GLOBAL ENVIRONMENT MONITORING SYSTEM

ASSESSMENT OF URBAN AIR QUALITY

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WORLD HEALTH
ORGANIZATION

Prepared in co-operation with the Monitoring and Assessment Research Centre, London

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Preface

Ever since the mid-1970s, the World Health Organization (WHO) in collaboration with the United Nations Environment Programme (UNEP) has, through the Global Environment Monitoring System (GEMS), been operating worldwide networks for monitoring air and water quality and with the Food and Agriculture Organization (FAO) for food contamination, and collecting information on environmental conditions and human exposures in different parts of the world. In 1988 this information, supplemented with other data, was compiled and analysed and for each topic an assessment was made on the global and regional levels and trends. These assessments were considered and endorsed by a government-designated Expert Meeting which was held in Geneva from 12-16 September 1988. Amendments proposed at the Expert Meeting were incorporated into the assessment reports.

The UNEP/WHO Meeting was attended by delegates from 12 countries (Australia, Brazil, Canada, China, Egypt, Ghana, Hungary, India, Japan, The Netherlands, Sudan, U.S.A.), two international organizations (the Food and Agriculture Organization (FAO) and the World Meteorological Organization (WMO)) and the Monitoring and Assessment Research Centre (MARC). The government-designated Expert Meeting was chaired by Dr. Ahmed Amin El-Gamal, Advisor, Egyptian Environment Agency, with Dr. Vic Armstrong, Head, Criteria Section, Environment Health Directorate, Health and Welfare, Canada, serving as Rapporteur. In addition to the review of the assessment reports, the Government Experts also made recommendations concerning the ways in which the monitoring programmes and future assessments might be improved. These recommendations are reflected in the report of the meeting.

This report contains an assessment of urban air quality. Similar assessments on chemical contamination in food and freshwater quality are presented in separate companion documents entitled "Assessment of Chemical Contaminants in Food" and "Assessment of Freshwater Quality" respectively.

ASSESSMENT OF URBAN AIR QUALITY

CONTENTS

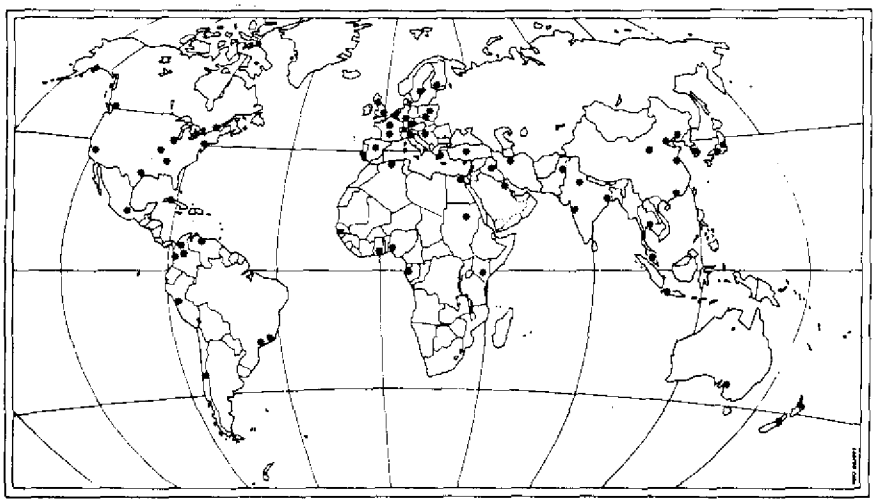
1. INTRODUCTION

WHO and UNEP have been collaborating since 1974 on a project on air monitoring in urban areas. Referred to as GEMS/Air, the project forms part of the Global Environment Monitoring System (GEMS). GEMS is the collective effort to monitor the world environment in order to protect human health and preserve essential natural resources. The coordination centre for GEMS was established within the United Nations Environment Programme in 1975.

The scope of GEMS, however, extends beyond projects supported by UNEP. In over 30 international monitoring projects implemented by UNEP, WHO, WMO, FAO, UNESCO and other United Nations and Inter-Governmental Organizations, national activities in countries worldwide are strengthened and united under the GEMS umbrella. Quality and comparability of data are stressed to provide useful input for assessments of environmental conditions. The monitoring covers climate, health, terrestrial natural resources, the oceans and long-range transport of pollutants. The monitoring and assessments are conducted to guide the rational management of our world environment.

As part of the Health Related Environmental Monitoring Programme, GEMS/Air is active in some 50 countries of which about 35 provide representative data sets for major urban areas for suspended particulate matter and sulfur dioxide. Figure 1.1 shows the current network of cities participating in GEMS/Air.

Figure 1.1 Location of GEMS/Air monitoring stations



The GEMS/Air cities were selected to provide as broad a global coverage as possible. The cities were also chosen to represent different climatic conditions, levels of development and pollution situations. In most cities, there are three GEMS/Air monitoring stations: one located in an industrial zone, one in a commercial area and one in a residential area. The data obtained from these stations permit a reasonable evaluation of minimum and maximum levels, and of long-term trends of average concentrations.

The main part of this report is based on GEMS/Air data for sulfur dioxide (SO_2) and Suspended Particulate Matter (SPM) for which fairly extensive data sets exist. Additional analyses are presented for nitrogen dioxide (NO_2), carbon monoxide (CO) and lead (Pb). The data for these last three pollutants have been obtained from national reports, the open literature and through the use of a questionnaire. These pollutants were selected because they are:

- ubiquitous
- emitted in large quantities
- related to different industries and processes
- known to cause health effects at commonly occurring concentrations

Indoor pollution has been considered separately in Appendix I, both in respect to the situation in industrialized countries, where emissions from certain building materials, use of consumer products, unvented heating and cooking devices and tobacco smoking are among the topics of concern, and in developing countries where the dominant problem is often the open combustion of wood and other biomass fuels inside houses for cooking purposes.

The overall purpose of this report is:

- to continue the ongoing process of producing periodic evaluations of the global air pollution situation in urban areas;

- to continue to develop and advance the techniques used for evaluating air pollution monitoring data with regard to human exposure and the associated risks implied;

- to prepare a background document for consideration by the forthcoming meeting of Government Designated Experts on the GEMS Health Related Monitoring Programme which is scheduled to be held in Geneva in June 1988.

The remainder of this report is divided into a number of sections, the first of which deals with sources, effects, and control of the pollutants selected for consideration in this report. The next 5 sections deal with SO_2, SPM, NO_2, CO and Pb. In each of these an attempt is made to link trends of emissions with those of ambient levels and the associated control strategies. Where possible, statements are made with regard to population exposures above (and below) relevant WHO guidelines. The main features are illustrated with diagrams in the text, with more detailed information appearing in a series of tables in Appendices II and III. The last section deals with a global assessment and listing of emerging air pollution issues.

This report was prepared in close collaboration with the Monitoring and Assessment Research Centre (MARC) in London. The US Environmental Protection Agency, which operates the GEMS/air data bank, provided substantial support with the analysis of the data. The following persons were specifically involved in the preparation of this report:

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Definitive statements and conclusions in this document have been made in an effort to characterize the air pollution situation in urban areas as clearly as possible. The information and data for this have been taken from many sources which may have varying degrees of accuracy. It is probable therefore that some conclusions, particularly relating to trend analysis, may need to be modified as improved information becomes available.

2. SOURCES, EFFECTS AND CONTROL OF AIR POLLUTION

2.1 Background

During the forties and fifties, episodes of severe air pollution which lasted for several days or more occurred in a number of urban and industrial areas. They were responsible for ill health and in some cases caused deaths among the populations concerned. As the scientific and public information base on the adverse effects of air pollution increased, so did public demand for control measures. As a result of this, countries began to introduce comprehensive air pollution control laws from the mid-fifties onwards.

It has become clear though that air pollution control (and environmental control in general) cannot be solved solely by national action on selected pollutants from industrial, domestic and vehicular sources. Today, we know of many other air pollution problems that are potentially threatening man's health and well-being. These include:

Warming of the atmosphere: Increases of levels of carbon dioxide, and certain other pollutants are thought to produce a global warming effect. This will have a major impact on climate, agriculture and sea and ground water levels.

Reduction of the stratospheric ozone layer: Of principal concern is the release of stable chlorofluoro carbons used in aerosols, refrigerants, solvents and foam plastics, which catalyze ozone depletion. The ozone layer shields living organisms from harmful effects (skin cancer) of ultraviolet radiation.

Acidic deposition: Oxides of sulphur and nitrogen emitted from tall stacks are converted to acidic compounds and deposited at great distances from the source. The effects of acidic deposition are associated with fish kills, forest damage and is also thought to be linked to some forms of ill health.

Indoor air quality: Problems can be several ranging from high radon levels coming from building materials and/or underlying soil and groundwater to high nitrogen dioxide levels from unvented cooking or heating appliances. Other problems involve formaldehyde emanating from home insulation materials, asbestos used as fire retardant, tobacco smoke and organic substances from household products. In developing countries, extremely high levels of smoke and gaseous pollutants are frequently encountered in rural houses where biomass fuels are used for heating and cooking.

Industrial accidents: Although these have occurred for a long time, recent major incidents such as in Bhopal, Chernobyl and a fire in a chemicals storage area in Basel are calling for renewed and stricter preventive measures.

Urban air pollution: In 1980 there were 35 cities with populations over 4 million, and it is projected that there will be 66 in the year 2000 and 135 by 2025. Accompanying this rapid growth are increases in industrial activity and transportation. The resulting deterioration of environmental conditions, including air quality, can already be observed in many large cities, particularly in the developing world.

2.2 Scope of present report

All of these issues are currently of major interest and the subject of much research and scientific debate. For each of them there is also the risk of major impacts on human health either directly or more indirectly by affecting man's well-being. This document deals primarily with issues of urban air quality considered to lead to the most widespread direct effects on human health while the topic of indoor air quality that differs greatly in its characteristics in different parts of the world is taken up in Appendix I. A summary of pollutants and associated sources is given in Table 2.1.

Table 2.1 Typical sources of some pollutants grouped by origin (adapted from NAS, 1981)

Pollutants	Sources
Sources predominantly outdoor	
Sulfur oxides (gases, with secondary production of particulate sulfates)	Fuel combustion, smelters
Ozone	Photochemical reactions
Lead, manganese	Automobiles, smelters
Calcium, chlorine, silicon, cadmium	Suspension of soils or industrial emission
Organic substances	Petrochemical solvents, natural sources, vaporization of unburned fuels
Sources both indoor and outdoor	
Nitric oxide, nitrogen dioxide	Fuel-burning
Carbon monoxide	Fuel-burning
Carbon dioxide	Metabolic activity, combustion
Suspended particulate matter	Resuspension, condensation of vapours and combustion products
Organic substances	Volatilization of petroleum products, combustion, paint, metabolic action, pesticides, insecticides, fungicides
Ammonia	Metabolic activity, cleaning products and agricultural activities
Sources predominantly indoor	
Radon	Building construction materials (concrete, stone), water and soil
Formaldehyde	Particleboard, insulation, furnishings, tobacco smoke
Asbestos, mineral, and synthetic fibres	Fire-retardant, acoustic, thermal, or electric insulation
Organic substances	Adhesives, solvents, cooking, cosmetics,
Aerosol containing nicotine and wide range of organic substances	Tobacco smoke
Mercury	Fungicides in paints, spills in dental-care facilities or laboratories, thermometer breakage
Aerosols of varying composition	Consumer products
Viable organisms	Infections
Allergens	House dust, animal dander

2.3 Health effects of air pollution

The effects of different pollutants vary according to the intensity and duration of exposures and the health status of the persons exposed. It is beyond the scope of this document to list all the pollutants that have been found in the indoor and outdoor environment or to describe their effects on human health. A summary of the effects of the major pollutants which are emitted in relatively large quantities and are common to virtually all outdoor and indoor environments is presented in table 2.2, together with WHO guidelines for the protection of human health.

Table 2.2 Effects and guidelines for major air pollutants

Pollutant	Effects	WHO Guidelines	
		Annual mean (ug/m^3)	98* percentile (ug/m^3)
Sulphur dioxide	Exacerbations of respiratory illness from short-term exposures Increased prevalence of respiratory symptoms, including chronic bronchitis from long-term exposures	40-60	100-150
Suspended particulate matter	As for SO_2 Combined exposure to SO_2 and SPM are associated with pulmonary effects	Black smoke: 40-60 Total Suspended Particulates 60-90	100-150 150-230
Lead	Blood enzyme changes Anaemia Hyperactivity and neurobehavioural effects	0.5-1	
Nitrogen dioxide	Effects on lung function in asthmatics from short-term exposures	1 hr 400	24 hrs 150
Carbon monoxide	Reduced oxygen-carrying capacity of blood	15 min (mg/m^3) 100 1 hour (mg/m^3) 30 COHb:	30 min (mg/m^3) 60 8 hrs (mg/m^3) 10 2.5-3%

*The 98 percentile (or P98) value stipulates that 98% of the daily averages must fall below a given concentration. This means that less than 2%, or less than 7 days per year, may exceed that concentration.

The above guidelines have in general been derived from minimum observed effect levels in epidemiological or experimental studies, introducing a safety factor of about 2 in most cases.

2.4 Socio-economic factors affecting air pollution

There are several factors which tend to aggravate air pollution problems, particularly in developing countries. These are discussed in more detail below:

Economic development: To reduce the gap in economic and social wellbeing, most countries in the third world consider rapid industrial development essential. Such development should lead to progress and improved quality of life. However, it can also produce serious deterioration of environmental quality and conditions that are potentially damaging to human health. It is important in this regard to develop integrated policies which take account both of priorities among competing issues (such as cleaning up of the environment, feeding the hungry and improving urban slum areas) and the value of incorporating preventative environmental pollution control measures.

Urban growth: Cities in developing countries are now the centres of the most rapid urbanization and industrialization in the world. In 1950, 13 cities had more than 4 million inhabitants; by 1980 35 cities were at least this large. The proportion of these cities in developing countries rose from just under 40% to more than 60% over this period. It is projected that there will be 66 such large cities in 2000 and 135 in 2025 (UN 1985). The high growth rate of the total population and the sustained rural-to-urban migration account for the rapid growth of cities in developing countries where, by the year 2000 the two largest cities in the world (Mexico City - 30 million and Sao Paulo - 27 million) will be located. Table 2.3 shows the increases in urban populations in different parts of the developing world.

Table 2.3 Populations living in cities of 1 million or more inhabitants (Repetto 1985)

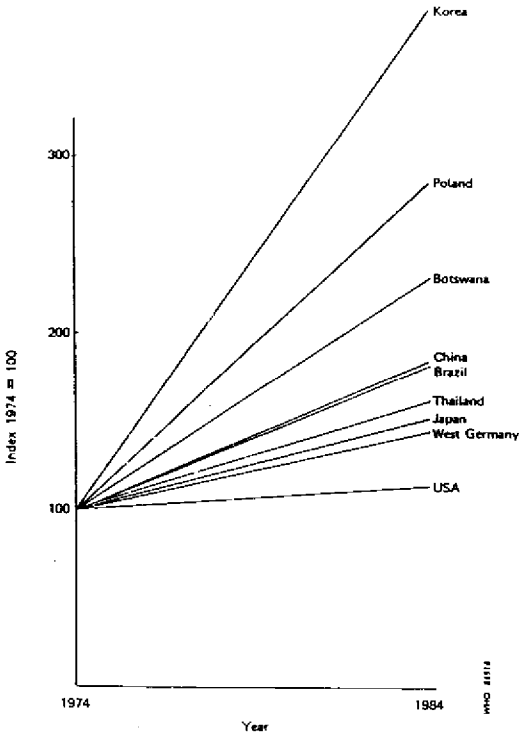
	1950		1980		2000	
	($\times 10^6$)	%	($\times 10^6$)	%	($\times 10^6$)	%
Africa	3.5	1.6	36.5	7.9	154.6	19.0
Latin America	15.3	9.7	101.3	27.3	232.2	37.5
East Asia	31.1	4.6	131.9	12.1	261.5	19.1
South Asia	17.9	2.6	105.9	7.4	328.2	14.5

The unplanned growth of cities is accompanied by increased traffic, energy consumption, industrial activity and pollution. Stationary sources emit most of the sulphur dioxide and part of the suspended particulate matter and nitrogen oxides. Most of the carbon monoxide and lead and most of the rest of the suspended particulate matter and nitrogen oxides are emitted from mobile vehicular sources.

Aside from bringing with it the deterioration of the environment, rapid growth of urban areas may also bring problems in the area of resource utilization and planning. For example, inadequate planning of industrial facilities might cause settlements of workers to be located very close to industry. As a result of this, the impact of an accident, such as occurred for example in Bhopal, may have disastrous effects.

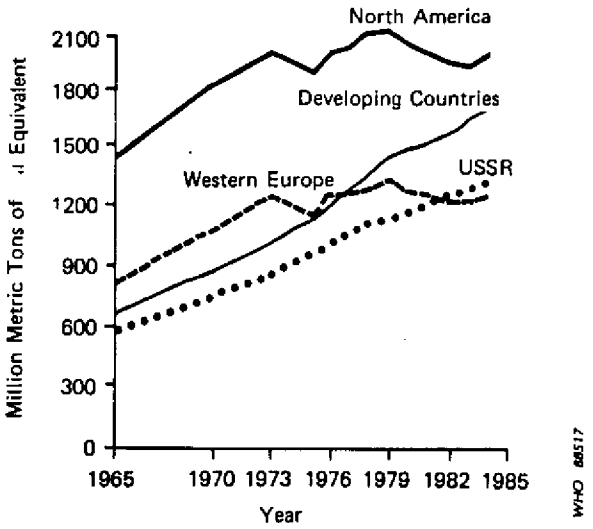
Motor vehicle traffic: One of the most significant indices of air pollution potential is provided by statistics on motor vehicle use. On a global scale the number of vehicles in use continues to rise although the rate of growth has slowed in North America and Europe as a whole, where vehicle densities are the highest in the world. Since 1979, the most rapid growth has occurred in Asia and South America where vehicle ownership has more than doubled. Figure 2.1 shows vehicle ownership trends with time in a number of countries around the world.

Figure 2.1 Trends in vehicle numbers (per 1000 population) in selected countries 1974-1984 (UNEP 1987)



Energy utilization: There are marked differences in patterns and trends of energy consumption among different groups as well as in the specific energy issues that face them. The situation has been summarized in Figure 2.2.

Figure 2.2 Primary energy consumption by region, 1965-1984 (WRI 1986)



During the last decade the developing countries have experienced the impact of two energy crises simultaneously. The oil crisis of 1974 and subsequent years which proved a severe burden to their economies. The other crisis of the fuel wood shortage in developing countries on the other hand has drawn much less attention. This crisis relates to the rapid rate with which fuel wood is consumed in rural areas of most developing countries for heating and cooking. The fuel is mostly burned in primitive open fires with low efficiency and the production of large amounts of smoke and pungent gasses indoors. This situation not only affects the health of millions of women and young children, but has a disastrous effect on the availability of fuel (see also Appendix I).

2.5 Strategies to control air pollution

Before the 1950s, the main air pollution control strategies employed by industrialized countries were to disperse emissions through tall stacks and to re-locate major point sources away from urban areas. However, it became apparent to many nations that more stringent controls were needed to prevent further deterioration in urban air quality. The major target for control was fossil fuel combustion, though the principal sources of concern varied from one country to another, ranging from domestic heating sources to industrial power production. In some countries, attention was also directed to the control of motor vehicle emissions.

Over the years, five general approaches have been developed to control air pollutants from human activities; these are used in a range of combinations by different countries to formulate overall control strategies.

Pre-combustion techniques: These include the selection of low pollutant fuels for consumption. Reserves of low sulphur oil and coal are limited but fuel cleaning is widely used to reduce the sulphur content of oil and coal as well as the ash content of coal. Distillate oils have lower sulphur contents than residual fractions, and these may be specified for use in densely populated urban areas. The switching to sulphur free fuels such as natural gas and nuclear power is also an important means of reducing air pollution emissions in some countries. The reduction of elimination of lead additives in petrol is also a pre-combustion control technique.

Combustion modification: This approach uses advanced and costly technology to control SO_2 and NO_x emissions. Techniques used include the use of low NO_x burners and fluidized bed combustion; in the latter, NO_x emissions are reduced and most of the sulphur is retained in the bed as calcium sulphate.

Post-combustion control: The removal of pollutants from flue gases and vehicle exhausts also requires relatively costly equipment. Nevertheless, flue gas desulphurization is being increasingly adopted by many industrialized nations to reduce SO_2 emissions from power stations. The use of catalysts to control pollutant emissions from vehicles has led to significant reductions in CO and hydrocarbon emissions in urban areas; this technique can also reduce NO_x emissions.

New processes: In recent years, new processes have been developed in several sectors of industry which have led to significant reductions in pollutant emissions. For example, in the case of primary production of several non-ferrous metals, low temperature hydrometallurgical techniques are now widely employed in developed countries. These processes emit much smaller quantities of SO_2 than the traditional pyrometallurgical methods. The recent introduction of smaller, fuel efficient automobiles is another example.

Energy conservation measures. Since the 1970s, many developed countries have adopted energy conservation measures which have proved effective in limiting the quantities of fossil fuels consumed. Reductions in energy demand and increased efficiency of energy generation and energy distribution have all contributed to reduced air pollution emissions.

The overall control strategies employed by countries have, in many cases, been found to be effective in urban areas and, occasionally, at the national level. However, financial cost has a major influence in any national pollution control policy and in developing countries, investment in industrial expansion will often be the overriding priority This has led to the current situation where emission reductions are being achieved in many industrialized countries while in many cases air quality in the developing world, may be deteriorating.

3. SULPHUR DIOXIDE

3.1 Origins and properties

Sulphur dioxide (SO_2) is formed primarily from the industrial and domestic combustion of fossil fuels. The combination of SO_2 (at extremely high concentrations approaching 4000 ug/m^3) and suspended particulate matter was chiefly responsible for the renowned London smog episode of 1952 which caused 4,000 deaths.

Tall stacks of modern power plants facilitate the transport of SO_2 emissions over hundreds of kilometres. In the atmosphere SO_2 is oxidized which, in the presence of moisture, is subsequently converted to sulphuric acid droplets and particulate sulphate bringing acid deposition to non-source regions which, in some cases, may be beyond national boundaries.

On a global scale, man-made emissions of sulphur dioxide are currently estimated to be around 160-180 million tonnes per year and slightly exceed estimates of natural emissions largely from volcanic sources. The northern hemisphere accounts for approximately 90% of man-made emissions of sulphur and in that region man-made emissions dominate (Möller 1984; Varhelyi 1985).

Sulphur dioxide is a potent irritant. Short-term exposure to elevated SO_2 levels can induce severe effects to the respiratory tract.

3.2 Trends in SO_2 emissions

Over the past few decades global SO_2 emissions have risen by approximately 4% per year corresponding to the increase in world energy consumption. Fossil fuel combustion accounts for around 90% of the global man-made SO_2 emissions. Other sources, such as copper, lead and zinc smelting and sulphuric acid production represent only a small percentage of total man-made emissions on a global scale. However, the importance of these sources can be substantial in certain countries, particularly at the local or regional level.

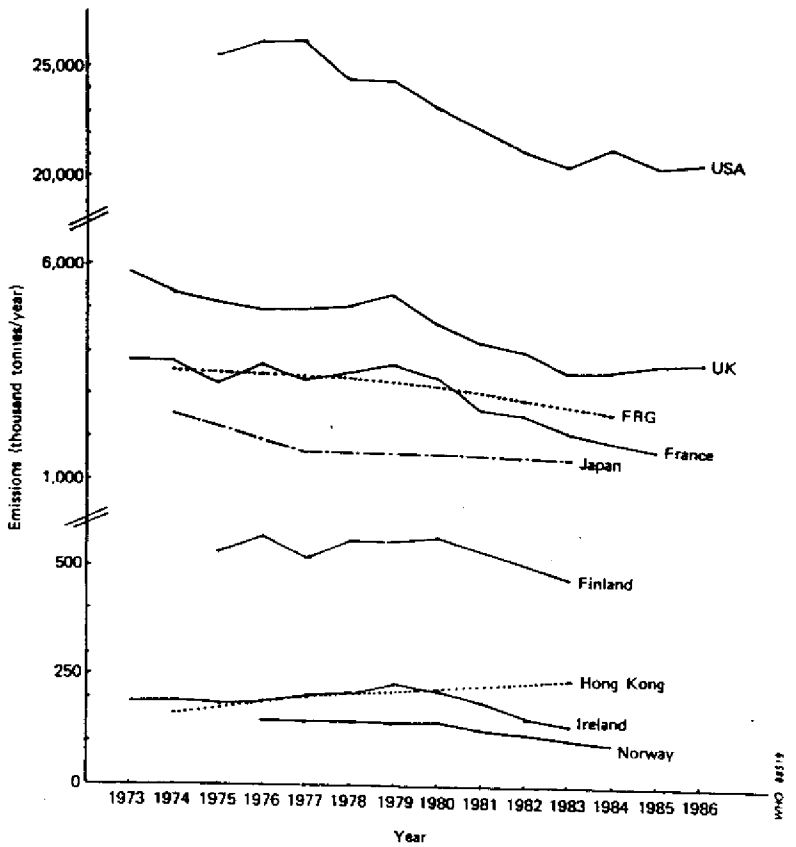
Total emissions of SO_2 from countries are derived primarily from estimates of fossil fuel production or consumption, sulphur contents of fuels and mean emission factors. The validity of national and global estimates of SO_2 emissions, as well as of other major pollutant emissions is improving, but discrepancies and the uncertain reliability of earlier estimates leave some questions in trend assessments.

The emission estimates available (Table 1 in Appendix II)) are mostly from developed countries with the most complete record reported for 1979-84. The total of the entries in this listing, 68 million tonnes SO_2 per year, represents about 40% of the global man-made release of 160-180 million tonnes per year. Emissions from the USSR are still uncertain and have not been included in the listing. Nevertheless one estimate (Varhelyi 1985) of 28 million tonnes for 1979 indicates this country is one of the largest sources of SO_2 emissions in the world.

Figure 3.1 shows that many industrialised countries experience declining trends in SO_2 emissions. During 1974-84, for example, there were decreases of 58% in Sweden, 39% in France, 19% in the Netherlands and 18% in the USA (table 1, Appendix II). Despite these declines, total emissions in Europe have not diminished between 1972 and 1982 (Highton & Chadwick 1982) and global discharges of SO_2 have increased.

Much less information is available on emission trends in industrializing countries. However, there are indications that SO_2 emissions have increased for example, in Greece, Hong Kong and Portugal over the ten-year period (Table 1, Appendix II).

