at present. However, research on blood lead levels shows generally elevated concentrations. Blood lead levels have been measured in newborn babies, seven-year old children, pregnant women and street sellers who lived or work in either the historic city centre or in the outskirts of the city (Suarez Torres et al., 1992). Mean Pb levels in blood for these groups varied from 14 to nearly 29 $\mu g\ dl^{-1}$, the highest concentrations being found in children and street sellers. All groups were exposed to levels above the guideline of 10 $\mu g\ dl^{-1}$ proposed by WHO (WHO, 1987).

Dustfall, total suspended particulates (TSP) and sulphur dioxide (SO_2) have been monitored in Quito since 1976 (see Figures 19.2 and 19.3). Dustfall concentrations were high (4–6 mg cm^{-2} per 30 days) during 1984/85 which coincided with an increase in construction

Table 19.1 Estimated total gasoline market in Ecuador (1989)

Petrol	Octane number	gPb l^{-1}	Consumption (tonnes per annum)
Super	92	0.40 maximum	7.4
Extra	80	0.84 maximum	92.6

Source: Octel, 1989

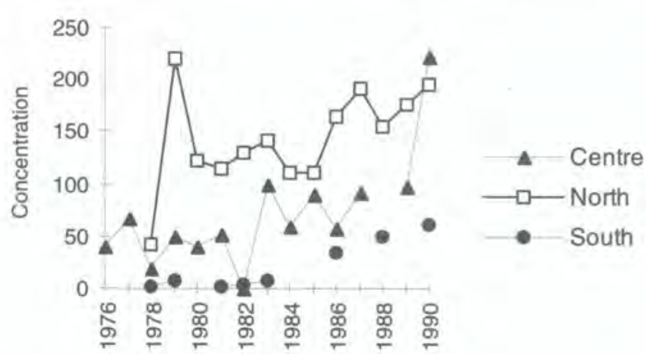


Figure 19.3 TSP annual mean trends, 1976–1990 ($\mu g\ m^{-3}$)

Source: Vasquez and Polo Yepez, 1992

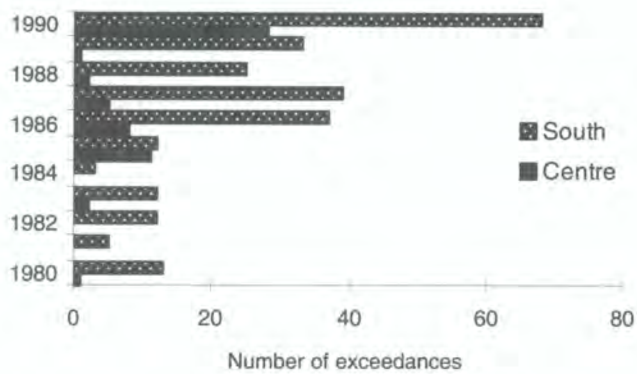


Figure 19.4 Number of exceedances of daily standard of TSP at two locations in Quito (1980–1990)

Source: Vasquez and Pelo Yepez, 1992

activities and road paving. In recent years dustfall concentrations have declined to below 1 mg cm^{-2} per 30 days. Total suspended particulates and SO_2 concentrations have steadily increased since 1976, especially at the sites located in the city centre and south of the city. TSP concentrations currently exceed the national standard at some of the sampling stations. In 1990, the 24-hour maximum TSP standard (185 µg m^{-3}) was exceeded 28 and 68 times at the city centre and south sampling stations respectively (Figure 19.4). Exceedance at the north location only occurred once in this year. The maximum 24-hour standard of 295 µg m^{-3} for SO_2 has never been exceeded (Vasquez and Polo Yepez, 1992).

Monitoring Networks

Red Ecuaire

The Pan-American Health Organization (WHO/PAHO) set up a monitoring network in the early 1970s, the Red Pan-American de Muestreo Normalizado de la Contaminacion del Aire, to obtain data on air quality from various Latin American cities. Ecuador is included in this network under the name of Red Ecuaire. Data are assessed to determine trends and compliance with national air quality standards. The Red Ecuaire has sampling sites in four cities: Quito, Guayaquil, Cuenca and Ambato. Measurements are taken for three variables at all locations: dustfall, TSP and SO_2. No measurements have been taken for carbon monoxide (CO), nitrogen dioxide (NO_2) or ozone (O_3).

The Instituto Ecuatoriano de Obras Publicas (IEOS) operates the network in Quito through the Direccion Nacional del Medio Ambiente. They have three urban sampling stations situated in the south, centre and north of the city which have been operational since 1976 (Figure 19.1). The city centre station is representative of a kerbside location whilst the north and south stations are situated in predominantly urban/residential areas. All sampling stations are located on the roof of a public health building; the sampling systems are located inside the building with the sampling probe extending through the wall. The inlet to the probe extends approximately 2 m from the wall and 10 m above ground level (Mitchell and Childers, 1994). Measurements are taken during the last 10 days of each month. Dustfall is collected passively and measured gravimetrically. Total suspended particulates are collected using active low-volume samplers and the mass of the particles on the filter are measured using a reflectance technique and a conversion chart. Sulphur dioxide samples are collected using bubblers and concentrations are then determined by titration using sodium tetraborate solution. The procedures followed to measure dustfall, TSP and SO_2 are as specified by the WHO 1976 guidelines (WHO, 1976).

No information is available on the quality assurance/quality control procedures followed. No inter comparison studies have been conducted so far by IEOS. Once the data have been processed, they are stored in a data base. Information is not published, although extensive tabulation and review of the data are conducted and presented in internal bulletins and are available on request.

Lead monitoring at various locations in Quito (1991)

Lead is not monitored routinely as part of the Red Ecuaire network, although monitoring has been conducted for short periods and some data are currently available. The Instituto Ecuatoriano de Obras Publicas and the Central University of Ecuador have carried out a one year city-wide project in order to determine the levels of ambient Pb in the atmosphere of Quito and an internal report has been produced (CIEOS/UCE, 1992). Samples were taken over a period of five consecutive months (May–October, 1991) and covered 32 monitoring stations. From each site 24-hour samples were taken, collecting between 7 and 15 m^3 of air. A total of 10 samples were taken from each station to ensure data were representative of the sample location. Samplers were calibrated and a quality control/quality assurance procedure was followed. Samples were analysed using Atomic Absorption Spectrophotometry (AAS). Data capture was 89 per cent.

Another short-term study was also conducted to collect samples near main roads and tunnels over 180-minute periods to determine variations in Pb concentrations throughout the day. A total of 40 samples were collected near tunnels and 40 in other sectors of Quito (Suarez Torres et al., 1992). Samples were analysed using AAS.

Automatic Air Quality Monitoring Network

An automatic monitoring network is currently proposed for Quito with the intention to begin operating in 1995. This is to be run by the Department of Environmental Quality Control, of the Health and Environment Division (Departamento de Control de la Calidad Ambiental, Direccion de Higiene Medio Ambiente). Objectives for this network include: the expansion of the air quality monitoring network in the city to include a larger number of pollutants; the determination of air pollution trends; evaluation of the effects of new strategies to control air pollution; and, determination of compliance with air quality standards. It is intended that data will be used in future urban development planning to determine the most appropriate locations for urban and industrial developments. Mathematical models will be used to determine: the air pollution profile of the city; the possible distribution and concentrations from new pollution sources; and, the most appropriate long-term actions needed to ameliorate problem caused by new air pollution sources. There are eight proposed monitoring stations; six situated in urban locations (shown in Figure 19.1) and two in rural areas west of the city (the rural sites are beyond the range in the map and are, therefore, not shown). Dustfall, TSP, particulate matter less than 10 µm (PM_{10}), Pb, SO_2, NO_2, CO, O_3 and possibly hydrocarbons (HCs) will be measured. Particulate matter will be measured at all sites using manual monitors and Pb concentrations will be determined using AAS. Gaseous compounds will be measured using a continuous (on-line) system. Four automatic meteorological stations will also be set up. Three of these will be installed at urban monitoring stations and one in a rural location to measure wind speed and direction, relative humidity, temperature, precipitation and solar radiation. The monitoring frequency and number of sampling sites are summarized in Table 19.2.

Table 19.2 Number of proposed monitoring sites and sampling frequency for compounds measured by the automatic monitoring network

Compound	Sampling Frequency	No. sites
Dustfall	30 days	8
TSP/PM_{10}	24 hours every 3 days	8
SO_2	24 hours every 3 days	5
NO_2	24 hours every 3 days	6
CO	daily, 8 hours	5
O_3	daily, 6–18 hours	3
Pb	3 months	8

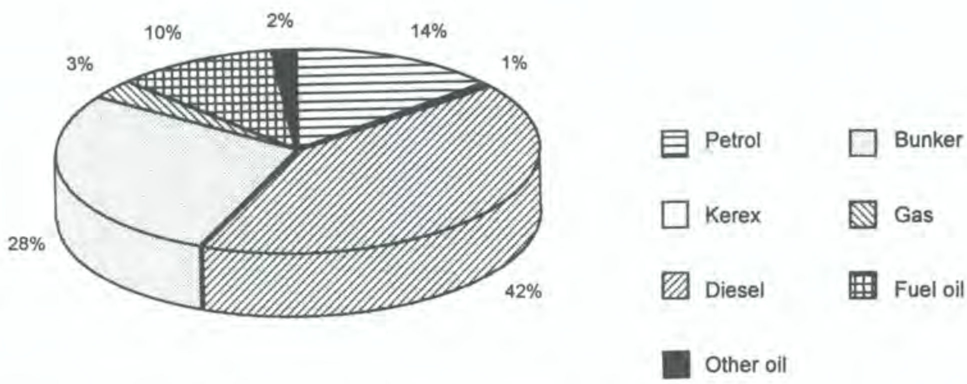
Source: DCCA/ACCA, 1993

Emissions Inventories

Fuel consumption by industry and vehicles has been estimated for the whole of Ecuador and for individual provinces, including the province of Pichincha where Quito is located. This province uses over 24 per cent of the total energy consumed by industry in Ecuador, a figure exceeded only by the province of Guayas (where Guayaquil is located) which consumes a total of 35 per cent (Suarez Torres et al., 1992). In 1988 an estimated 183 million gallons of fuel - diesel, bunker and petrol - were consumed in Quito by industry; accounting for 84 per cent of total consumption in the province (Figure 19.5). The food and textile industries account for 72 per cent of the total fuel consumed by industry in Pichincha (Figure 19.6).

In 1990 there were 326,333 vehicles in Ecuador, 34 per cent of which (i.e., 128,691) were registered in Pichincha. Most vehicles are private passenger cars (40 per cent) or lorries (52 per cent). No information is available on motorbike numbers. Public transport only accounted for 8 per cent of the total registered vehicles in 1990 (INEC, 1993). A total of 95.37 million gallons of petrol were consumed by vehicles in Ecuador in 1988 (Suarez Torres et al., 1992); 92.6 per cent of which had a low octane value of 80 (Octel, 1989) (Table 19.1).

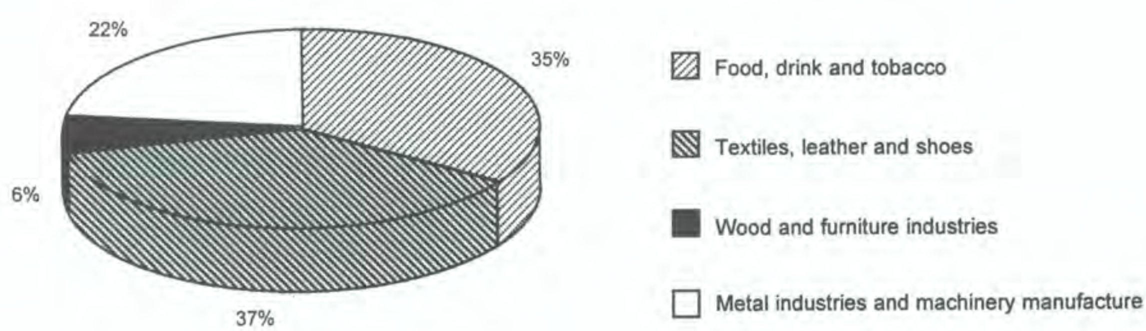
Emissions inventories have not been carried out on a regular basis, although basic estimates were made for the city of Quito, in 1989, to determine emission levels from industry and vehicles. Estimates were based on questionnaires sent to industries, as well as available data on fuel consumption by stationary and mobile sources. Domestic emission sources were not included in the inventory. In Quito domestic emissions sources are unlikely to have a significant effect on the quality of ambient air. This is because gas is the main fuel used for cooking and because heating is for the most part unnecessary; owing to the mild climate.



Data based on 474 industries (74 per cent of the total industries in the province).

Figure 19.5 Percentage use of different fuels by industry in the province of Pichincha (1988)

Source: Suarez Torres et al., 1992



Total energy consumed: 183 million gallons per year.

Figure 19.6 Percentage energy used by industrial sources in Quito (1988)

Source: Suarez Torres et al., 1992

Table 19.3 Estimated emissions for Quito for 1989 (tonnes per annum)

Compound	Annual emissions (tonnes)
TSP	8,008
SO_2	11,086
NO_x	6,058
HCs	6,916
CO	105,523
Pb	89

Source: DCCA/ACCA, 1993

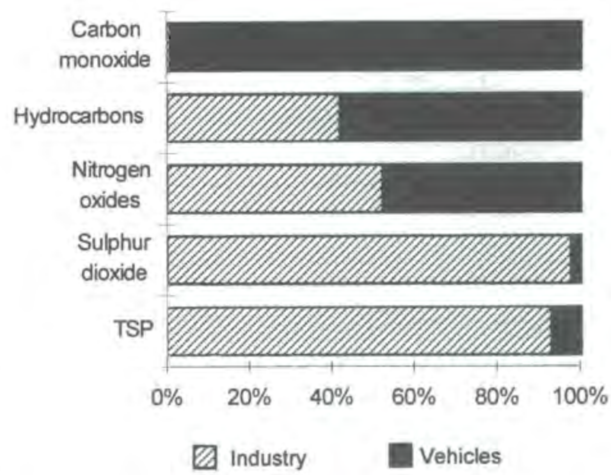


Figure 19.7 Contribution of industry and vehicles towards total emissions in Quito (1989)

Source: Puga, 1993

The inventory was based on the 500 industries and 119,210 vehicles officially registered in Quito. Data are summarized in Table 19.3. A total of 140,000 tonnes of pollutants were emitted in 1989 (DCCA/ACCA, 1993). Sulphur dioxide emissions come almost exclusively from industrial sources, owing to the high sulphur content of fuels used, especially Bunker, (Figure 19.7). Industry also contributes most of the TSP emitted in Quito (92 per cent) whilst vehicles account for 58 and 99 per cent of total HCs and CO emitted respectively (Figure 19.7). Seventy-four per cent of all industrial emissions are produced in the southern area of Quito where most industrial enterprises are located (Figure 19.8).

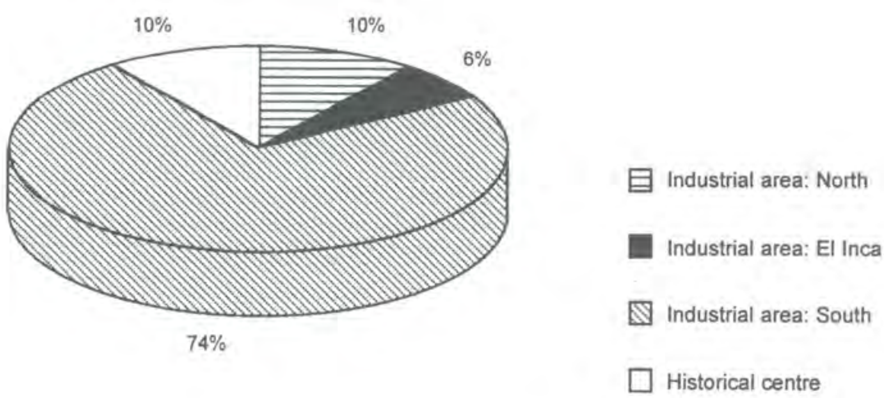


Figure 19.8 Estimated industrial emissions from different areas in Quito (1989)

Based on data from 90 industries and 119,210 vehicles.

Air Quality Management

Air quality standards have been set by national government and are aimed at preventing and controlling the contamination produced by industrial liquid discharges and atmospheric emissions under the Reglamento de Aplicacion de la Ordenanza Municipal No. 2910, 1992 (Consejo Municipal de Quito, 1992). Local authorities can also set standards to take into account local conditions, such as high altitude. The severity and frequency of adverse health effects, the damage to wildlife, the population exposed and environmental degradation were taken into account when setting these standards (UNAMA, 1994). If ambient air concentrations are exceeded in Quito's city centre, the local authority can impose vehicle restrictions in the affected areas. Air quality standards for various compounds are summarized in Table 19.4. Standards for TSP (as an annual mean concentration), CO, O_3, and Pb are within the guideline range given by WHO (WHO, 1987). The standard for NO_2 is only reported as an annual average concentration, this being similar to the US and Brazilian standards for this compound. The national standards for TSP (24-hour averaging time only) and SO_2 are, however, less strict than the WHO guidelines for Europe: 150–230 µg m^{-3} for TSP and 40–60 µg m^{-3} and 100–150 µg m^{-3} for an annual mean and 24-hour maximum exposure to SO_2 respectively (WHO, 1987). Quito, however, has a stricter standard than the national standard in order to account for the high altitude of the city.

Emission limits exist for stationary sources, with the exception of domestic sources. These are law and are subject to enforcement. If levels are exceeded above 100 per cent of the maximum permissible value measured over two consecutive months, a fine can be imposed on the polluting company (UNAMA, 1994); exceedances can also lead to closure until corrective measurements are taken to reduce emissions. (Ordenanza No. 2920, 1992). However, industrial exceedances are not routinely measured.

Table 19.4 Air quality standards applicable to Ecuador (and Quito) (values in µg m^{-3}, unless otherwise specified)

	Short-term averaging time				Long-term averaging time		
Compound	1 hour	3 hours	8 hours	24 hours[a]	30 days	3 months	Annual mean
TSP	–	–	–	250 **(185)**	–	–	80 **(58)**
Deposition[b]	–	–	–	–	1	–	–
SO_2	–	1,500		400 **(295)**	–	–	80 **(58)**
CO[c]	40	–	10 **(7.3)**	–	–	–	–
O_3[a]	200	–	–	–	–	–	–
NO_2	–	–	–	–	–	–	100 **(73)**
Pb	–	–	–	–	–	1.5	–

(a) Values not to be exceeded more than once a year.

(b) mg cm^{-2} per 30 days.

(c) mg m^{-3}.

Numbers in bold refer to local air quality standards applicable to Quito.