Figure 3.1 Trends in SO_2 emissions in selected countries

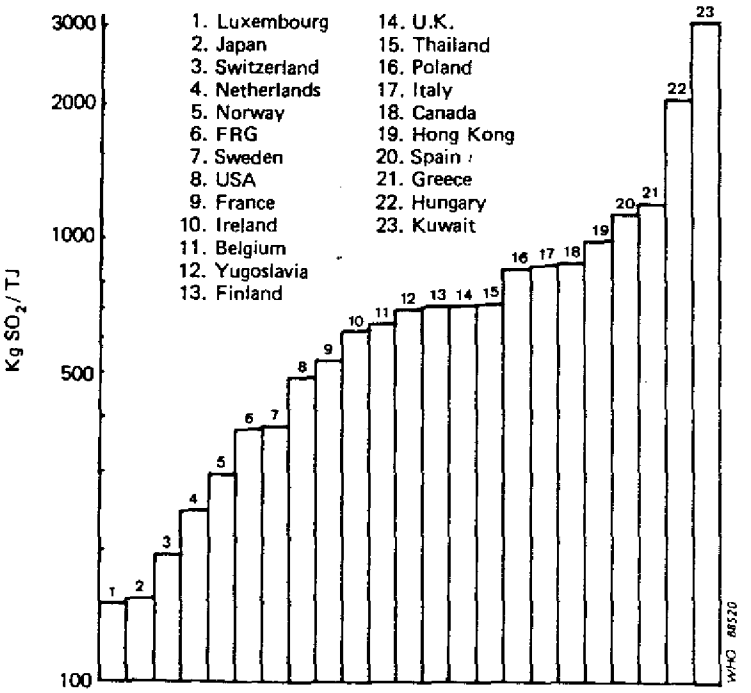


The easiest option to control SO_2 emissions is to use low sulphur-containing coal and oil. However, reserves of coal and oil with a sulphur content of less than 1% are limited. Many countries have set standards to regulate the amount of sulphur in fuel and these are gradually

being tightened (UN/ECE 1987). In order to meet these standards an increasing number of countries are depending on pre- or post-combustion sulphur removal techniques. Coal washing, coal gasification and oil desulphurization are all pre-combustion methods for reducing both sulphur and, in the case of coal, particulate emissions. The most widely used post-combustion sulphur removal method (flue gas desulphurization) involves spraying a lime slurry into the stack to absorb SO_2. However, if widely used, disposal of the resulting product can create other environmental problems.

The ability of countries in limiting SO_2 emissions from coal and oil burning in recent years is shown in Figure 3.2. The lowest emission rates, less than 500 kg SO_2/terrajoule are achieved by use of low-sulphur coal and oil and by sulphur removal control strategies. The highest emission rates reflect the use of high sulphur fuels with limited or no controls.

Figure 3.2 SO_2 emissions per unit coal and oil energy consumed, 1980-83 (kg/10^{12} joules) (based on data from UN 1986)



Japan and the U.S.A. have applied the most rigorous controls to date, investing heavily in advanced technologies. Japan was the first country to embark on a substantial programme of flue gas desulphurization in the late 1960s, and by 1984 had some 1600 units in operation, although mostly on small

oil-fired industrial boilers and smelters. In conjuction with the widespread practice of oil desulphurization in Japan, emissions of SO_2 decreased by nearly 40% between 1974 and 1983 (Figure 3.1).

To meet new ambient air quality standards, the U.S.A. has initiated a programme of fitting flue gas desulphurization equipment to new coal-fired power plants. More than 100 units are now in operation. National emission reductions of 18% were achieved between 1974 and 1985 (Figure 3.1), but the retrofitting of old plants has been limited. In addition, coal cleaning also contributes significantly to emissions reductions and although ambient levels of SO_2 have improved on average by 36% during this period (EPA 1986), this is in part attributed to the continued use of tall stacks to alleviate local air pollution problems.

Under new legislation, West Germany is planning the largest flue gas desulphurization capacity in Europe. Elsewhere in Europe and Canada only a few units are in operation and proposals to fit equipment are still being considered. Similarly, fluidized bed combustion techniques for SO_2 reduction are not yet widely applied.

It should be stressed that the steps currently being taken by industrialized countries to reduce SO_2 emissions mainly originate from concern over the environmental effects of acid deposition, rather than any need to reduce urban levels of SO_2.

Typically, national pollution control policies involve a combination of emission control strategies, but the key issue in policy decisions is usually one of cost rather than availability of control technology. In many countries less costly SO_2 emissions abatement strategies have been followed. The use of high-sulphur coal in power plants and domestic heating appliances in Eastern Europe and China is recognized as contributing to serious SO_2 pollution especially in urban areas. These countries have drafted plans to upgrade coal quality, at least in sensitive areas. The U.S.S.R. reports that this approach was in part responsible for a 2 million tonnes reduction in SO_2 emissions between 1980 and 1984 (McCormick 1985).

In some countries shifts to alternative energy sources have contributed to SO_2 emissions decreases. In the United Kingdom and the Netherlands, for example, the proportion of the energy demand supplied by natural gas increased during the 1970s, and Belgium and France have expanded their nuclear energy generating capacities significantly in recent years. It is anticipated, however, that increasing energy demands are likely to prolong the dependence on oil and particularly coal in most countries, requiring additional control measures to be adopted if air quality standards are to be met.

The achievements of many developed countries in reducing SO_2 emissions must be viewed against a continued steady increase in global man-made emissions. It can therefore be assumed that emissions in many non-reporting countries (predominantly developing) are rising and are predicted to continue to do so where industrialization and coal combustion are expanding. More data are required to establish SO_2 emission estimates in developing countries. As these are acquired and monitoring capabilities are also established, it may be expected that control strategies will be implemented, to the extent that economic resources will allow.

3.3 Trends in SO_2 ambient levels

In general, declining SO_2 levels with time are noted within the GEMS network and these correspond with declining emission trends. Certain activities, such as the use of tall stacks for wider dispersion of emissions or the location of power plants and industries outside cities, have led to a proportionately greater reduction in urban levels; these, however, have no impact on total emissions.

All cities in the network with 5 or more years of representative annual averages between 1973 and 1985 were assessed for trends in SO_2 levels, These are shown in Figure 3.3. Of 33 cities, 27 have downward (3% per year or more) or stationary trends and 6 have upward trends (at least 3% per year) with most improvements noted in cities of developed countries.

Figure 3.3 Trends in annual average SO_2 concentrations in cities. (Values in brackets refer to the number of sampling years)

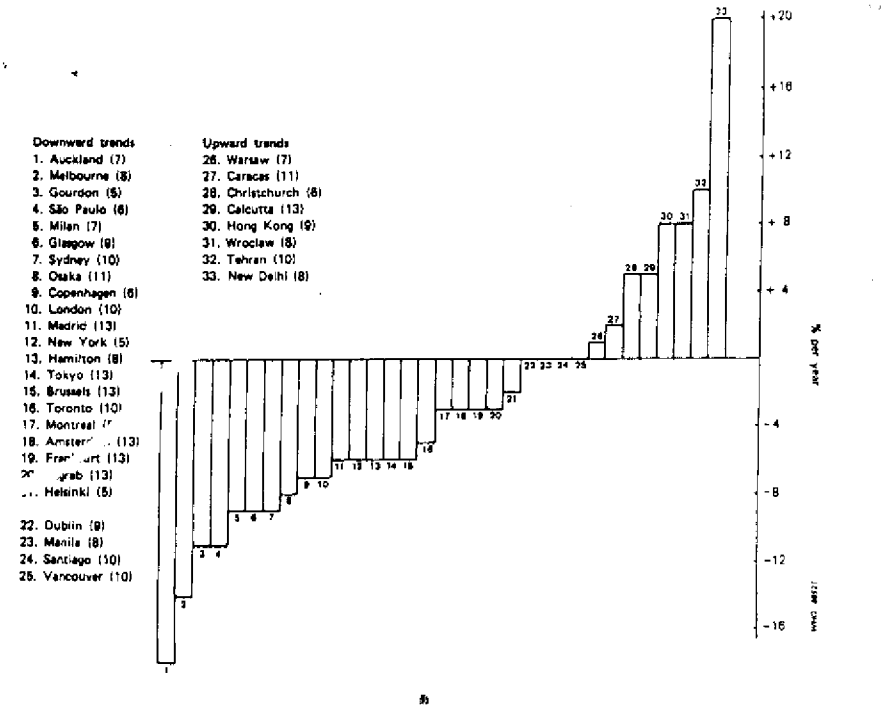
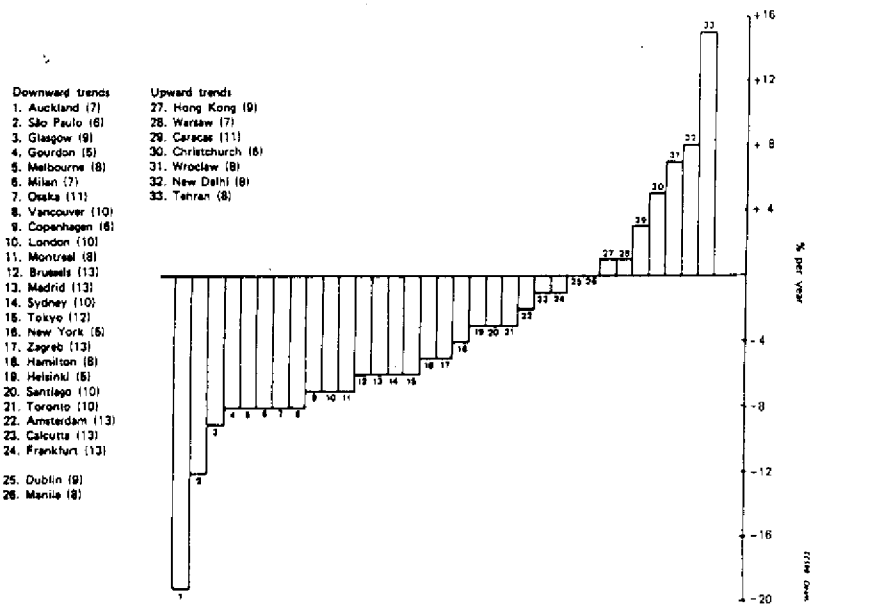


Figure 3.4 Trends in 98 percentile SO_2 concentrations in cities worldwide. (Values in brackets refer to the number of sampling years)

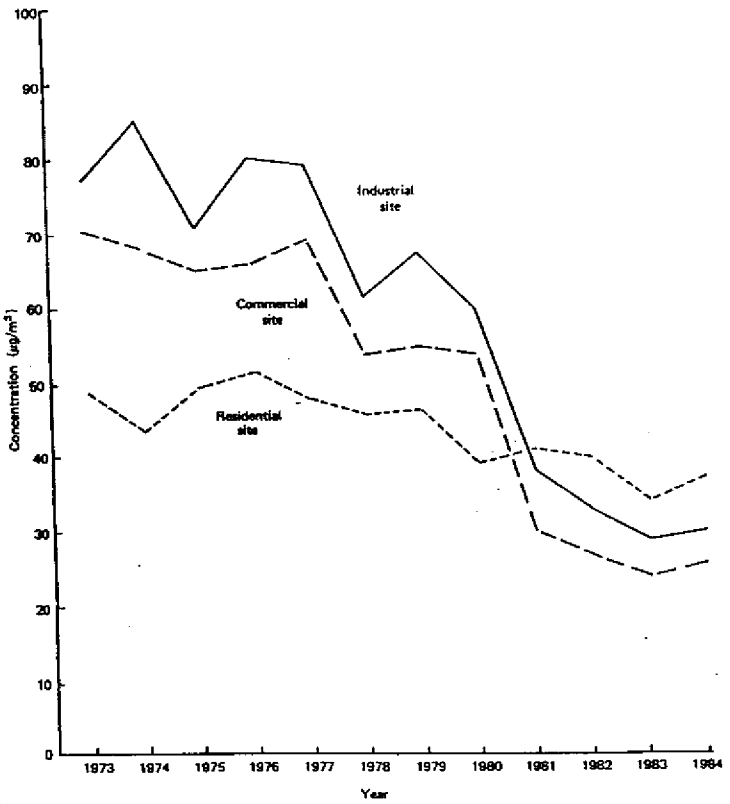


Transient peaks in SO_2 are of particular health concern. Therefore, trends have also been assessed in terms of the higher levels recorded in the year (98 percentile values) (Figure 3.4). The majority of these data also indicate improving air quality conditions for SO_2. In 5 of 33 cities surveyed worsening trends are indicated. Again, the greater proportion of deteriorating trends is in cities of developing countries.

3.4 SO_2 concentrations in cities

The GEMS/Air network also provides a good indication of the current levels of SO_2 in urban areas throughout the world. Monitoring results for each city include separate data from an industrial, a commercial and a residential site. These have mostly been selected as typical sites from more extensive national or urban networks. It is generally observed that SO_2 levels at industrial and commercial sites are higher than at residential sites. However, the distinction is not always clear, especially in more recent years as local sources have been reduced or removed. The monitoring results for Tokyo (Figure 3.5) illustrate this point.

Figure 3.5 SO_2 trends at different sites in Tokyo



A summary of the annual average SO_2 levels in 52 cities of the GEMS/Air network during 1980-84 is provided in Figure 3.6. It shows the range of annual values at individual sites and the overall average for the city for the period. This is obtained by averaging all annual values for all sites together. The levels at individual sites range from less than 10 ug/m^3 to nearly 300 ug/m^3.

Figure 3.6 Summary of the annual SO_2 averages in GEMS/Air cities, 1980-84

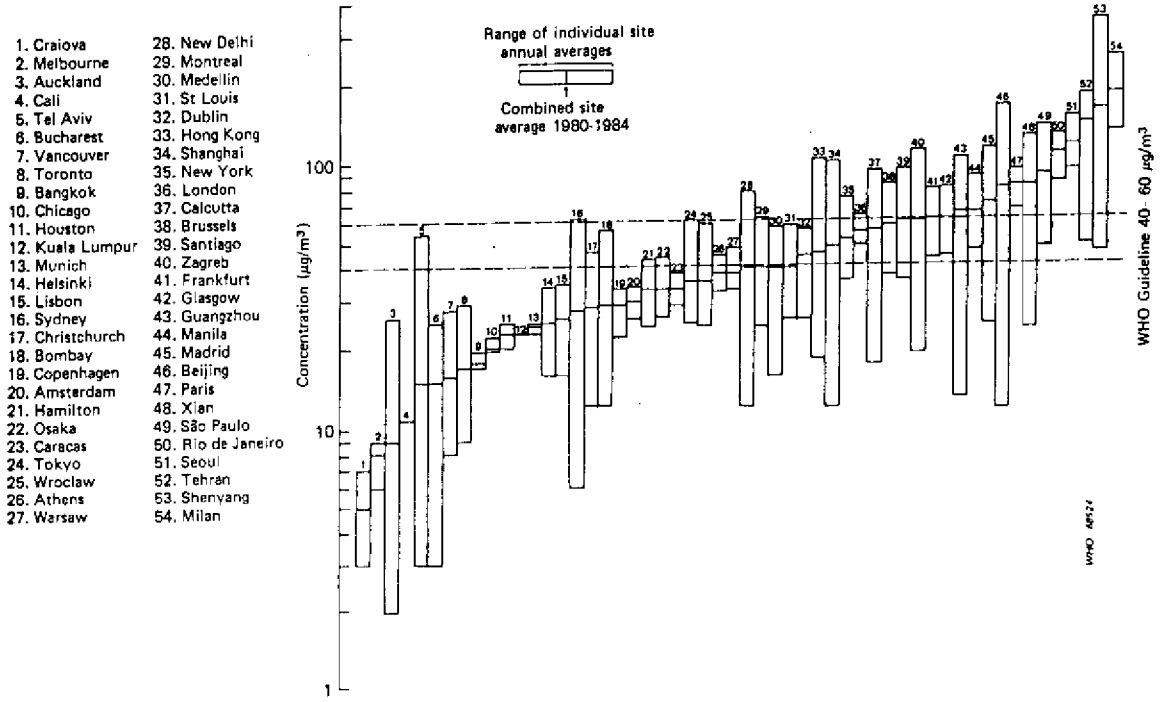
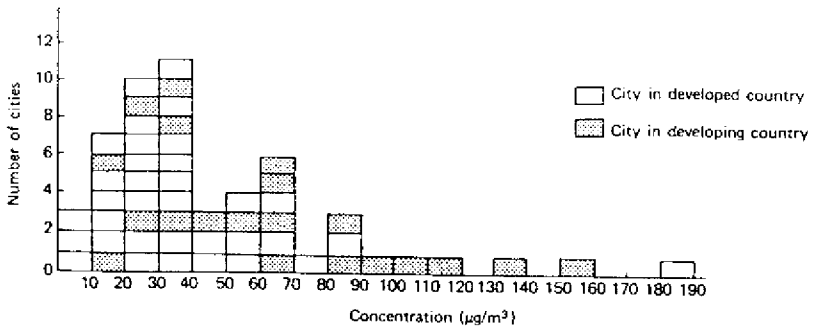


Figure 3.7 Distribution of 1980-84 average SO_2 levels



The distribution of average SO_2 levels annual average 1980-84 SO_2 values for cities is shown in Figure 3.7. The most commonly occurring values are between 20 and 60 ug/m^3. Thirty percent of cities have higher values, however, with the highest annual average SO_2 level being at 185 ug/m^3. Cities in developing countries are distributed throughout the entire range of reported average values.

3.5 Comparison with guidelines

An insight into the possible impact on human health of urban SO_2 concentrations may be gained by comparing the data with suggested guidelines for population exposures. The guideline published by WHO (1979) specifies a range of 100 to 150 ug/m^3 for the 98 percentile* of daily average concentrations, designed to ensure that even particularly sensitive members of the population should be protected from short-term adverse effects. Additionally, there is a separately derived guideline of 40-60 ug/m^3 annual mean intended to avoid any risk of increased respiratory illnesses in children or of increased prevalences of respiratory symptoms in both children and adults through long-term exposures. Each of these guidelines has been derived from epidemiological studies in which the populations were exposed to suspended particulate matter as well as SO_2 and in general effects of these pollutants need to be considered jointly.

Results from the GEMS/Air network show cities both below and above the guideline ranges. The summary in Table 3.1 gives the number of cities considered to have acceptable air quality conditions (below the guideline range), to be marginal (within the guideline range) or to be unacceptable (above the guideline range).

Table 3.1 Air quality in cities with reference to WHO SO_2 guidelines

Air quality conditions	Number of cities	
	Annual average	P98 levels*
Acceptable	27 (50%)	20 (37%)
Marginal	11 (20%)	11 (20%)
Unacceptable	16 (30%)	23 (43%)

Air quality levels continue to exceed the WHO guidelines for SO_2 in many cities in some cases by large margins. The extent of the risk in terms of either acute or chronic respiratory effects clearly depends on the degree to which the guidelines are exceeded. Particular concern should be expressed over continuous exposures of young children to concentrations well above guideline values, since there is mounting evidence that early respiratory illnesses, enhanced by air pollution at the time, contribute to the development of chronic respiratory disease in later life. In this connection, concentrations in residential areas are more likely to be relevant than those in industrial or commercial ones. In some cities the guidelines are exceeded consistently, while in others they are exceeded for some sites in some years, but not all. The results show that continued attention is required in cities of both developed and developing regions to improve air quality conditions.

3.6 Evaluation of high pollution days

As noted already, the 98 percentile values of the daily SO_2 levels exceed the upper limit (150 ug/m^3) of the WHO guideline in a significant number of cities. A clearer insight into the actual situation may be obtained by evaluating the actual number of days per year this 150 ug/m^3 was exceeded, as well as the average during the 1980-84 period.

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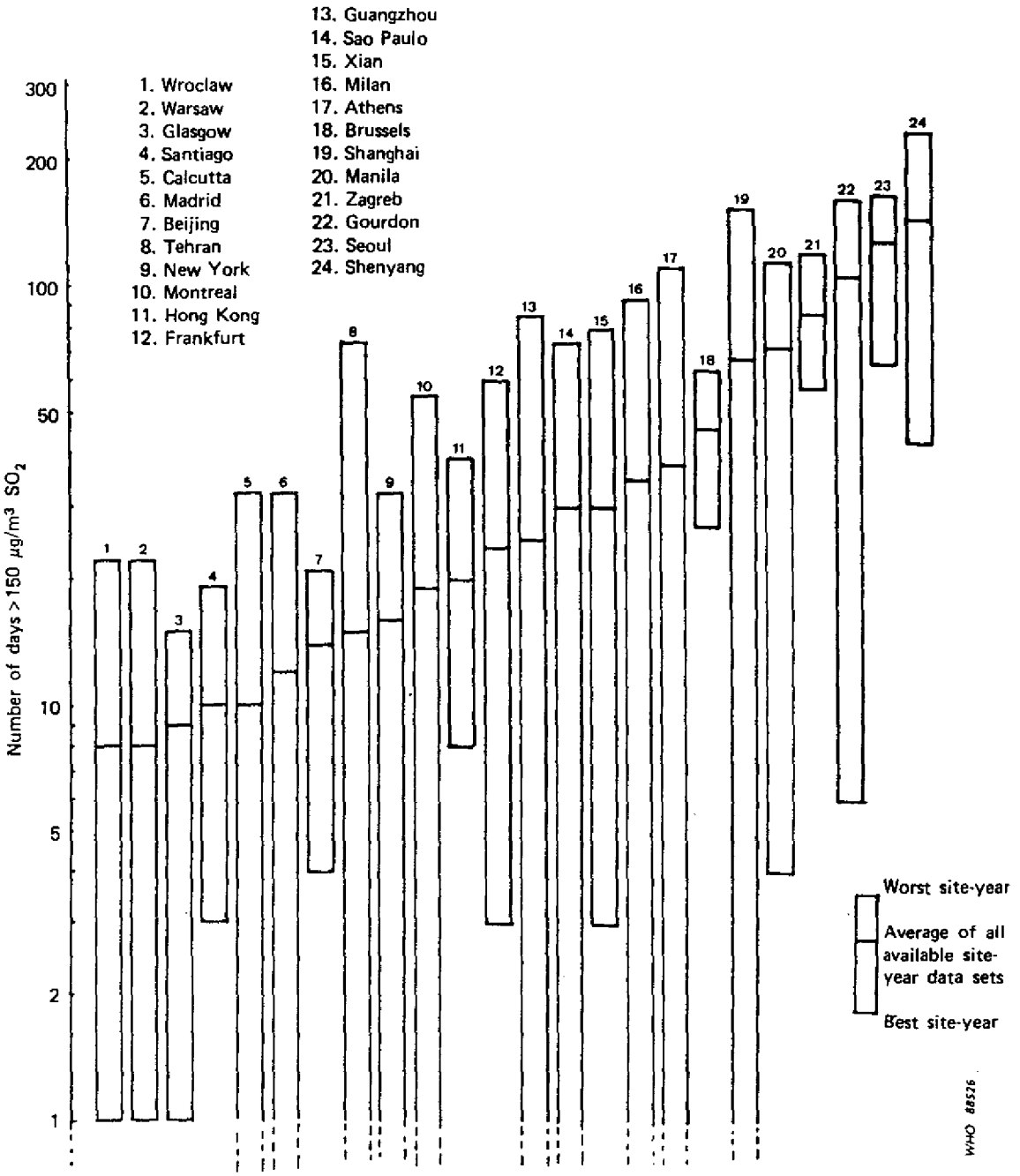
*The 98 percentile (or P98) value stipulates that 98% of the daily averages must fall below a given concentration. This means that less than 2%, or less than 7 days per year, may exceed that concentration.

The results of this analysis are listed in Table 1 of Appendix III and summarized in Figure 3.8 which show that for a number of cities all sites reporting to the GEMS/Air project are above the guideline, i.e. more than 7 days a year exceed 150 ug/m^3.

Figure 3.8 Exceedances of the 98 percentile guideline value for SO_2, 1980-84. This refers to cities which, on average, exceed the 150 ug/m^3 limit on more than 7 days/year



3.7 Estimation of population exposed

The cities of the GEMS/Air network were selected to represent a wide range of geographic locations, climatic conditions, level of development and pollution conditions. Therefore, a rough approximation of global urban populations which may be "at risk" from sulphur dioxide air pollution can be obtained from the available GEMS/Air data. A total population of 1.8 billion is used in this calculation to represent the estimated global urban population in 1978 in cities of similar size to those monitored (cities greater than 200,000 population) (UN 1980). Combining this number with annual average concentrations and 98 percentile values gives the results shown in Table 3.2 .

Table 3.2 Estimates of populations residing in urban areas of given air quality

Air quality conditions (SO_2 concentrations)	Number of persons (millions)	
	Annual average	P98 levels
Acceptable	625	550
Marginal	550	275
Unacceptable	625	975

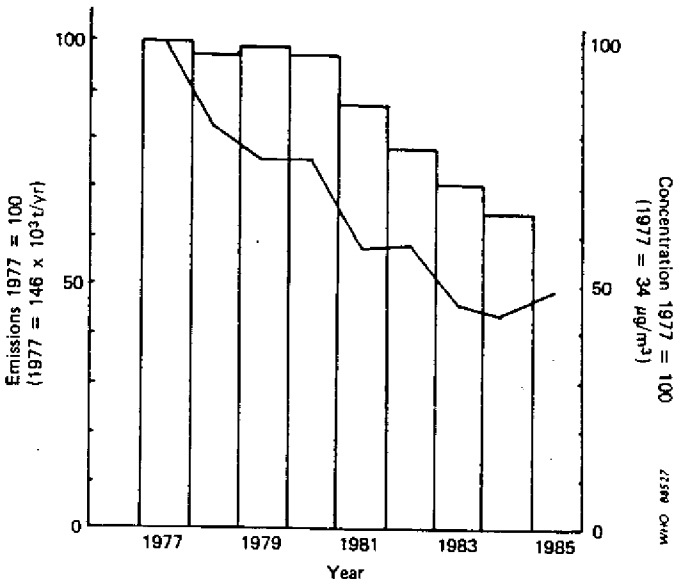
The results are similar to those of Table 3.1. The large number of cities extrapolates to large populations exposed to air quality conditions considered to be unacceptable, with over 600 million people living in urban areas where average SO_2 levels exceed the WHO recommended annual guideline. Only 30 to 35% of the total population resides in urban areas where SO_2 pollution is kept below the WHO recommended guidelines.

3.8 Case studies from individual countries

3.8.1 Norway

The emissions of SO_2 in Norway, currently around 100 x 10^3t/yr, are amongst the lowest in Europe. (Central Bureau of Statistics 1987). Emission reductions shown in Figure 3.9 have been achieved largely by the use of low sulphur oils. In 1961, the maximum sulphur content of fuel oil was set at 2.5%, since this time these limits have been progressively tightened. From the beginning of 1986 all stationary sources in the 13 southern most districts of Norway are required to use fuel oil with a maximum sulphur content of 1%. In the long-term the Norwegian government is also planning a larger role for flue gas desulphurization technologies for SO_2 control. Financial incentives are currently offered in respect of existing SO_2 sources and new sources are required to incorporate plans for possible future installation of flue gas treatment systems. Sea water scrubbers have been installed only in a number of large chemical plants, in refineries and in smelters close to the sea.

Figure 3.9 National SO_2 emissions and annual average urban concentrations in Norway



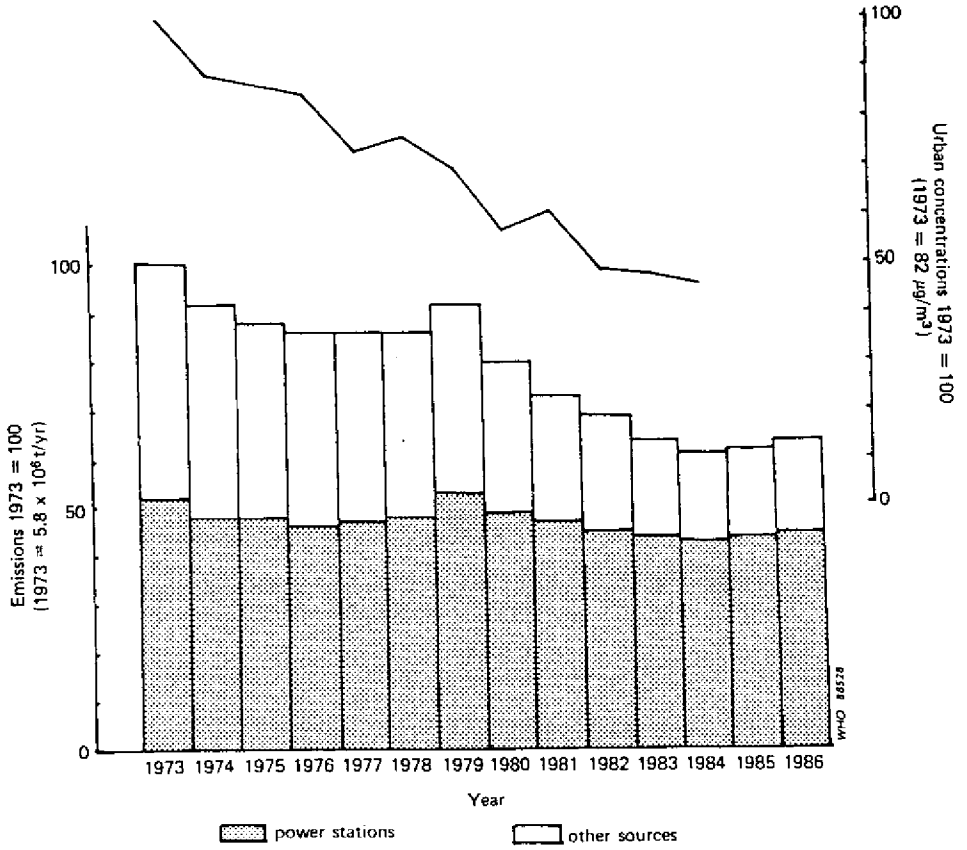
Ambient SO_2 concentrations in urban areas have declined steadily during the past decade (Figure 3.9). Between 1977 and 1985 annual average SO_2 levels decreased by 50%, compared with a 35% decrease in emissions over the same period. Improved air quality with respect to SO_2 in the larger towns is again attributed to reductions in the permissible sulphur content of fuel oils in district heating units and industrial combustion units: in Oslo and Drammen even stricter limits apply with a maximum 0.08% sulphur in fuel oils. Decreases in SO_2 levels may also be due to careful planning of sites for industrial plants in order to mitigate the local effects of SO_2 emissions.

3.8.2 The United Kingdom

Trends in SO_2 emissions by type of source and annual average urban concentrations for the U.K. are displayed in figure 3.10. Total emissions were relatively stable in the 1960s and early 1970s at about 6 x 10^6t/yr but subsequently declined to around 5 x 10^6t/yr in 1976 and to 3.5 x 10^6t/yr by 1984. Reductions are attributed to a combination of several measures including limits on the sulphur content of fuels, changes in fuel use, a lower demand for electricity for industrial purposes and energy conservation measures.

The most recent data for 1986, however, indicate a reversal in this SO_2 emission trend as a result of the upturn in the U.K. economy. Increases from power stations, oil refineries and industrial sources have caused SO_2 emissions to rise to their highest level since 1982 (ENDS, 1987).

Figure 3.10 Fossil fuel emissions of SO_2 and annual average urban concentrations in the UK

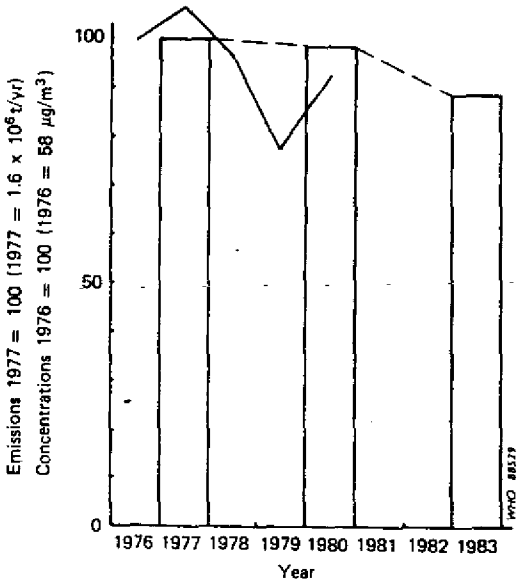


Annual average urban SO_2 concentrations have fallen by over 75% since 1961, compared with a 40% reduction in national emissions over the same period. The more rapid decline in urban SO_2 levels relative to national emission reductions has been observed in other industrialized countries. In the U.K., this disparity is largely a consequence of adopting a 'tall stack policy'; release of SO_2 through tall stacks reduces the impact of emissions on a local scale but has no effect on national emissions. The siting of power plants and other point sources of SO_2 in rural locations has also contributed to improved air quality in urban areas (Wetstone and Rosencranz 1984). Low level emitters, such as domestic and commercial combustion units have a greater impact on urban concentrations of SO_2. Emissions from such sources have fallen by 70% since the early 1960s as an indirect result of the Clean Air Act, that in effect eliminated the use of coal for such purposes, and this change corresponds more closely with the decline in urban concentrations. Emissions from power plants have remained relatively constant since the 1960s and this sector now makes a larger contribution to total emissions, as seen in Figure 3.10.

3.8.3 Hungary

Many of the air pollution problems in the majority of Eastern European countries stem from the widespread reliance on indigenous supplies of high sulphur hard coal and poor quality lignite. During the mid-seventies, imported sources of energy, particularly oil, accounted for over 50% of the total primary energy consumption in Hungary. As a result of rising prices, Hungary in the eighties is making an effort to reduce its dependence on imported hydrocarbons. Increased consumption of existing brown coal and lignite resources is thus likely in the future. Consequently, Hungarian emissions of SO_2 are expected to rise in coming years, reversing the slight downwards trend (10%) evident during the period 1977-1983 (Figure 3.11). In the absence of emission control measures, this energy switch is forecast to bring about annual emissions of SO_2 in excess of 2 x 10^6t/yr (Laszlo, 1984).

Figure 3.11 National SO_2 emissions and urban concentrations in Hungary



In 1980, emissions of SO_2 were divided between industry (80%), domestic sources (15%) and transport (5%). However, the principal sources of SO_2 and the main cause of serious SO_2 pollution problems in urban areas are the home heating units (usually coal or oil-fired burners) and diesel engined vehicles (Jaszay & Bede, 1984).

Annual average SO_2 values in the larger Hungarian cities typically range between 40-150 ug/m^3, well in excess of the guideline levels recommended by the WHO (1987). Over the five year period, 1976-1980, for which data are available, levels of SO_2 show possibly a downward trend.

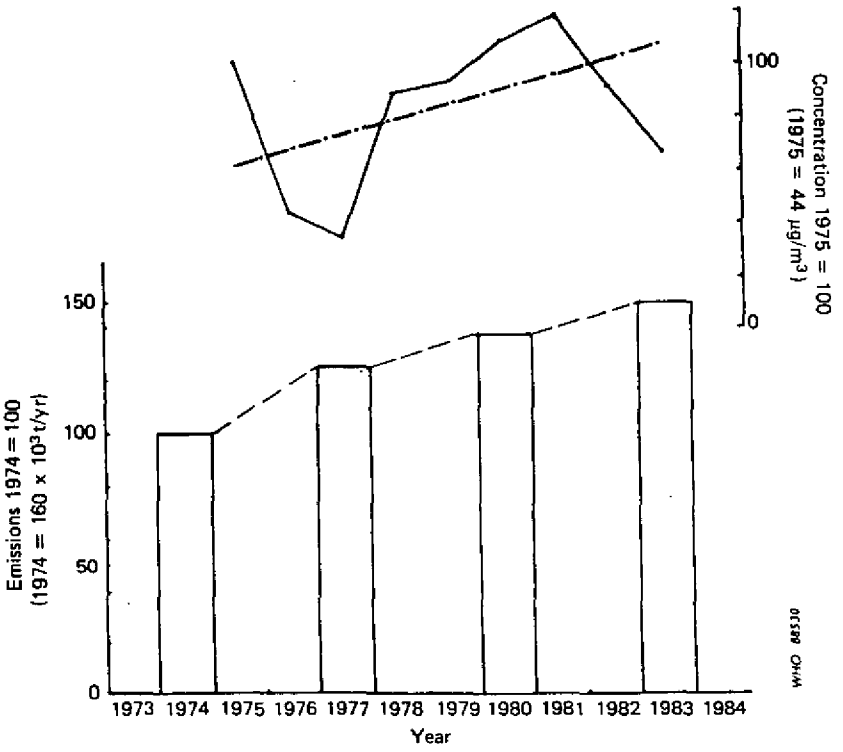
In order to reduce air pollution caused by home heating systems, district heating networks are being constructed and the use of natural gas for home heating is encouraged in the larger cities, such as Budapest. The introduction and strengthening of fuel quality standards for fuel oils, solid fuels and diesel in specially protected areas is also likely to produce improvements in urban air quality in the 1980's. In 1985, the general standard for light fuel oil and diesel fuel was tightened from 1% to 0.5% maximum sulphur

content. In addition, buses are being increasingly supplied with diesel fuel with a maximum sulphur content of 0.2% and the burning of all lignite, coal and fuel oil with a sulphur content above 0.5% is prohibited in specially protected areas (UN/ECE 1987). Currently there are no technological devices for SO_2 control installed in power stations and industrial plants in Hungary.

3.8.4 Hong Kong

The information available for Hong Kong clearly indicates a trend towards increasing SO_2 emissions as shown in Figure 3.12. Over the period 1974-1983 emissions rose by 50%. as a result of increasing industrial activity and energy use. Consumption of oil in Hong Kong increased by 58% between 1975 and 1982 (UN 1984).

Figure 3.12 SO_2 emissions and urban concentrations in Hong Kong



GEMS/Air data for 3 sites in Hong Kong are plotted in Figure 3.12. Trends are difficult to assess in view of the variability of the data. The general trend in ambient concentrations appears to be upwards, though there are signs that a decline may be developing in recent years.

4. SUSPENDED PARTICULATE MATTER

4.1 Sources

Particles are emitted into the atmosphere from numerous natural and man-made sources and are also formed upon condensation of gases and vapours. Direct emissions of Suspended Particulate Matter (SPM) arise from a variety of human activities including combustion, industrial and agricultural practices; the remainder is formed from gas-particle conversions (chiefly from SO_2). Particles larger than about 10 um in diameter deposit in the vicinity of the sources, but smaller particles, may remain airborne for extended periods and be transported long distances.

Particles in the atmosphere are distributed into two principal size groups: fine particles (up to 2 um particle diameter) from combustion processes and from coagulation and condensation of gases and vapours and a larger fraction (2 to 100 um) which can be derived from wind-blown and industrial dusts, sea spray, volcanic particles and plant pollen. Respirable particles are generally considered to be those less than 10 um in diameter.

Global inventories of total particulate emissions are notoriously difficult to estimate, largely because of the problems involved in quantifying natural sources. Annual man-made particulate emissions are estimated to be approximately 300 million tonnes, about half of which are sulphate particles formed from SO_2 conversion (Robbins & Robinson 1972). Man-made emissions, however, are estimated to be only between 5-50% of total particulate emissions although in most urban regions particles from human activities dominate (WHO, 1987).

4.2 Determination and properties of suspended particulate matter (SPM)

Sampling of particulate matter in air is usually done either by the smoke stain method, in which the darkness of filter paper through which air has been drawn is determined, or by gravimetric measurement. Smoke values are influenced primarily by the black, finely divided, carbonaceous material from incomplete combustion. The gravimetric observations include additional material such as sulphates produced from SO_2 through reactions in the air, and, when collected with high volume samplers, some relatively large dust particles beyond the respiratory range. Sampling with size fractionating devices is becoming more common as this allows the concentrations of respirable particles to be determined. It is usually also useful to determine the chemical composition and biological activity of particles to evaluate the potential for health effects.

Respirable particles in urban areas contain lead, other metals and many organic compounds. Polynuclear aromatic hydrocarbon (PAH) compounds for example are released in vapour phase from combustion sources and then condense on atmospheric particles. These compounds and their subsequent transformation products are possible contributors to the mutagenicity of extracts from atmospheric particles.

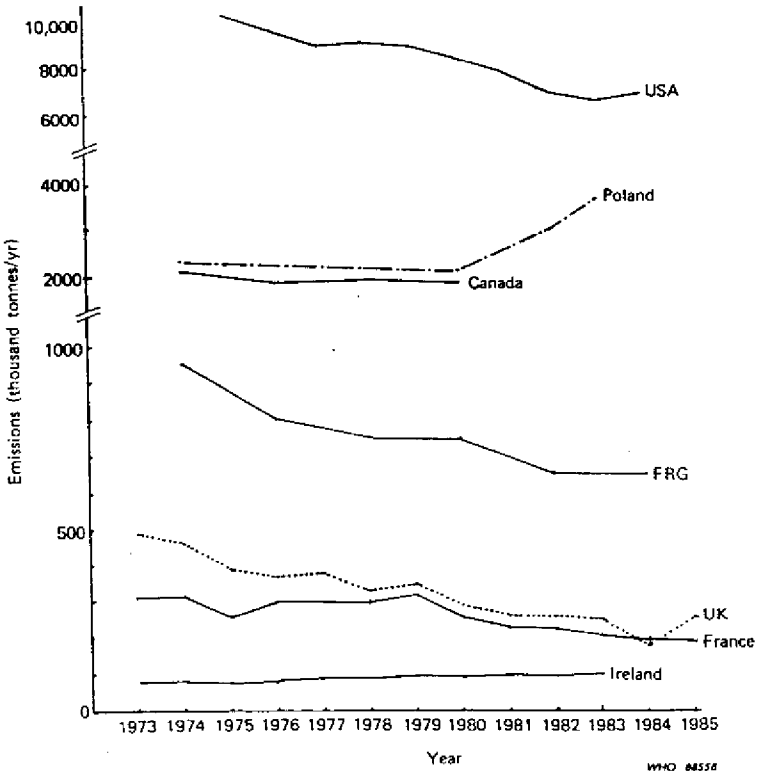
Health effects caused by particulates are generally viewed in terms of joint exposure with SO_2, and these have been described in section 3.5 above.

4.3 Trends in particulate emissions

Global estimates of man-made emissions are still somewhat uncertain and no trends have yet been established. Similarly, estimates of total SPM emissions from individual countries are also not well developed and generally represent releases from limited sources. Available data are listed in Table 2 in Appendix II. The total emissions reported in table 2 (Appendix II) for the period 1982-84 amount to about 27 million tonnes per year. This is only about 20% of the estimated total man-made suspended particle emissions.

Trends in national particle emissions are shown for some of the countries in Figure 4.1. It shows mainly downward trends in recent years, e.g. decreases of 49% in the U.K., over 30% in the U.S.A., Federal Republic of Germany and France during the 9-year period 1974-1983. There are, however, exceptions, such as in Ireland and Poland where increases are noted.

Figure 4.1 Trends in particulate emissions in selected countries



Reductions in particulate emissions have been achieved in some of these industrialized countries despite an increase in power generation from coal, through the use of more efficient combustion and particle removal equipment at power stations. Emissions have also declined through the wider use of coal washing and by switching to smokeless fuel and natural gas for domestic heating, especially in urban areas. Fuel conservation measures have also contributed to reductions in emissions.

There are indications of increasing trends in particulate emissions in certain developing countries and in Eastern Europe. Coal washing is less common in these areas and abatement equipment in industries and power stations can be absent or poorly maintained. Concern has also arisen in Western Europe and North America where smoke emissions from diesel engines are rising. This source can now account for up to 70% of smoke emissions in urban areas and may have important implications for human health. Diesel engines generate about 10 times more respirable particulates then petrol engines. Nevertheless, only the U.S.A. currently regulates the actual mass of particulates emitted from diesel engined vehicles. Elsewhere, less effective limits, based on the opacity of diesel exhaust smoke, have been widely applied.

The relocation of industry away from cities is a strategy which may effectively improve urban particulate concentration although it has no influence on total emissions. Inner city areas, particularly in developed countries, are often subject to stringent restrictions concerning the use of smokeless fuels which may further enhance discrepancies between ambient trends in urban areas and national emission trends.

4.4 Trends in ambient particulate levels

Most cities in the GEMS/Air network that monitor SO_2 also measure either suspended particulate matter or determine black smoke levels. All cities in the network with at least five years of representative annual average values between 1973 and 1985 were assessed for trends in particulate levels. The results are shown in Figure 4.2.

Figure 4.2 Trends in annual average particulate concentrations in cities. (Values in brackets refer to the number of sampling years)

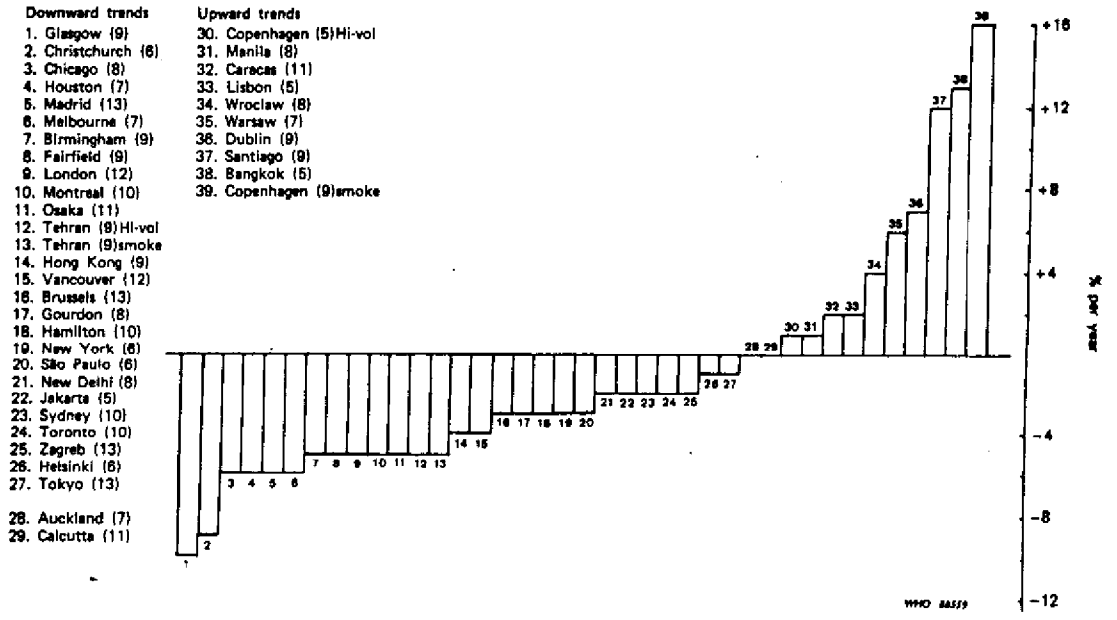
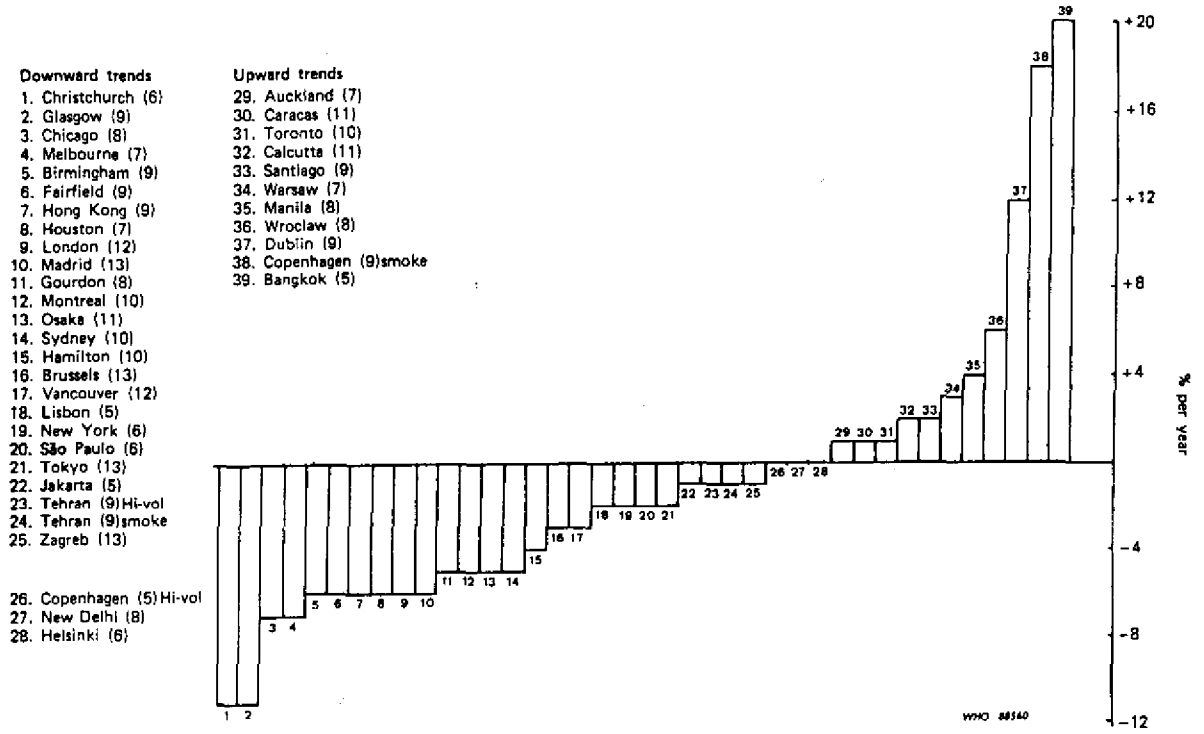


Figure 4.3 Trends in 98 percentile concentrations in cities. (Values in brackets refer to the number of sampling years)



In the 37 cities (two cities are mentioned twice) which met the above criteria, trends are mostly downward during the 1973-85 period (3% or more decrease per year). There were 19 cities with downward trends (51% of the cities listed), 12 stationary (32%) and 6 upward trends (16%). Among cities in developing countries, 2 out of 9 (22%) had upward trends.

Analysis of trends of the upper values (98 percentile values) in cities has also been made (Figure 4.3). There were 17 of 37 cities with downward trends (46%). The highest yearly average increase was 20% per year in Bangkok, followed by Copenhagen (18% per year), Dublin (12% per year) and Wroclaw (6% per year).

4.5 Particulate concentrations in cities

The sites in the GEMS/Air network provide an insight into current urban particulate concentrations in cities around the world. Annual average values for SPM or smoke for the 1980-84 period were available for a total of 54 cities (three of which monitor particulates using both procedures) and are summarized in Figures 4.4 and 4.5 respectively.

Figure 4.4 Summary of the annual SPM averages in GEMS/Air cities, 1980-84

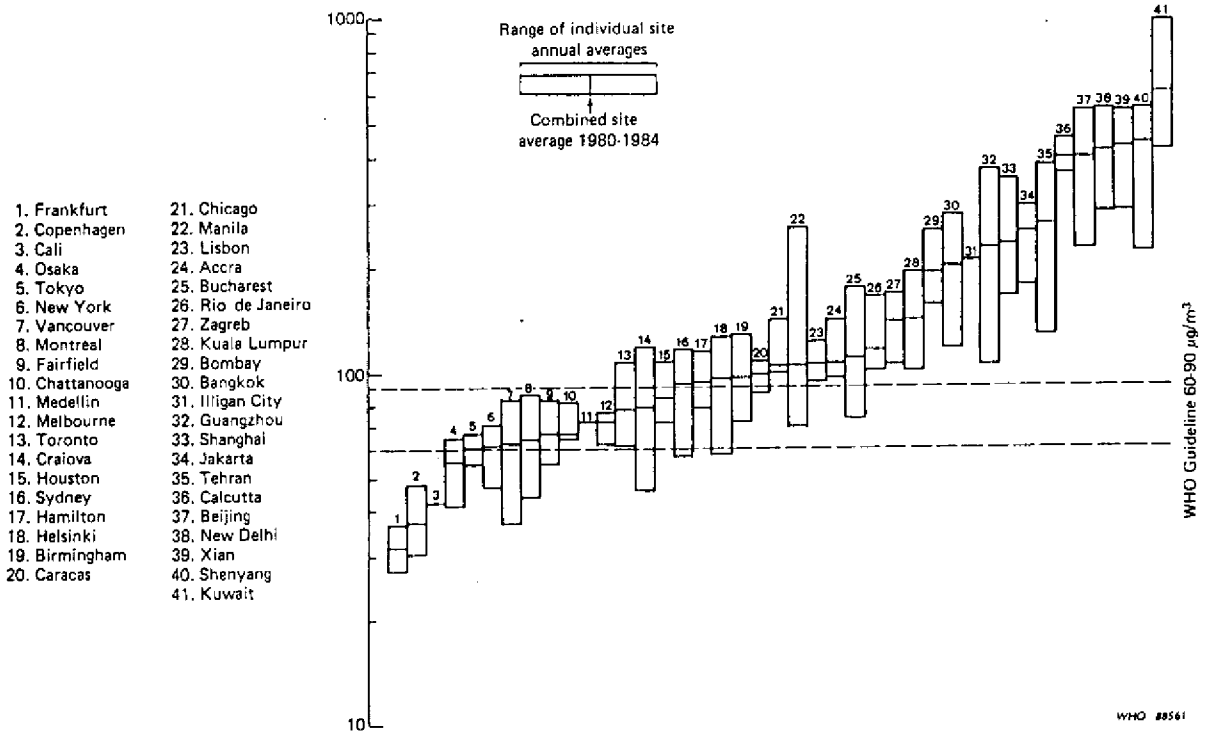
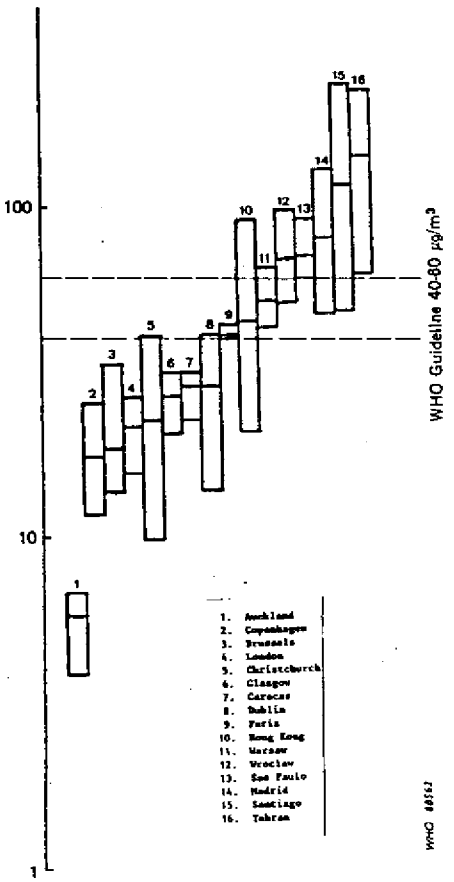


Figure 4.5 Summary of the annual smoke averages in GEMS/Air cities, 1980-84



Annual mean levels of SPM at individual sites range from 24 ug/m^3 to over 800 ug/m^3 and from 4 ug/m^3 to more than 200 ug/m^3 for smoke. For most cities average 1980-84 SPM values are between 55 and 115 ug/m^3. The most commonly occurring average values for smoke are between 15 and 55 ug/m^3. About one third of cities monitoring either SPM or smoke have levels higher than these, with maximum average values of 603 ug/m^3 and 140 ug/m^3 respectively. The distributions of 1980-84 values for SPM and smoke in cities are shown in Figures 4.6 and 4.7.