Sources: Suarez Torres et al., 1992; UNAMA, 1994

Comment

Some, albeit limited, air quality monitoring has been carried out in Quito; available data provides useful information regarding pollution trends and distribution for dustfall, TSP and SO_2. No monitoring has been carried out for oxides of nitrogen (NO_x), CO, O_3 or HCs; it is, therefore, difficult to estimate the extent of the problem caused by these pollutants. The proposed automatic air quality monitoring network will greatly enhance measurement capabilities. However, the proposed sampling frequency (see Table 19.2) may produce less reliable results than if the automated instruments were used continuously. Prior to establishing the network, detailed quality assurance and control protocols will have to be produced, as will manuals for site operators who will be unfamiliar with the new instrumentation. Service agreements and so forth will also need to be established with the equipment manufacturers in order to ensure that when instruments cease operating properly they can be promptly and properly repaired. Once operational the data should also be subject to validation, and sites should be audited at regular intervals. Operating a continuous monitoring network, such as that proposed, can cause considerable difficulties – particularly for inexperienced staff. The data which can be obtained, together with the proposed analysis, will, however, provide capabilities to ensure that the decision makers charged with managing air quality are provided with the best available information.

Available monitoring data indicate that the most serious air quality problems in Quito are associated with TSP; particularly in the industrial south of the city. Exceedance of the daily air quality standards occur frequently and the existing emissions inventory shows over 90 percent of TSP emissions are attributable to industrial sources. Diesel and Bunker fuels account for 70 per cent of industrial fuel use and both produce relatively high amounts of particulate matter and TSP when burnt. Gas, a relatively clean fuel, accounts for only 3 per cent of industrial fuel use. If the number of exceedances of TSP standards are to be reduced there will clearly need to be either considerable expenditure upon emission control technologies by industrial plant, or a change in fuel use towards cleaner sources of energy. Diesel and bunker also contain relatively high amounts of sulphur and if consumption of these fuels continue to increase, concentrations of SO_2 – currently at acceptable levels – will rise. The emissions inventory has produced very useful information but will need to be updated and expanded to improve the confidence with which the results obtained can be treated. An accurate emissions inventory will be particularly important to incorporate into the proposed air-shed models to link with the proposed new monitoring network.

Although ambient lead monitoring indicates that at most locations in the city concentrations are acceptable by WHO guidelines, mean blood lead levels of 25–28 $\mu g\ dl^{-1}$ in certain street sellers and children will give cause for concern. Continuing research may be warranted to monitor the trend in blood lead levels and, if a rising trend is detected, attention should be given to reducing the currently very high lead content of petrol. Research would also be useful to identify and quantify other important sources of lead exposure such as water or paint.

Quito is unfortunate that its topography and meteorology are particularly conducive to the production of photochemical smogs and temperature inversions. The development of the new monitoring network to expand the range of pollutants and extensiveness of measurements made is an important milestone in the development of the city's air management capabilities. The proposed modelling, and the intention to use the information generated to assist decision makers in planning future industrial and urban developments should be invaluable. Experience and time will, of course, be required before new models made more appropriate to local conditions; they will need to be tuned appropriately to provide the best data outputs. The next step will be to ensure that recommendations made to control emissions are enforced. Resources will also have to be made available to monitor stationary emissions and controls upon mobile sources of pollution are also likely to be required in the future. The proposed plans for Quito could provide the best information currently available for air quality management.

Summary

- Dustfall, TSP and SO_2 concentrations have been monitored since 1976 at three urban locations in Quito.

- Annual mean TSP concentrations are above the national air quality standard at two of the sampling stations in the city. The maximum 24-hour concentrations for this compound was exceeded by 28 and 68 times in 1990 at these two stations. Blood lead concentrations are also elevated, although ambient concentrations are generally acceptable.
- Emissions from industrial and mobile sources of pollution were estimated for 1989, although some uncertainty exists over the accuracy of these figures. Vehicle emissions are believed to be the main air pollution source in Quito, accounting for an estimated 82 per cent of total emissions.
- An automatic monitoring network is currently being established to monitor for TSP, PM_{10}, SO_2, NO_2, O_3, CO, Pb and hydrocarbons at six urban and two rural sites. It is proposed to incorporate this with modelling capacity which would provide excellent air quality management capabilities.

References

CIEOS/UCE 1992 Proyecto medicion de niveles de plomo en el aire de la ciudad de Quito, Informe final, Convenio Instituto Ecuatoriano de Obras Sanitarias/Universidad Central del Ecuador, Quito.

DCCA/ACCA 1993 Propuesta para un programa de vigilancia de la calidad del aire en Quito, Direccion de Higiene y Medio Ambiente, Departamento de Control de la Calidad Ambiental, Area: Control Contaminacion Atmoferica, Quito.

IEOS 1992 *Analisis de la situacion actual de la contaminacion del aire en la ciudad de Quito*, Informe technico numero 123-dia-92, Instituto Ecuatoriano de Obras Sanitarias, Quito.

INEC 1993 *Serie estadistica 1986–1990*, Instituto nacional de estadistica y censos, Quito.

Mitchell, W. and Childers, L. O. 1994 Preliminary assessment of the status of air pollution measurement and data use in São Paulo, Brazil, Santiago and Ecuador, Assignment Report for WHO/UNEP, February 1–12, 1994.

Octel 1989 *Worldwide Survey Motor Gasoline Quality 1989*, the Associated Octel Company Limited, South Wirral.

Consejo Municipal de Quito 1992 Ordenanza No. 2910, Ordenanza para la prevencion y control de la contaminacion producida por las descargas liquidas industriales y las emisiones hacia la atmosfera, Consejo Municipal de Quito, Quito.

Puga, E. 1993 Presentation given on: An air quality monitoring case study, during the First Seminar/Workshop on the monitoring and evaluation of water and air quality, Quito – Ecuador, 22–25 November 1993.

Suarez Torres, J., Oviedo Carrillo, J., Alban Gomez, J., Reascos Vallejo., N., Barreto Vaquero., R. and Gordillo Tobar, A. 1992 Medio Ambiente y Salud en el Ecuador, Fundacion Natura, Quito.

UNAMA 1994 Response to questionnaire: Air quality standards questionnaire, Unidad Asesora de Medio Ambiente, Quito.

Vasquez, V. and Polo Yepez, D. 1992 *Analisis de la situacion actual de la contaminacion del aire en la ciudad de Quito*, Infome tecnico No. 123-DIA-92, Instituto Ecuatoriano de Obras Sanitarias, Quito.

WHO 1976 *Selected Methods of Measuring Air Pollutants*, Publication No. 24, World Health Organization, Geneva.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

20

Santiago

Statistical Summary

Country: Chile
Estimated population 1990 (millions): 4.87
Projected population 2000 (millions): 5.75
Map reference: 33°20'S, 71°0'E
Area (km²): 135
Altitude (m): 519
Climate: Mediterranean
Average temperature range (C): 5–16
Annual mean precipitation (mm): 363

Situational Analysis

Santiago is the capital, most industrial and populous city in Chile; accounting for 40 per cent of the national population and industry and about half of all registered vehicles. The city is located at an altitude of over 500 m in the Mapocho Valley which is 120 km long by 60 km wide. To the east of the valley are the Andes Mountains, rising to an altitude of 7000 m; to the west are the Coastal Cordillera Range which are 2000 m high; and to the north and south of the city are the Cerros Hills. As a consequence, Santiago experiences very poor dispersion of air pollution and persistent temperature inversions (with gradients as severe as 20C). These conditions cause air to be trapped in the valley for long periods, particularly during the winter months between April and September. Topographic and meteorological conditions make Santiago particularly susceptible to poor air quality.

Emissions of air pollutants in Santiago are also substantial. One of the principal sources of air pollution in Santiago is the very large number of diesel buses, most with poorly maintained engines, which operate in the city, producing substantial emissions of black smoke. Between 1980 and 1988 the number of buses doubled to 12,000 vehicles. In 1985, road traffic was estimated to be responsible for 71 per cent of ambient concentrations of fine particles. From a health perspective, particulate matter is the most serious pollutant in Santiago; annual mean concentrations of particulate matter less than 10 µm (PM_{10}) vary between about 100 and 140 µg m^{-3} in the city centre, with concentrations lower in residential areas (Figure 20.1). The daily maximum concentration in 1993 in the city centre was 375 µg m^{-3} (Gil, 1994). Figure 20.2 shows that there has been a small decline in PM_{10} and $PM_{2.5}$ levels since monitoring was initiated in 1988, and that there is also a very clear season pattern with monthly concentrations in the winter more than double those in the summer. Recent figures for the summer months of 1995 show average PM_{10} and $PM_{2.5}$ levels

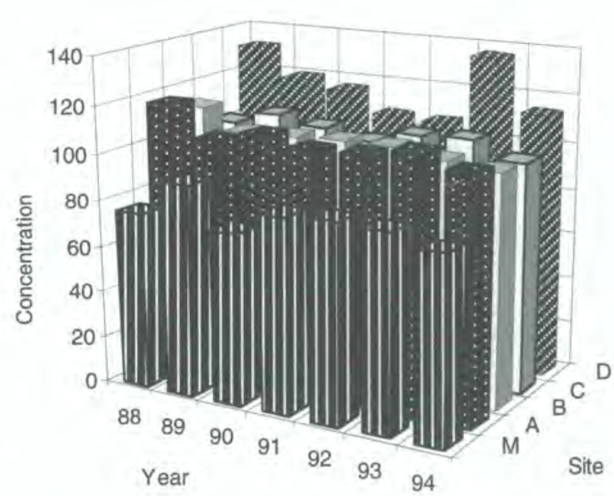
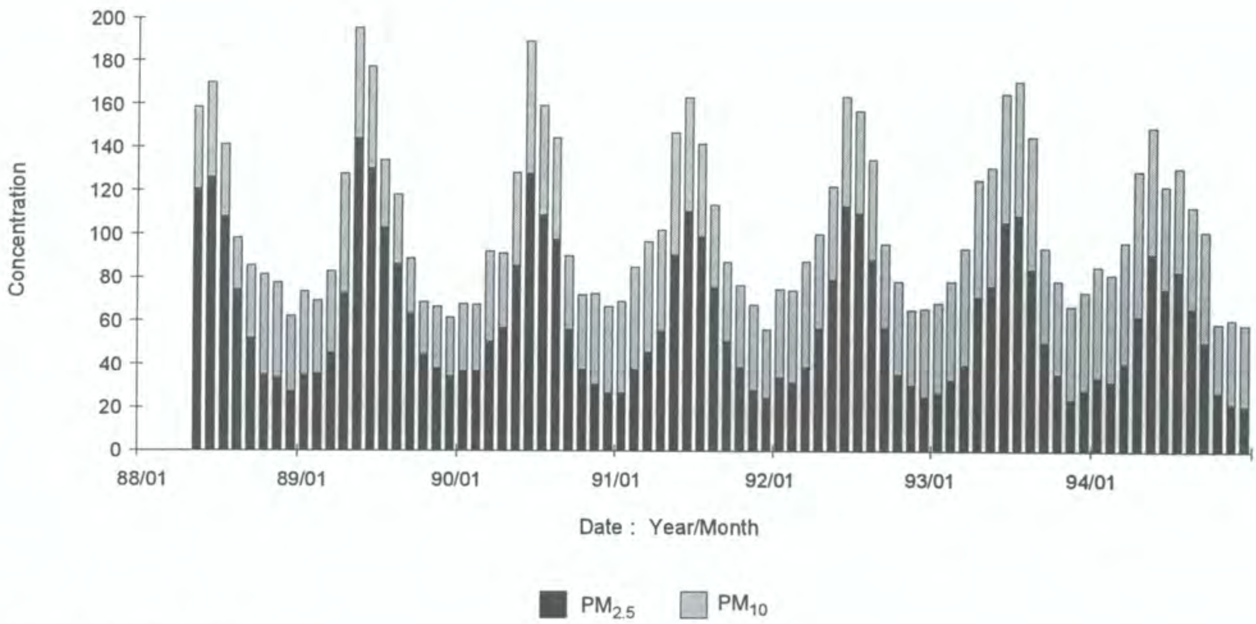


Figure 20.1 PM_{10} trends at five sites in Santiago, 1988–1994 (µg m^{-3})

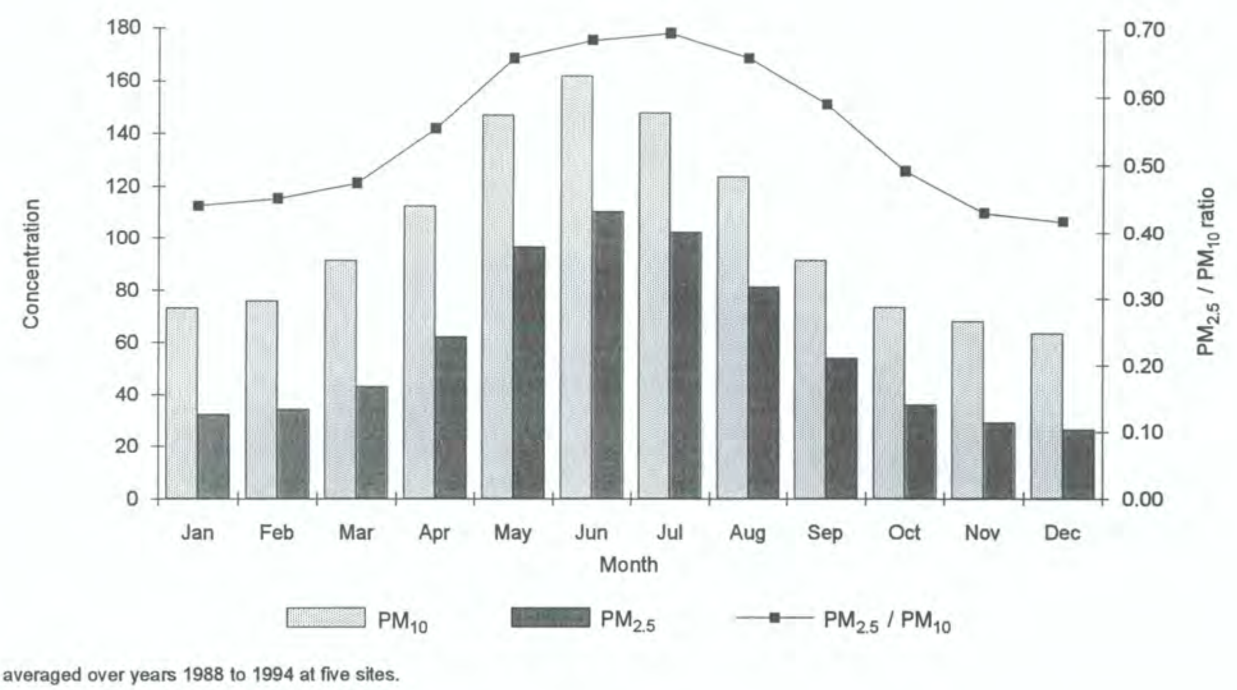
Source: Olaeta, 1995



Data averaged over five sites.

Figure 20.2 Monthly mean PM_{10} and $PM_{2.5}$ concentrations, 1988–1994 (µg m^{-3})

Source: Olaeta, 1995



Data averaged over years 1988 to 1994 at five sites.

Figure 20.3 Monthly variation in PM_{10} and $PM_{2.5}$ (µg m^{-3})

Source: Olaeta, 1995

Table 20.1 Air quality in Santiago, 1993 (μg m^{-3})

	Residential area	City centre	Industrial area	WHO Guideline
NO_2	83 (341)	84 (215)	121 (451)	(150)
SO_2	30 (189)	28 (129)	53 (166)	50 (125)
PM_{10}	114 (311)	119 (375)	–	(70)
CO	25.2(1),(2)	55.7(1),(2)	–	25.7(1)
O_3	330(1),(3)	270(1),(3)	–	150–200(1)

Annual mean values (24-hour maximum in parenthesis).

(1) Hourly value.

(2) Converted from ppm using factor 1.165.

(3) Converted from ppb using factor 2.000.

Source: Gil, 1993

of 69 and 27 μg m^{-3} respectively, with winter months in 1996 averaging 133 and 76 μg m^{-3} respectively (Olaeta, 1996). Closer examination of this seasonal variation (Figure 20.3) demonstrates that the proportion of $PM_{2.5}$ in the PM_{10} fraction also increases significantly during winter, following the same pattern as the level of absolute concentration. This seasonal variation is explained by the increase in space heating during winter; and, the fact that there is a reduction in resuspended dust due to increased rainfall during the winter months. In winter, therefore, the proportion of particulate matter which can be inhaled deeply into the lungs increases to about 70 per cent of the total PM_{10}; as a consequence, adverse health effects are likely to be most acute during this time.

Table 20.1 shows the concentrations of some other pollutants measured in Santiago and indicates that many monitored pollutants in Santiago exist at concentrations in excess of WHO Guidelines (WHO, 1987). Particularly extreme ozone episodes are shown to occur.

The effects of air pollution upon the health of Santiago residents is well documented. The results of an epidemiological study by Sandoval (Hinner and Knoke, undated) examined the relative risk of living in Santiago with that of Los Andes a town 70 km to the north. The results, shown in Table 20.2, indicate a significantly increased risk of developing acute or chronic respiratory and pulmonary disease among Santiago residents relative to those living in Los Andes. This higher risk was found to be very closely associated with the concentrations of nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter. Studies on the mutageniety of Santiago air have also been conducted (Adonis and Gil, 1993), which found the mutagenic activity of the samples to be greater than those of many other cities.

Table 20.2 Comparison of relative risk of living in Santiago with Los Andes

Complaint	Relative risk
Lung irritation (all ages)	1.75
Lung irritation (school children)	1.87
Lung irritation (elderly)	4.39
Upper respiratory infection (annual)	1.76
Upper respiratory infection (winter)	2.41
Upper respiratory infection (infants)	2.5
Upper respiratory infection (elderly)	8.95
Pulmonary diseases (all ages)	3.72
Pulmonary diseases (older infants)	5.54
Pulmonary diseases (preliminary children)	4.56

Source: Hinner and Knoke, undated

Monitoring Networks

There are three monitoring networks in Santiago, all operated by the Servio de Salud del Ambiente Region Metropolitana (SESMA): the Macam, Panaire and Moderna networks.

Macam network

The Macam network has been operational since 1987 and consists of five automated monitoring stations: four fixed sites, one of which measures meteorological parameters, and a mobile site. Sites are located in the city centre/commercial district and residential areas (listed in Table 20.3). Continuous measurements are made for a wide range of pollutants (shown in Table 20.4). The sampling inlets for gaseous pollutants are located 6 m above the ground; those for particulate monitoring are located 1.5 m above the roof of the shelter; and, the meteorological instruments are located on 15 m towers. No studies have been conducted to ascertain the representativeness of these sites; they are considered representative and a visual inspection during a 1993 site visit by USEPA staff, for GEMS/AIR, agreed. Conclusive studies are planned. Field operations, site maintenance and instrument calibration are the responsibility of a sub-contractor (INMEL). Stations are visited daily and zero and span checks are performed weekly. Multi-point calibrations are performed at a 90- to 120-day interval, on-site, for carbon monoxide (CO), SO_2, NO_2 and total hydrocarbons (THC); calibrations for ozone (O_3) are conducted at the laboratory. Tapered Oscillating Micro Balance (TEOM), beta-detector and dichotomous particulate monitors/samplers are calibrated using a dry-flow meter. No certified gas mixtures are available in Chile; however, state-of-the-art instruments are used and independent checks have been carried out with the support of the USEPA. The efforts made for ensuring good data quality are substantial.