Figure 4.6 Distribution of 1980-84 average SPM levels

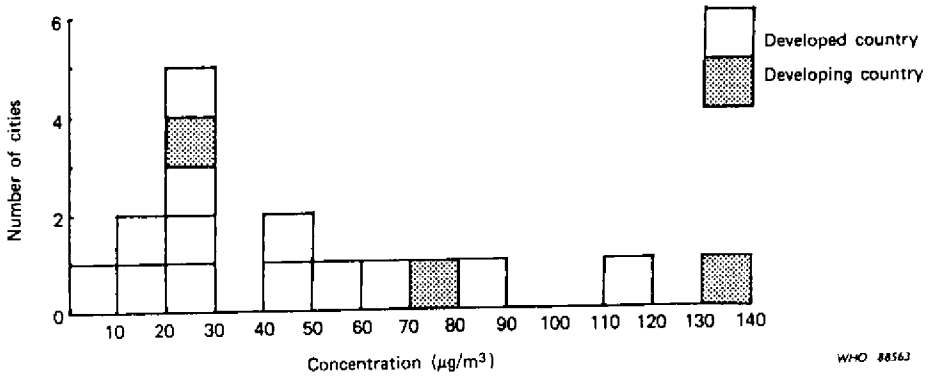
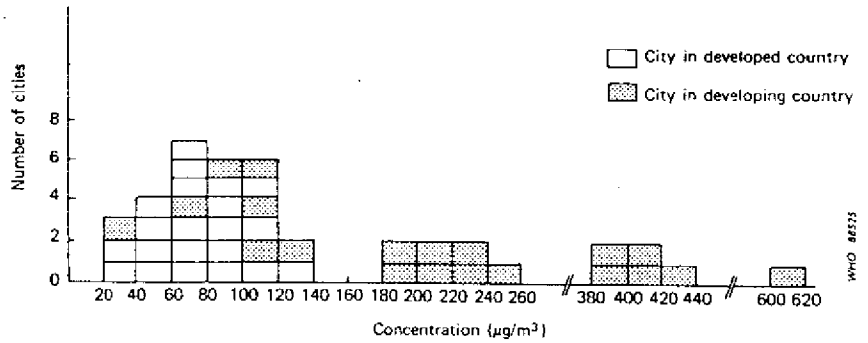


Figure 4.7 Distribution of 1980-84 average smoke levels



Cities with the highest particulate concentrations tend to be in the developing regions. In some cases this is partially caused by much higher levels of naturally occurring dust.

4.6 Comparison with guidelines

The severity of particulate pollution problems may be judged by comparing the observed air quality concentrations with health based guidelines established by WHO (1979) for both smoke and gravimetrically determined SPM. These were based on joint exposures to SO_2 and suspended particulate matter, as mentioned in section 3.5 above. To avoid risks of acute effects from short-term exposures the guidelines specify a range of 100-150 ug/m^3 for smoke, and a range for SPM, as measured by high volume sampler, of 150-230 ug/m^3, each being interpreted as the 98 percentile* of daily average concentrations. The corresponding guidelines in respect of chronic effects related to long-term exposures are 40-60 ug/m^3 for smoke and 60-90 ug/m^3 for SPM. An evaluation of the global situation during the 1980-84 period with respect to WHO's guidelines is given in Table 4.1. Cities below the guideline ranges are regarded as having acceptable air quality conditions, those within are said to be marginal and cities exceeding the guidelines are considered as having unacceptable air quality.

Table 4.1 Air quality in cities with reference to WHO SPM and smoke guidelines

Air quality conditions	SPM Number of cities				Smoke Number of cities			
	Annual average		P98 levels*		Annual average		P98 levels*	
Acceptable	7	(17%)	10	(24%)	8	(50%)	5	(31%)
Marginal	10	(24%)	9	(22%)	3	(19%)	4	(25%)
Unacceptable	24	(59%)	22	(54%)	5	(31%)	7	(44%)

Inspection of Table 4.1 indicates a large proportion of the cities in the GEMS/Air network have unacceptably high particulate levels. For SPM, 54% of all cities simultaneously exceed the guidelines for both the yearly average and 98 percentile levels, whilst only 12% of all cities have both these values below the WHO guidelines. With respect to smoke, 31% of all cities simultaneously exceed both guidelines although another 31% record both levels below the guidelines.

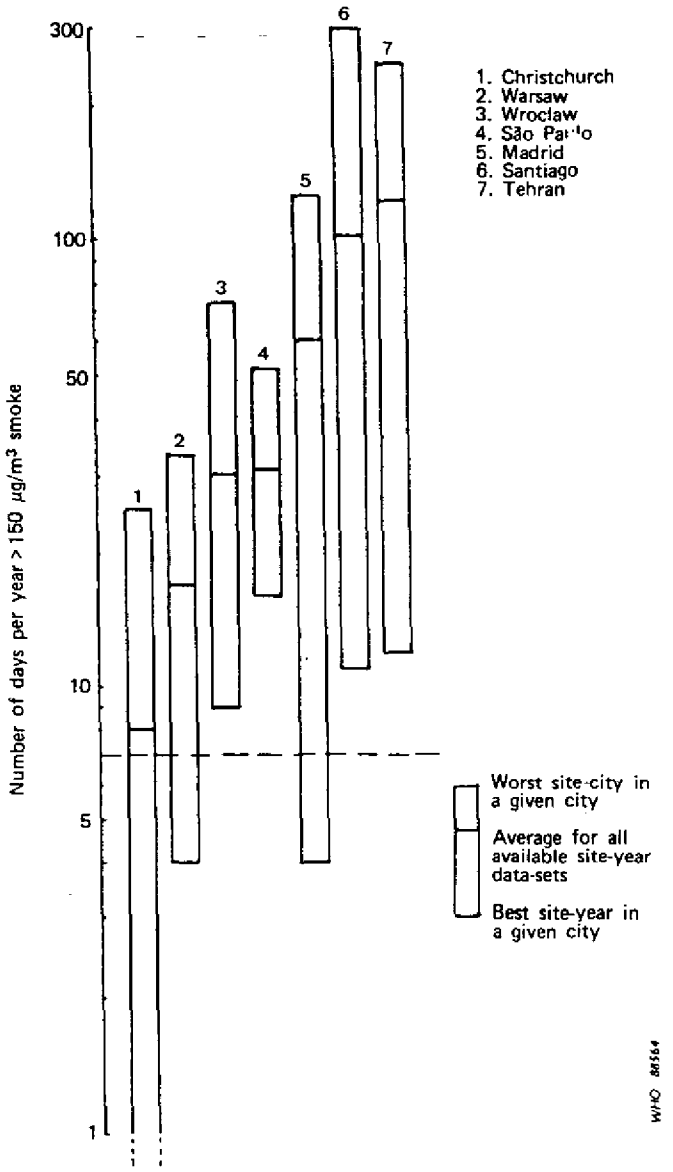
This situation initially appears to be worse than the corresponding air quality data for SO_2. However, it should be stressed that most of the cities with the highest particulate levels are in areas where natural wind blown dusts make a major contribution to the urban aerosol. Most human health concern is centred around respirable (less than 10 um) particles , derived largely from combustion processes, which may contain potentially toxic pollutants such as polycyclic aromatic hydrocarbons and trace metals.

*The 98 percentile (or P98) value stipulates that 98% of the daily averages must be below or alternatively only 2%, or 7 days in the year, may exceed a guideline value.

4.7 Evaluation of high pollution days

Table 4.1 shows that about 50 percent of the cities exceed the 98 percentile guideline. This means that in such cities high pollution levels occur more frequently than is desirable. The extent and severity of the situation is assessed by analyzing the actual number of days at which the limit of 150 ug/m^3 for smoke or 230 ug/m^3 for SPM is exceeded. The results of this analysis are given in tables 2 and 3 of Appendix III. A summary of these tables is presented in figures 4.8 and 4.9.

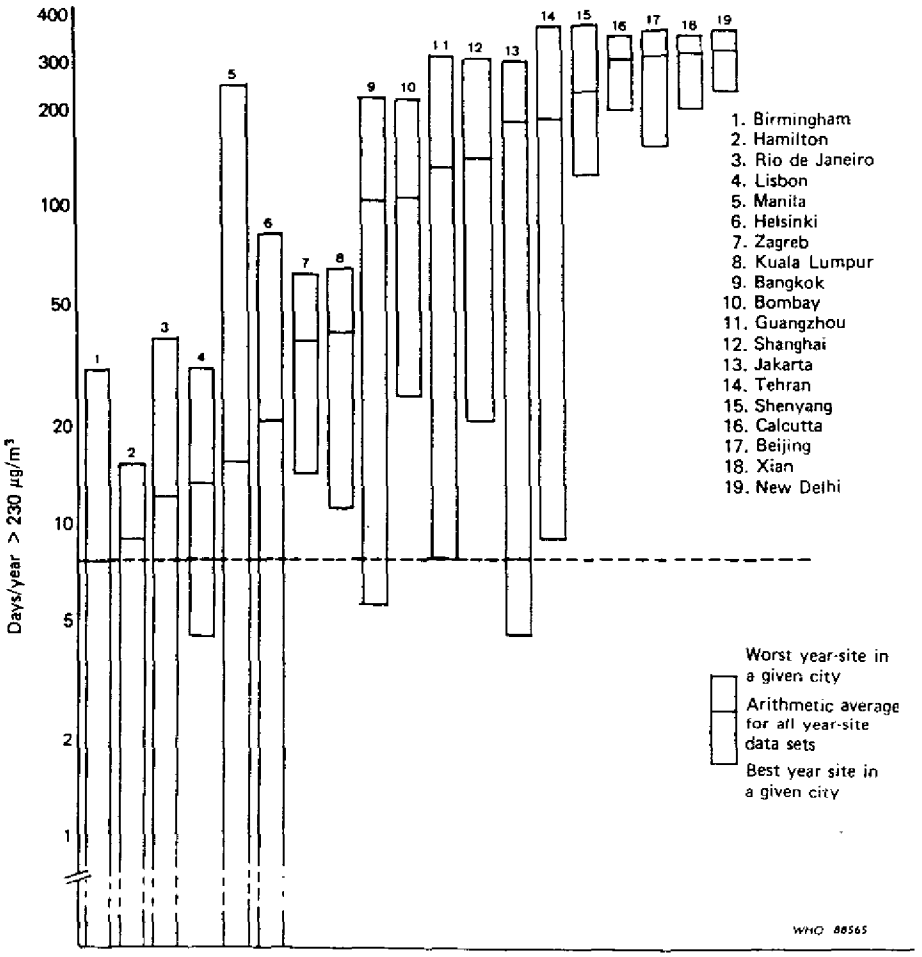
Figure 4.8 Exceedances of the 98 percentile guideline value for smoke, 1980-84. This refers to cities which, on average, exceed the 150 ug/m^3 limit more than 7 days/year



For some site-year combinations exceedances from around 10 days per year up to almost 300 days per year were recorded. City-wide yearly average exceedances even reach 100 days in two cities. In these two cities and also in two others, periods of more than 7 days above the 150 ug/m^3 level were noted every year in each of the sites for which data were reported.

The data for gravimetrically determined SPM levels as presented in Figure 4.9 reveal a similar situation. Ten cities had periods of more than 7 days above 230 ug/m^3 every year at each of their sites. Five of these cities even exceeded the 230 ug/m^3 level for more than 100 days every year, although it must be stressed that natural windblown dust may influence these measurements.

Figure 4.9 Exceedances of the 98 percentile guideline value for SPM, 1980-84. This refers to cities which, on average, exceed the 230 ug/m^3 more than 7 days/year.



4.8 Estimation of population exposed

This section presents an estimation of the number of persons worldwide exposed to different air quality conditions for particulates. In this calculation, the two forms of measurement have been combined. The proportions of the population in the GEMS/Air cities exposed to SPM or smoke levels below, within or above the WHO guideline values were extrapolated to an equivalent global urban population of 1.8 billion. Table 4.2 presents the results of this analysis.

Table 4.2 Estimates of populations residing in urban areas of given air quality

Air quality conditions SPM & smoke concentrations	Number of persons (millions)	
	Annual average	P98 levels
Acceptable	350	275
Marginal	200	275
Unacceptable	1250	1250

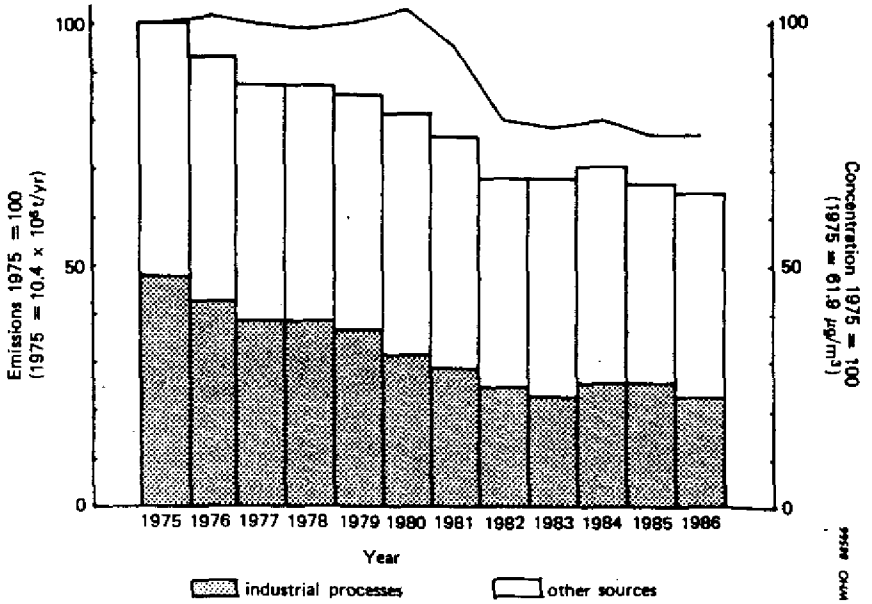
The situation reflects that of Table 4.1 in that the majority of urban populations reside in cities where particulate levels are considered to be unacceptablly high. Less than 20% of people living in cities are exposed to air quality conditions regarded as acceptable. Although it is known that in some cities high particulate levels are in part due to natural wind-blown dusts, clearly many cities require more effective control strategies to reduce the number of people 'at risk' from exposure to particulates.

4.9 Case studies from individual countries

4.9.1 The United States of America

Trends in particulate emissions in the U.S.A. are illustrated in figure 4.10. During the 10-year period 1975-1984 particulate emissions from human activities have fallen from 10.4 x 10^6t/yr to 7 x 10^6/yr, a decrease of 33%. The greatest emissions reductions have been achieved in the industrial sector, following the installation of more efficient particulate control equipment and a decline in industrial activity (EPA 1986). Emissions from other sources such as transport, fossil fuel combustion and waste incineration have, in contrast, remained relatively constant.

Figure 4.10 National suspended particulate emissions and annual average concentrations in the USA



Levels of suspended particulate matter (SPM) in urban areas have similarly declined during the 1975-1984 period. Trends in average SPM concentrations for 1344 urban monitoring stations distributed throughout the U.S.A. are also shown in Figure 4.10. Despite uncertainty in the data collected during the period 1979-1981, the long-term downward trend of 19% for 1975-1984 is considered valid (EPA 1986).

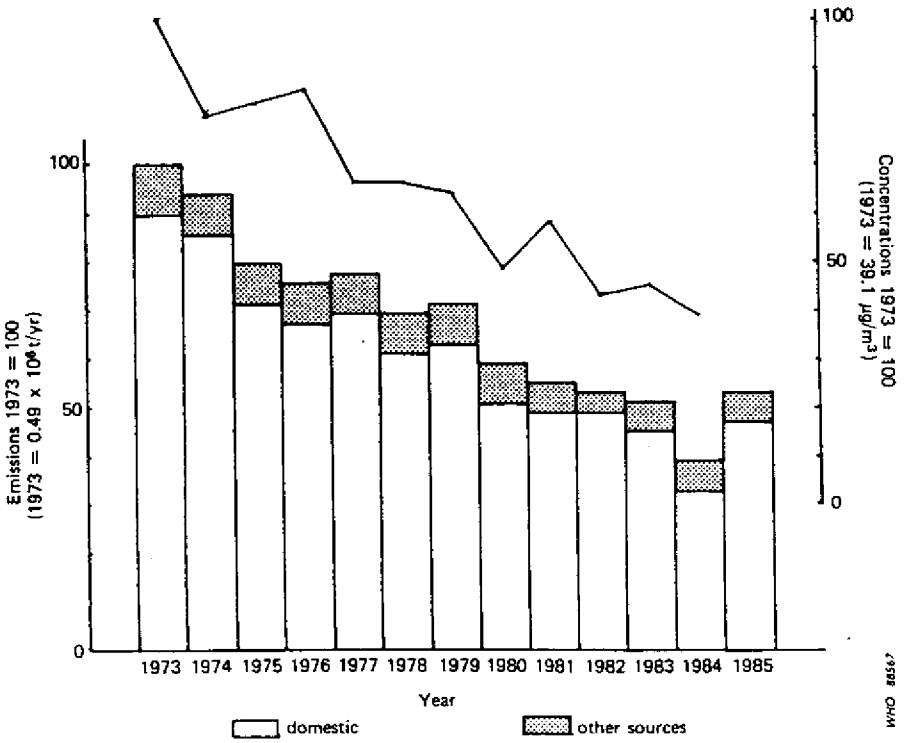
The US EPA considers it unlikely that the improvement in ambient particulate levels observed in urban areas is due entirely to emission reductions. The decrease in SPM in 1982 and 1983 for example, is attributed, in part, to greater than average precipitation in those years. Rainfall has the effect of minimizing fugitive dust releases and washing particles out of the air. In 1984, average SPM levels again increased following a return to more normal levels of rainfall.

4.9.2 The United Kingdom

Figure 4.11 illustrates a steep downward trend in 'smoke' emissions from coal combustion sources in the U.K. since the 1970s. The 47% reduction in emissions between 1973 and 1985 is generally attributed to the introduction of the Clean Air Acts in 1956 and 1968 which require that only smokeless fuels be burnt for domestic heating purposes in defined urban areas and that nationally all industrial and commercial installations should operate smokelessly.

There are now over 6000 smoke control orders operating in the U.K. covering over 50% of urban areas (Department of the Environment 1986). Adoption of these measures has resulted in similar reductions in annual average smoke concentrations in the majority of urban areas in the U.K. Ambient smoke levels have fallen by over 61% since 1973 and are currently below the WHO guidelines (Figure 4.11)

Figure 4.11 Smoke emissions from coal combustion and annual average urban concentrations, United Kingdom



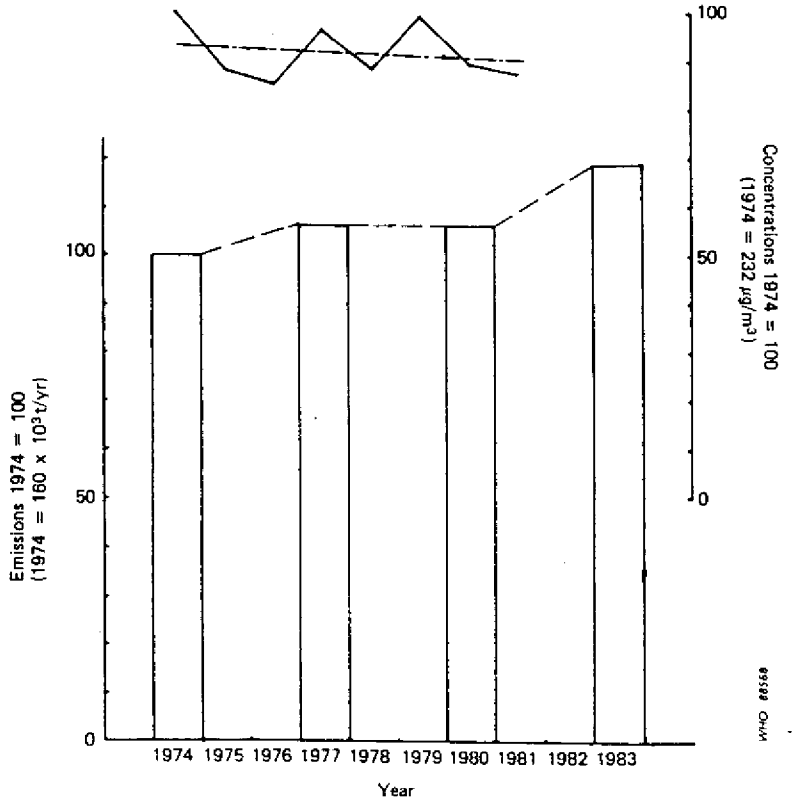
In contrast to the decrease in coal use in the domestic sector, consumption of coal in power plants has remained relatively stable during the past decade. However, power generating stations make only a small contribution to the total emissions of particulate matter. The electrostatic precipitators installed in U.K. coal-fired plants have a high efficiency of particulate removal.

Recently, increasing attention has been given to the rising contribution of diesel engined vehicles to particulate emissions, both in the U.K. and in other European and North American countries. Diesel engines emit less carbon monoxide and hydrocarbons than petrol-engined vehicles but over ten times the amount of total particulate matter. The majority (80%-96%) of the particulates emitted are in the submicron range (OECD 1986).

4.9.3 Greece

Although SO_2 emissions have declined in Greece since the mid-70s, following the introduction of limits on the sulphur content of fuels, emissions of particulates have increased (Figure 4.12). National emission data indicate an increase of approximately 20% over the period 1974-1983. Growth in industrial activity and traffic levels without significant emission controls are likely to have been responsible for the increase (CEC 1987).

Figure 4.12 National suspended particulate emissions and annual average concentrations in Greece



The absence of stringent control measures for particulates is reflected by the high ambient particulate levels in Athens. Levels at all 3 monitoring cities have remained relatively constant during this period and are well in excess of WHO recommended guidelines. However, when averaged and expressed as a percentage of 1974 values, as in Figure 4.12 there is a slight tendency towards a decline in concentrations, despite the rising emissions.

Concern over rising air pollution in Athens prompted the Government to introduce control measures in 1981. Stack emission standards were adopted for new power stations and selected industries. Steps have also been taken to improve the quality of fuel used in residential heating systems and vehicles.

Priority has been given to reducing peak levels of pollution. In 1982 short-term emergency procedures aimed at the prevention of worsening air pollution during days of unfavourable weather conditions were introduced (OECD 1983). These include:

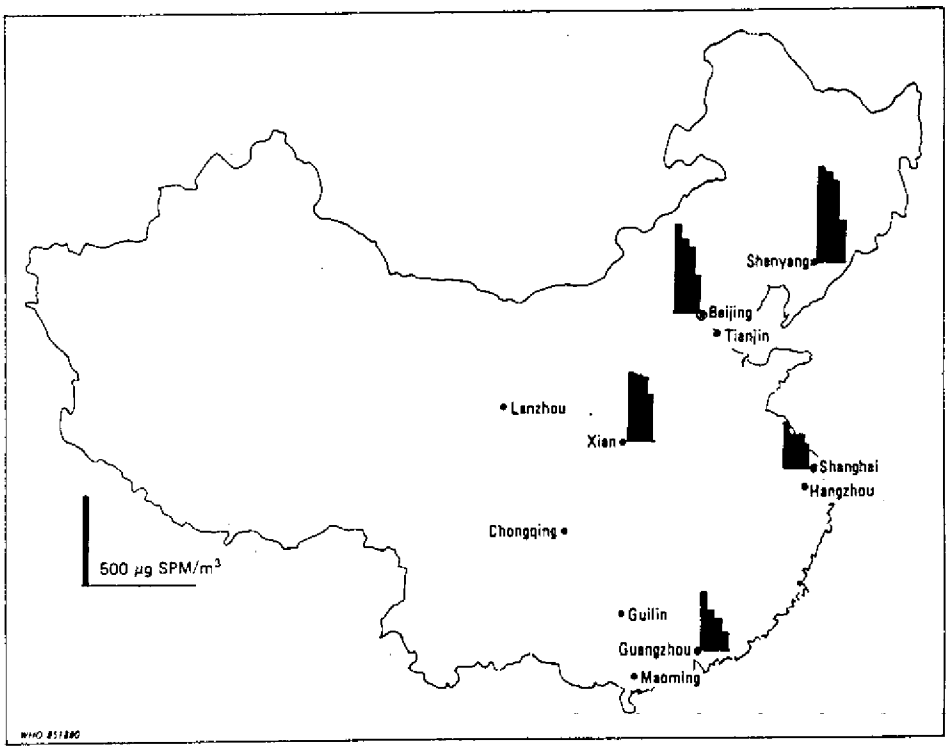
(i) reducing industrial emissions by cutting production by 30-40%.
(ii) shutting down space heating.
(iii) restrictions of vehicle use.

In the absence of more recent (post 1981) air quality data, assessment of the impact of the above control strategies is not yet possible.

4.9.4 China

Coal combustion which accounts for over 70% of the total energy production, is the principal source of the high levels of particulates observed in Chinese cities. Over half of the total coal consumed is burnt in medium-small sized furnaces with low smokestacks and in domestic stoves for cooking and heating purposes. The majority of coal burning units are outdated and inefficient, i.e. national average rate of energy utilization is only 28%. Control equipment for particulates is either lacking or in- efficient. (Yuanjun and Zhongxing 1987). Urban air problems are further exacerbated by the lack of zoning of activities in Chinese cities.

Figure 4.13 SPM levels in Chinese cities, 1983 (WHO 1985)



Levels of particulates in the 5 cities participating in the GEMS/Air Network are illustrated in Figure 4.13 for 1982/3. Concentrations of SPM in the northern cities (Shenyang, Xi'an and Beijing) are higher than those in the southern cities (Shanghai and Guanzhou). This is attributed to the higher level of industrial activity as well as contribution of natural wind-blown dust in the northern cities. Another reason is the greater quantity of coal consumed, especially in winter when the demand for space heating is greatest. It is estimated that in Beijing, particulates from coal burning and wind-blown dusts account for 40% and 60% respectively of the SPM

concentrations in the summer. In winter the relative contributions are reversed Analysis of the chemical composition of particulate matter from Beijing and Tianjin indicates the presence of relatively high levels of organic compounds, including the carcinogen benzo-pyrene (Zhao and Sun 1986).

In respect to the prevention and control of industrial pollution, the main emphasis has been placed on renovating old industrial processes and upgrading the utilization rate of energy. The more prosperous steel and petrochemical industries have made the greatest progress to date, installation of dust collection devices at Anshan steel works, for example, has reduced particulate emissions. In addition, adoption of energy conservation measures has meant that coal consumption per ton of steel produced has dropped by about 25%.