Data are sent by modem link to the central computer at SESMA as 5-minute averages where they are reviewed daily to identify anomalous values; after verification these values are then stored in a computer data base. Data are used to produce a range of statistics including percentile values, trends, and the spatial distribution of pollutants using the Airviro dispersion modelling software. This software is also linked with population data for Santiago to estimate personal exposure throughout the city. Data are produced daily for the media as 24-hour average values and a qualitative report on the air quality is also regularly provided. Data are also published by the authorities; in addition to the production of internal bulletins and research papers.

Table 20.3 The Macam network

Location	Site nature	CO	NO_2	SO_2	O_3	THC	PM_{10}	$PM_{2.5}$	Met
Moneda/Bombero Salas	City centre	+	+	+	+	+	+	+	+
Providencia/Seminario	City centre	+	+	+	+	+	+	–	+
Avenue La Paz 1003	Urban, residential	+	+	+	+	+	+	–	+
O'Higgins Park	City centre	+	+	+	+	+	+	–	+
Quinta Normal	Urban, residential	–	–	–	–	–	–	–	+(1)
Avenue Las Condes(2)	Urban, residential	+	+	+	+	+(3)	+	–	+

(1) Including global and net radiation and tri-dimensional velocity.

(2) Mobile site.

(3) Including methane.

Source: Mitchell and Childers, 1994

Table 20.4 Monitoring methodologies

Pollutant	Analytical method	Instruments
NO_2	Chemiluminescence	5
SO_2	Fluorescence	5
PM_{10}	TEOM	1
PM_{10}	ß-radiation	1
$PM_{2.5}$	TEOM	1
PM_{10} and $PM_{2.5}$	Dichotomous sampler	5
O_3	Chemiluminescence	3
O_3	Spectrophotometry	2
CO	Continuous – NDIR	5
Total hydrocarbons	FID	5

Sources: *Gil, 1995; Mitchell and Childers, 1994*

At the Moneda/Bombero Salas site an inter-comparison study is being conducted using different particulate monitoring techniques. These include measuring PM_{10} and $PM_{2.5}$ by TEOM and a dichotomous sampler; PM_{10} alone is also measured by beta-radiation detection. The intention of this study is to assist SESMA in deciding which particulate monitoring technique to adopt in the future (Mitchell and Childers).

Panaire network

This network, outlined in Table 20.5, consists of six manual sampling stations and has, in the past, provided data to the GEMS/Air Network. The Panaire network has now been superseded for most purposes by the Macam network and consequently the number of monitoring sites has been reduced to six stations in 1994. The data produced remain extremely useful for deriving trends as the sites have been operational since 1978. SESMA oversees the general operation of the monitoring stations and the interpretation of results, whilst a contractor (SERPROIN) is responsible for the field operation and maintenance of the stations.

Table 20.5 Panaire monitoring network

Location	Site nature
Ministry of Health	City centre
Municipality of Providencia	City centre
Public Health Institute	Urban, residential
Conchali	Urban, residential
Pudahuel	Urban, residential
La Pintana	Urban, residential

Source: Mitchell and Childers, 1994

Monitoring for SO_2, NO_2 and total suspended particulates (TSP) is conducted in accordance with WHO recommendations (WHO, 1976). Sulphur dioxide (SO_2) is measured using the paroarosaniline method using potassium tetrachloromercurate as the trapping agent in the impinger. Samples are collected every fourth day for 24 hours. Nitrogen dioxide (NO_2) is trapped in sodium arsenite and is analysed using the Saltzman procedure; using the same sampling line and protocol as that for SO_2. Flow rates are checked annually using a calibrated flow meter. TSP is measured every fourth day, for 24 hours, using a high volume sampler; sedimented dust is collected monthly in a bucket. All the data produced are validated manually and used for trend determination (Mitchell and Childers, 1994). The data are also submitted to the PAHO Chilean Office and a report containing data from all the sites in the network has recently been produced for the period 1978 to 1991; future reports are also planned. A recent visit was made to several of the sites in the Panaire network and the laboratories by a GEMS/Air review team (Mitchell and Childers, 1994). In general, sites were found to be suitably located; some problems were identified with the sampling procedures which have now been rectified.

Moderna network

The Moderna network has only been operational since 1993 and comprises of two mobile stations provided by the Netherlands to SESMA. The objectives of this network include: the determination of air pollution trends; ensuring compliance with air quality standards; identifying possible point sources of pollution; and, to issue alarm warnings and forecast pollution episodes. The vans are each equipped with meteorological instruments and automatic analysers to measure NO_2 (chemiluminescence), SO_2 (fluorescence), O_3 (spectrophotometer) and CO (NDIR). Measurements are recorded by a data logger and a computer is available on site for downloading data. There are also high volume PM_{10} samplers available to be co-located with the vans, the flow rate of which is logged continuously. Instruments are calibrated in a similar way as those used in the Macam network.

Emissions Inventory

A number of emissions estimates have been derived for Santiago but they have produced conflicting results. See Table 20.6 showing an inventory for PM_{10} estimating the quantity of emissions from different source categories (Ulricksen, 1992; INTEC, 1994). There is considerable debate concerning the proportion of PM_{10} produced through resuspension as a result of vehicle movement; a recent estimate asserted that 74 per cent of PM_{10} originated from resuspension. The meteorology of Santiago (Figure 20.4), however, shows that the months of highest rainfall correspond to those of highest pollution; this is not consistent with the idea that resuspension is the predominant source of PM_{10}. Furthermore, a high proportion of PM_{10} is smaller than $PM_{2.5}$ (Figure 20.3) and studies on the composition of TSP (RomoKroger, 1990) indicate that a high proportion of these particulates are of combustion origin. Another inventory produced in 1988 by CADE-IDEPE estimated total PM_{10} to be 9,450 t a^{-1} – 20 per cent of TSP.

Table 20.6 PM_{10} emissions estimates (metric t a^{-1})

Source	t a^{-1}	Proportion (%)
Point sources	**3,862.0**	**12.5**
Industrial process	607.5	
Industrial boiler	2,746.2	
Commercial and residential boilers	358.2	
Bakeries	150.1	
Mobile sources	**2,698.4**	**8.7**
Cars	411.6	
Taxis	32.1	
Buses	1,860.6	
Trucks	394.1	
Grouped sources (except street dust)	**1,506.7**	**4.9**
Formal (legal) residential firewood	486.1	
Informal (illegal) residential firewood	1,020.6	
Street dust by mobile sources	**22,810.1**	**73.9**
Paved roads	9,634.6	
Unpaved roads	13,175.5	

Sources: Ulriksen,1992; INTEC, 1994

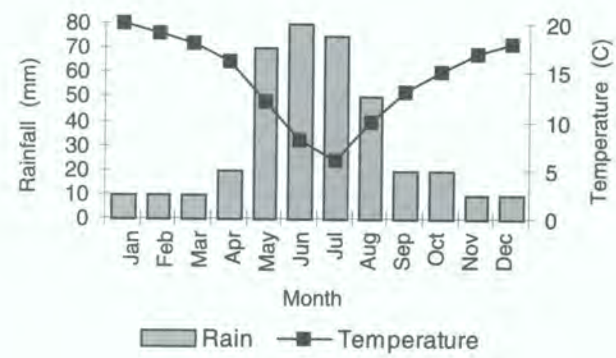


Figure 20.4 Santiago meteorology

Source: The Times Atlas of the World, 1985

Air Quality Management

The Chilean government has introduced a number of policies to alleviate the worst effects of the significant air pollution problems facing Santiago. Principal amongst these is the restructuring of environmental legislation in Chile. New legislation is based upon the Framework Environmental Law, to which secondary Clean Water and Clean Air Acts and a Soil Protection Law will be drafted. The Framework Law is intended to provide the basis for a gradual improvement in environmental quality and avoid conflict between industry, government and pressure groups.

Specific measures already implemented to reduce industrial emissions of air pollutants include the Ministry of Mining Decree 185. Adopted in 1992, this decree seeks to drastically reduce SO_2 emissions, to ensure that air quality meets USEPA standards in the mining interests in the north of the country and the strict Scandinavian standards for the protection of forestry in the south (The Chile Inc. Source Book, 1994). Under this decree Santiago has been declared saturated and, therefore, a targeted clean-up area; it has not been possible for this study to ascertain the measures which have been adopted as a consequence of this decree. An estimated 90 per cent of SO_2 emissions in Chile originate from copper smelting, a process which is also responsible for the high ambient concentrations of heavy metals, such as arsenic. Clean-up plans are apparently in preparation to reduce emissions from this source and they will be introduced in 1996.

Quantification of the sources of emissions of particulate matter in Santiago is still a matter for debate (Olaeta, 1995). However, it is generally agreed that diesel vehicles represent an important source and one which has increased significantly since the deregulation of bus services in the 1980s. Poor engine maintenance and the use of second-hand engine parts has exacerbated the problems created by the doubling of bus numbers between 1980 and 1988. Measures have now been introduced in an attempt to reduce vehicle emissions through vehicle bans; which become progressively more rigorous as air quality worsens (details of the vehicle restrictions are shown in Table 20.7). In addition to restrictions on vehicle use during

Table 20.7 Santiago traffic prohibitions

<table>
<tr><th></th><th>Permanent restrictions</th><th>Emergency Ban 300</th><th>Emergency Ban 500</th></tr>
<tr><td></td><td>Applies 1.4–15.12</td><td>Applies when air quality index exceeds 300</td><td>Applies when air quality index exceeds 500</td></tr>
<tr><td>Private cars</td><td>0700 to 2100 ban daily on 20 per cent of the car fleet based upon registration numbers.</td><td rowspan="2">0700 to 2100 ban daily on 20 per cent of the car fleet based upon registration numbers.

Additional 20 per cent ban in the central area (a specially designated 3 x 2 km zone).</td><td rowspan="3">Restrictions applied as for Emergency Ban 300, but the whole city becomes a restricted zone in place of the central area.</td></tr>
<tr><td>Buses</td><td>0700 to 2100 ban daily on 20 per cent of the car fleet based upon registration numbers.

50 per cent restriction covering the whole city at weekends.</td></tr>
<tr><td>Taxis</td><td>0700 to 2100 ban daily on 20 per cent of the car fleet based upon registration numbers.

50 per cent restriction covering the whole city at weekends.

30 per cent restriction covering an inner core of blocks from 1000 to 1700 on weekdays.</td><td>20 per cent additional restriction in the central area replacing the 30 per cent restriction applied to the inner core.</td></tr>
<tr><td>Parking</td><td>Roadside parking eliminated in the inner core blocks.</td><td>Roadside parking eliminated in the inner core blocks.</td><td>Roadside parking eliminated in the inner core blocks</td></tr>
</table>

Source: Faiz et al.,1992

Table 20.8 Chilean air quality standards

Pollutant	Annual mean	Daily maximum	Hourly maximum	Other
TSP	75	260	–	–
PM_{10}	*50*	*150*	–	–
SO_2	*80*	*365*	1,000	–
NO_2	*100*	300	470	–
CO	–	–	*35*	*9 (8 hours)*
O_3	–	–	160	–

Values in italics correspond to USEPA standards.

Source: Gil, 1994

air pollution episodes, the Emergency Bans 300 and 500[1] also trigger cuts in industrial emissions of 20 and 50 per cent respectively and in the use of polluting domestic fuels (Faiz et al., 1992). These drastic measures have been implemented on several occasions but with unclear success. Chile has also established a number of ambient air quality standards which are very similar to US National Ambient Air Quality Standards. The Chilean air quality standards, which are shown in Table 20.8, are used as reference values with which to compare air quality and long-term objectives.

(Note:[1] Emergency Bans 300 and 500 correspond to levels in the Chilean Pollution Standards Index (PSI); this index is similar to the USEPA PSI scale, except that for PM_{10} the Chilean PSI of 500 represents a level of 330 $\mu g\ m^{-3}$ while the USEPA figure is 600 $\mu g\ m^{-3}$.)

Comment

Overall, Santiago has good, and improving, air quality management capabilities with an excellent monitoring network, an emissions inventory and improving regulatory and administrative structures. The proliferation of highly polluting sources in the city combined with extremely unfavourable meteorological and topographical features continue, however, to result in high concentrations of a number of pollutants. Furthermore, there is still considerable uncertainty concerning the relative importance of different emissions sources in Santiago, particularly for PM_{10}. Accurate quantification of emissions is crucial if the most important sources of pollution are to be targeted for much needed abatement action; verification procedures also require attention.

The authorities in Santiago have clearly made a start in improving air quality through emissions reductions and recently there has been a decline in measured concentrations of PM_{10} and $PM_{2.5}$. The newest data show clearly that levels of particulates (especially $PM_{2.5}$ in winter) continue to decrease, suggesting the effectiveness of air pollution counter measures. However, the level of pollution in the air has been shown to have significant health consequences by a number of excellent epidemiological studies and the current levels of pollution are likely to result in substantial costs to health, productivity and quality of life. Clearly, more rigorous controls upon all significant sources of pollution are required if the improvements seen so far are to continue. The recently announced cooperation programme between Chile and Japan to implement a National Environmental Centre (CENMA) and renew and extend the air pollution monitoring system, together with the introduction from early 1997 of improved data acquisition systems, should also help to improve Santiago's air quality (Olaeta, 1996).

References

Adonis, M. and Gil, L. 1993 Mutageneity of organic extracts from Santiago (Chile) airborne particulate matter, *Mutation Research*, **292**(1), 51–61.

CADE-IDEPE 1988 *Universe of Air Pollution Emission Sources in Metropolitan Region*, CADE-IDEPE, Santiago.

Faiz, A., Weaver, C., Kumares, S., Ward, M and Carbajo, J. 1992 *Air Pollution from Motor Vehicles*, World Bank, New York and Industry and Environment Programme Activity Centre, Paris.

Gil, L. 1994 Personal communication, Faculty of Medicine, University of Chile, Santiago.

Hinner, H. and Knoke, A. Undated Air Pollution in Santiago and its Effects on Human Health, Personal communication, Environmental Protection Section, Bingen Division, Technical College Rheinland-Pfalz, Santiago and Department of Health and the Environment, Hamburg Health Authorities, Hamburg.

INTEC 1994 *Santiago Road Dust*, INTEC, Santiago.Mitchell, W. J. and Childers, L. O. 1994 Assignment report for WHO/UNEP, United States Environmental Protection Agency, Research Triangle Park.

Olaeta, I. 1995 Personal communication, SESMA, Santiago.

Olaeta, I. 1996 Personal communication, SESMA, Santiago.

RomoKroger, C. M. 1990 Elemental analysis of airborne particulate in Chile, *Environmental Pollution*, **68**(1–2), 161–170.

The Times Atlas of the World 1985 The Times Atlas of the World, 7th edition, Times Books, London.

Time 1990 Choking on El Smog, 22 October 1990.

Ulriksen, P. 1993 Developing survey about Air Pollution Emission during 1992, PROCEFF, SECTRA, INTEC, PRIEN, Santiago.

WHO 1976 *Selected Methods of Measuring Air Pollutants*, Publication No. 24, World Health Organization, Geneva.

WHO 1987 *Air Quality Guidelines for Europe,* WHO Regional Publications, European Series No. 23, World Health Organization, Regional Office for Europe, Copenhagen.

21

Singapore

Statistical Summary

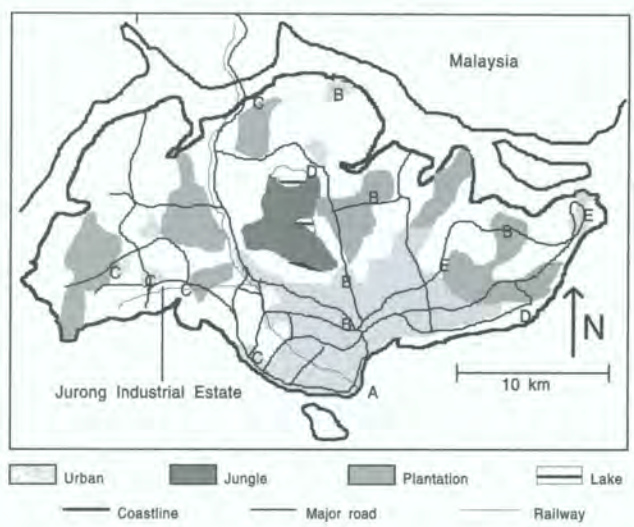
Country: Singapore
Estimated population 1990 (millions): 2.87
Projected population 2000 (millions): 3.08
Map reference: 1°29'N, 103°38'E
Area (km²): 641.4
Altitude (m): 0–162
Climate: Tropical
Average temperature range (C): 26–32
Annual mean precipitation (mm): 2,355.4

Situational Analysis

Located off the southern tip of the Malayan Peninsula, the state of Singapore comprises one major island and some 60 smaller ones; linked to mainland Malaysia by a causeway across the Johor Strait. Singapore has been a major trading centre since the beginning of the nineteenth century and since full independence in the 1960s it has developed into a major industrial and commercial centre. Singapore is the world's busiest port in terms of shipping tonnage, with about 700 ships loading and unloading at any one time. Singapore is also the world's third largest refining centre; its petrochemical industry services much of south-east Asia (Ministry of Information and the Arts, 1993a).

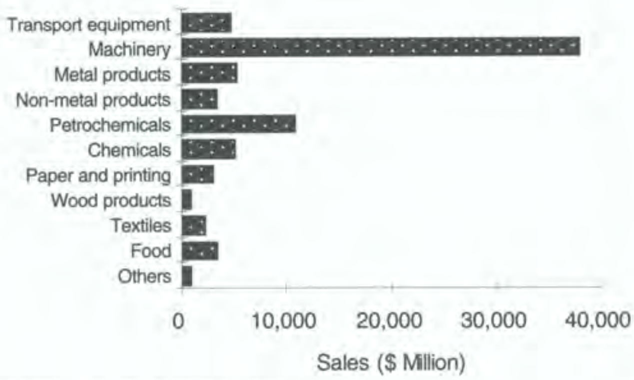
The main island measures 42 km from east to west and 23 km north to south. Of the total land area, 48 per cent is classed as urban, 43 per cent reservoirs, quarries and plantations (predominantly rubber and coconuts), 5 per cent is forested and the remaining 3 per cent is either farmed or marshland and tidal waste (see Figure 21.1). The mean daily temperature is 26.7C and heavy rain occurs throughout the year; it is particularly heavy during the two monsoon seasons when it is common for the relative humidity to exceed 90 per cent. The wind direction varies with the monsoons: from the north or north-east during the north-east monsoon season and from south or south-east during the south-west monsoon season. Topographically the island is dominated by a central igneous hilly centre, much of which has been set aside as a nature reserve, with an undulating western area, and relatively flat alluvial sediments in the east.