Reducing emissions from domestic stoves is more difficult because it involves transforming the traditional fuel use structure and the implementation of gas and electricity for heating and cooking. Since the early 1980s progress in this area has, however, been made. The number of urban households using gas for cooking has increased from 15% in 1980 to 22% in 1985. The proportion of urban areas served by district heating systems has also increased.

National emission data for particulates ("soot") are only available for recent years but they do suggest that emissions are declining. Thus between 1981 and 1983 emissions of particulates fell from 15.2 x 10^6t/yr to 13.4 x 10^6t/yr, a decrease of just over 10% (State Statistical Bureau 1985).

5. NITROGEN OXIDES

5.1 Sources and properties

Oxides of nitrogen (NO_x) are significant pollutants, both in urban environments and on a regional scale. One global inventory has estimated that a total of about 150 million tonnes NO_x are emitted to the atmosphere each year, divided equally between natural and man-made sources (Goldberg 1982). However, the accuracy of global inventories is uncertain because of the great difficulties in quantifying both natural emissions and releases from certain human activities such as biomass burning.

Natural sources of NO_x include releases from lightning, forest fires and soil microbial processes, but being globally distributed these create only low background values. In urban areas, man-made emissions dominate, producing elevated ambient levels. Worldwide, fossil fuel combustion accounts for about three-quarters of man-made NO_x emissions, divided equally between stationary sources, such as power stations, and mobile vehicular sources. These high temperature combustion processes emit the primary pollutant nitric oxide, NO, which is subsequently transformed to the secondary pollutant nitrogen dioxide NO_2 through photochemical oxidation.

Concern over NO_x as a pollutant is partly based on the potential human health effects of NO_2, a respiratory irritant. In addition, NO_x is an important precursor of other oxidants such as ozone, which is a major constituent of photochemical smog. Much of the NO_x from stationary sources sources is discharged through tall stacks and is thus subject to long-range transport. Following conversion to nitric acid, these discharges ultimately contribute to acid deposition in areas distant from the source.

Recently, attention has focused on the risk of indoor NO_x exposure arising from gas appliances, oil stoves and other combustion processes, a problem which is exacerbated by inadequate ventilation.

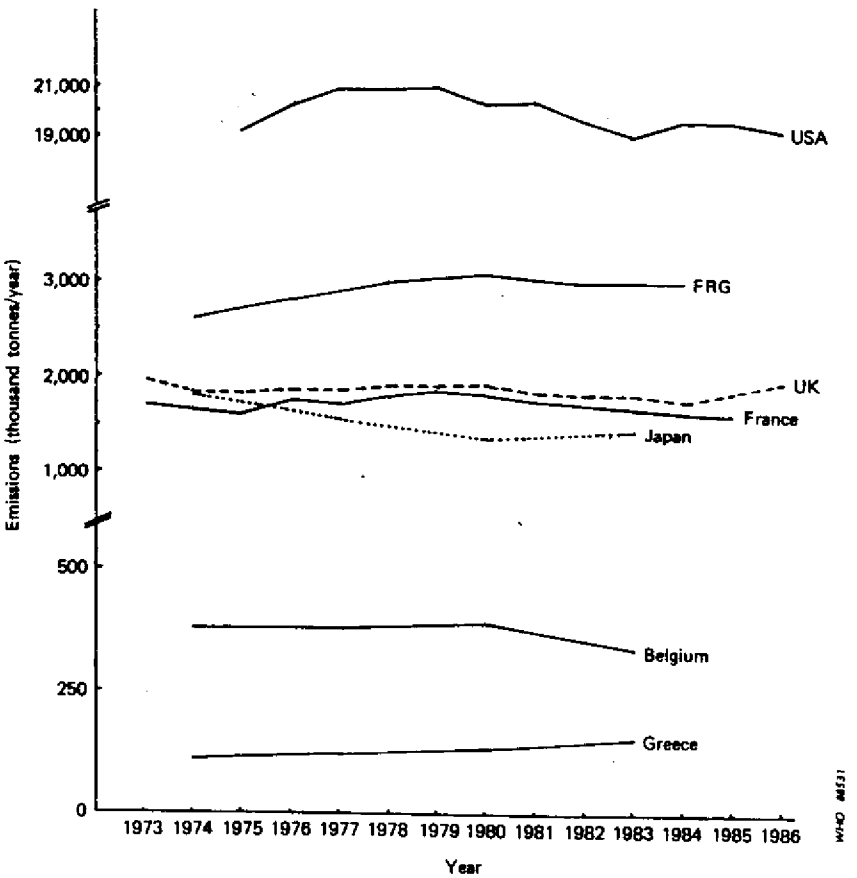
5.2 Trends in NO_x emissions

The problems involved in estimating man-made NO_x emissions on a global scale are also encountered at the national level so that comparisons between countries may be less reliable than trends within a country. Table 3 in Appendix II summarizes national NO_x emissions estimates between 1973 and 1984.

Average annual emissions reported during 1982-84 as shown in Table 3 in Appendix II amount to about 50% of the estimated global emissions from human activities. These emission estimates contain no data for the USSR, a country expected to be a major emitter of NO_x. Figure 5.1 illustrates the emission trends for a selected number of countries.

Despite increases in energy consumption, particularly in the vehicle sector, emissions of NO_x in many developed countries have remained fairly constant over the 1973-1984 period. In Japan, there has been an overall decline in NO_x emissions while in France, the Federal Republic of Germany and several other European countries there are indications of increasing emissions. Inspection of the emission estimates in Appendix II indicates that total NO_x emissions in the earliest period (1973-75) are similar to the total for the latest period (1982-84).

Figure 5.1 Trends of NO_x emissions in selected countries



Reductions in NO_x emissions from stationary sources have been achieved through modifications in the combustion process which include the use of low-NO_x burners, flue gas recirculation and/or a 2-stage combustion process. However, combustion modifications can only achieve limited reductions and attention has also focused on flue gas denitrification as an additional means to control NO_x emissions from stationary sources. Flue gas treatment, however, is a relatively costly option and is not yet widely applied, except in the case of Japan.

Japan, the first country to set emission standards for NO_x for stationary sources, places great importance on NO_x control. The use of low-NO_x combustion techniques is widespread in Japan but the stringent emission standards introduced by this country also necessitate flue gas treatment. By 1984 over 250 flue gas denitrification units had been installed in power plants and other combustion processes throughout Japan. The adoption of such policies is likely to be responsible, at least in part, for the 21% reduction in emissions between 1974 and 1983. In contrast, NO_x emissions from stationary sources in other industrial nations remain largely uncontrolled, although a number of countries are currently considering drawing up proposals for NO_x abatement.

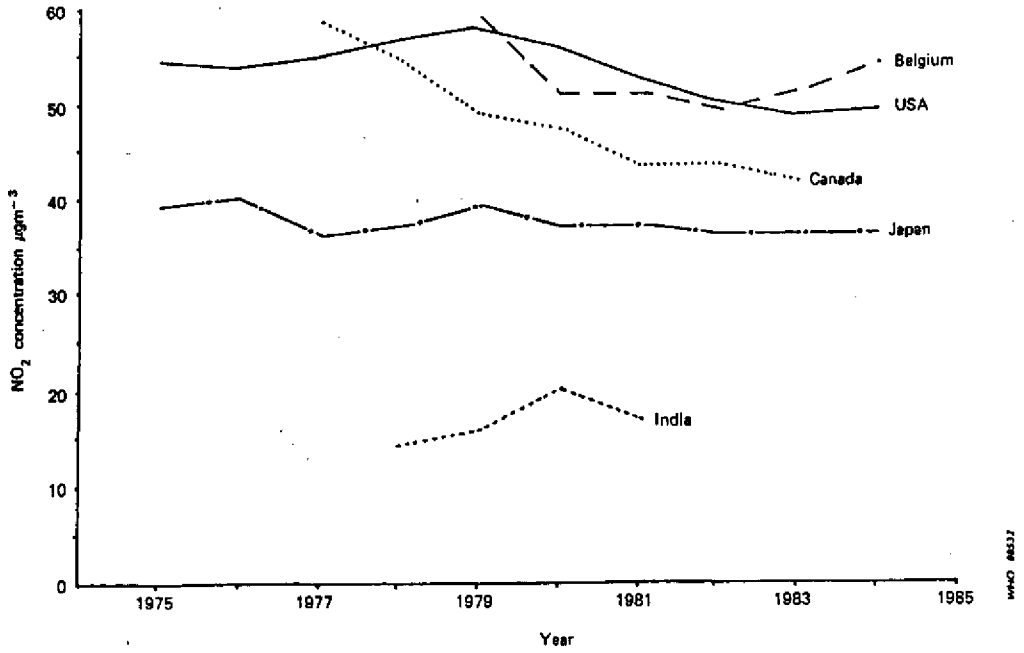
Since vehicle exhausts constitute a major source of NO_x in the urban atmosphere, the reduction from this source in emissions is widely viewed as the more effective option for reducing NO_x levels in cities. Emissions of NO_x from car exhausts may be reduced by up to 90% by the fitting of 3-way catalytic convertors (such devices also limit CO and hydrocarbon emissions). These convertors were first introduced in the late 1970s and are compulsory in new cars in Japan, the U.S.A., Canada and, since 1986, in Australia. In Japan, automobile exhaust emissions of NO_x from the new car fleet were reduced by 92% during the years 1972-1978 as a result of this policy (Environment Agency Japan 1986). In the U.S.A., the corresponding decrease in emissions from new petrol-engined vehicles over the period 1970-83 was 75%. However, these reductions in exhaust emissions have not made a significant impact on total NO_x emissions in the U.S.A., as shown in Figure 5.1.

5.3 Trends in ambient NO_2 levels

Analysis of the trends in urban concentrations is constrained by the lack of reliable long-term records for NO_2. In the majority of developed countries the database for NO_2 is limited compared with that for SO_2 and suspended particulate matter. In developing countries, where NO_2 monitoring has only recently begun, trend information is generally not available.

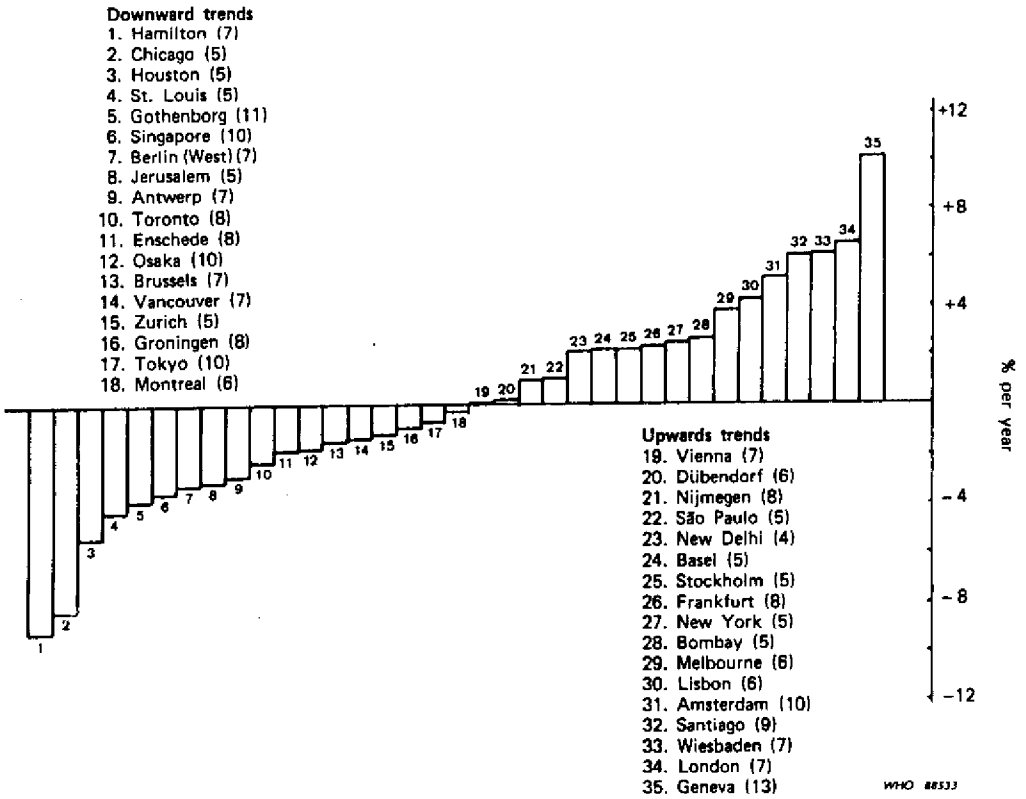
Fig. 5.2 shows the trends in NO_2 levels from selected countries, the data being based on the results of national urban monitoring networks. In Japan and the U.S.A., ambient NO_2 levels have remained relatively constant over the 10 year period, 1975-1985. Levels of NO_2 in Canadian cities appear to be decreasing. The database for India is too limited to ascertain any trend, but the much lower NO_2 values compared with the other countries in Fig. 5.2 are notable.

Figure 5.2 Trends in annual urban NO_2 levels in selected countries



Cities worldwide reporting at least five years of representative annual average values between 1973 and 1985 were assessed for overall trends in NO_2 levels. The results are shown in Figure 5.3.

Figure 5.3 Trends in annual average NO_2 concentrations in cities. (Values in brackets refer to the number of sampling years)



Initial inspection of Figure 5.2 indicates that the implementation of NO_x control strategies on mobile sources in both the USA and Japan and on stationary sources in Japan have failed to bring about improvements in air quality of the kind observed for SO_2 and suspended particulate matter. However, this static trend must be viewed against the large increases in vehicle numbers in these countries. Thus, between 1974 and 1983 the number of vehicle kms travelled increased by 28% in the U.S.A. and 54% in Japan. Therefore control strategies have made significant achievements, particularly in Japan albeit by preventing an increase in urban levels of NO_2.

Figure 5.3 indicates an upward trend for NO_2 levels in several of the larger European cities including London, Frankfurt and Amsterdam. Although patchy, these data correspond to the upward trends in emission of NO_x noted earlier in certain European countries. A breakdown of the emission data by sector, where available, reveals that the upward trends in these countries are caused by increased emissions from motor vehicles. This is particularly noticeable for the Federal Republic of Germany and The Netherlands (CEC 1987). Most European countries do not have the stringent vehicular emission standards of the U.S.A. and Japan. Some have relied on lean burn technology, but this achieves only limited reduction in NO_x emission. The European Commission has proposed NO_x emission standards for vehicles but these are less strict than those of the U.S.A. It remains to be seen whether these controls will bring about marked decreases in NO_x emissions and ambient levels, par- ticularly if motor vehicle densities continue to increase in the EEC.

Traffic planning and time zoning of industrial operations have also attempted to deal with the NO_x problem. Severe restrictions have been implemented in Athens, Greece where traffic is banned from the city centre at specified times and certain industrial operations are closed down in summer when pollution problems are at their worst.

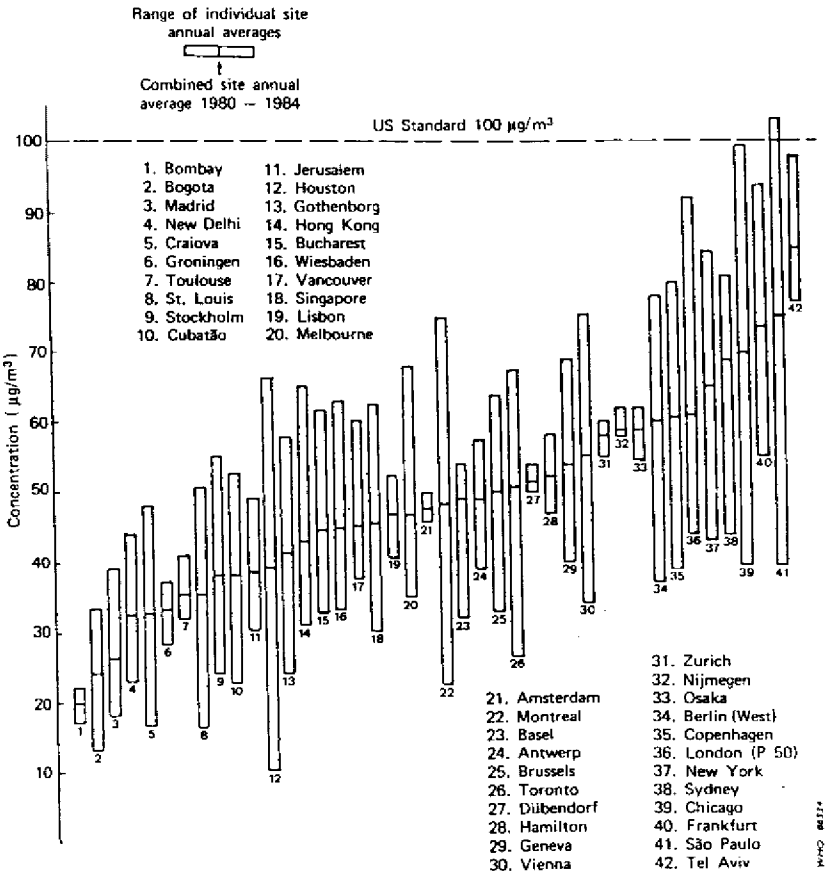
Although data are very scarce, it is probable that urban NO_x levels are increasing in the rapidly industrializing countries. Certainly, vehicle numbers have increased in recent years in Brazil, Chile, Hong Kong, and India (UNEP 1987). Figure 5.3 indicates increases in NO_2 levels in Bombay, Sao Paulo and Santiago. Hong Kong is considered separately as a case study (section 5.7.3). The situation may be exacerbated in developing countries by the relatively high numbers of old and poorly maintained vehicles which produce proportionately larger NO_x emissions.

It should not be assumed, however, that urban NO_2 levels are increasing in all rapidly industrializing countries. Figure 5.3 reveals, for example, that NO_2 levels in Singapore have declined markedly over the last 10 years, 1976-85.

5.4 NO_2 concentrations in cities

An overview of the NO_2 situation throughout the world can be obtained by comparing annual average levels available for 42 cities during the period 1980-84. The results are presented in Figure 5.4.

Figure 5.4 Summary of the annual NO_2 averages in cities 1980-1984. The horizontal line represents the National Air Quality Standard for NO_2 in the USA and Canada



This figure shows that the overall mean concentrations of NO_2 in all these cities range from about 20 to 90 ug/m^3. The variation in individual year averages is greater, with extremes of about 10 and 103 ug/m^3. Figure 5.4 reveals large differences between cities in the variability of average values over the five-year period. For example, cities numbered 31-33 show little difference over this period while cities numbered 12, 22, 39 and 41 display large inter-year variation. The reason for this situation is not clear but it may result from differences in the number and location of monitoring stations used within a particular city.

Cities of the developing and developed countries are found at both extremes of the concentration range in Figure 5.4. Thus, some of the lowest NO_2 values are reported from the two Indian cities Bombay and New Delhi, presumably because traffic levels are relatively low. However, St. Louis and Houston in the U.S.A. also have low NO_2 levels yet traffic density is expected to be high. At the other end of the range are Chicago and Sao Paulo. Once again, it is likely that the levels encountered in these two cities relate to the high traffic density although no evidence is available to confirm this. At this point, it should be borne in mind that little information is available on either the characteristics of the monitoring stations of the conditions within the cities shown in Figure 5.4.

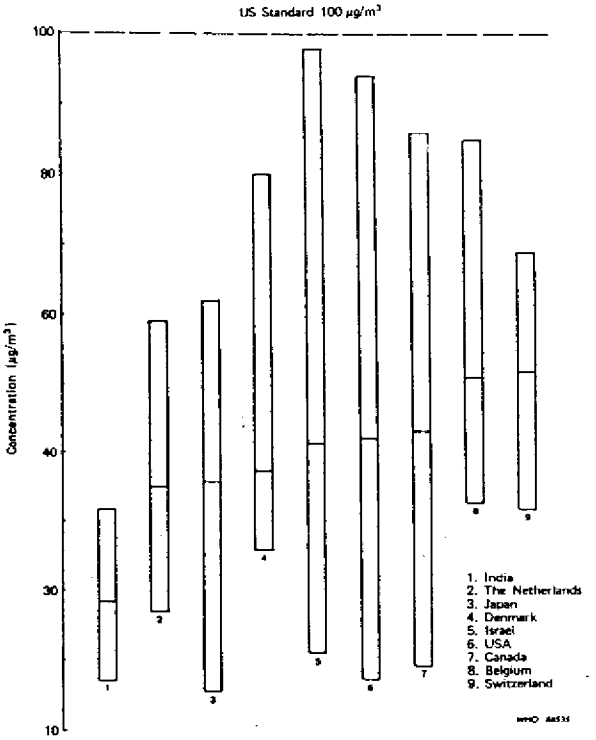
In particular, ambient levels of NO_2 can be profoundly affected by:-

(i) Local topography. The 'canyon' effect of tall buildings may bring about locally elevated roadside NO_2 levels.
(ii) Meteorological conditions. Temperature inversions over a city will reduce the mixing of air and lead to increased NO_2 levels.
(iii) Monitoring station location. Roof top stations consistently measure lower NO_2 levels than roadside stations. Similarly, stations next to roads with a low traffic density will obtain lower NO_2 levels than those in the vicinity of busy roads.

With few exceptions, the information noted above is not available for the cities and their monitoring station in Figure 5.4 Thus caution should be exercised when drawing comparisons between cities and linking the NO_2 levels found with vehicle emissions.

Some countries have nationwide urban monitoring networks for NO_2. For these nations, annual mean values of NO_2 averaged over the participating cities for the five-year period are shown in Figure 5.5. With the exception of India, the overall mean NO_2 levels are similar to one another and range between 35 and 50 ug/m^3. Annual averages for individual years are more variable with extremes of less than 10 ug/m^3 to almost 100 ug/m^3.

Figure 5.5 Summary of the national annual NO_2 averages in urban areas 1980-84. The horizontal line represents the National Air Quality Standard for NO_2 in the USA and Canada



Maximum daily and hourly values of NO_2 are also reported for a small number of cities and are summarized in Figures 5.6 and 5.7 respectively. The log scale (which tends to "compress" high values) on the vertical axis should be noted in both figures.

Figure 5.6 Summary of annual maximum daily NO_2 averages in cities 1980-84. The horizontal line represents the WHO 24-hr guideline value

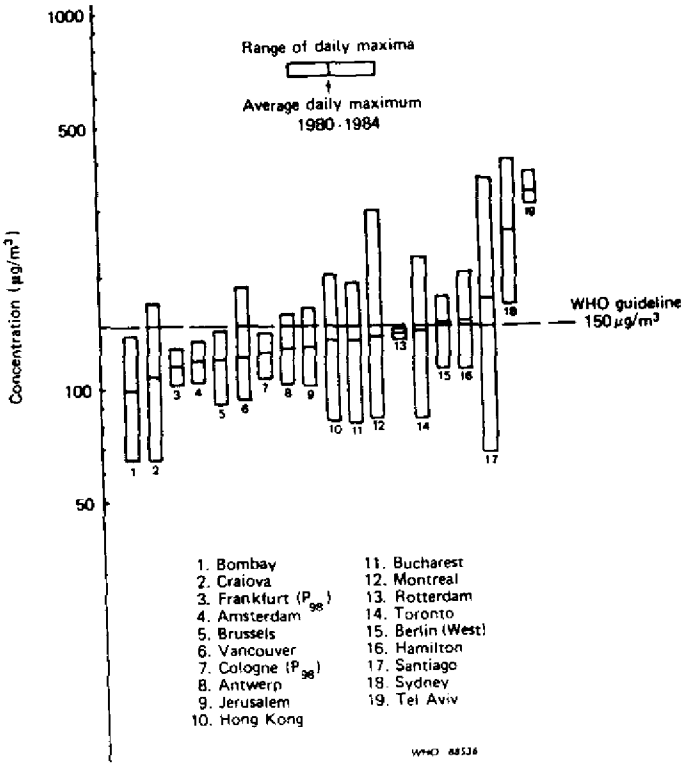
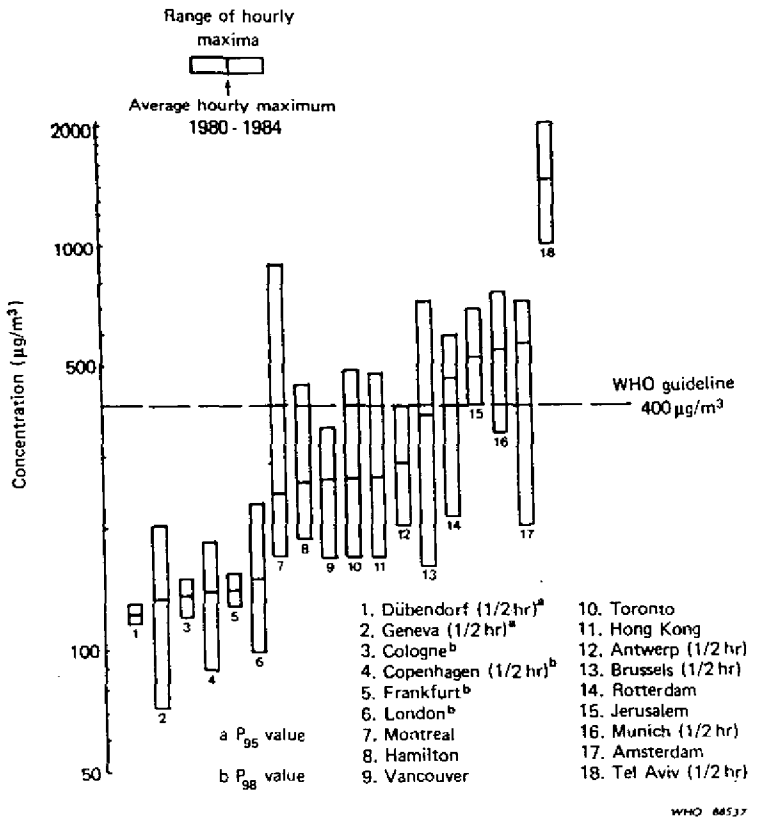


Figure 5.7 Summary of maximum hourly NO_2 averages in cities, 1980-1984. The horizontal line represents the WHO 1-hr guideline value



The maximum daily average NO_2 levels are commonly between 100 and 200 ug/m^3 with concentrations at individual sites ranging from 60 to 400 ug/m^3. Maximum hourly (or half-hourly) values show more variability, with average values typically between 100 and 600 ug/m^3 and levels at individual sites ranging from 70 to 2,100 ug/m^3.

A characteristic diurnal pattern of NO_2 concentrations is observed in many major cities throughout the world with high traffic densities. Two peaks in daily NO_2 concentrations which correspond roughly to rush-hour traffic emissions are superimposed on an urban background level of NO_2. Maximum hourly mean values of NO_2 may typically be 3-10 times the annual mean concentrations (WHO 1987). Seasonal variations in NO_2 concentrations and other pollutants are also apparent in some cities. In temperate regions, for example, there is a marked peak in NO_2 levels during winter months due to greater demands for energy, slower traffic and less favourable meteorological conditions.

5.5 Comparison with guidelines

The WHO has not specified an annual mean guideline value for NO_2 because the data from studies of long-term NO_2 exposure were not considered sufficient (WHO 1987). Annual National Air Quality Standards for NO_2 of 100 ug/m^3 have, however, been set in the U.S.A. and Canada. Nearly all of the cities for which data are available are below this value. However, Figure 5.4 shows that some sites in several cities did approach this limit and in Sao Paulo it was exceeded in some years.

The proposed EC Air Quality Standards for NO_2 includes a "guide value" of 50 ug/m^3. It is evident from Figure 5.4 that most cities contain monitoring stations where this value is exceeded. It should, however, be stressed that this guide value has been set with the intention of long-term protection of the environment rather than the protection of human health alone.

Based on observations of adverse effects on pulmonary function in asthmatics, WHO has recently recommended that 1-hour and 24-hour guideline values of 400 ug/m^3 and 150 ug/m^3 NO_2 respectively should not be exceeded (WHO 1987). These values were exceeded at a significant number of sites during the period 1980-84 in cities where NO_2 data averaged over these periods are available. The significance of such peak concentrations to health is of concern, as it is considered that repeated exposure to intermittently high concentrations contributes more to the toxicity of NO_2 than the total dose (WHO 1987).

Worldwide, fewer cities are regularly monitoring urban NO_2 levels than those of SO_2 or SPM. Of the 18 cities reporting maximum hourly values, nearly all are in Europe or North America. The average maximum 1-hour (Figure 5.7) value for each city over the five year period exceeded the guideline in five cities, or 28% of the sample.

Of the 19 cities worldwide reporting maximum daily NO_2 levels, five cities (26%) reported average values over the five year period which exceeded the 24-hour guideline.

5.6 Estimation of population exposures

The data presented in figures 5.4 to 5.7 showing NO_2 concentrations in different cities and countries are mainly from the industrialized world. It is therefore not possible to draw global conclusions with regard to the proportions of populations exposed to levels of NO_2 above the guidelines. Also, the data that are presented came from a variety of different sampling sites, the characteristics of which are not always precisely known.

It is nevertheless possible to draw some very tentative conclusions with regard to urban populations in North America and Europe as follows:

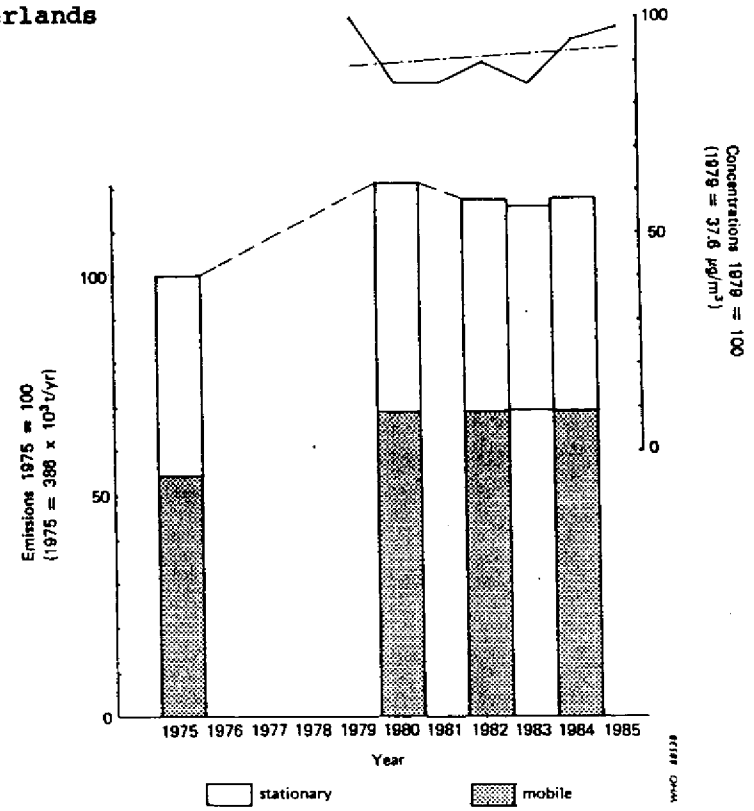
- long-term exposure of urban populations, as evaluated by annual averages, remains well below 100 ug/m^3, the USA and Canadian standard;
- short-term exposures of urban populations, as evaluated by 24-hour and 1-hour maxima, exceed the relevant WHO guideline values in about 25-30% of the cities surveyed;
- based on the proportion of NO_2 concentrations above and below the WHO short-term guideline values in the cities surveyed, it is estimated that approximately 15-20 percent of urban residents in North America and Europe are at increased risk to short-term high NO_2 exposures.

5.7 Case studies from individual countries

5.7.1 The Netherlands

Emissions of nitrogen oxides in The Netherlands (Figure 5.8) have increased by 18% over the 10 year period, 1975-1984 (Staatsuitgeverij Yearbook 1985). This rising trend is largely due to increases in emissions from mobile sources which rose by 27% (i.e. from 210 x 10^3t/yr to 267 x 10^3t/yr) between 1975 and 1984.

Figure 5.8 National NO_x emissions and urban NO_2 concentrations in the Netherlands

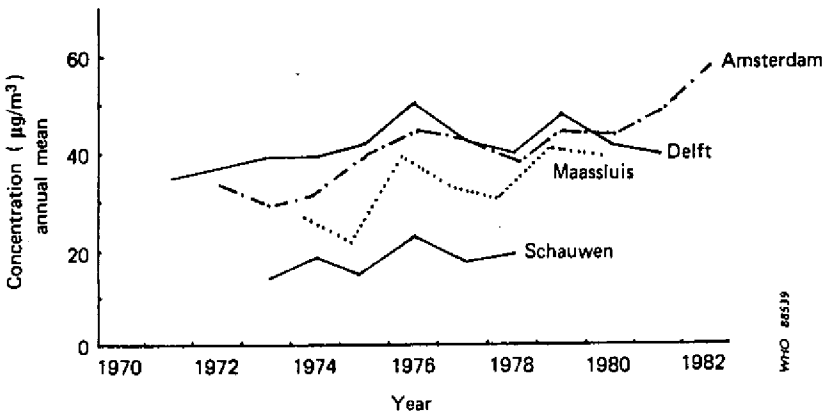


The national air quality monitoring network in The Netherlands classifies its stations into "general" and "traffic influenced" for the purpose of reporting NO_2 data. In general, levels of NO_2 at "traffic influenced" sites are approximately twice those at stations reflecting urban background NO_2 levels. Figure 5.8 shows trends in values averaged over all "general" reporting sites, indicating little change over the period 1979-1985. However, data from a number of individual cities and towns, for example Amsterdam and Maassluis, show a trend of rising NO_2 levels, presumably due to increases in vehicle numbers and emissions (Figure 5.9).

Emission standards for vehicles in The Netherlands are in agreement with the current EEC regulations. From October 1988 however, much stricter limits for passenger cars will come into force.

Emissions of NO_2 from stationary sources at present are uncontrolled. Over the past two decades emissions of SO_2 and NO_x have, however, been reduced by increasing the consumption of natural gas, while reducing dependence on coal and oil.

Figure 5.9 Trends in NO_2 levels in selected cities of The Netherlands (CEC 1986)

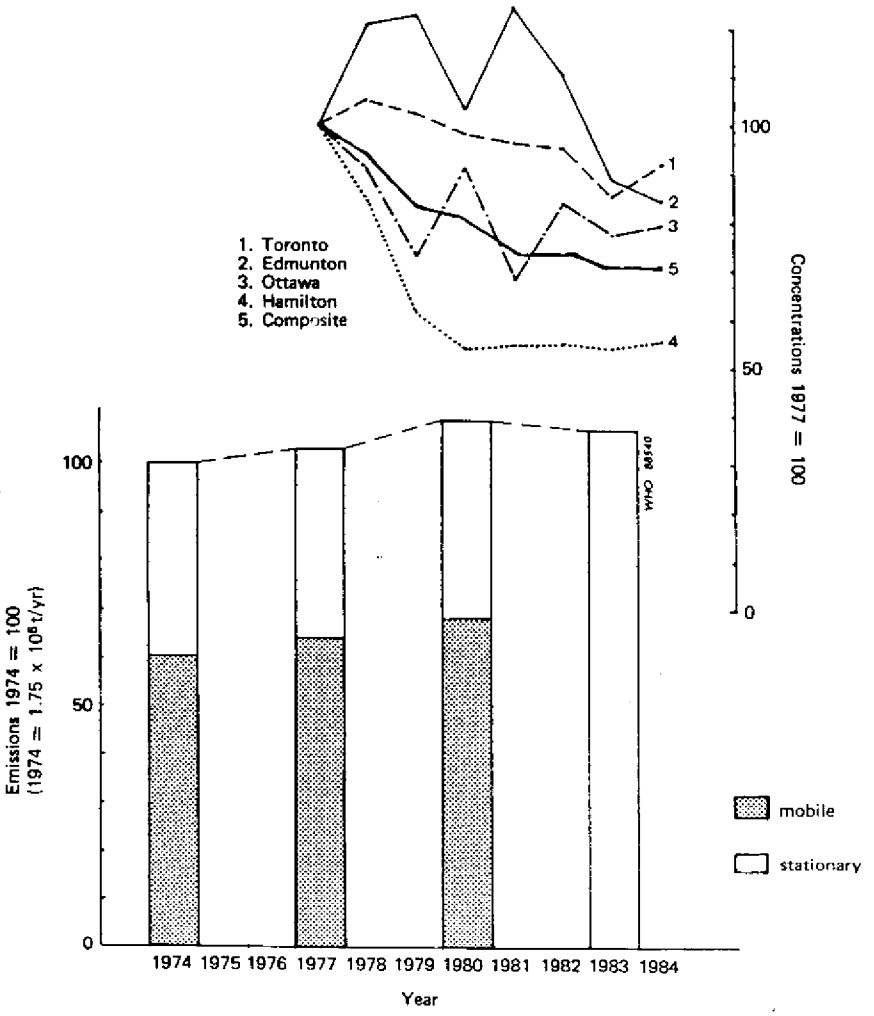


5.7.2 Canada

Trends in emissions of nitrogen oxides from Canadian sources for the decade 1974-1983 are illustrated in Figure 5.10. The data indicate that emissions have slightly increased throughout the 1970s with a total increase of about 7% in the 11-year period. Mobile source emissions have risen at the faster rate of 36% during this time. A growing vehicle fleet is responsible for this trend, the number of light duty vehicles for example, increased by 34% between the years 1973-1982 (OECD 1986).

Emissions from stationary fuel combustion sources have increased by approximately 20% between 1970 and 1980. This increase is largely due to rising emissions (60%) from electric utilities. In contrast, emissions from residential and commercial combustion sources have declined by 15%. This reflects changes in fuel use patterns, such as an increased use of electricity for domestic heating.

Figure 5.10 National NO_x emissions and annual average NO_2 concentrations in Canada



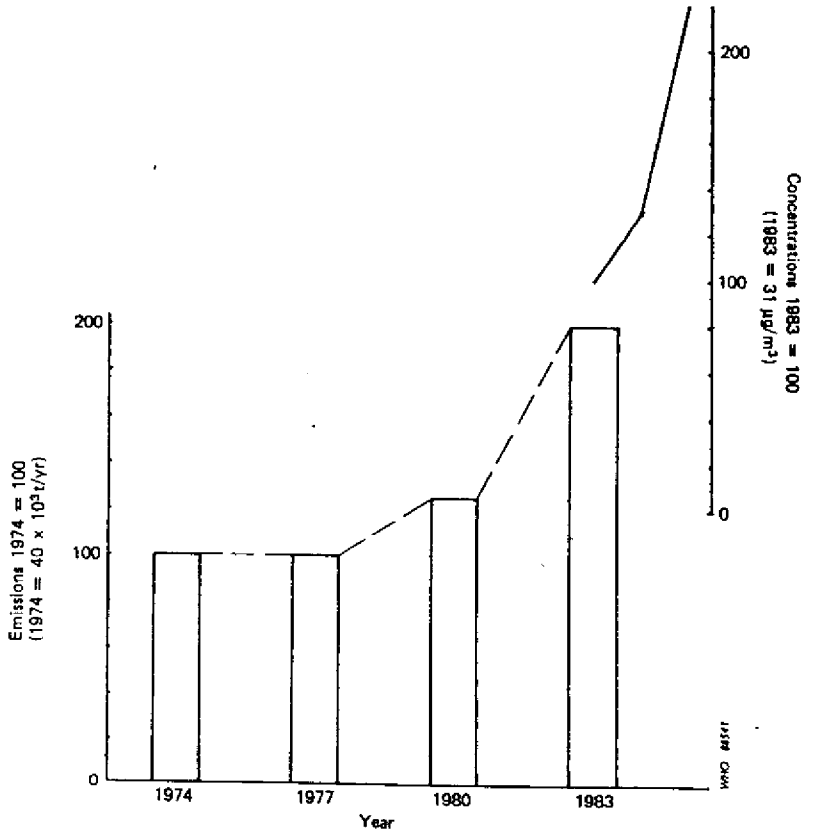
Reliable NO_2 monitoring data are available from 1977 onwards. Trends in ambient NO_2 levels averaged over the National Air Pollution Surveillance (NAPS) network for the period 1977-1984 are shown in Figure 5.10. In contrast to the situation in the majority of other countries, urban levels of NO_2 appear to be declining in Canada. Annual mean levels fell by nearly 30% from 58 ug/m^3 in 1977 to 41 ug/m^3 in 1984. Downward trends are also observed in maximum 24-hr and 1-hr average NO_2 levels. In 1977, 16% of the monitoring stations exceeded the 24-hour standard of 200 ug/m^3 compared with only 8% in 1983 (Environment Canada 1986).

Control strategies for NO_x in Canada focus on mobile sources. Emissions from stationary sources are largely unregulated, but switching from coal and oil to other fuels are considered to be responsible for the observed decreases in urban NO_2 levels (Environment Canada 1987).

5.7.3 Hong Kong

NO_x emission trends for Hong Kong are shown in Figure 5.11. A doubling of emissions between 1974 and 1983, from 40 x 10^3t/yr to 80 x 10^3t/yr is apparent. Over a similar time period, vehicle numbers have increased from 39 to 53 per 1000 population, or by 36%. Vehicle kilometres travelled have risen more dramatically, increasing by 69% during 1974-1984 (UNEP 1987). Emissions from stationary sources are also likely to have increased as the consumption of fossil fuels (oil and coal) has increased by 23% from 1981-1984 (UN 1986).

Figure 5.11 National NO_x emissions and annual average NO_2 concentrations in Hong Kong



As monitoring of NO_2 levels in Hong Kong only began in 1983, trends are difficult to evaluate. On the basis of 3 years data from a single rooftop site, 1983-1985, however, it appears that NO_2 concentrations may be increasing (Figure 5.11).

6. CARBON MONOXIDE

6.1 Sources and properties

Carbon monoxide (CO) is one of the most widely distributed air pollutants. It is formed by natural biological and oxidation processes, the incomplete combustion of carbon-containing fuels and various industrial processes.

By far the largest individual source of man-made emissions is motor vehicle exhausts which account for virtually all CO emitted in some urban environments. CO is also an important indoor pollutant, being released from domestic combustion appliances particularly when the air supply is inadequate. In developing countries where biomass fuels are commonly used for cooking and heating, indoor exposure to CO, particularly amongst women and children, may be especially high.

Global emissions of CO probably exceed the combined emissions of all other major air pollutants, but the amount released from natural sources is very uncertain. It is also difficult to establish global man-made emissions with estimates ranging from 300 to 1,600 million tonnes per year (Jaffe 1973, Logan et al. 1981). If emissions from human activities such as forest clearing, burning of fuel wood, savannah burning and the oxidation of man-made sources of hydrocarbons (mainly methane) are included, a quantity towards the upper end of the range is obtained. This is estimated to be approximately 60% of total global CO emissions.

The high affinity of inhaled CO for haemoglobin to form carboxyhaemoglobin restricts oxygen binding and transport in the blood and may lead to adverse neurobehavioural and cardiovascular effects. With moderate exposures these are short-term and reversible, but high exposures that may occur accidentally in closed environments can lead to permanent impairment or death.

6.2 Trends in CO emissions

Since man-made emissions of CO are dominated by releases from motor vehicles, it is considered that global emissions have risen along with the rapid growth in vehicle numbers since the 1940s. In the U.S.A., for example, the number of motor vehicles increased fourfold between 1940 and 1970 whilst CO emissions rose from 73 to more than 100 million tonnes per year over the same period (EPA 1973).

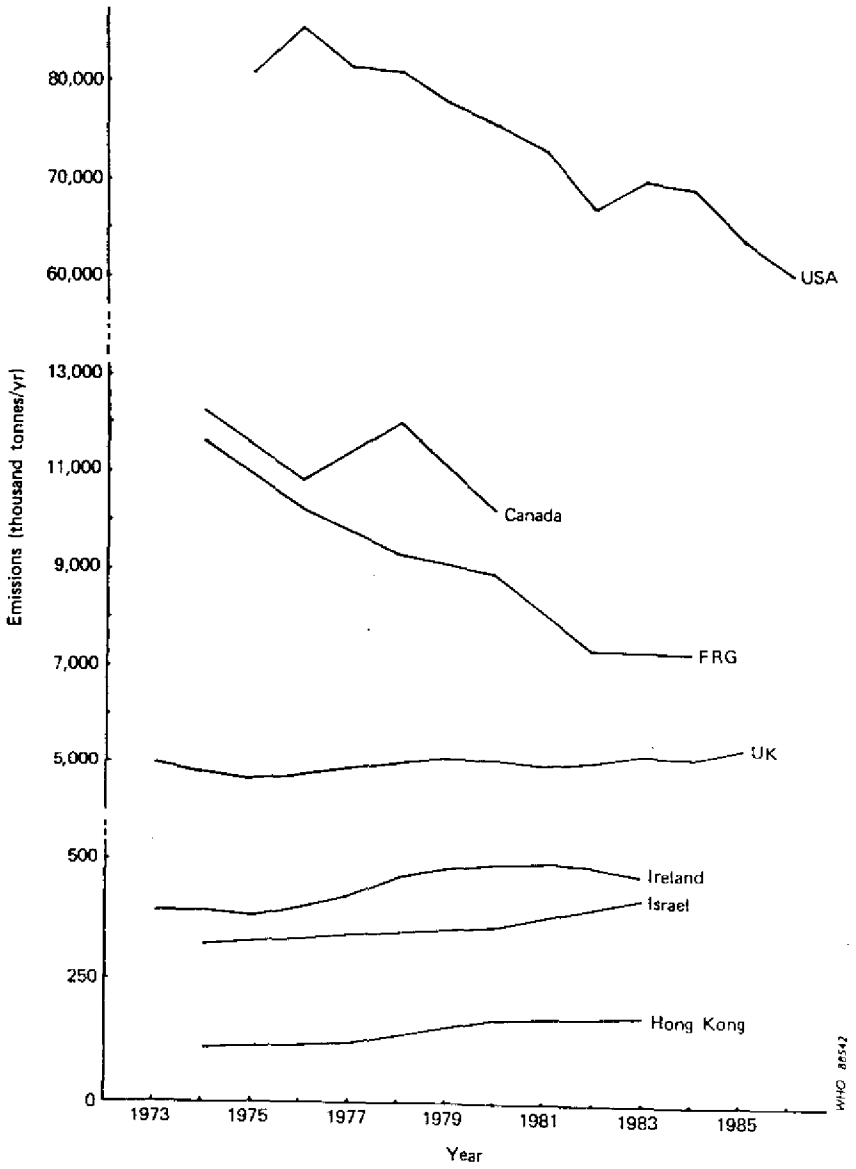
Estimates of CO emissions are available for more recent years in a number of countries and are summarized in Table 4 (Appendix II). As with other emission inventories, differences in methods of estimation make trends within a country more reliable than comparisons between countries.

Understandably, CO control strategies centre on mobile sources. The U.S.A. and Japan pioneered the first effective control strategies in the late 1960s with improvements in engine design and exhaust emission controls enabling most of the CO to be converted to CO_2. The subsequent oil crisis of 1974 also encouraged the design and use of more fuel-efficient vehicles with lower CO emission rates. By the mid-1970s, Canada and parts of Europe had also introduced control strategies although these are less stringent than those in Japan and U.S.A. Australia, Austria, Canada, Norway, Sweden and

Switzerland are among countries now bringing vehicle emissions standards in line with those currently applied in the U.S.A. The outcome of these controls has been a gradual decrease or stabilizaton of CO emissions in North America and some Western European countries despite increases in traffic density. Figure 6.1 illustrates trends in emissions in a number of selected countries. In the USA, for example, emissions have declined by approximately 1.5% per year since 1975, which by 1984 represented an overall decrease of more than 11 million tonnes.

In contrast to several other Western European countries, the U.K. and Ireland both show increased CO emissions. In the case of the U.K., there was an upward trend of 7% between 1973-84. In both The Netherlands and Federal Republic of Germany (table 4, Appendix II) however emissions of CO over the same period have declined by 32% and 37% respectively.

Figure 6.1 Trends in CO emissions in selected countries



Data from Hungary and Poland suggest that CO emissions are also rising, at least in some countries, in Eastern Europe. Similarly, it is expected that upward trends will be found in some of the rapidly industrializing Asian and South American countries due to increasing number of motor vehicles.

6.3 Trends in ambient CO levels

There are few national networks for the measurement of carbon monoxide, but monitoring is carried out quite widely in cities in relation to emissions from motor vehicles. In general, concentrations fall off sharply in moving away from the kerbside: thus the precise location of a sampler can have a substantial effect on the values obtained.

Since it takes between 4 and 12 hours for carboxyhaemoglobin levels to reach equilibrium with ambient air CO levels, observations are often averaged over 8 hour periods, though annual averages may also be calculated from the continuous records in order to examine long-term trends.

Trends in annual values for reporting cities are illustrated in Figure 6.2, calculated over varying numbers of years between 1973 and 1985. Figure 6.3 depicts trends in annual average CO concentrations in those countries which possess nationwide urban monitoring networks.

Figure 6.2 Trends in annual ambient CO concentrations in selected cities (Values in brackets refer to number of sampling years)

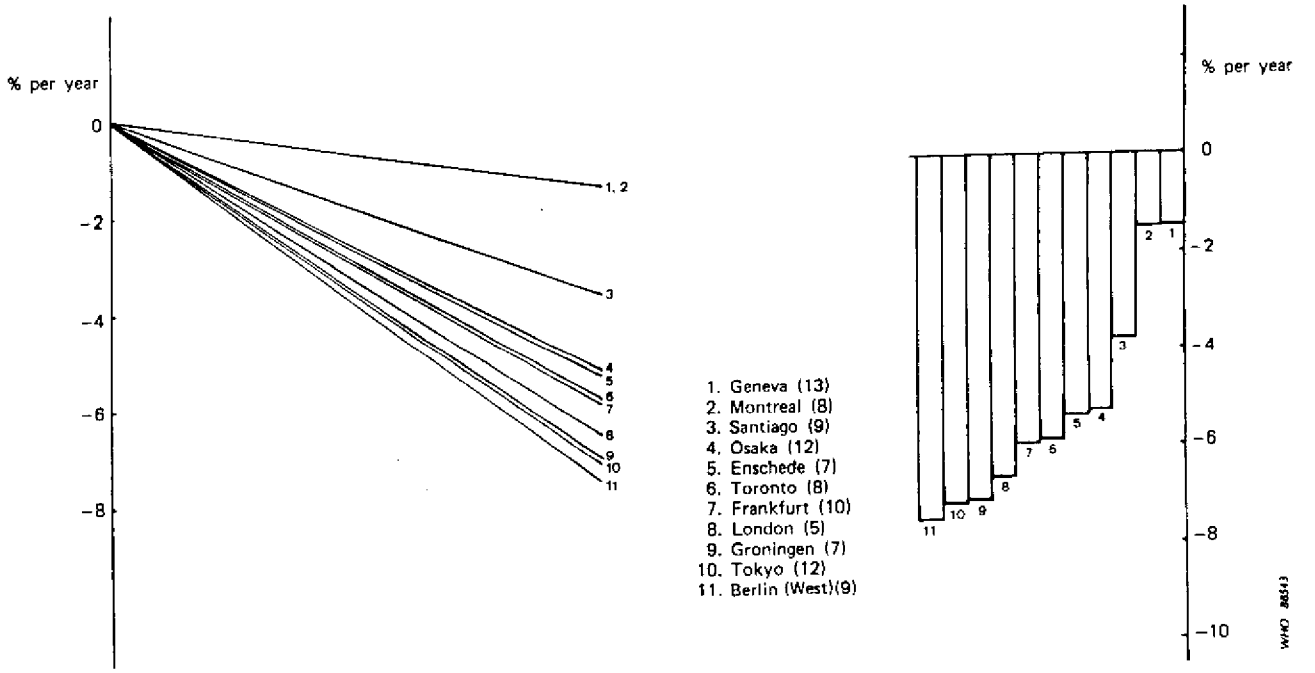
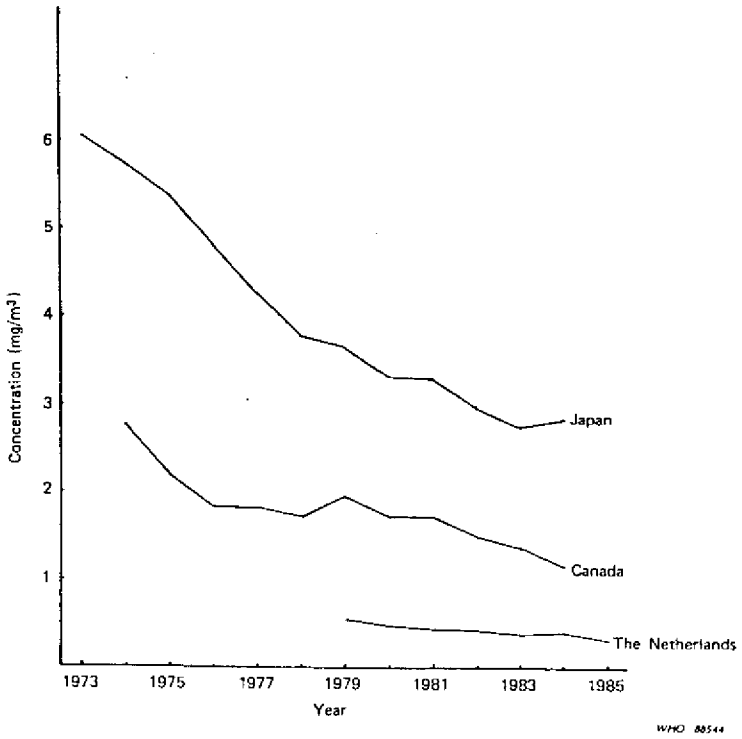


Figure 6.3 Trends in annual average CO concentrations in selected countries



The cities in Figure 6.2 are mainly in Europe and North America; all show declining trends in CO concentrations. Annual decreases range from about 1% in Berlin (West) to nearly 8% in Geneva. The three countries which operate national CO monitoring networks in Figure 6.3 also show decreasing CO concentrations with time. In Japan, the decrease amounts to over 50% between 1973 and 1984. In The Netherlands, the national network operates on a grid pattern throughout the country, and the overall average as shown in Figure 6.3 reflects a relatively constant background level.