Singapore is a large producer of a wide range of manufactured products: chemicals and petrochemicals, machinery and appliances, clothing, textiles and trans-



A Station and Empire Docks.
B Urban monitoring site.
C Industrial monitoring site.
D Rural monitoring site.
E Airport.

Figure 21.1 Sketch map of Singapore



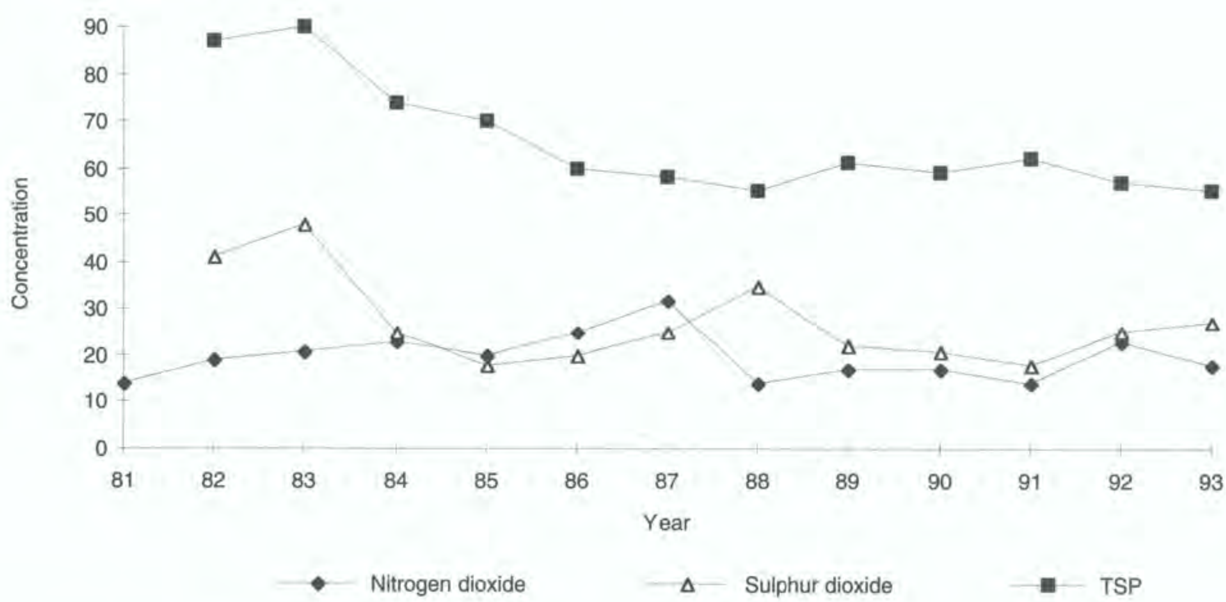
Textiles includes wearing apparel.
Machinery includes appliances and precision equipment.
Non-metal products includes processing rubber and plastic.

Figure 21.2 Manufacturing sales, 1992

Source: Department of Statistics, 1991

port equipment (sales for 1992 of different industries are shown in Figure 21.2). In 1991, 28.2 per cent of the workforce were employed in manufacturing, 22.7 per cent in commerce, 21.1 per cent in community and social-related work (civil servants), 6.5 per cent in construction and about 10 per cent each in transport/communications and business/finance (Department of Statistics, 1991). Industry is sited all over the island, but primarily based in six large industrial complexes the largest of which is near Jurong. The main energy sources used by industry are: electricity, fuel oil and gas. Electricity is supplied by three large generating plants burning fuel oil and gas. Electricity, water and gas (which is manufactured from naphtha at Kallang Gasworks) are the responsibility of the Public Utilities Board.

Parallel with its economic development plans, Singapore has utilized sophisticated environmental protection strategies (detailed in the Air Quality Management Section). As a consequence, air quality has been rated as good or moderate, almost throughout the year, on the US EPA Pollutant Standards Index (PSI). In 1993, air quality was rated as good on 247 days and as moderate on 118 days (Ministry of the Environment, 1993). Trends in some annual mean pollutant concentrations are shown in Figure 21.3.



US EPA Primary Standard: TSP: 75 μg m^{-3}; NO_2: 100 μg m^{-3}; SO_2: 80 μg m^{-3}.

Figure 21.3 Trends in annual mean concentrations for urban NO_2 and industrial TSP and SO_2 (μg m^{-3})

Sources: Department of Statistics, 1991; Ministry of the Environment, 1993

Singapore has controlled the explosion in car ownership which usually accompanies economic development by imposing restrictions on vehicle ownership and use and by employing powerful financial disincentives. These measures have been accompanied by the development of an extensive public transport infrastructure such as the new Mass Rapid Transport system, a fully automated rail network. Details of these measures are included on the section on Air Quality Management. Singapore, therefore, has considerably fewer vehicles per head of population than would be expected from its per capita income statistics and comparison with other countries. This is discussed in greater detail in the Comment section (UNEP, 1993).

Monitoring Networks

Air quality monitoring has been conducted since the 1970s through an island-wide network of stations. The main objectives of the programme are to:

- Assess the nature and magnitude of air pollution problems;
- Monitor trends in the ambient air quality so as to enable the government to make policy decisions to prevent air pollution episodes;
- Assess the effectiveness of the pollution control measures implemented to improve ambient air.

Prior to 1994 a combination of continuous and semi-automatic, active monitoring sites were used; five in urban areas, five in industrial areas and two at rural sites. At these sites a range of pollutants were monitored; including total acidity, smoke, total suspended particulates (TSP), dust fallout, nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and O_3. The monitoring methodologies employed either produced chart outputs which were manually interpreted, or samples requiring subsequent analysis. During 1993, semi-automatic sampling equipment was replaced with a telemetric air quality monitoring and management network. This network comprises 15 continuous monitoring stations linked to a central control station which downloads the resulting air quality data at regular intervals. The sites monitor for SO_2, NO_2, nitrogen monoxide (NO), O_3, carbon monoxide (CO), total hydrocarbons and suspended particulates. The analysers are calibrated using certified gas standards. Some stations are also equipped with wind, temperature and humidity sensors; the data from which enables dispersion modelling to be conducted, using computers, at the central control station. The central control station also has data management and presentation capabilities.

Daily concentrations are reported in the media on the US EPA Pollutant Standards Index (PSI) score. This score classifies air quality as good, moderate, unhealthy, very unhealthy and hazardous; it is based upon the health effects of five pollutants: SO_2, NO_2, particulate matter less than 10 µm (PM_{10}), O_3 and CO. Annual reports are also produced by the government department responsible for the control of air pollution: the Pollution Control Department of the Ministry of the Environment.

Emissions Inventories

The Ministry of the Environment maintains inventories of NO_x, CO_2 , unburnt hydrocarbons and SO_2 (which forms a significant component of Singapore's emissions). In 1993, an action plan was drawn up to limit the total SO_2 emissions to the same level as the 1991 inventory.

Air Quality Management

Philosophy

Since the 1970s, environmental protection strategies in Singapore have accompanied those of economic development. Air quality management is based on the philosophy of emissions standards which employ the "best practical means" (BPM) concept. Air quality is assessed using the USEPA primary air quality standards and the WHO long-term goals given in Table 21.1. The strategy for pollution control is based upon three fundamental components (Ministry of the Environment, 1991b):

- **Planning regulations** to ensure the BPM are adopted, with more stringent emission controls near residences and emissions minimized from factory construction through operation to demolition;

Table 21.1 Ambient air quality standards

Pollutant	Averaging time	US EPA Primary Air Quality Standard	WHO long-term goal
SO_2	Annual mean 24 hours	80 365	– –
Total Acidity	Annual mean	–	60 (98% of observations below this limit)
CO	8 hours 1 hour	9[(a)] 35[(a)]	9 35
NO_2	Annual mean 1 hour[(a)]	100 –	– 0.1–0.17[(a)]
O_3	1 hour 8 hours	12[(b)]	7.5–10[(b)] 5–6[(b)]
Smoke	Annual mean	–	40 (98% of observations below this limit)
TSP	Annual mean 24 hours	75 260	– –
PM_{10}	Annual mean 24 hours	50 150	– –
Lead	3 months	1.5	–

Units $\mu g\ m^{-3}$ unless otherwise stated.

(a) ppm.

(b) pphm.

Source: Ministry of the Environment, 1991a, 1993

- **Emissions controls** on mobile and stationary sources including rigorous inspection and enforcement procedures;
- **Monitoring** to provide information on the nature and magnitude of air pollution problems and the effectiveness of the air quality management strategies implemented.

Stationary sources

Since 1991, responsibility for planning proposals and building plans have been under the centralized control of the Central Building Planning Unit (CBPU) in the Ministry of the Environment. This provides a "one-stop" service for those seeking to develop industrial or trade premises; reducing the number of administrative bodies whose consent must be obtained by investors.

Air pollution control legislation empowering the Ministry of the Environment to limit emissions from trade and industrial premises in Singapore is based on the Clean Air Act of 1971. Sites are categorized as scheduled (with greater polluting potential), or non-scheduled. Scheduled premises are required, before opening, to obtain written consent from the Director of Air Pollution Control; who will in turn require compliance with certain, variable, conditions before giving the necessary authorization. Further consent is required if changes to the production operation are likely to alter emissions. Examples of scheduled premises include factories producing or using cement and concrete, ceramics, chemicals, coke and charcoal, ferrous and non-ferrous metals, petroleum and abrasive blasting.

There have been several subsequential amendments to the Clean Air Act aimed at increasing its effectiveness and/or progressively tightening emissions standards. In 1973, open fires, widely used to dispose of industrial waste, came under the jurisdiction of the act; in 1975, construction sites were classified as industrial and trade premises in order to facilitate the imposition of emissions controls upon these sources. The storage of large quantities of toxic and inflammable substances were controlled in 1980; controls on cleaning by abrasive blasting were further tightened in 1990. The act is constantly under review as new sources of emissions become significant.

Emissions limits are set, and vigorously enforced, according to the nature of the pollutant. In 1995, there were 36,957 inspections of industrial premises and 10,137 inspections of non-industrial premises (domestic, farm premises, etc.). A further 411 source tests of gaseous emissions, fuel analysis and smoke observations were made. There were a total of 73 prosecutions in 1995 under the Clean Air Act (Ministry of the Environment, 1996).

Emissions are controlled, at source, by a combination of air pollution control equipment, fuel quality regulations and fuel burning condition restrictions. New pollution control equipment is being constantly evaluated and introduced; by 1995 over 1,980 pollution abatement installations had been approved (Ministry of the Environment, 1996). Emissions of smoke and SO_2 are controlled by limiting the sulphur content of fuel oil (to less than 2 per cent by weight) and, where undesirable effects are likely to result (such as close to residential areas), the use of cleaner fuels such as electricity, gas and diesel are required. The height of chimneys and the exit velocity of the flue gases are regulated to control dispersion. Industrial boilers generating more than 2,300 kg hr^{-1} of steam are required to fit smoke density meters to ensure continuous compliance with the smoke emissions standard (Ringleman No. 2).

Mobile sources

Singapore has limited emissions from mobile sources using a wide range of strategies. These include: the imposition of technological vehicular developments; changes in fuel composition; controlling the number of vehicles in the country (see Figure 21.4) and the number of vehicles driven during peak periods; and, fiscal measures to encourage the replacement of older, more polluting vehicles with cleaner technologies. These strategies have been combined with the plan-

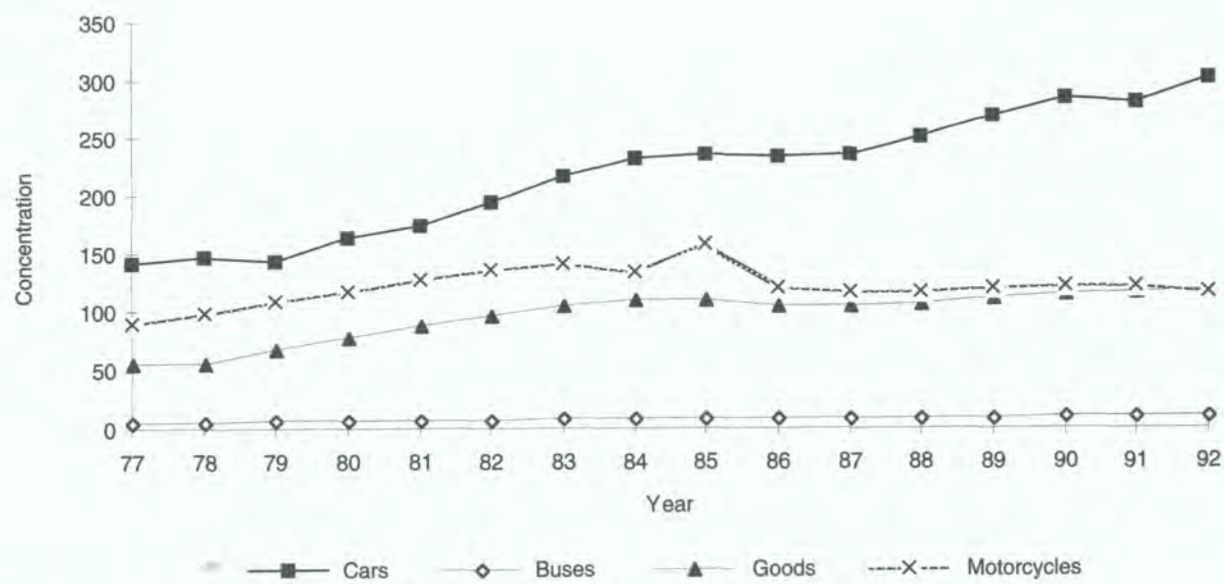


Figure 21.4 Trends in vehicle numbers, 1977 to 1992

Source: Department of Statistics, 1991

ning and development of a transport infrastructure aimed at providing an integrated alternative to the "car culture". Singapore is one of extremely few developed countries with relatively limited public reliance upon motor vehicles; accordingly, it has effectively controlled the emissions of the major pollutants from these sources: CO, oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and O_3.

Road transport has been tightly managed in Singapore since 1974; after the establishment of an inter-ministerial Road Transport Action Committee (RTAC) to co-ordinate transport planning measures and to formulate appropriate transport policies. In particular, the RTAC considered a number of potential approaches to eliminate congestion resulting in the introduction of the Area Licensing Scheme (ALS) in 1975. At the time of the ALS introduction it was estimated that expenditure of US$ 1.5 billion on road infrastructure would be required to alleviate congestion problems until 1992. The costs of implementing the ALS and developing public transport were met out of savings made by eliminating the need for some of this expenditure (OECD, 1988).

The ALS required the purchase of supplementary licenses giving the holder permission to enter a designated restricted zone during the peak morning period. To encourage high car occupancy rates, vehicles containing four persons or more were exempt. To ensure enforcement, road traffic schemes were adopted to prevent vehicles from entering the zone anywhere but at 28 monitored locations and extensive public awareness campaigns were conducted. The introduction of the ALS reduced rush-hour traffic volumes by 45 per cent (Singapore National Government, 1992). Simultaneously, strategies were adopted to maintain the geographical mobility of the workforce through the introduction of park and ride schemes using fringe car parks on the edge of the restricted zone. The park and ride scheme proved to be unpopular with drivers preferring to use buses from the residential suburbs rather than drive to the edge of the restricted zone. The availability and convenience of using buses was enhanced by, for example, the introduction of more bus lanes. In 1991, there were 3,047 buses travelling on 227 routes within Singapore. To protect the commercial viability of the shops within the restricted zone fiscal controls on parking rates were introduced; encouraging short-term parking for shopping and similar activities but penalizing commuters driving to work. The building of the East Coast Parkway, completed in 1981, enabled cross-town traffic to by-pass the restricted zone and has consequently eased the movement of traffic around the ALS zone. In 1989, restrictions within the ALS were tightened to include all vehicles other than public buses. The scheme now operates from 0730 to 1015 hours on Monday to Saturday. Daily or monthly licenses can still be purchased with company car rates being twice those of domestic owners (Ministry of Information and the Arts, 1993b).

New restrictions on vehicle use and additional controls on vehicle ownership continue to be introduced. Singapore has recently adopted an auction-style quota system under which prospective car-owners must bid for a quota-limited Certificate of Entitlement (COE) giving the bearer permission to own a car. Certificates of Entitlement are valid for 10 years and mean that car ownership is no longer a right in Singapore. Auctions are held once a month for a fixed number of vehicles in each of eight categories based upon car engine size, or whether the vehicle is a bus, goods vehicle, motorcycle or weekend car (which can only be used at limited times). Those individuals bidding successfully in the auction pay the Quota Premium (the lowest successfully bid price).

Other fiscal controls are also being imposed to limit car ownership. Import duty is currently paid at 45 per cent of the open market value of the car; there is a registration fee of Singapore $1,000 (Singapore $5,000 for a company car) and an additional registration fee of 150 per cent the face value of the car. Car ownership is also being discouraged by the imposition of high, and increasing road taxes which are set according to engine size. For example, cars with engine capacities below 1,000 cc currently pay 70 cents per cc; engine capacities between 1,001 to 1,600 cc are charged at 90 cents per cc and so forth. Company cars are charged at twice the standard rate; equivalent diesel vehicles pay six times the standard rate, in recognition of their greater pollution potential than that of petrol-driven vehicles fitted with a catalytic converter.

The Weekend Car was introduced in May 1991, to remove some of the severe financial penalties imposed on car ownership for those only wishing to use the vehicle during off-peak periods. These cars are distinguished by a red number plate with white lettering - different from other Singaporean vehicles - and they can only be used between 1900 and 0700 hours on Monday to Friday, after 1500 hours on Saturdays, and all day Sundays and public holidays. There are substantial tax incentives on the Weekend Car; including a 70 per cent reduction in road tax and a Singapore $15,000 tax rebate on car registration. Drivers currently pay Singapore $20 per day for a license to use the vehicle during other periods. In the near future it is proposed to introduce Electronic Road Pricing, a computerized network to charge motorists for peak-hours road usage.

Drivers are also encouraged to scrap cars over 10 years old (which have higher emissions) through the Preferential Additional Registration Fee (PARF) scheme. This scheme imposes penalty road taxes if vehicles are retained beyond 10 years of age and provides financial incentives to encourage the purchase of new vehicles. This policy enables the more rapid introduction of new technologies into the Singaporean vehicle fleet. Consequently, new technology has a faster impact upon total emissions from motor vehicles because the annual turnover of vehicles is increased.

Emissions limits from individual vehicles have been progressively tightened since they were first introduced in the late 1970s. Since July 1994, new petrol vehicles have been required to meet either the European Union's Consolidated Emissions Directive or the Japanese Emissions Standard, both of which require the fitting of three-way catalytic converters. All in-use vehicles are required to undergo a regular inspection to ensure they are roadworthy; exhaust emissions are checked as part of this procedure.

The lead content of petrol has been progressively reduced from 0.6 g l^{-1} in 1981 to 0.15 g l^{-1} in 1987; well below WHO guidelines. Unleaded petrol was introduced in January 1991, accompanied by a price differential of 10 cents per litre and by an extensive public education programme promoting its use. Information on the makes and models of vehicles for which it was suitable was also provided. By the end of 1991, unleaded petrol accounted for 47.5 per cent of petrol sales. This figure rose to more than 66 per cent of petrol sales by the end of 1993 (Ministry of the Environment, 1996). In order to prevent accidental misfuelling, which would poison the catalyst, unleaded petrol pumps in Singapore petrol are fitted with smaller nozzles.

Since January 1991, diesel vehicles are required to meet UN-ECE emission standard *R 24.03* before the vehicles are allowed to be registered for use. In use diesel vehicles are required to pass a smoke emission test of 50 HSU (Hartridge Smoke Units). The PCD works closely with the Land Transport Authority and Traffic Police to ensure these standards are met, including on-the-spot measurements taken by mobile units. With stringent enforcement action, the number of smoky vehicles noted in surveys continues to fall.

Controls on car use and availability have encouraged the use of motorcycles and scooters, which are now also subject to ownership and emissions controls prior to their being registered for use. Since October 1991, all new motorcycles and scooters must meet the United States Code of Federal Regulation *(40 CFR 86.410-80)* which controls hydrocarbon and CO emissions over an urban test cycle.

The rigorous controls on the availability and use of motor vehicles have been offset by improvements in an affordable and efficient public transport system. There are extensive public bus services, and a new US$ 2.9 billion mass rail transit system which was commissioned in 1987. There are currently 42 stations and 67 km of track with new lines and stations being established. 560,000 people now use the service daily; the system is fully automated and uses recyclable plastic tickets. Trains run every three minutes during peak periods, and every six minutes at other times.

Singapore's Green Plan

In 1992, prior to the United Nations Conference on Environment and Development (UNCED), the Singaporean Government prepared a Green Plan (Ministry of the Environment, 1992) outlining the Government's environmental strategies, targets and long-term objectives. The plan included a number of statements of intent; those concerning air quality are listed below:-

- All monitoring equipment will be automated and updated. Telemetric systems for air monitoring will be in place by 1995. (This has been achieved).

- A PSI of less than 50 will be achieved at all times barring any external circumstances beyond the Singaporean Authorities' control.
- Singapore will take all technically feasible steps to limit SO_2 emissions by the year 2000 to 1991 levels.
- Stricter emissions standards will be introduced to stabilise the emissions of SO_2, NO_x, particulates and CO_2.
- Odorous industries will be required to take more stringent measures to contain odour by the year 1995.
- Vehicles will be subjected to more stringent emission inspections to ensure they are properly maintained and that they comply with emission standards.
- The necessary infrastructure will be developed to make possible the use of environmentally friendly and effective modes of transport such as electric cars as soon as the technology is commercially available.
- Public transport will be further improved and upgraded to serve as an alternative to private cars. The mass transport system will be extended to serve a greater population.
- Extensive networks of cycling tracks to link mass rapid transit and bus stations, commercial and neighbourhood centres to nearby residential areas are being planned. For recreational purposes, cycling tracks will be planned within parks, reservoirs, along waterways, coastlines and nature reserves. These cycling tracks will ultimately be linked together creating an island-wide cycling circuit.

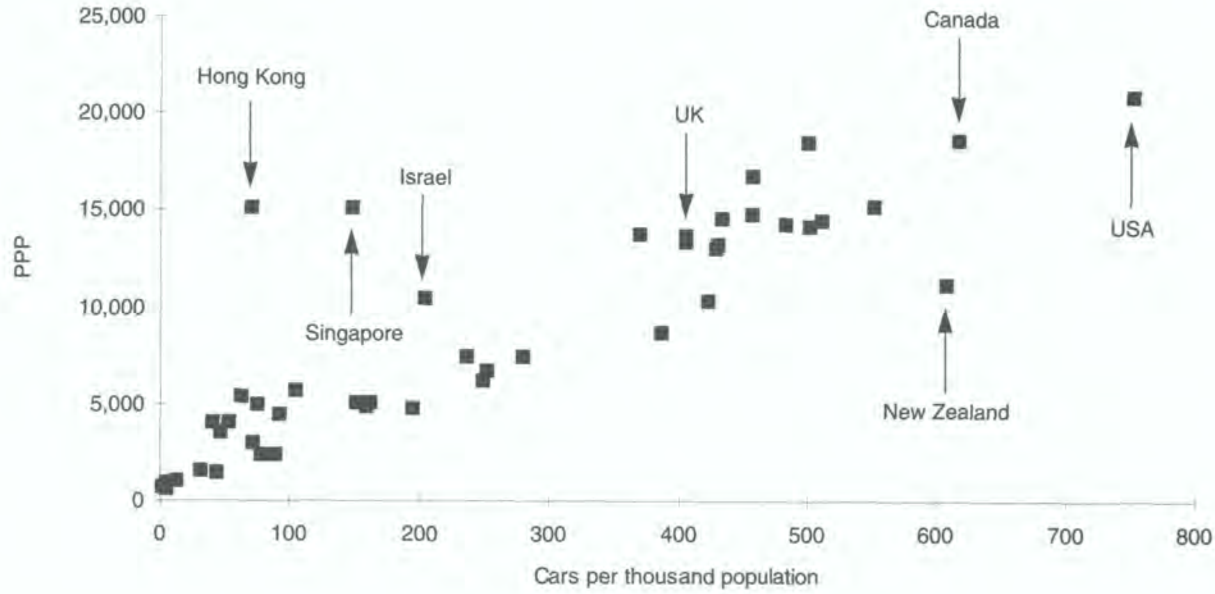
Comment

The introduction of a continuous telemetric monitoring network, with excellent spatial disaggregation across the island, measuring a wide range of pollutant species, has greatly increased Singapore's monitoring capabilities which were already very extensive. The data being produced by the network are used in a variety of applications; including the prediction of episodes of poor air quality through dispersion modelling - combining information on air pollution concentrations with meteorological data. This is an extremely useful development which could be used to impose emissions controls when potentially harmful levels of pollution are predicted – thus preventing occurrence of the forecast problem. Daily air quality bulletins are also produced and widely disseminated; of particular use are the US EPA PSI scores, classifying air quality in lay terms to ensure public understanding. The data are also widely available through Singaporean government publications. Singapore has not only developed a comprehensive monitoring programme, but also makes excellent use of the data to meet stated monitoring objectives.

Singapore has imposed rigorous controls on its extensive manufacturing industries. In order to ensure that emissions are reduced by the "Best Practical Means" it has developed a "cradle to grave" approach to controlling industrial pollution through planning legislation. This process has been streamlined by placing responsibility for the setting of approved operating conditions with one body. Rapid economic development has not resulted in extensive environmental degradation due to the use of environmental safeguards and strategies to protect Singapore's air and water.

It is especially interesting that Singapore's economic growth has not resulted in an unsustainable rise in vehicle ownership. This has been achieved by the combined use of severe financial disincentives and by limiting vehicle availability. Vehicle use has also been discouraged by the introduction of limited access zones and fiscal policies to encourage the use of cars outside of peak periods only. Emissions from individual vehicles have also been rigorously controlled and Singaporeans have been provided with an excellent public transport alternative.

Singapore has significantly fewer vehicles per thousand people than most countries of comparable wealth: approximately 150 passenger cars per thousand people as compared to approximately 450 elsewhere (see Figure 21.5). This is evidence that the controls imposed on limiting and discouraging vehicle ownership have been extremely effective. Correspondingly congestion on the island has been prevented without enormous



PPP values are from 1989.
Passenger vehicles numbers are primarily from 1991, although some data are from 1990 and 1989; they generally include vehicles capable of carrying up to 9 people.

Figure 21.5 Real GDP against number of vehicles per thousand of the population

Data are derived from the *UNEP Environmental Data Report, 1993*

expenditure on roads building programmes, and emissions from vehicles have been effectively managed.

Continued expansion of Singapore's emissions inventory will make more information available to decision makers responsible for managing air quality. Such progress will be enhanced by Singapore's current use of BPM which is particularly valuable in demanding the highest reasonable standards of emission control from all sources.

The commitments made in the Singapore Green Plan demonstrate far-sighted, innovative thinking on how to manage air quality in the future. The objective of introducing a telemetric monitoring network has already been met and the intention to stabilize emissions of SO_2, NO_2 and particulates should protect future air quality. The commitment to provide the enabling infrastructure to take advantage of cleaner electric vehicles is particularly significant, providing a potential large-scale pilot project from which other countries will be able to learn. The building of cycle lanes should encourage the use of this means of transport, and linking this network to the mass rapid transport system (MRT) and other public transport will further reduce the need for cars.

Summary

- Singapore has a network of 15 continuous air quality monitoring stations which provide daily PSI scores and are linked to dispersion modelling software to enable prediction of poor air quality episodes.
- Manufacturing is the major source of employment in Singapore, which has the third largest petroleum refining industry in the world. Industry is made to adopt BPM to limit its emissions.

- Vehicle numbers and use are severely restricted, as are emissions from individual vehicles.
- Singapore has carried out an inventory emission for sulphur oxides in 1991. Action programmes have been drawn up to limit the sulphur oxide emissions to the 1991 level by the year 2000.
- Singapore has developed many innovative and original strategies to manage air quality and therefore can provide a number of examples of good practice which could be adopted and adapted by other countries.

References

Department of Statistics 1991 *Yearbook of Statistics*, Department of Statistics, Singapore.

Ministry of the Environment 1991a *Pollution Control Report*, Pollution Control Department, Ministry of the Environment, Singapore.

Ministry of the Environment 1991b *Annual Report*, Ministry of the Environment, Singapore.

Ministry of the Environment 1992 *The Singapore Green Plan*, Ministry of the Environment, Singapore.

Ministry of the Environment 1993 Personal communication, Strategic Planning and Research Department, Ministry of the Environment, Singapore.

Ministry of the Environment 1996 Personal communication, Strategic Planning and Research Department, Ministry of the Environment, Singapore.

Ministry of Information and the Arts 1987 *Singapore*, Ministry of Information and the Arts, Singapore.

Ministry of Information and the Arts 1993a *Singapore Facts and Pictures*, Ministry of Information and the Arts, Singapore.

Ministry of Information and the Arts 1993b *Singapore*, Ministry of Information and the Arts, Singapore.

Murley, L. (Ed.) 1991 *Clean Air Around the World*, International Union of Air Pollution Prevention Associations, Brighton.

OECD 1988 *Cities and Transport*, Organisation for Economic Co-operation and Development, Paris.

Singapore National Government 1992 *Singapore's National Report for the 1992 UN Conference on Environment and Development Preparatory Committee*, Singapore National Government, Singapore.

UNEP 1993 *United Nations Environment Programme Environmental Data Report 1993-94*, Blackwell Publishers, Oxford.

US EPA 1993 *National Air Quality Trends Report*, US Environmental Protection Agency, Research Triangle Park, North Carolina.

22

Taipei

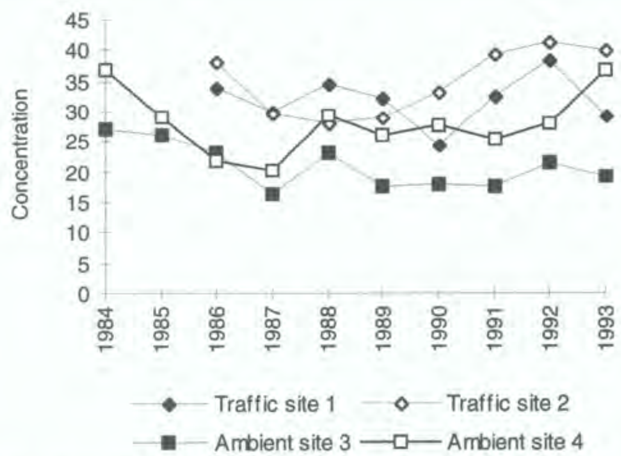
Statistical Summary

Country: Taiwan
Estimated population 1990 (millions): 2.7
Projected population 2000 (millions): 4.1
Map reference: 25°5'N, 12°12'E
Area (km²): 35,876
Altitude (m): 50
Climate: Sub-tropical monsoon
Average temperature range (C): 10–30
Annual mean precipitation (mm): 2,200

Situational Analysis

Located off the eastern coast of mainland China, the island of Taiwan is 394 km long and 142 km wide at its broadest point. The central mountain range runs from north to south down the island, characterising over 50 per cent of the island's total land area. The western part of the island, an open area of rich plains, is very densely populated. Taipei City, the capital of Taiwan, is situated in the north of the island in a basin surrounded on three sides by mountains with an elevation of 600 to 800m; the western edge of the basin is an estuary. Taipei city has developed at a very fast rate over the past 30 years; it is the largest city on the island and is still rapidly expanding. As a consequence of this, the ambient air quality of the city has deteriorated, mainly due to an increase in industrial and, more recently, traffic sources of pollution. This has led to the introduction of new regulations aimed at controlling atmospheric emissions from industry and cars.

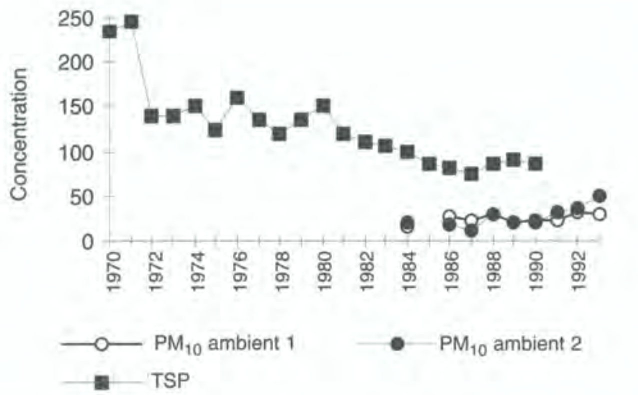
Taipei has a comprehensive air quality monitoring network. In the late 1970s and early 1980s, emission controls on industry led to an overall reduction in sulphur dioxide (SO_2) and total suspended particulate (TSP) concentrations. Sulphur dioxide concentrations, however, still exceed the national annual mean air quality standards (Figure 22.1). Levels of particular matter of less than 10 µm diameter PM_{10} are currently below the national, annual mean standard (Figure 22.2), but have been increasing in recent years. Furthermore, the daily maximum standard for PM_{10} is exceeded on a regular basis. Ambient air concentrations of carbon monoxide (CO) have also been increasing since 1980 with levels in Taipei city being the highest in the country: the 8-hourly standard of 9 ppm is frequently exceeded, especially at traffic monitoring stations. Annual mean concentrations for NO_2 show an upward trend (Figure 22.3) although, like O_3, they generally comply with national standards; hourly maxima values are occasionally exceeded.



Taiwan annual mean air quality standard 30 ppb.

Figure 22.1 SO_2 air concentrations at two kerbside and two background sites in Taipei, 1984–1993 (ppb)

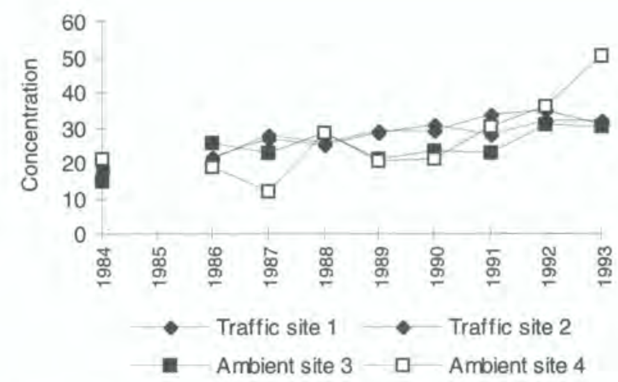
Source: EPA, 1994



Taiwan annual mean standard for PM_{10} = 65 μg m^{-3}; TSP = 130 μg m^{-3}.

Figure 22.2 TSP and PM_{10} concentrations at three urban background sites in Taipei, 1970–1993 (μg m^{-3})

Sources: TSP data from EPA, 1991; PM_{10} data from EPA, 1994



Taiwan Standard 50 ppb. Traffic sites = kerbside locations; Ambient sites = urban background locations (shown in Figure 22.5).

Figure 22.3 NO_2 concentrations at two kerbside and two background locations in Taipei, 1984–1993 (ppb)

Source: EPA, 1994

Monitoring Networks

There are currently three air monitoring networks in Taipei, with a total of 42 sampling sites, run by two organizations: the Bureau of Environmental Protection (BEP) and the Environmental Protection Administration (EPA). Monitoring networks in Taipei form part of a larger programme run by national and local government agencies with, as of 1991, 180 monitoring stations in Taiwan (EPA, 1992). Most of these stations, with the exception of those in Taipei and Kaohsiung, are manual particulate monitoring stations (IUAPPA, 1991). The three monitoring networks in Taipei are summarized in Table 22.1.

Table 22.1 Air quality monitoring networks in Taipei city

Network name	Organization responsible	Period of operation	Network objectives	No. of sites
Taiwan Air Quality Monitoring network	Environmental Protection Administration	Sept. 1993–present	Monitoring, public information and alarm/forecasting	16
Taipei Air Quality Monitoring network	Bureau of Environmental Protection	1970–present	Monitoring, compliance and alarm/forecasting	22
Taipei vehicle emission monitoring network	Bureau of Environmental Protection	1970–present	Monitoring	4

Source: EPA, 1994

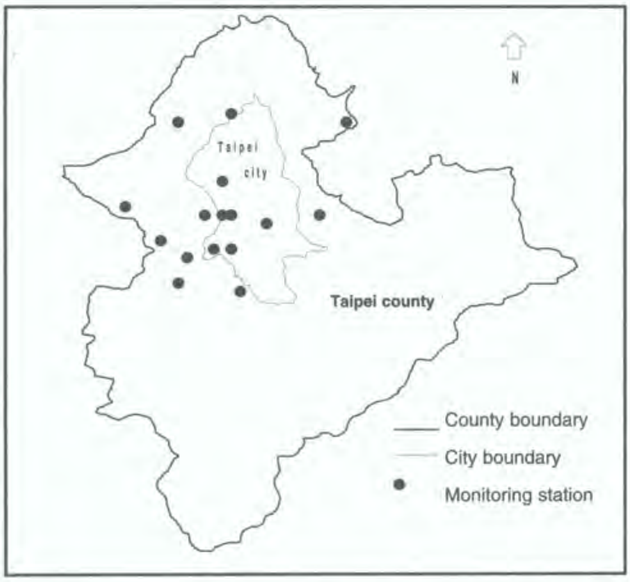


Figure 22.4 Sketch map showing sampling sites for the Taiwan AQMN

Source: EPA, 1994

Taiwan Air Quality Monitoring Network

The objective of the Taiwan Air Quality Monitoring Network (Taiwan AQMN) is to monitor levels of urban air pollutants in order to predict hazardous levels of pollution and to provide public information. This network is run by the EPA and forms part of a larger national monitoring scheme; in Taipei it monitors at commercial/city centre, residential and kerbside sites. Sixteen sites have been operating in Taipei county since monitoring began in September 1993 (see Figure 22.4 for locations). This network is still at an early stage of development and data will not be available until early 1995. Each monitoring station is linked, on-line to a computer data base and equipped with continuous automatic gaseous analysers which measure concentrations of NO_2, SO_2, PM_{10}, O_3, CO and hydrocarbons (HCs). Table 22.2 summarizes the analytical methods used to measure each of these compounds.