In many of the developing countries the issues involved in the control of CO from vehicles are complex. For example, car manufacturers in developed countries will be producing cars in the future which have the control technology to reduce CO and NO_x emissions. This will necessitate the use of lead-free petrol, an action some developing countries will view as unnecessarily costly. However, the car manufacturers will be reluctant to produce car fleets with a variety of control technology options. Unless countries seek agreement among themselves as, for example, the ASEAN (Association for South East Asian Nations) countries have done on uniform standards and technologies, it will be extremely difficult and costly to achieve effective CO controls in developing countries.

6.4 CO concentrations in cities

An insight into recent CO levels in cities throughout the world may be obtained by summarizing 1980-84 annual average or maximum 8-hourly values. The annual average CO levels, presented in Figure 6.4, range from 0.2 to 17.4 mg/m^3. The maximum 8-hourly values which are commonly reported in relation to CO standards and guidelines are shown for reporting cities in Figure 6.5. The concentrations shown in Figure 6.5 are higher than those in Figure 6.4 and extreme values range from about 2 to 50 mg/m^3.

Figure 6.4 Summary of the annual average CO concentrations in cities, 1980-84 (Note logarithmic scale).

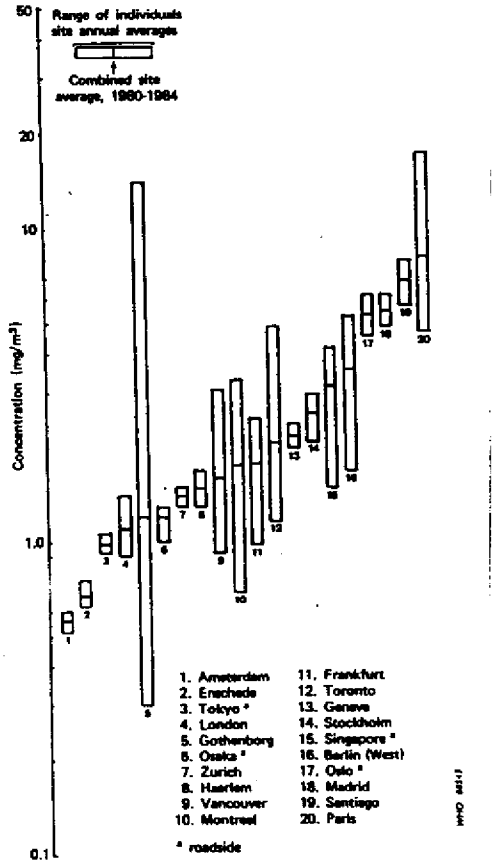
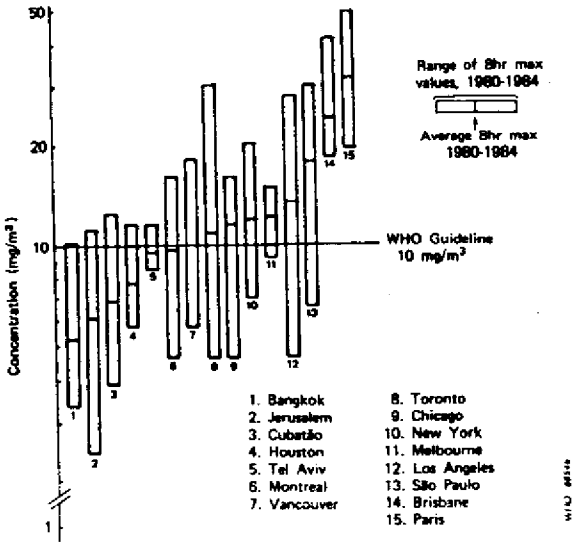


Figure 6.5 Summary of the maximum 8-hourly CO concentrations in cities, 1980-1984. The horizontal line represents the WHO 8-hr guideline value. (Note logarithmic scale).



6.5 Comparison with guidelines

In order to minimize human health risks WHO has recommended that 8-hourly CO concentrations do not exceed 10 mg/m^3 (WHO 1987). All 15 of the cities shown in Fig. 6.5 exceeded this guideline at some site and some time during 1980-84.

Of more importance is whether a given city exceeds the guideline on average over the five year period. Figure 6.5 reveals that 8 out of the 15 cities fell into this category. Most are in North America but Sao Paulo and two Australian cities are also represented. Indeed, one of the Australian cities, Brisbane, together with Paris are the only two cities which always exceeded the guideline. Care should however be taken in interpreting these findings, since variations over short distances within a city can be as great as those between cities.

6.6 Estimation of population exposures

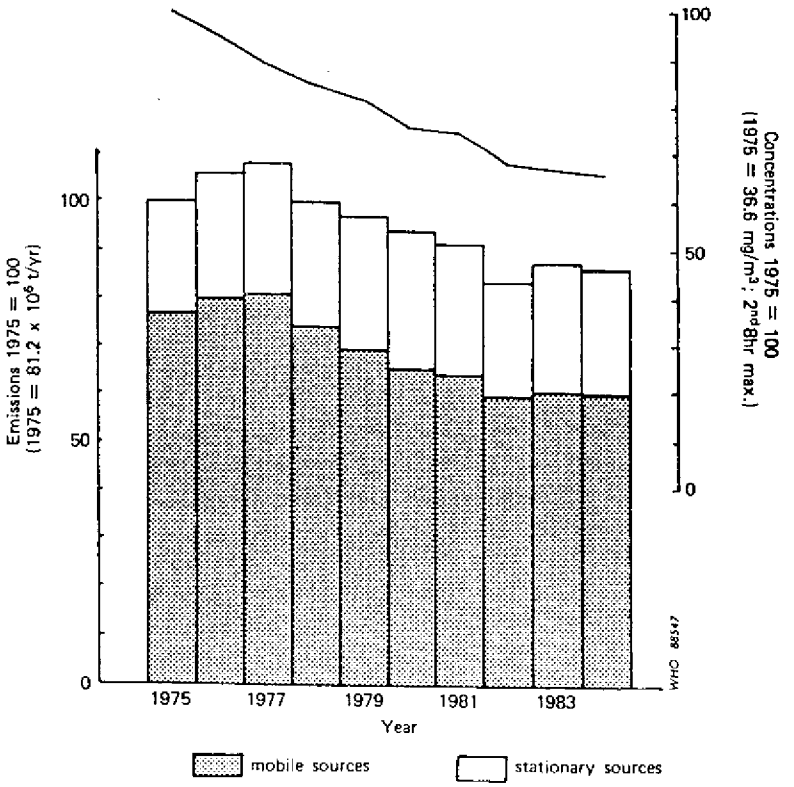
A very tentative conclusion from the relatively small sample of cities studied shows that people living in as many as half the cities in the world may be exposed to CO concentrations in excess of the WHO short-term guideline. At particular risk may be urban dwellers who travel, work or live in areas of high traffic density. In addition, groups such as traffic policemen, garage attendants, taxi and truck drivers will also be subject to high exposures. People most at risk in respect of acute effects would be those with pre-existing heart disease, whose symptoms of angina may be exacer- bated.

6.7 Case studies of individual countries

6.7.1 The United States of America

Emissions of carbon monoxide in the USA, as in other countries, arise largely from mobile sources. In 1984, the transportation sector accounted for over two thirds of the total emissions. Trends in national emissions are illustrated in Figure 6.6 for the period 1975-1984. During this time, an overall reduction in emissions of 14% has been achieved. Emission decreases are primarily due to a reduction of vehicular emissions. These have fallen by 22% between 1975-1984, whereas emissions from other sources, such as stationary fuel combustion, waste incineration and industrial processes have remained fairly constant (EPA 1986).

Figure 6.6 Trends in national CO emissions and 8-hour average concentrations in the USA.



Decreases in mobile source emissions have been achieved despite a 30% rise in vehicle miles travelled and are a result of progressive strengthening of exhaust emission controls (EPA 1986). The development of oxidation catalysts and 3-way catalytic convertors have made such reductions possible. Oxidation catalysts which reduce exhaust missions of CO and hydrocarbons have been compulsory in new cars since 1975. Three-way catalysts, which also remove oxides of nitrogen have been obligatory in new cars from 1981.

Ambient levels of CO in urban areas of the USA. are reported in terms of second highest non-overlapping 8-hour values. Trends in CO concentrations averaged over a total of 157 reporting sites are shown in Figure 6.6. Between 1975 and 1984 national average ambient CO levels declined by 34% with the greatest improvements being noted before 1982.

The declining trend is proportionally greater than the trend observed for national emissions, a finding ascribed by EPA (1986) to the location of the CO monitoring stations in "traffic-saturated" areas. They argue that these areas are unlikely to have experienced the increases in vehicle miles of travel which have occurred nationally, resulting in greater decreases in ambient CO levels than national vehicular emissions.

7. LEAD

7.1 Sources and properties

Lead (Pb) is released to the atmosphere from both natural and man-made sources. From the very low lead levels measured in glacier ice at remote locations, it is inferred that natural sources, mostly from windblown dusts and volcanoes, are relatively small and of the order of 2 thousand tonnes per year (Settle and Patterson 1980, EPA 1986).

Man-made emissions arise from both the production and use of lead and its compounds and these overwhelm natural sources. One global inventory estimates that an annual total of 450 thousand tonnes are released by human activities (Nriagu 1979). The single largest source results from the use of alkyl lead as an anti-knock agent in petrol. Petrol combustion globally con- tributes an estimated 60% of the total lead emissions from human activities. In individual countries, this source accounts for 50 to 90% of national man-made lead emissions depending on vehicle numbers and effectiveness of lead emission control strategies. Lead from petrol combustion is largely emitted on fine particules in the inorganic state. Other sources of lead include the smelting and refining of non-ferrous metal ores, coal combustion, refuse incineration and the production of lead-containing articles such as batteries and cables.

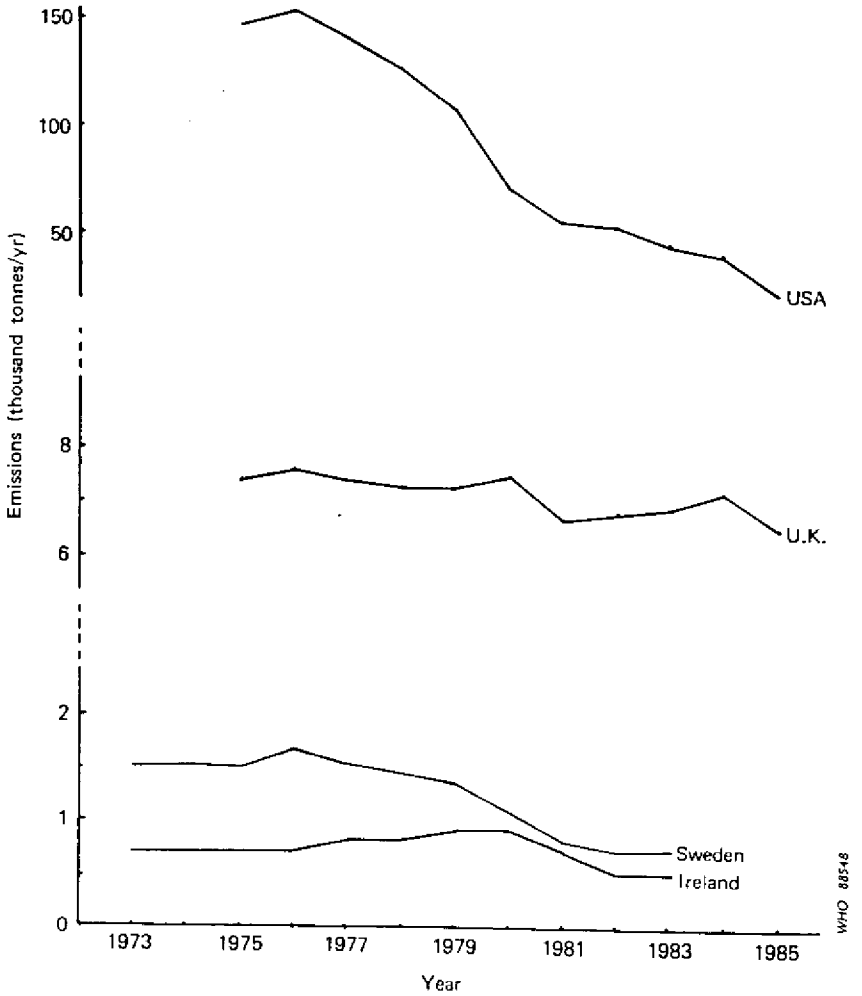
Lead can exert effects on heam biosynthesis and on the nervous system. Children represent the critical group for lead exposure. They show greater susceptibility to lead than adults, resulting from relatively higher rates of intake and uptake, together with greater sensitivity to the metal. The threshold for interference with haem formation is about 20 ug/dl blood lead in adults. In children the threshold is lower, at 10-20 ug/dl. The neurotoxicity of high lead exposures is well known and there is continuing concern about such effects in children.

7.2 Trends in lead emissions

The history of global lead emissions has been inferred from records of lead deposition in ice, marine and freshwater sediments and in annual tree rings (MARC 1985). These records indicate that a gradual increase in emissions first occurred in pre-Roman times and this is linked to the smelting of non-ferrous metals. It would appear that emissions rose rapidly in Western Europe with the advent of the Industrial Revolution. A further increase around the 1940s is attributed to the widespread introduction of alkyl lead as a petrol additive.

Relatively few countries report annual lead emissions estimates. Available data are summarized in Table 5 in Appendix II. A summary of this table is presented in Figure 7.1 which reveals the declining trends in lead emissions in several nations.

Figure 7.1 Trends in lead emissions in selected countries.



The regulation of lead in petrol, the major source of urban emissions, is the most widely applied strategy for reducing ambient levels. In recognition of the health hazard posed by lead, virtually all industrialized countries have progressively reduced the maximum permissible lead content in petrol over the past decade. The USA was among the first countries to begin the phasedown in 1973 and in 1975 also introduced unleaded petrol in conjunction with the requirement that new cars be fitted with catalytic convertors. Unleaded petrol now accounts for almost 60% of petrol sales in the USA. In 1975 the total quantity of lead used in petrol in the U.S.A. was around 170 thousand tonnes. By 1984 only 40 thousand tonnes were used (EPA 1986). Japan has progressed further with an almost complete switch to unleaded petrol to improve the efficiency of catalysts. Few developing countries have yet made significant reductions in petrol lead content, as Table 7.1 shows.

Table 7.1 Ranges of lead levels (g/l) in premium (super) grade petrol in different regions of the world (The Associated Octel Company Ltd 1976 and 1985)

	Range	
	1974	1984
Africa	0.63-0.84	0.63-0.84
Asia	0.31-0.84	0.17-0.56
South and Central America and Caribbean	0.46-0.84	0.64-0.84
North America	0.58-0.95	0.22-0.77
Europe	0.40-0.84	0.15-0.40

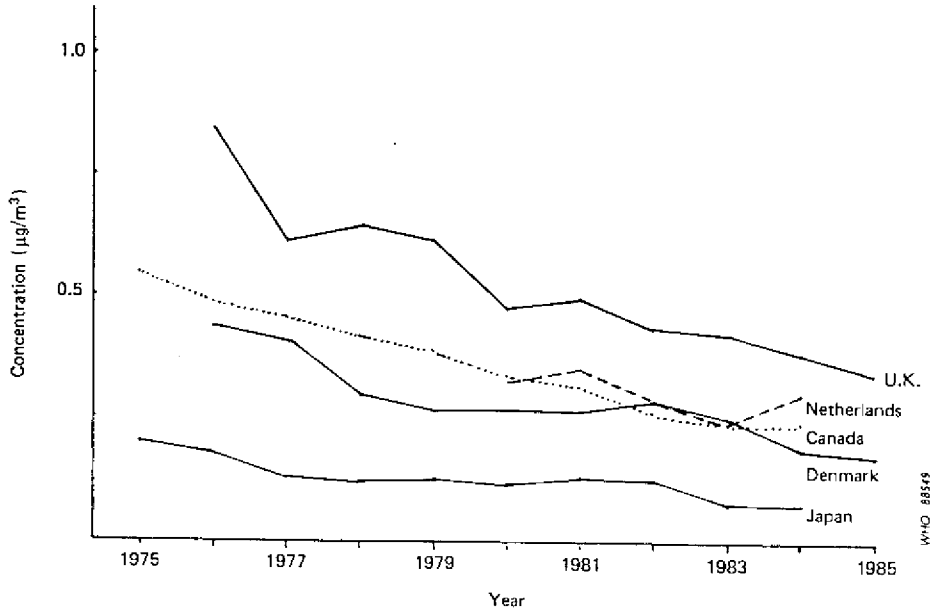
The ranges given in Table 7.1 are indicators of the general levels that occur in premium or super grade petrol, although there are exceptions to each. Thus, it should be noted that other grades of petrol, including unleaded, may account for the bulk of petrol sales in many individual countries. The data, nevertheless, indicate that lead in petrol is generally being decreased in North America, European and Asian countries but not in Africa or South and Central America. In these regions the development of policies for reducing relatively high petrol lead levels is now a priority, especially where vehicle ownership is increasing in rapidly industrializing countries.

Lead emissions from stationary sources such as non-ferrous smelters and battery plants, have also effectively been reduced in countries where stack controls on particulate emissions operate. Indeed, for lead such controls may be a more important strategy than vehicle emissions abatement. Severe lead pollution problems have occurred where emissions from single point sources have in some developing countries caused excessive exposure to large numbers of people living close to the facility.

7.3 Trends in ambient lead levels

Although many factors contribute to total lead exposure the relationship between ambient lead levels and human health is an important one. Lead particles emitted into the atmosphere may be both inhaled directly or ingested following their deposition on food crops. Consequently ambient lead levels have been widely monitored, particularly in conjunction with epidemiological studies, although monitoring for trends has not usually been the objective. A number of national urban air quality monitoring networks, predominantly in developed countries, have routinely monitored ambient lead levels over the past decade. Figure 7.2 summarizes results during the period 1975-85. In general, decreasing trends in urban levels reflect the widespread application of lead emission control strategies.

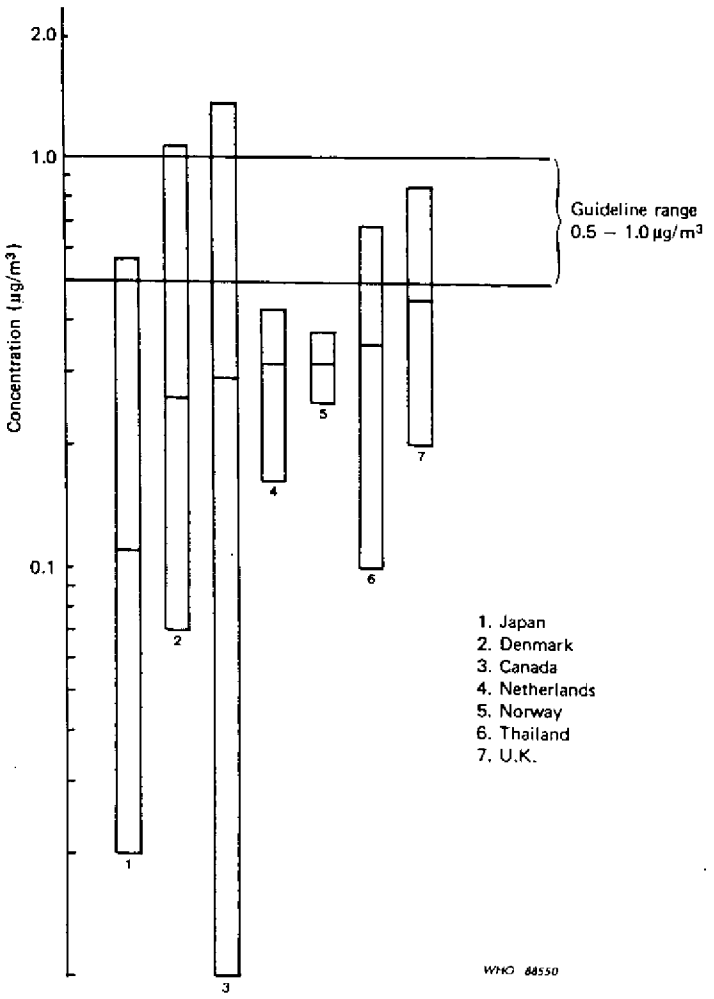
Figure 7.2 Trends in annual ambient lead levels in selected countries



7.4 Lead concentrations in cities

By the late 1970s virtually all industrialized nations had begun to phase down petrol lead content and set emission limits for lead in order to meet new ambient air quality standards. National average ambient lead levels during 1980-84 are summarized in Figure 7.3.

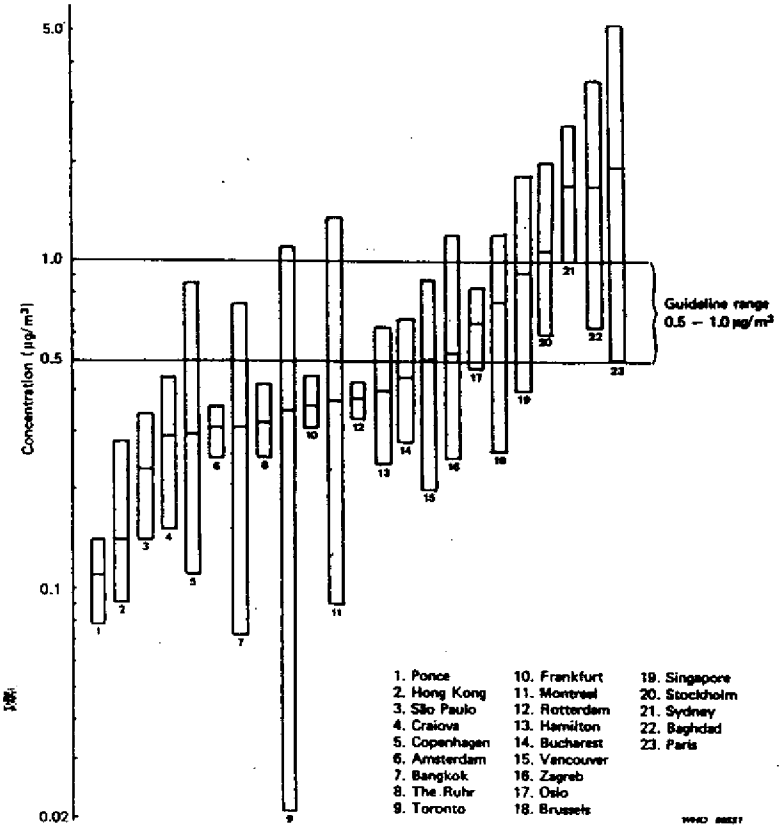
Figure 7.3 Summary of the national annual average lead levels in urban areas, 1980-84



It is evident from Figure 7.3 that urban lead levels in six of the eight countries fall within or exceed the WHO guideline range in at least one year out of the five. However, only in one country, Belgium does the average annual lead level over the five year period fall within the guideline range. The lowest average level was observed in Japan where petrol has been virtually lead-free since 1976. In the USA, nearly all the 220 urban sites in the national network reported annual average lead concentrations below 1 ug/m^3 in 1980 (EPA 1986).

Recently, a number of cities in developing countries have initiated ambient lead monitoring. Thus 1980-84 average ambient lead levels may be compared in cities throughout the world (Figure 7.4).

Figure 7.4 Summary of the annual lead averages in cities 1980-84. Note the log scale. The horizontal lines represent the WHO guide- line range



Annual mean concentrations of lead in the 23 cities range from 0.13 to 2.0 ug/m^3 with levels at individual sites as low as 0.02 ug/m^3 and up to 5.3 ug/m^3. Cities in developing countries record levels throughout most of the range.

Some countries have not taken steps to reduce the lead content of petrol and there is evidence that air lead levels in urban areas are also elevated. In Saudi Arabia, for example, where maximum permissible lead levels in petrol remain high, at 0.84 g/l, monthly average city-centre lead levels up to 9 ug/m^3 were recorded in 1983-84 (Nasralla 1986). In Ahmedabad, India, where high lead petrol is also used, average annual roadside values up to 15 ug/m^3 were reported in 1981 (Shrivastava 1984). There is an obvious need for systematic monitoring surveys in these areas to determine the full extent of the situation.

7.5 Comparison with guidelines

WHO has recently proposed an annual average guideline value for ambient lead of 0.5-1 ug/m^3 (WHO 1987). City-wide annual average levels in a number of countries exceeded this range and at some sites values reached five times the upper value. Inspection of Figure 7.4 reveals that average air lead levels in 15 out of the 23 cities (65%) were below the WHO guideline range. Another four cities (17%) were within the range while four cities were above the range.

While most developed countries have begun to phase out or reduce lead in petrol with considerable effect on ambient concentrations, progress has generally been slow in developing countries. Future increases in vehicles, petrol consumption and lead emissions can be expected in many rapidly industrializing countries. There is, therefore, a clear need for these nations to take steps in order to prevent unacceptable air lead levels in urban areas in the future.

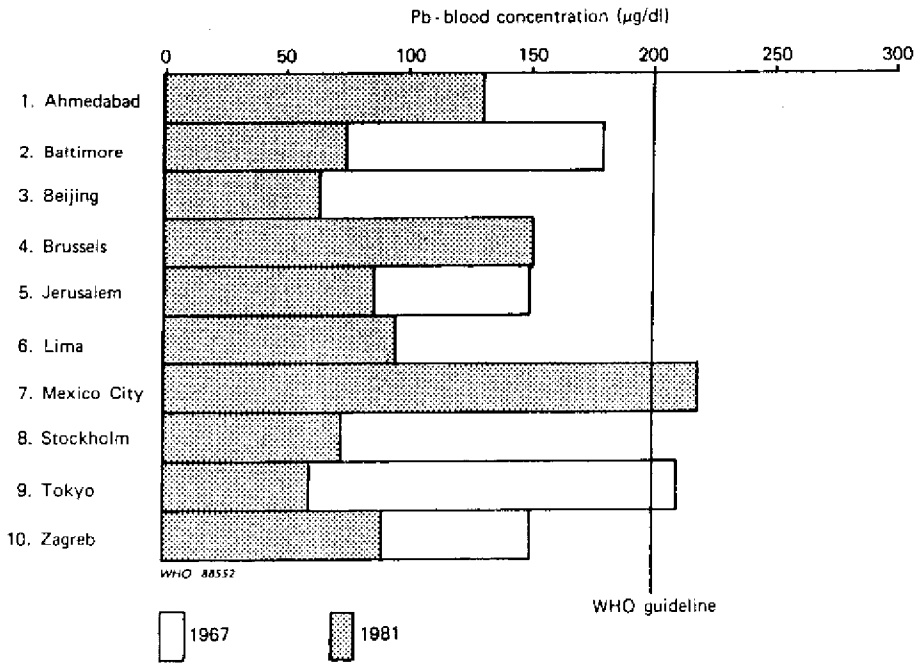
7.6 Estimation of populations exposed

Extrapolation of the data obtained in this study to the situation worldwide leads to a tentative estimate that people living in about one third of the cities of the world are liable to be exposed to air lead concentrations which are either marginal or unacceptable. Thus, despite control measures by many countries to reduce lead in petrol, air lead contamination continues to be a major urban pollution problem. The problem is probably most acute in large urban areas in developing countries with dense automobile traffic.