Taipei Air Quality Monitoring Network and Taipei Vehicle Emission Air Quality Network

The Taipei Air Quality Monitoring Network (Taipei AQMN) and the Taipei Vehicle Emission Air Quality Network (Taipei VEAQN) are both run by the Bureau of Environmental Protection (BEP) and both provide concentration trends for Taipei. Monitoring has been carried out since 1970 at 26 sites throughout the city (see Figure 22.5 for sampling locations); four sites are next to roads and are used to estimate vehicular emissions and to give an indication of the level of ambient air pollution caused by traffic. Other sites aim at monitoring background levels in commercial/city centre locations; all of these sites (22 in total) monitor for dustfall, lead (Pb) and hydrocarbons while 11 of the sites monitor for NO_2, SO_2, O_3 and CO as well (Table 22.2).

Figure 22.5 Sketch map showing sampling sites for the Taipei AQMN and the Taipei VEAQN

Source: EPA, 1994

Table 22.2 Air Quality Monitoring Networks in Taipei city and Taipei county

Pollutant	Analytical method	Number of sites at each monitoring network		
		Taiwan AQMN	Taipei AQMN	Taipei VEAQN
NO_2	Chemiluminescence	16	11	4
SO_2	Fluorescence	16	11	4
PM_{10}	ß-radiation	16	22	4
O_3	Chemiluminescence	16	11	4
CO	Gas filter correlation	16	11	4
Pb	Atomic absorption spectrometry	–	22	–
HCs	Flame ionization detection	16	22	4

– Network does not monitor for this compound.

Source: EPA, 1994

Quality assurance and data reporting

All three monitoring networks follow similar quality control and assurance procedures. Analysis is carried out by an independent body; equipment is calibrated on a regular basis; and, all data are validated to ensure the exclusion of incorrect data. The Taiwan AQMN plans to routinely inspect all the site locations at five-year intervals to ensure that sampling sites remain suitable and representative. Data from the Taipei AQMN are published on a quarterly and annual basis in: internal bulletins, scientific journals, State of the Environment Reports (e.g., EPA, 1991 and 1992) and newspapers. Information obtained from the monitoring networks is also presented in a Pollutant Standards Index (PSI), as used in the USA, in which air pollution data is made available to the general public in a simple and meaningful way. Further details on quality assurance and data reporting in Taipei are shown in Table 22.3.

Emissions Inventories

Taiwan has carried out annual emission inventories since 1987 for both stationary and mobile sources of pollution. Inventories are calculated for oxides of nitrogen (NO_x), SO_2, suspended particulate matter (SPM), CO, O_3, lead (Pb) and HCs. They cover the three main regions of Taiwan: northern (including Taipei), central and southern. Fuel consumption figures and emissions measurements from industrial and other sources of pollution are used to estimate overall emissions into the environment (EPA, 1994). The objectives for estimating emissions for Taiwan are to allow for the development of models that will predict the spatial distribution of the different air pollutants and to provide data that will form the basis for modelling future emission trends. These data are published in internal bulletins and state of the environment reports. They are used to classify the areas within Taipei into different air pollution control categories and to prepare strategic management plans aimed at reducing the emissions from industry, domestic sources and motor vehicles.

Industrial energy consumption in the Taiwan area has increased at an average annual growth rate of 8.3 per cent since 1971: from 11 million kilolitres of oil equivalent in 1971 to 54 million kilolitres in 1991 (GIO, 1993). The industrial sector is the greatest energy consumer in Taiwan accounting for 57 per cent of total energy consumption; it is followed by transport and domestic use (Figure 22.6).

Table 22.3 Quality assurance and reporting in the Taipei air quality networks

	Taiwan AQMN	Taipei AQMN	Taipei VEAQN
Calibration using standard solutions	-	-	-
Calibration using gas standards	+	+	+
Inter-comparisons between networks carried out	-	-	-
Data validated	+	+	+
Data processed by computer	+	some	+
On-line data acquisition	+	+	+
Long-term trends analysed	+	+	+
Temporal variations examined	+	+	+
Spatial distributions determined	+	-	-
Exceedences of air quality standards recorded	+	+	+
Modelling carried out using the data	+	-	-
Data reports published	*	+	+
Data freely available	*	+	+

+ yes; - no; * will be as from January 1995.

Source: EPA, 1994

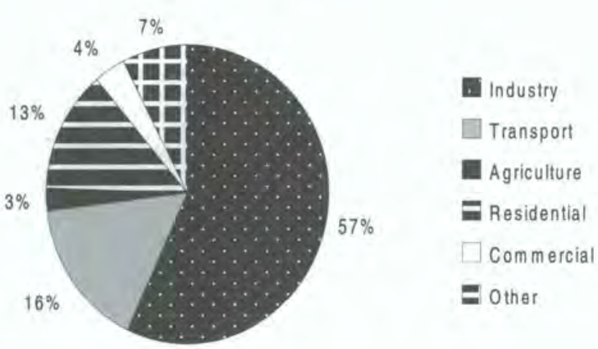


Figure 22.6 Percentage energy consumption by sector, 1991

Source GIO, 1993

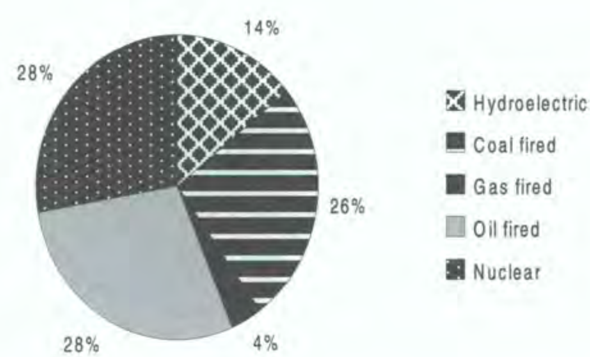


Figure 22.7 Percentage energy generation by power-generating stations, 1991

Source GIO, 1993

In 1991 there were 57 power-generating stations in Taiwan, of which 35 were hydroelectric, 19 thermal and 3 nuclear; with a total installation capacity of 18,382 megawatts. Most electricity is generated by nuclear, hydroelectric, oil and coal-fired power stations (Figure 22.7). Natural gas only contributes to a small fraction of the total energy generated and is predominantly used for domestic heating and cooking.

Waste is disposed of in landfills or burned in incinerators, some of which are within the Taipei's boundary (EPA, 1994). Two more waste incinerators are currently being built in Taipei with a daily treatment capacity of 900 and 1,350 tonnes respectively (GIO, 1993).

Motorbikes are the main source of transport in the city and their numbers are expanding rapidly. There were 12.6 million motor vehicles in Taiwan in 1991; including 3.4 million cars and 9.2 million motorcycles (GIO, 1993). These figures represent a more than 10 per cent increase over the previous year. Traffic in Taipei city and the Greater Taipei Metropolitan area is considered to be the worst in Taiwan. The increase in private car ownership, combined with the numerous construction projects, places an increasingly intolerable burden on Taipei's already clogged streets (GIO, 1993). In 1990, there were over 500,000 automobiles operating in Taipei and nearly 900,000 motorcycles and scooters (Table 22.4). An average of nearly 2,000 additional vehicles and motor scooters are predicted to take to Taipei's streets each month during the present decade. At present there are more than four cars for every parking space in Taipei; 184,000 parking places for Taipei's 900,000-plus cars (GIO, 1993). The Taipei City Government planned to construct 54 municipal parking lots with 22,700 additional parking places by 1994.

Table 22.4 Motor vehicles numbers in Taipei city

	1980	1990	2000 (predicted)
Passenger	68,982	511,308	600,000
Lorries	20,885	67,517	70,000
Buses	4,110	5,496	6,000
Motorcycles	343,116	887,633	1,000,000

Source: EPA, 1994

Table 22.5 Estimated air pollutant emissions in Taiwan for 1989 (values in thousand of tonnes)

	NO_x	SO_2	TSP	CO
Burning fossil fuels	273	460	1,997	184
Industrial	31	141	416	184
Transport	376	104	63	1,262
Solid waste incineration	57	2.4	162	521
Other	–	–	446	–
Total	**737**	**707**	**3,084**	**2,151**

Source: EPA, 1991

Table 22.5 and Figure 22.8 summarize the estimated 1989 emissions inventory for different sources of NO_x, SO_2, SPM and CO. They show that overall fuel burning and transport make the largest contribution towards NO_x emissions (88 per cent of total emissions) and account for most of the SO_2 (65 per cent) and particulate (65 per cent) emissions into the atmosphere. Moreover, carbon monoxide emissions are primarily caused by vehicle combustion (65 per cent) and, to a lesser extent, by the incineration of solid waste (24 per cent).

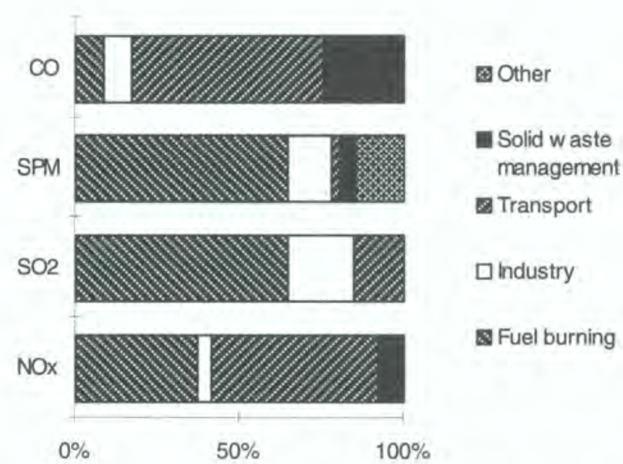


Figure 22.8 Sources of emissions for 1989 in Taipei

Source: EPA, 1991

Air Quality Management

Rapid economic development has led to a deterioration in air quality which the authorities in Taiwan are now making substantial efforts to ameliorate. Legislation was first introduced in 1975, - *Air Pollution Control Act* and *Ambient Air Quality Standards of the Taiwan Area* - and has been subsequently revised and tightened. The Taiwan Air Quality Standards (summarized in Table 22.6) are not currently enforced by law (EPA, 1994), but are proposed to become mandatory by the year 2001 (EPA, 1992). The Taiwanese authorities are currently working towards these targets. In order to achieve these national ambient standards, emission standards for stationary and mobile sources have been established by provincial, regional and municipal levels of government; supplementary to policies initiated by central government.

In 1991 the National Government initiated a US$303 million six-year National Development Plan designed to address problems such as transport congestion, chaotic urban development, air and water pollution, inadequate medical and recreational facilities and inadequate cultural awareness (GIO, 1993). The largest part of the plan's budget is funnelled into extensive transportation and telecommunications projects which include a mass rapid transit system for six metropolitan areas, including Taipei. Construction of motorways, road networks and high-speed railway links also form part of this six-year plan.

Industry has been targeted in order to reduce emissions of SO_2 and particulate matter; due to the high proportion of these pollutants coming from industrial sources. The sulphur content in fuel-oil has been progressively reduced: from 3.5–4 per cent in 1982 to 1 per cent in 1993. Currently, only installations with flue gas desulphurization equipment are allowed to burn fuel oil with a higher sulphur content (IUAPPA, 1991). This policy has led to a reduction in total emissions of SO_2 into the atmosphere and a subsequent decline in SO_2 concentrations. In recent years SO_2 levels have stabilized (Figure 22.1) although concentrations still exceed annual mean standards of 30 ppb at some locations.

Regulations also seek to address the emissions of particulates from industrial sources such as steel, iron, cement and coke factories. If these industries are found to seriously infringe the *Air Pollution Control Act* they are penalized with a daily fine and ordered to comply with the relevant regulation by a given date

Table 22.6 Air quality standards which apply to Taipei values in $\mu g\ m^{-3}$ (and ppm), unless otherwise specified

	Annual mean $\mu g\ m^{-3}$ (ppm)	Daily maxima $\mu g\ m^{-3}$ (ppm)	Hourly maxima $\mu g\ m^{-3}$ (ppm)	8-hourly maxima $\mu g\ m^{-3}$ (ppm)	Monthly maxima $\mu g\ m^{-3}$
PM_{10}	65	125	–	–	–
TSP	130	250	–	–	–
SO_2 [(a)]	86 (0.03)	286 (0.1)	715 (0.25)	–	–
NO_2 [(a)]	94 (0.05)	–	470 (0.25)	–	–
CO[(b)]	–	–	40 (35)[(b)]	10 (9)[(b)]	–
O_3 [(a)]	–	–	240 (0.12)	120 (0.06)	–
Pb	–	–	–	–	1

(a) Converted from ppm to $\mu g\ m^{-3}$: 1 ppm = 2,860 $\mu g\ m^{-3}$ for SO_2, 1,880 $\mu g\ m^{-3}$ for NO_2 and 2,000 $\mu g\ m^{-3}$ for O_3.

(b) Values in $mg\ m^{-3}$; converted from ppm to $mg\ m^{-3}$: 1 ppm = 1.145 $mg\ m^{-3}$ for CO.

Source: EPA, 1994

(IUAPPA, 1991). Larger companies are also required to keep records and to report their emissions to the Department of Air Quality Protection and Noise Control. Companies exceeding permitted levels of emissions are given a warning, persistent exceedances can lead to fines and ultimately the enforced closure of the polluting factory (EPA, 1994). Companies' emission levels are regularly inspected (EPA, 1994). Between September 1989 and February 1992 a total of 1,553 stack emissions and open burning inspections were made in Taipei county; 1,160 in Taipei city. Of these, 13.5 per cent in Taipei county and 12 per cent in Taipei city, found companies not complying with the necessary regulations and resulted in charges being imposed on the polluters (EPA, 1992). Strategic plans to reduce emissions from industry in the future include the development of emission standards for different industrial categories, such as steel refining, asphalt and cement manufacturing (EPA, 1994).

Policies have also been implemented to control motor vehicle emissions which are an increasingly important source of air pollution in Taipei (Table 22.4). Motorbikes and scooters are of particular concern, accounting for 60 per cent of the total number of vehicles in Taipei. Emissions controls on motorbikes and scooters were established in 1984. Regulations controlling smoke from diesel engines was introduced in 1976, and requires that exhaust smoke should not exceed 40 per cent obscuration. The maximum sulphur content in diesel has also been reduced progressively to 0.3 per cent in July 1993. The regular inspection of exhaust emissions of CO and HCs were introduced for petrol-engine cars in 1981. Emissions controls upon vehicles are generally being tightened: unleaded petrol is now required for all new cars and motorcycles (EPA, 1992 and IUAPPA, 1991) and new cars are required to employ a three-way catalyst. Individual motor vehicles are also checked on a regular basis (once a year for vehicles over three years old and every six months for vehicles over five years old) (EPA, 1994). Exceedances of vehicle emission standards can lead to a fine ranging from New Taiwan dollars 1,500 to 60,000 (Air Pollution Control Act, 1992).

Public information and use of the Pollutant Standards Index

Data collected at selected monitoring stations around the country, including a site in Taipei, are used to calculate the Pollutant Standards Index (PSI). Index scores, based on the US EPA index system, are calculated for the main criteria pollutants: SO_2, NO_2, CO, PM_{10} and O_3 and relate to the concentration of each in air. Each pollutant concentration is then converted into a score which aims to give a general indication of the quality of the air. In this way, the data are presented in an easy, comprehensive and understandable form which is meaningful to the general population. Pollutant Standards Index values are based on: 24-hour averages for PM_{10} and SO_2, hourly averages for NO_x, O_3 and 8-hour averages for CO.

The PSI has a scale from 0 to 500 and is subdivided into categories which indicate whether the air quality is good (0–50), moderate (51–100), unhealthy (101–199), very unhealthy (200–299), or hazardous (>300). National air quality standards are generally on the borderline between the moderate and unhealthy scale. Producing scores for each air pollutant identifies those of particular concern. It then becomes possible to pin-point the criteria pollutant affecting a sampling area. Once a pollutant is identified as being the main hazard in a particular area it may then be possible to take remedial action to reduce the known pollutant by, for example, diverting traffic away from the area or by imposing stricter rules/regulations on a particular industrial source of emission. Pollutant Standards Index values are sent to the mass media twice a day. In 1991 the monitoring station in Taipei (Sungshan) reported a total of 41 days as being unhealthy or very unhealthy. This poor air quality was attributed mainly to PM_{10} and occasionally to CO and O_3 (EPA, 1992). Data for 1991 are summarized in Table 22.7.

Table 22.7 Number of days in each PSI band in Sungshan (Taipei)

Air quality	PSI for 1991	
	No. of days	No. of days as a percentage
Good	35	9.6
Moderate	289	79.2
Unhealthy	40	11
Very unhealthy	1	0.003
Hazardous	0	0

Source: EPA, 1992

Comment

Taipei has significant air quality monitoring capabilities. The ambient air quality monitoring network is extensive, technically advanced and is used for a wide variety of purposes including public information, forecasting of pollution episodes, and local air quality management. It also identifies local problems and introduces local solutions at a sub-national level of government. A comprehensive emissions inventory exists and is combined with the ambient monitoring data in an air quality model; a powerful tool assisting decision makers in formulating the most effective emissions control strategies at a local level and assessing the impact of new industrial developments on air quality. Substantial emissions monitoring also enables air quality targets to be met.

In addition to local strategies implemented to address pollution hot-spots, national government has also introduced a number of regulations such as those improving fuel quality and controlling vehicle emissions. Government seeks to ensure that air quality standards are met by the target date of 2001. However, the growth in emissions, from motor vehicles in particular, may threaten the attainment of these targets. Data available for NO_x and O_3, for 1988–1990, show occasional exceedances of the 1-hour and 8-hour national standards, while in 1991, CO (especially near traffic-congested areas) was often found to exceed the 8-hourly averages. All these pollutants have been increasing in recent years. Stricter vehicle emissions are being introduced in an attempt to counter these problems; together with measures to reduce road congestion such as improving public transport alternatives to the use of cars and motorcycles. The predicted growth in vehicle numbers (Table 22.4) is nevertheless significant and road congestion is likely to become more of a problem in the future unless the use of alternatives to private vehicles can be further encouraged.

Excellent use is generally made of Taipei's air quality monitoring data; public information being a particularly important objective of the new Taiwan Air Quality Monitoring Network. The display of PSI scores on bulletin boards in the city and the twice daily reporting of air quality to the media provides a comprehensive system for public information.

The PSI shows that Taipei has good or moderate air quality for most of the year with a total of 16 and 41 days being reported as unhealthy in 1990 and 1991 respectively. On these days, high index values were caused by excessive levels of PM_{10} and occasionally by high O_3 and CO concentrations. However, PSI values are only reported by one site in Taipei and the authorities could consider whether monitoring from more sites would provide more useful public information.

Taipei is making excellent use of air quality data in formulating, implementing and enforcing air quality management strategies. It provides an excellent example of an industrialized city actively addressing its air pollution problems.

Summary

- There is a well established national and city-wide monitoring network in Taiwan covering SPM, PM_{10}, SO_2, NO_2, CO, O_3 and HCs.

- Sulphur dioxide and TSP concentrations have declined in recent years. Particulate matter less than 10 µm, O_3, CO and NO_2 occasionally exceed air quality standards in Taipei.

- There is a comprehensive emission inventory for Taipei. Currently, fuel burning is the main source of particulate and SO_2 emissions, vehicle combustion and incineration is the main source of CO, and fuel burning and transport are the major contributors of NO_2 emissions.

- Major air pollution problems are caused by industry and motorbike and car emissions. The EPA has adopted stricter pollution control measures to reduce emissions from these sources which has led to an overall reduction in TSP emissions from industry. Traffic emissions are likely to become of predominant importance in the future. Improvement in vehicle emissions could be counteracted by rapid growth in the number of vehicles.

- Information on the air quality in Taipei is provided to the general public on a daily basis through the mass media in the form of a Pollution Standard Index. Particulate matter less than 10 µm and, to a lesser extent, CO and O_3 were reported as exceeding "healthy" air concentration levels in Taipei on 41 occasions in 1991, PM_{10} being the most serious pollution problem affecting health.

References

Air Pollution Control Act 1992 Revised and Promulgated (February 1992) Environmental Protection Administration, Government of the Republic of China, Taipei.

EPA 1991 *Environmental Information 1990*, Environmental Protection Administration, Government of the Republic of China, Taipei (in Chinese).

EPA 1992 *Environmental Information 1991*, Environmental Protection Administration, Government of the Republic of China, Taipei (in Chinese).

EPA 1994 Response to Questionnaire: Air Quality Monitoring and Assessment Capabilities questionnaire, Environmental Protection Administration, Government of the Republic of China, Taipei.

GIO 1993 *A Brief Introduction to the Republic of China*, (3rd Edition), Government Information Office, Taipei.

IUAPPA 1991 *Clean Air Around the World*, (2nd Edition), International Union of Air Pollution Prevention Associations, Brighton.

23

Summary

Among the specific recommendations on air pollution made in Agenda 21 was **the development of appropriate air quality management capacities in large cities and the establishment of adequate environmental monitoring capabilities for surveillance of environmental quality and the health status of populations** (UNEP/WHO, 1993). The development of appropriate urban air quality management strategies requires both sound urban air quality information and the establishment of an appropriate legislative and administrative framework to implement emissions controls. This report has identified the information required for the development of appropriate air quality management strategies; it also provides a perspective on the air quality management capabilities of all cities of similar size worldwide. The study clearly identifies the component capabilities of effective management strategies and examines their use in 20 cities. The report provides unique and valuable information for both cities developing air quality management strategies, and international organizations which support this task; it therefore assists in meeting the recommendation of Agenda 21 stated above.

The air quality management capability of a city has been defined in this report as the **capacity to generate and utilize appropriate air quality information within a coherent administrative and legislative framework; to enable the rational management of air quality**. Management capabilities can be broadly divided into three categories depending on their objectives:

1. Capabilities to provide decision-relevant and public information

i. Ambient air quality monitoring to characterize the nature and severity of air pollution in a city in order to ascertain its human and environmental consequences, the acceptability and distribution of air pollution; and to measure trends in concentration and provide public information.

ii. Emissions inventories to quantify the nature, extent and location of sources of pollution in a city and to ascertain trends and make projections of future emissions.

iii. Air quality models to determine the distribution and dispersion of pollution in a city; to estimate the impact of changes to the emissions profile of the city; and, to predict pollution episodes in order that additional short-term emissions controls can be introduced and warnings be issued to the public.

2. Capabilities to enable more effective air quality management

i. An administrative and legislative framework within which regulators can effectively formulate and implement an air quality management strategy; including penalizing breaches of regulations.

ii. Emissions limits on specific sources and standards supported by an inspection and maintenance programme; including monitoring of individual sources, to verify that legislation is being adhered to.

iii. Air quality standards to define acceptable air quality and procedures to ensure that these are attained.

3. Capability enhancing capabilities

These capabilities increase the effectiveness of other capabilities to provide decision-relevant, value-added information and to enable the effective management of air quality.

i. Quality assurance and control of air quality and source monitoring data; and emissions inventory verification to ensure that data collected are of known quality and are adequate for their intended use.

ii. Data assessment to provide value-added information for decision makers and in an understandable format for non-experts.

iii. Data dissemination to enable a wide input of views to be contributed to a transparent decision-making process and to provide public information in a readily understandable format.

Each category of capabilities is essential for the overall success of the management process; to enable attainment and maintenance of acceptable air quality. A detailed analysis of the components of air quality management capability is described in Chapter Two.

A global perspective of the air quality management capabilities of cities has been constructed through case-studies of 20 cities with a projected population of between 3 and 10 million by the year 2000. The presence of the different components of capability has been examined in detail in each city chapter and an overview presented in Chapter Four. In order to objectively assess and quantify the capacity of each city, with respect to the different components of capability, an index score was developed (Chapter Three and Appendix D) and applied (Chapter Four). The scores achieved by each city, both overall and with respect to the component indices have been grouped into bands which define the management capability of each city. The capabilities of the 20 collaborating cities have been defined by these bands; which are shown in Figure 23.1.

Only Hong Kong, Kiev, Pusan, Santiago and Taipei have good or excellent management capacity in every element of capability; Birmingham will also achieve this distinction once its emissions inventory is complete in 1995. Only Taipei achieved an excellent overall management capability rating. Half of the participating cities achieved a good overall rating, two were moderate, six limited and one minimal. It is apparent that few cities in this study possess all the required capabilities to generate effective air quality management strategies; most, however, possess some level of useful capability. In most cities management capabilities can be effectively developed through making better use of existing resources and through training; some cities require more expensive infrastructure developments in order to significantly improve the range of information available to decision makers.

The cities collaborating in this study are probably not entirely representative of cities globally; they have better capabilities than would perhaps be anticipated (an unavoidable consequence of the collaborative nature of the project). Figure 23.1, however, demonstrates that the cities in this study do represent a complete range of capacities. This report can, therefore, be viewed as presenting a genuine overall picture of global management capabilities.

The following points summarize our main findings:

- Of the different components of management capability, cities generally possess the greatest capability to measure air quality. Eighty-five per cent of the cities participating in the study have established, operational monitoring networks. In the remaining cities, some measurements are being, or have recently been, made. Measurement of particulate matter (SPM) and sulphur dioxide (SO_2) is the most widespread; the least measurements being made for lead (Pb), ozone (O_3) and carbon monoxide (CO). Active sampling techniques are the most widely used methodology, with continuous monitoring networks being increasingly introduced. Passive samplers are in very limited use in the cities participating in this study; this technique could provide useful additional information for characterizing air quality at minimal cost.

- Most cities in this study carry out routine calibration and flow checks to ensure the accuracy of their monitoring data; less cities formally validate their results and very few have established formal data quality objectives, or conduct technical reviews or site audits. For many cities it is, therefore, difficult to determine the quality of monitoring data and whether it is adequate for its intended purpose.

- Assessments carried out on monitoring data were generally limited to simple statistics, percentiles, trends and exceedances of air quality standards. Very few cities use air quality monitoring data in combination with health indicators in epidemiological studies, or use meteorological and emissions data to produce dispersion models or

Figure 23.1 Assessment of air quality management capability

City	Measurement of air quality	Data assessment and availability	Emissions inventory	Air quality management	Overall score
Alexandria	Minimal	Moderate	Minimal	Limited	Limited
Ankara	Moderate	Good	Moderate	Good	Good
Belo Horizonte	Limited	Limited	Minimal	Moderate	Limited
Birmingham	Excellent	Excellent	Limited	Excellent	Good
Ekaterinburg	Good	Moderate	Good	Moderate	Good
Hong Kong	Excellent	Good	Good	Good	Good
Hyderabad	Good	Moderate	Minimal	Moderate	Moderate
Johannesburg	Moderate	Moderate	Minimal	Moderate	Limited
Katowice	Excellent	Moderate	Moderate	Good	Good
Kiev	Good	Excellent	Good	Excellent	Good
Lagos	Minimal	Limited	Minimal	Limited	Limited
Lahore	Limited	Limited	Minimal	Limited	Limited
Madras	Good	Moderate	Minimal	Moderate	Moderate
Nairobi	Minimal	Limited	Minimal	Minimal	Minimal
Pusan	Good	Good	Good	Good	Good
Quito	Limited	Limited	Moderate	Moderate	Limited
Santiago	Good	Good	Good	Good	Good
Singapore	Excellent	Excellent	Minimal	Good	Good
St Petersburg	Excellent	Moderate	Good	Moderate	Good
Taipei	Excellent	Good	Excellent	Excellent	Excellent

Minimal · Limited · Moderate · Good · Excellent forecasts of pollution episodes. Computers were, however, used for data analysis in 80 per cent of participating cities. In general, cities do not make optimum use of their air quality data.

- Access to air quality information in most cities is available through published annual summary reports, although the numbers printed are sometimes very limited and, consequently, the documents may not be widely distributed. Air quality information is available through the media in over half of the participating cities and, in a number of these, qualitative descriptions are used to assist non-experts in understanding. Only 6 of the 20 cities in the study issue alerts during periods of poor air quality; the issuing of advice to sensitive individuals to describe how to reduce the impact of, and exposure to, air pollution is, therefore, uncommon. Additional emissions controls during periods of poor air quality have been introduced in very few of the collaborating cities.

- Estimation of emissions is generally the most limited component of management capability; only 60 per cent of the cities participating in this study have calculated any emissions estimates. Furthermore, in most cities in which estimates have been derived, few are validated and most do not include non-combustion sources. In many cities which have constructed emissions estimates these must therefore be considered, particularly for some pollutants, to be first approximations and of unknown certainty.

- Air quality standards to define the level of acceptable air quality have been established in all but two of the countries collaborating in this study. Compliance with these standards, requiring remedial action to be taken to control emissions in areas in which exceedances occur is, however, only required in less than half of these countries; and enforced in even less. In a number of cities, standards have been established for which no monitoring is conducted. The application of air quality standards is substantially less widespread than their existence.

- The use of emissions controls on industrial and mobile sources of pollution within cities is widespread. However, in significantly less cities is a serious attempt made to ensure that these standards are met. Emissions controls on domestic sources are only implemented in 25 per cent of the participating cities, although domestic sources contribute significantly to poor air quality in about half of the cities.

- In many countries there is no single body or ministry with responsibility for maintaining acceptable air quality. This results in a slow and disjointed decision making process. The presence of an effective municipal government, supported by national legislation, is a feature of those cities with the most developed air quality management capabilities.

Overall, it can be concluded that existing capabilities could be more effectively used in many cities in the development and implementation of management strategies. Furthermore, although additional resources could be utilized to further characterize air quality and emissions in all of the cities studied it is only likely to be worthwhile if management strategies, based on this information, are going to be formulated and effectively and rigorously implemented. Many countries, despite establishing emissions control plans, do not act on these for five main reasons:

1. The lack of the necessary expertise and capabilities to formulate policies.

2. Low priority given to reducing air pollution compared with other social and environmental problems.

3. Insufficient financial resources or concern over the economic consequences of introducing policies to control emissions.

4. Inadequate political will.

5. An administrative framework in which responsibility for air quality is divided between a number of government ministries and local administrations, thus complicating policy making.

Details of the management capabilities in the collaborating cities, and the extent to which management plans have been formulated and implemented, are discussed in each of the individual city chapters.

Although maintaining or achieving acceptable air quality must compete with other pressing resource demands it cannot be ignored. The costs of excessive air pollution are substantial. The scale of emissions in many cities is such that local air quality management is essential to ensure that levels of air pollution remain tolerable. In order to secure acceptable air quality in the most cost-effective and appropriate manner, air quality management strategies, based on sound information, must be formulated and implemented. These management capabilities are a fundamental requirement for sustainable living. It is hoped that this report will provide an impetus to assist countries in developing effective, appropriate air quality management strategies which will ultimately result in a reduction in the health and environmental consequences of air pollution. Further support from international agencies promoting capacity building and technology transfer is needed to support developing countries in their efforts to improve their urban air quality.

Reference

UNEP/WHO 1993 GEMS/Air – *A Global Programme for Urban Air Quality Monitoring and Assessment*, WHO/PEP 93.7, UNEP/GEMS/93.A.1, United Nations Environment Programme, Nairobi, World Health Organization, Geneva.

Appendix A

Effects of Urban Air Pollution

The public health implications of exposure to high levels of air pollution are currently giving concern in cities throughout the world. These health effects can be classified into three main categories:

1. **Acute health effects** – resulting from exposure to an episode of air pollution, e.g., an asthma attack. In certain conditions acute episodes of air pollution are also associated with an overall increase in respiratory and cardiovascular mortality (WHO, 1987).
2. **Chronic health effects** – owing to long-term exposure to lower levels of pollution, e.g., bronchitis resulting from SO_2 exposure, or the increased respiratory and cardiovascular mortality observed in a number of epidemiological studies due to exposure to particulate matter (ENDS, 1994).
3. **Carcinogenic and toxic health effects** – from exposure to carcinogenic substances such as benzene, 1,3 butadiene, benzo-a-pyrene, or effects from exposure to heavy metals such as lead and cadmium.

Table A.1 Health effects of common air pollutants

Pollutant	Acute health effects	Chronic/Toxic health effects
SO_2	Narrowing of the airways, particularly in sensitive individuals, producing symptoms ranging from coughing and wheeze to bronchitis and asthma.	Increased prevalence to chronic bronchitis.
Particulate matter	Increased cardio-respiratory mortality and morbidity – particularly in combination with SO_2.	Increased respiratory mortality and morbidity; no observable threshold.
NO_2	Sensitizes the lungs to other pollutants and allergens.	No definitive effects of outdoor exposure but indoor exposure suggests a range of effects upon lung function.
O_3	Powerful oxidant reacting with most biological substances; a lung irritant and sensitizer to other pollutants and allergens; can produce runny eyes and sore throats.	None known for certain but it has recently been suggested O_3 is a geno-toxin.
CO	Reduces oxygen carrying capacity of the blood by combining with haemoglobin.	None known.
Pb	None known.	Neurotoxin, (suggestion of impairment to cognitive development); affects blood biochemistry and can raise blood pressure.
PAHs	None known.	Benzo-α-pyrene and certain other species are carcinogenic.
Benzene	None known.	Powerful carcinogen linked to leukaemia.

The synergetic relationships between certain pollutants such as SO_2 and particulate matter, and NO_2 and O_3, raise the question of the extent to which the "cocktail" of pollution breathed is more harmful than the sum of the individual effects of its components. Studies are currently being undertaken to obtain a better understanding of how pollutants interact; and how this interaction affects their potency. This issue is still not well understood since relationships between measured concentrations of pollutants and their effects on health are complex. Sensitive individuals, such as those with respiratory diseases like asthma or bronchitis, generally experience more acute effects as a result of exposure to air pollution. Physiological experiments exposing individuals to the same dose of pollutants and allergens frequently produce inconsistent results and cannot be used to expose subjects to low doses for long periods of time in order to ascertain chronic effects. Determining the actual exposure of an individual to pollutants also presents serious practical problems. Most air quality monitoring takes place at fixed locations outdoors which may not be representative of the air breathed by an individual; particularly when indoors or at some distance from the monitor location. Furthermore, exercise increases the volume of air, hence pollutants, inhaled. In addition to these problems there are also difficulties in attempting to identify the effects of individual pollutants which occur in combination and under different weather conditions.

In addition to the health effects of urban air pollution there are a number of other environmental consequences. The most visible of these are the soiling and degradation of buildings caused by deposition of black acidic particulate matter and the public nuisance caused by dust and dirt produced by construction and demolition sites and resuspension from roads by the movement of vehicles. Fumes, especially odorous ones, from industrial processes are also often a source of irritation and complaint from urban residents. The loss of amenity caused by reduced visibility is another effect of urban air pollution which can be observed both in cities and downwind of them. This is considered a serious environmental issue, especially in areas of outstanding natural beauty. Maintenance of visibility has led to the imposition of tighter air quality standards in certain parts of the USA (USEPA, 1992).

References

ENDS 1994 *ENDS Report*, **237**, Environmental Data Services, London.

USEPA 1992 *National Air Quality and Emissions Trends Report 1992,* United States Environmental Protection Agency, Office of Air Quality Planning and Standards, EPA 454/R-93-03, North Carolina.

WHO 1987 *Air Quality Guidelines for Europe*, WHO Regional Publications, European Series No. 23, World Health Organization Regional Office for Europe, Copenhagen.

Appendix B

Emissions Sources

Mobile sources

The most significant source of urban air pollution is the motor vehicle. Fuel combustion produces a number of pollutants which are emitted primarily through the exhaust. Carbon monoxide and hydrocarbons are generated through incomplete fuel combustion. Hydrocarbons, through a series of reactions in the presence of bright sunlight, are the major precursors to the production of ozone which is a powerful lung irritant and the main constituent of photochemical smog (a cocktail of noxious oxidizing pollutants such as that for which Los Angeles is infamous). One of these unburnt hydrocarbons, benzene, is a known carcinogen for which there is no known safe concentration. Nitrogen oxide (NO) – produced in all high temperature combustion processes – is rapidly oxidized in the air to nitrogen dioxide (NO_2), a much more harmful pollutant to health. This in turn is oxidized to nitric acid (HNO_3) which contributes to acid deposition. Lead (mainly in the form of lead bromide) is also emitted in the exhaust of petrol-engined vehicles running on "leaded petrol" containing added tetraethyl lead to improve the combustion process. The effects of these pollutants on health are described in Appendix A.

Diesel-powered engines and those of two-stroke petrol motors also emit large amounts of particulate matter which is the most visible form of urban air pollution; most city inhabitants are familiar with the clouds of black smoke emitted from the exhausts of some heavy goods vehicles and buses. The composition and size fraction of airborne particulate matter varies considerably and it is only fine particulate matter, PM_{10} (respirable particles with a mean aerodynamic diameter of less than 10 μm), which is considered to be harmful to health. These particles can be readily taken into the lungs.

Stationary sources

The nature of pollution from industrial plant, power generation facilities and domestic cooking and heating is totally dependent on the fuels used and the extent of pre-combustion treatment of these fuels (such as production of coke from coal). Coal contains sulphur and ash impurities which are released as sulphur dioxide (SO_2) and smoke (particulate matter) respectively when the fuel is burnt. Sulphur dioxide is subsequently oxidized in the air to sulphuric acid aerosol particles which are both harmful to health and a major cause of transboundary acidification problems. Toxic substances such as benzo-a-pyrene and other polyaromatic hydrocarbons are produced during the combustion of coal and other fossil fuels. Natural gas is a relatively clean fuel but does produce NO_2 through the combustion process.

A number of industrial processes also emit appreciable amounts of air pollution. The nature of this pollution is dependent on the process being undertaken; common examples include metals such as chromium emitted in iron and steel production, mercury in waste incineration and lead during smelting. Hydrocarbons in solvents are emitted from paint, in dry cleaning and from many other chemical processes. Petrochemical refineries and processing plants are also major sources of emissions of a wide range of toxic and other substances. Although production techniques can be modified to reduce emissions they are often quite expensive; for example, the fitting of pollution abatement equipment to the chimneys and flues of industrial plants to trap pollutants before they are emitted. In cities with poor planning controls where large residential areas develop adjacent to, or downwind of, industrial zones, emissions from stationary sources contribute appreciably to residents' exposure to air pollution. Waste burning and incineration are also an important contributor to emissions of certain toxic substances such as heavy metals, dioxins and furans if combustion conditions are not carefully controlled. Although incinerators are usually fitted with tall stacks, under certain meteorological conditions these can ground emissions, or provide a transboundary source of pollution for an adjacent urban area. High concentrations of toxic substances have also been identified immediately in the vicinity of such plants. High domestic consumption of solid fuels, such as wood and coal, present particular problems for some urban areas since emissions are derived from multiple low-level sources which are not as effectively dispersed as from tall stacks. Furthermore, provision of cleaner domestic fuels is a major undertaking owing to the volume of domestic consumption in some large cities and reluctance of people to switch from traditional fuel sources. Nevertheless, there are many examples of cities addressing their air quality problems caused by domestic fuel use (see the example of Ankara in this report).

Appendix C

Monitoring Methodologies

Passive samplers

Passive samplers have been developed for nitrogen dioxide (NO_2), nitrogen oxide (NO), ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO), ammonia (NH_3) and non-methane volatile organic compounds (NMVOCs). Some have also been adapted to enable determination of daily mean concentrations (Krochmal and Gorski, 1991). The technique is based on diffusion of the pollutant along a path of air within a tube with one closed end where the gas is trapped on an absorbent substance. The rate of diffusion, and hence the sampling rate of the pollutant, is dependent on Ficks constant, temperature, pressure and the dimensions of the tube. The tube is exposed for a known period of time after which it is sealed and returned to the laboratory where the analyte is extracted and the quantity present determined. Knowledge of the sampling rate, period of exposure and concentration of the analyte enables the integrated mean concentration over the period of exposure to be determined. The primary problems with passive samplers are associated with the stability of the adsorbed pollutant and the turbulent diffusion of air in the tube caused by wind; these problems can lead to sampling inaccuracies. The samplers themselves are very cheap but a moderately equipped laboratory is required for their analysis; trained technicians are also required to ensure that the analytical procedures produce accurate, precise results. The financial, technical and human resources required to employ passive samplers in measuring ambient air quality are, however, the lowest of all the different methodologies. Details of passive and active sampling techniques are provided in a previous GEMS/Air publication (WHO/UNEP, 1994d).

Active sampling

Active sampler systems pump air through a physical or chemical trapping medium which collects the pollutant for subsequently analysis to determine the quantity present. The concentration of the pollutant is then determined from knowledge of the volume of air sampled – commonly measured by a gas meter. The pollutant is usually collected on an adsorbing surface such as a filter (impregnated with a trapping reagent for gaseous pollutants) or by passing the pollutant through a solution within a bubbler or impinger. The use of a pump enables the flow rate to be altered (hence volume of air sampled) changing the effective limit of detection and enabling daily or hourly values to be measured. The use of a pump does however necessitate the presence of an electricity supply and as with passive samplers a laboratory is required for analysis of the samples.

Common actively sampled pollutants are SO_2, NO_2, O_3, CO, a range of organic species such as VOCs and particulate matter. The inlet to particulate matter samplers can be fitted with a size selective inlet in order that only particles of a specified size are collected – such as PM_{10}. Particulates are collected on filters and their mass determined either gravimetrically, or by determining the blackness of the filter and comparing this to a known calibration scale. Figure C.1 shows the minimum equipment required to conduct active sampling of a gaseous pollutant (WHO/UNEP. 1994c).

The principle problems associated with active sampling systems are leaks, evaporative losses, reactant product instability and absorption of the pollutant onto the sample inlet or walls of connecting piping – which can be avoided by use of unreactive tubing. Quality control at the sampling site is primarily concerned with ensuring that the passage of the pollutant through the sampling system does not alter the concentration at

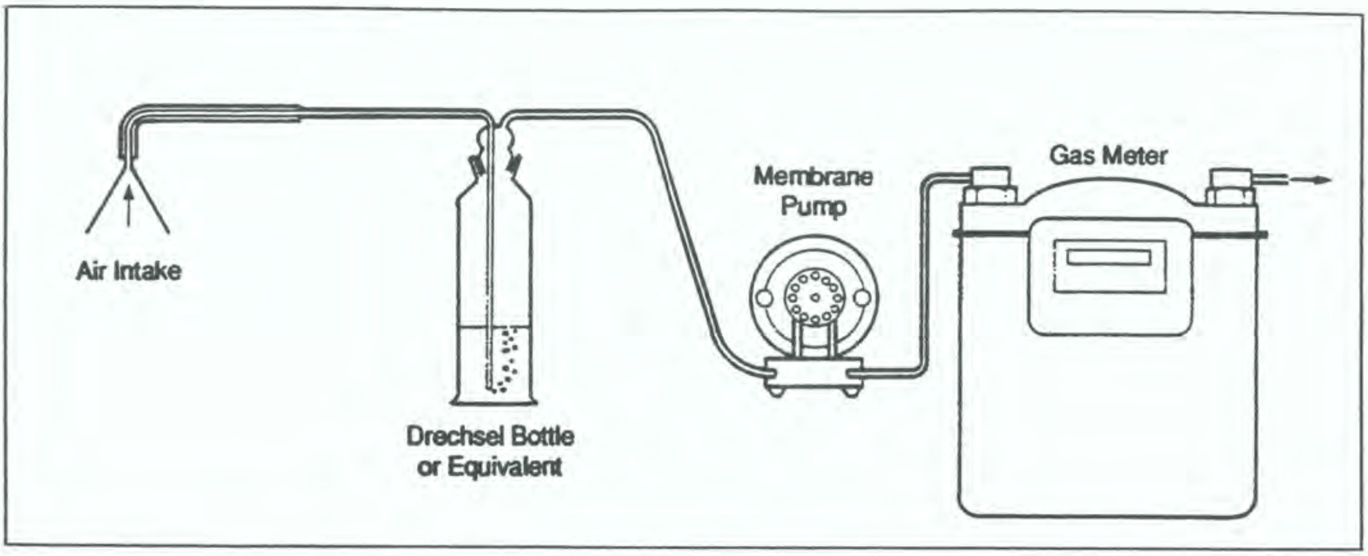


Figure C.1 Minimum equipment for active sampling of a gaseous pollutant

Source UNEP/WHO, 1994d

Technical note:

If the gas meter is located downstream from the pump, it must be ensured that the pump does not leak. The meter can, however, be located between the sample collection device and the pump, in which case Boyle's Law must be applied to correct pressure changes across the meter. The basic system shown above can be enhanced by the use of a flow controller to maintain air flows at the required rate, and a pre-filter (in systems measuring gaseous pollutants) to remove particulate matter which may contaminate the absorbing medium (such as aerosol strong acid in some SO_2 analysis). Valves and timers can be deployed to enable several samples to be collected consecutively and to switch the equipment on and off automatically.

which it is present, and ensuring the measured sampled volume of air is correct. As with passive samplers the accuracy and precision of the results obtained are highly dependent on the sampling and analytical procedures adopted and performance of the technical staff at the field site and in the laboratory. Active sampling is considerably less capital intensive than using automated techniques and unless hourly concentrations are required, routinely present a good alternative technique – particularly in countries with limited technical and financial resources.

Automatic analysers and remote sensors

Automatic analysers continuously measure changes in the ambient concentration of a pollutant, although these concentrations are usually averaged over 30 minutes or 1 hour. Air is pumped into the instrument and the concentrations measured by comparing the response against a calibration standard. The most commonly used continuous instruments are shown in Table C.1.

Automatic analysers are current state-of-the-art and are able to provide information on peak concentrations unlike samplers which integrate concentration over a period of a day or longer. The high costs and technical capabilities required to establish, calibrate, maintain and repair these instruments is such that they are beyond the means of most countries; this monitoring technique is therefore inappropriate for most cities.

Remote sensors employ sending and receiving dishes, usually hundreds of metres apart, between which infra-red or ultra violet radiation is passed. The extent

Table C.1 Continuous monitoring instruments in common use

Pollutant	Technique
NO	**Chemiluminescence** (reaction with excess O_3 present).
NO_2	**Chemiluminescence** (reduction to NO using a molybdenum converter prior to reaction with O_3; also through reaction of NO_2 with luminol).
SO_2	**Fluorescence**
CO	**Non-dispersive infra-red** **Coulometry** **Gas filter correlation** **Cross flow correlation**
O_3	**Spectrophotometry** (UV absorption). **Chemiluminescence** (gas phase titration with NO).
VOCs	**Ionization.** Collection upon an absorbing solid followed by thermal desorbtion separation using gas chromatography (GC). Species identification on the basis of retention time compared with known standards and quantification using a flame ionization detector (FID) or electron capture detector.[a]
Particulate matter	**Tapered Element Oscillating Microbalance** – TEOM. Measures the frequency of oscillation of a resonating piezo-electric element fitted with a filter cartridge to collect the sample. As particles collect the mass increases which reduces the speed of vibration which is measured and converted into a mass. **Beta attenuation**. Absorption of ß-radiation is dependent upon the mass of the sample and almost independent of composition. The attenuation of ß-radiation can, therefore, be used as a pseudogravimetric technique to determine the mass of particles collected at given intervals.

(a) Strictly speaking this is an active sampling procedure but, since development of the process has now been fully automated to provide 60-minute average concentrations, it can be equally considered a continuous instrument.

of spectroscopic absorption by specific polluting species along the path of the ray is measured at the receiving dish and average concentration of the polluting species along the path determined. Remote sensors have the advantage that they measure concentrations over a path rather than at a fixed point and are theoretically, therefore, more representative of the air in a given area. The instruments are however difficult to calibrate and the technology not well established; although USEPA approval has now been granted for measurement of some pollutants using this technique. There are considerable doubts about interference of different species leading to inaccuracy in measurements for many compounds which the instruments are reported by manufacturers to monitor. Remote sensors are currently very expensive but their use may become more widespread in the future if the existing problems with the technique can be overcome; potentially this method is superior to fixed point instruments for many monitoring objectives because of its potential to increase the representativeness of measurements by avoiding small-scale spatial differences in concentration.

References

Krochmal, D. and Gorski, L. 1991 Determination of nitrogen dioxide in ambient air by use of passive sampling technique and triethanolamine as absorbent, *Environmental Science and Technology* **25**, 531–535.

UNEP/WHO 1994c *GEMS/Air Methodology Reviews Vol. 3: Measurement of Suspended Particulate Matter in Ambient Air*, WHO/EOS/94.3, UNEP/GEMS/ 94.A.4, United Nations Environment Programme, Nairobi.

UNEP/WHO 1994d *GEMS/Air Methodology Reviews Vol. 4: Passive and Active Sampling Methodologies for Measurement of Air Quality*, WHO/EOS/94.4, UNEP/GEMS/94.A.5, United Nations Environment Programme, Nairobi.

Appendix D

Management Capabilities Assessment Index

The following questions were used as the indicators for the air quality management capability indices described in Chapter 3 and applied in Chapter 4. There are four component indices each comprising a maximum of 25 points. Cities were sent a questionnaire and asked to answer "yes" or "no" to a series of questions based upon each indicator question. On the basis of these replies the index scores were calculated.

Indicators of air quality measurement capacity

1. Indicator of capacity to measure chronic health effects **3**

- At least one site in a residential area which has been monitoring for one year or more with a frequency of greater than one day in six for the following pollutants:

NO_2	(½)
SO_2	(½)
Particulate matter	(½)
CO	(½)
Pb	(½)
O_3	(½)

2. Indicator of the capacity to measure acute health effects **2½**

- At least one site in a residential area which has been monitoring for one year or more and provides daily or hourly mean values, each day for the following pollutants:

NO_2	**(½)**
SO_2	**(½)**
Particulate matter	**(½)**
CO	**(½)**
O_3 [a]	**(½)**

a Daily mean ozone levels are not a useful indicator since night-time levels are usually very low; therefore, daytime hourly maximum or eight-hour concentrations indicators should be used for acute health effects.

There are no acute effects of lead and, therefore, no indicator.

3. Indicator of the capacity to measure trends in pollutant concentrations **3**

- At least one site in a residential area which has been monitoring for a minimum of five years capable of providing annual mean values for the following pollutants:

NO_2	(½)
SO_2	(½)
Particulate matter	(½)
CO	(½)
Pb	(½)
O_3 [b]	(½)

b Annual mean ozone is not a useful indicator and maximum, 98th percentile, second highest value or some equivalent statistic should be used.

4. **Indicator of the capacity to measure the spatial distribution of pollutants** **3**

- At least three sites, one site in each of a predominantly residential, commercial and industrial area of the city, which have been monitoring for at least one year using equivalent equipment and methodologies (or those for which inter-comparisons have been conducted), with a monitoring frequency greater than one day in six, for the following pollutants:

NO_2	(½)
SO_2	(½)
Particulate matter	(½)
CO	(½)
Pb	(½)
O_3 [c]	(½)

[c] The ozone sites should be located upwind and downwind in the suburbs of the city, and in the city centre, due to the secondary nature of O_3 pollution.

If mapping of pollutants had been conducted using modelling and an emissions inventory, this would be considered as meeting the indicator's criteria.

5. **Indicator of the capacity to measure kerbside concentrations** **2½**

- A site monitoring within 3 m of the roadside or kerb operating for one year or more at least one day in six, for the following pollutants:

NO_2	(½)
SO_2	(½)
Particulate matter	(½)
CO	(½)
Pb	(½)

There is no indicator for O_3 since concentrations are very low at the roadside due to depletion by reaction with NO.

6. **Indicators of data quality** **12**

- Instruments calibrated at least monthly (2)
- Calibrations and analysis conducted using certified solutions or gases (2)
- Site audits conducted to compare measurements from different instruments in the network, (inter-comparisons) (2)
- Auditing procedures conducted by an independent body (1)
- Sample analysis and audits performed by a laboratory with an accreditation certificate (1)
- Sites reviewed at least every five years to ensure they are still meet the objectives of the network and hence are appropriate (1)
- Data are validated (critically assessed) before they are finally ratified (2)
- Inter-comparison exercises are conducted between different measurement techniques and / or instruments from other networks (1)

Indicators of data assessment and availability

1. **Indicators of the capacity to analyse data** **14**

- Statistics and data analysis determined from the raw data include:

Means (Daily, monthly, annual)	(1)
Maximum values (Daily, monthly, annual)	(1)
Percentiles	(1)
Exceedances of national or WHO air quality standards	(2)
Trends	(1)
Spatial distribution (mapping)	(1)
Exposure assessments	(1)
Epidemiological studies	(2)
Modelling with meteorological measurements	(1)
Prediction modelling	(1)

- Computers are used in data assessment (2)

2. Indicators of data dissemination **11**

- Air quality information about the city is available:

As raw data	(1)
In newspapers	(1)
On television and radio	(1)
On information boards in the city centre	(1)

- Data are accessed through (select one):

Published reports which are readily available	(4)
Internal reports and bulletins	(3)
Only when requested – no formal documents available	(1)

- Air quality warnings are issued to the public during episodes of pollution (3)

Indicators of emissions estimates

1. Indicators of source emission estimates **8**

- Estimates of emissions from the following source categories are available:

Domestic emissions	(1)
Commercial emissions	(1)
Power-generating facilities emissions	(1)
Industrial emissions	(1)
Cars	(1)
Motor cycles	(1)
Others, e.g., ships, aircraft	(1)
HGV/buses	(1)

2. Indicators of pollutant emissions estimates **6**

- Estimates of emissions from the following pollutants are available:

Nitrogen oxides	(1)
SO_2	(1)
Particulate matter/smoke	(1)
CO	(1)
Pb	(1)
Hydrocarbons	(1)

3. Indicators of the accuracy of emissions estimates **9**

- The inventory is calculated using (either/or):

Estimates based upon some actual measurements	(2)
Estimates based upon fuel consumption statistics and emissions estimates only	(1)

- Emissions from non-combustion processes are included (2)
- The inventory is cross-checked (validated) (2)
- Inventories are conducted at least every two years (1)
- Future inventories are planned (1)

4. Indicators of the availability of the emissions estimates **2**

- Details of the inventory are (either/or):

Published in full	(2)
Partially available	(1)

Indicators of air quality management capability tools

1. Indicators of the capacity to assess air quality acceptability **8**

- Acute ambient air quality standards have been established for:

NO_2	(½)
SO_2	(½)
PM	(½)
O_3	(½)
CO	(½)

(Acute standards refer to those with an averaging time of one day or less.)

- Chronic ambient air quality standards have been established for:

NO_2	(½)
SO_2	(½)
PM	(½)
Pb	(½)

(Chronic standards refer to those with an averaging time longer than one day.)

- Regulations exist to enforce compliance with air quality standards (1½)
- Local air quality standards exist to take account of sensitive ecosystems (1)
- Air quality standards or guidelines are being introduced and or amended in the future (1)

2. Indicators of the capacity to use air quality information **17**

- Emissions controls imposed upon:

Cars	(1)
HGV/buses	(1)
Domestic dwellings	(1)
Heavy industry	(1)
Light industry	(1)

- Penalties imposed for exceeding emissions limits from:

Cars	(1)
HGV/buses	(1)
Domestic dwellings	(1)
Heavy industry	(1)
Light industry	(1)

- Local air quality considered in development of new:

Roads	(1)
Industrial plant	(1)

- Unleaded petrol available in the city (2)
- Additional emission controls are imposed during episodes of particularly poor air quality (3)