Current exposure levels from all pathways of lead may be represented by the concentration of lead in the blood. WHO (1987) concluded that the threshold level in adults above which adverse effects begin to occur is 20 ug/dl. The WHO guideline range of 0.5-1.0 ug/m^3 lead in air is considered to be the maximum recommended value for maintaining blood lead levels below 20 ug/dl when average contributions from other exposure pathways are also accounted for.

A UNEP/WHO study of lead exposure conducted in a single city for each of ten countries between 1979 and 1981 involved blood samples taken from adult volunteers.

Figure 7.5 Average lead in blood of residents of cities participating the the UNEP/WHO blood lead monitoring project (Vahter 1982)



Although many factors can influence the lead exposure levels, it is interesting to note that the lowest blood levels were observed in Tokyo, a city in which all petrol has been virtually lead-free since 1976. In contrast, petrol in Mexico City had the highest lead content of all sites studied and volunteers from that city also had the highest levels of lead in blood.

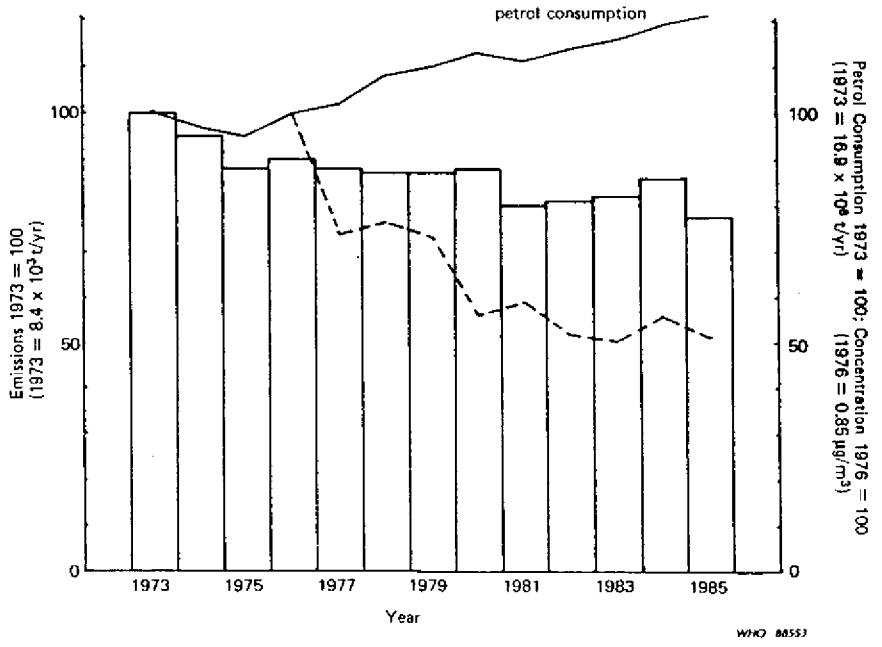
An indication of trends in blood lead levels can be obtained by comparing the results of the investigation with an earlier WHO-sponsored study completed in 1967. For Peru and Sweden, blood lead levels were about the same in 1967, while for France, Japan, the USA and Yugoslavia there had been substantial decreases over the 12-14 year period. The most striking observation was made in Tokyo, Japan, where the median level of 21 ug/l in 1967 had decreased to 6 ug/dl in 1981.

7.7 Case studies from individual countries

7.7.1. The United Kingdom

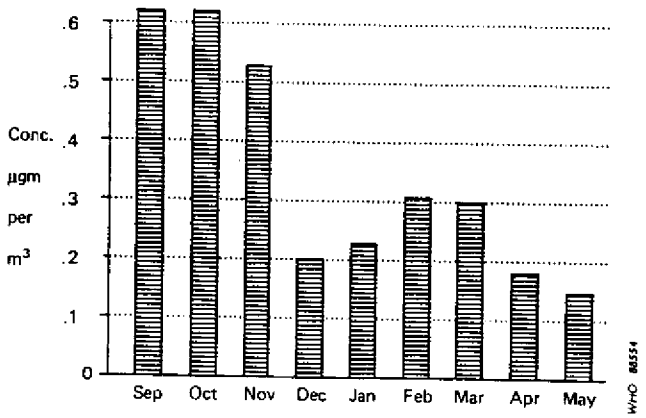
In the UK lead emissions from petrol engined vehicles in the period 1970-1985 period reached a peak in 1973 at 8.4 x 10^3t/yr but by 1985 these had declined to 6.5 x 10^3t/yr. During the period 1976-1985 emissions have fallen by about 15% (Figure 7.6). These reductions have occurred despite an increase in petrol consumption over a similar time period of 20%. This has been achieved by a decrease in the Pb content of fuel from a maximum permitted level of 0.84 g/l in 1972 to 0.4 g/l in January 1981 and finally to 0.15 g/l in December 1985.

Figure 7.6 Trends in national lead emissions, annual average concentrations and petrol consumption in the UK.



The reduction in the Pb-content of petrol in the U.K. has resulted in a corresponding decrease in ambient Pb levels in urban areas. Over the decade 1976-1985, annual mean Pb concentrations (averaged over 4 urban sites) fell by about 60%. The effect of the more recent reduction, to 0.15 g Pb/l in December 1985 was promptly reflected in monthly air Pb data from a site in central London as shown in Figure 7.7. Results of this and other monitoring studies in different parts of the U.K. (Pattenden and Branson 1987) indicate that decreases in petrol Pb-content produce rapid and comparable reductions in urban Pb concentrations.

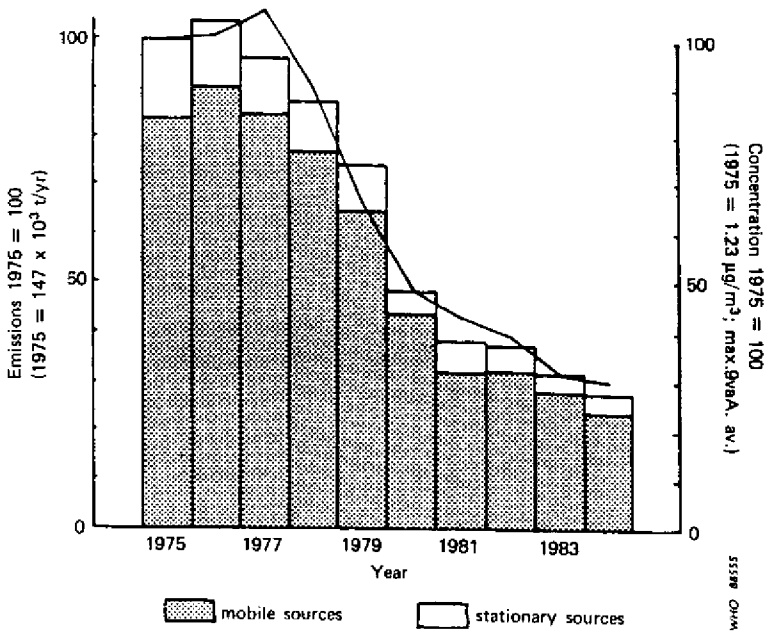
Figure 7.7 Monthly mean urban airborne lead concentrations, London, 1985/6 (Williams 1987)



7.7.2 The United States of America

Lead emissions, according to source category for the USA are shown in Figure 7.8. Motor vehicles account for the majority of Pb emissions contributing nearly 90% to the national total (EPA 1986). During the period 1975-1984 total Pb emissions have declined by about 73%. Transport emissions fell by 72% while emissions from stationary fuel combustion, industrial processes and refuse incineration decreased by about 95%, 78% and 45% respectively. Reductions in Pb emissions from stationary sources such as smelters, power plants and incinerators have been achieved by the installation of more efficient particulate control devices and, in some cases, the closure of several large smelters.

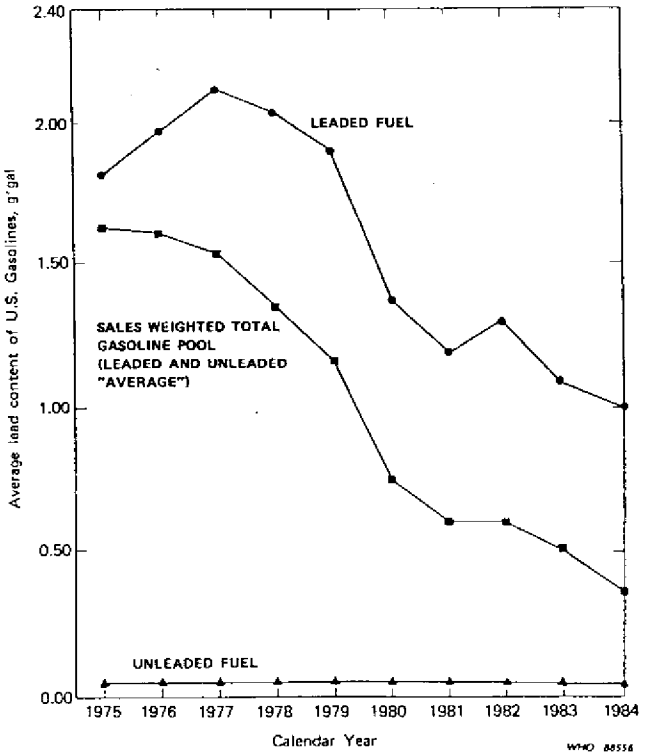
Figure 7.8 National lead emissions and urban concentrations in the USA



In the USA, most of the stationary Pb sources, particularly metalurgical facilities, are located outside major urban areas (EPA 1986). Reductions in emissions of these sources will, therefore, have limited impact on urban air quality.

Reductions in Pb emissions from motor vehicles will thus have had the greatest impact on lead levels in urban air. In the 1970s regulations were promulgated by the U.S. EPA requiring that (a) the Pb content of petrol be gradually reduced over a period of years, and (b) that unleaded fuel for use in vehicles fitted with catalytic convertors be available from 1975. Figure 7.9 shows the trend in the Pb-content of petrol from 1975 to 1984; the average Pb-content decreased by 73% from an average value of 1.62 g/gal (0.42 g/l) in 1975 to 0.44 g/gal (0.12 g/l) in 1984.

Figure 7.9 Trends in lead content of US gasolines

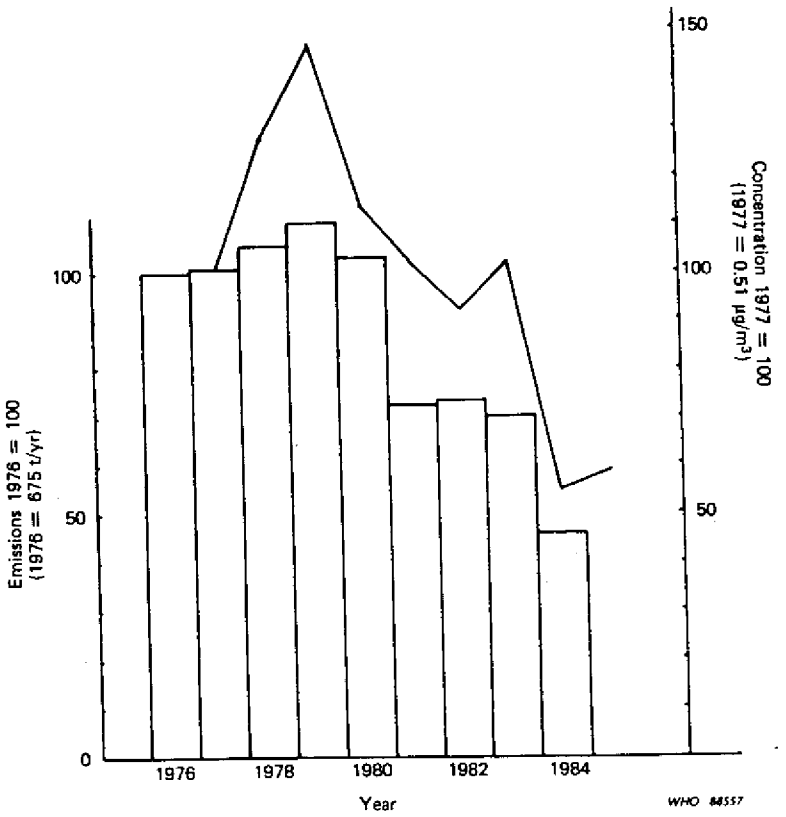


The control of Pb in petrol has produced a considerable decrease in ambient levels of Pb (Figure 7.8). Maximum quarterly average Pb concentrations have declined by 71% from 1.23 to 0.36 ug/m^3, in urban locations in the U.S. over the 10-year period 1975-1984. It should, however, be noted that these data are based on 36 monitoring sites, representing only 8 US states (EPA 1986). Nevertheless, measured Pb levels (quarterly averages) are currently well inside the National Ambient Air Quality Standard of 1.5 ug/m^3.

7.7.3 Norway

The transportation sector is by far the most important source of lead in Norway, accounting for over 90% of the national emissions in 1984. Lead emissions reached a maximum of 740 t/yr in 1979 but have since declined by almost 60% to 310 t/yr in 1984 (Figure 7.10) (Central Bureau of Statistics 1987).

Figure 7.10 National emissions and seasonal average urban concentrations in Norway.



Emissions reductions have primarily resulted from a step-wise decrease in the lead content of petrol over the past 15 years (Table 7.1) and have been achieved despite an increase in vehicle densities from 261 to 396 per 1000 population in the 1974-1984 period (UNEP 1987).

Table 7.1 Maximum permissible Pb-content of petrol (Central Bureau of Statistics 1987)

Year	Pb-content g/l	Petrol type
1970	0.70	High and low octane
1971	0.60	" " " "
1974	0.40	" " " "
1980	0.15	Low octane
1983	0.15	High octane

Ambient lead levels in urban areas shown in Figure 7.10 for the period 1977-1985, have similarly declined by about 60% as a result of lower Pb petrol content. Between 1979 and 1985, concentrations averaged over 8 Norwegian cities declined from 0.75 ug/m^3 to about 0.3 ug/m^3. It should be noted that Pb is only monitored during the months of February and August, the average values given in figure 7.10 represent the mean of these two months rather than an annual average. Nevertheless, the data indicate that current Pb levels are within the WHO guidelines range of 0.5-1.0 ug/m^3 (WHO 1987).

8. GLOBAL ASSESSMENT AND EMERGING ISSUES

8.1 Emissions and ambient air pollution levels in cities

In this report, air pollution emissions have been compiled for a number of countries for each of the five pollutants concerned: SO_2, Suspended Particulate Matter (SPM), NO_x, CO and Pb. These emissions estimates are nationwide and cover the period 1973 to 1984. Information on various control strategies employed in the different countries was gathered to permit an in-depth explanation of trends in emissions and ambient levels. The ambient air pollution levels reported relate just to cities and were calculated from data in the GEMS/Air data bank for SO_2 and Suspended Particulate Matter and from various reports and the open literature for NO_2, CO and Pb. Because of the availability of whole data sets for SO_2 and Suspended Particulate Matter, more detailed analyses of ambient conditions could be made for these two pollutants than for the others.

Based on the information base described above the following conclusions were reached:

- In the industrialized western countries various control strategies are showing their effect and trends in emissions of SO_2, Suspended Particulate Matter and Lead are generally downward since the mid-seventies.

- For CO and NO_x control strategies are less generally applied. For CO, emissions are decreasing in some countries while they are increasing in others. Based on a sample of industrialized countries NO_2 emissions have slightly increased (about 8%) over the past five years. It should be noted that these pollutants are closely associated with automobile traffic and that the number of vehicles is still increasing almost everywhere.

- The data base for pollution emissions in the developing countries is very incomplete. However, in many of these countries there are indications that emissions for all five pollutants studied are increasing. Further efforts should be made to clarify the trend.

- Taking into consideration total (man-made) global emission estimates for the different pollutants and similar estimates for industrialized countries the latter account for well over half of all emissions. This leaves proportionately less for the developing world.

- Ambient air pollution levels in urban areas are generally a reflection of emissions and the effort that is made to control such emissions. For SO_2 and Suspended Particulate Matter ambient concentrations are declining in the industrialized western countries. Also, lead levels in ambient air are decreasing. For NO_2, ambient levels in cities are generally constant or slightly increasing, except in North America where they are declining. For CO, ambient levels are variable, declining where controls are being applied.

- There are a substantial number of cities where the number of "high pollution days" exceeds the WHO guideline of a maximum of seven days per year. These cities occur both in industrialized and developing countries for SO_2, but mostly in developing countries for Suspended Particulate Matter.

The picture that emerges is that for SO_2, Suspended Particulate Matter and Lead the situation is improving in many industrialized countries as a result of various control and prevention strategies that are being applied. The data show that depending on the combination of control strategies the impact on ambient levels can be quite significant. Although, as the next section will show, ambient levels of SO_2 and Suspended Particle Matter in urban areas still give rise for concern in many urban areas, strategies to reduce SO_2 (as well as NO_2) pollution now tend to concentrate on control of acid deposition to limit ecological damage.

With regard to automobile related pollutants (NO_2 and CO) control efforts are much less generally applied. Reasons for this are that many sources (every car) need to be controlled which increases the complexity and cost of the effort involved. Both NO_2 and CO are potent toxic substances that can affect human health at relatively low concentrations and continued vigilance is required.

The image that can be formed about the situation in developing countries again demands continued attention. The data and information available are scanty but nevertheless indicate deteriorating conditions. Increased efforts to evaluate the problem in more detail by improved monitoring coverage, especially in Africa, Europe and South America, and to develop adequate protection measures for the populations affected are urgently required.

8.2 Health implications

The air quality guidelines, as recommended by the WHO, indicate the level and exposure time at which no adverse effects are expected and below which there is no hazard expected to the health of the population. However, guidelines are only given for single pollutants: exposure to pollutant mixtures may lead to adverse effects at levels below the recommended guidelines for individual pollutants.

Comparisons of ambient levels in each of the urban areas with WHO guidelines have been made for the five pollutants. In the case of SO_2 and Suspended Particulate Matter, as monitored by the GEMS/Air, extrapolations to the global urban population have been possible. It is estimated that out of an urban population of 1.8 billion, nearly 1.2 billion or two-thirds reside in areas with annual average SO_2 levels within or above the WHO guideline range. In the case of Suspended Particulate Matter, the situation is slightly worse, with 1.4 billion of the 1.8 billion urban population living in cities having air quality considered to be marginal or unacceptable. Many cities in the GEMS network frequently experience short-term high levels of SO_2 and SPM. Twenty per cent of the reporting GEMS cities have, on average, more than 30 days per year on which SO_2 levels exceed 150 ug/m^3. The health impact of these high pollution days cannot, at the present time, be accurately evaluated. These cities are distributed throughout both developed and developing nations. In nearly 40% of cities, populations are exposed to levels of suspended particulate matter in excess of the short-term guidelines for more than 30 days a year. Such cities are predominantly in the developing countries. Many of the cities with high particulate levels are in areas where natural wind-blown dusts make a significant contribution to the urban aerosol.

Based on the data available, estimates of the proportion of cities with exceedances of WHO guidelines, both in the short-term and long-term are calculated for NO_2, CO and Pb and given in Table 8.1. Because of the smaller sample sizes for these pollutants, no extrapolations leading to estimates of total urban populations exposed should be made.

Table 8.1 Percentages (rounded to nearest 5%) of cities reporting site-year averages in excess of guideline values. (Figures in brackets are numbers of cities for which data were available)

Cities exceeding:	SO_2(a)	SPM(b)	Smoke(b)	NO_2(c)	CO(d)	Pb(e)
Long-term guidelines	30(54)	60(41)	30(16)	0(42)	-	20(23)
Short-term guidelines	45(54)	(55(41)	45(16)	30(28)	55(15)	-

Sources of data

(a) Table 3.1, based on annual averages and 98 percentiles exceeding guideline range.

(b) Table 4.1, based on annual averages and 98 percentiles exceeding guideline range.

(c) Section 5.5, based on annual averages (against US standard) and either the 1-hour or 24-hour guideline.

(d) Section 6.5, based on 8-hour guidelines.

(e) Section 7.5, based on annual averages above guideline range.

In the case of NO_2 there is no WHO guideline and the US standard was used. On average none of 40 cities exceeds the US air quality standard of 100 ug/m^3 (annual mean). However, in 10% of the cities, annual mean levels of NO_2 approached that value at least once during the period 1980-1984. Approximately 30% of the cities exceed the WHO short-term guidelines, and it may be inferred that in these cities the urban population may be at increased risk of adverse effects from short-term exposures to NO_2.

Exceedances of the short-term guideline for CO appear relatively common in the reporting cities. Exposures to levels of CO which may pose a risk to health are more likely in locations with high traffic densities during commuting hours.

With regard to Pb levels, in 30% of cities annual guidelines are never exceeded, another 30% of cities are, on average, within or above the guideline range while the remainder occasionally exceeds. Locations where Pb guidelines are exceeded can be in cities of both developed and developing nations. Some biological monitoring studies have indicated that reduction of the lead content of petrol has led to concomitant decreases in the blood-lead levels of the general population.

8.3 Information gaps and need for further work

Air pollution in urban areas arises from a number of sources which will vary from location to location. The actual concentration of air pollutants depends not only on the quantities that are emitted but also on the ability of the atmosphere to either absorb or disperse these emissions. In an assessment of urban air pollution worldwide, it is important to recognize that the accuracy of the assessment relies heavily on the accuracy and completeness of the emission data, the coverage, representativeness and quality of the monitoring data, and finally the extent to which exposure to the population can be inferred from the monitoring data. Each of these three areas will be discussed in some detail below relative to the present assessment.

8.3.1 Emissions

Ideally emission inventories or global assessments should include city-wide emission inventories summarized by source category (e.g. transportation) collected over the same periods for which there are monitoring data. In this report, however, the emission data were limited to nationwide estimates mostly from developed countries. From this information it was possible to obtain a very general picture of the countrywide emission situation; however, these patterns do not always parallel the monitored air pollution patterns. There are many reasons for these disparities, such as local source control and meteorological and topographical features of the specific urban location. Nevertheless, the extent to which there is general agreement between the concentration patterns and emission inventories is a strong indication that results of country-wide control efforts are reflected in the air people breathe in the local urban areas used in this report.

8.3.2 Monitoring

The combined effects of source configurations and of meteorological and topographical features are unique to each and every area. As a result, the monitoring network design is very important - it must have sites properly located to give adequate coverage so as to capture the varying levels of air pollution across the city and to be representative of the surrounding areas. Appropriate quality assurance measures applied to the collection and analysis of the data are also required. This includes periodic visits to the site to determine that the immediate surroundings have not changed and that there are no new emission sources which could influence the representativeness of the site. The monitoring data used in this report fall into two different categories, of known and relatively unknown quality.

Known quality: For the suspended particulate matter and SO_2 data, the GEMS air network provides the following four standard features: monitoring system design, training, methods comparisons and data validation. In monitoring system design, guideline documents have been prepared which discuss the acceptable monitoring methods and suitable siting requirements. Sites in each city are chosen by the local staff, generally to represent in an acknowledged way residential, commercial and industrial areas of the city. Samplers are usually placed 3-15 metres above ground level in an area not greatly influenced by nearby sources. Training is provided when needed, especially in the operation and maintenance of the equipment.

The quality of the resulting data is a primary concern. Because data validation is primarily the responsibility of the reporting country, the GEMS data management system assists in this process by comparing the actual reported data against specified criteria to judge results of the reported returns. These acceptance procedures can identify various types of anomalies in the data so as to check for possible errors and to seek subsequent verification by the country.

Data summaries and statistical analyses are performed on the validated data provided data completeness requirements are met. Such a provision ensures that the seasonal cycles are adequately represented before a yearly summary is constructed. This procedure permits a more accurate and meaningful assessment of the air pollution results; it may not guarantee a perfect outcome but will reduce some of the uncertainty.

Unknown quality: The NO_2, Pb and CO data have been provided directly by individual countries or have been taken from published reports. The characteristics of these data include uncertainties as to the monitoring procedures, the siting requirements, representativeness of the site location and data and quality assurance practices. In addition, the very limited data available from which to judge world-wide levels makes inferences defendant upon qualitative knowledge of similar conditions elsewhere where data may not be available. A future assessment would be strengthened with the inclusion of data from Eastern Europe, Africa and a better mixture of urban locations from developing and developed countries.

8.3.3 Exposure

The variable nature of air pollution implies that actual exposure of an individual as he or she goes through his or her daily activities will be a summation of exposures experienced in successive "zones" with differing air pollution levels. Different life-styles and associated living conditions in different parts of the world will also contribute to widely varying human exposure to air pollution.

Exposure assessment is in fact the weakest link in the chain when considering the possible risks to health resulting from air pollutants. It may be reasonable to use ambient air monitoring data as an indicator of the exposure of population groups within a country or region experiencing a fairly uniform lifestyle, but the relationships between such data and actual exposures are likely to vary greatly among individuals and between population groups in different regions. One of the most important factors is the time spent indoors, which may be as much as 90% in developed countries in temperate zones, and the contrasts in air pollution inside and out. Thus the data in Appendix I indicate that certain risks may be enhanced indoors, as in the case of suspended particulate matter from cooking activities inside homes in many countries, or in respect of NO_2 from the use of unflued gas appliances.

Ambient concentrations are related to actual emission levels and reflect the results of nationwide control. The validity of using monitoring data as a surrogate for actual exposure can be checked in the one example available, for lead, where it can be seen that patterns in blood levels reflected a change with countrywide control and levels dropped below the WHO guideline of 20 ug/dl, consistent with recorded ambient levels. Biological monitoring is also possible for CO, but in general, assessment of individual exposures to each of the pollutants considered here requires the use of personal samplers. Pilot

studies of that type would help to establish relationships between exposure and ambient results for use in future assessment reports. The WHO/HEALs programme will be of assistance in this effort.

8.4 Issues requiring further attention

Although great progress has been made by many countries in reducing air pollution problems, the situation worldwide is still of great concern. It is certainly true that many developed countries in recent years have been able to make significant reductions in emissions of SO_2 and particulates. This has been achieved in some cases through controls on large numbers of small sources, such as domestic coal fires, and in others by reducing emissions from large single sources such as power stations. Examination of emission inventories and ambient air levels of the different pollutants as described in this report can, coupled with a knowledge of local practices, point the way forward to the type of action required to improve air quality.

The information presented in the section on nitrogen oxides indicates that only very few countries have introduced measures which have been sufficiently strict to reduce the overall emissions of NO_x, and in most countries, there is little indication of any significant improvement in urban levels of this pollutant. Other countries show increasing emissions of NO_x. Indeed, it is considered that NO_x will become an increasingly important air pollution issue in both the developing and developed world. In rapidly industrializing countries, large increases in traffic density will lead to increases in NO_2 levels in city areas. The rapid population growth and influxes to urban areas which characterize these countries will lead to larger numbers of people exposed to NO_2 levels approaching or exceeding guideline values. In developed countries, the controls planned for vehicle emissions may well be offset by the increasing numbers of motor vehicles. Although not addressed in this report directly, increasing attention is being paid to the role of NO_x along with SO_x emissions in the issue of acid deposition.

The issue of NO_x is also of concern for another reason, namely because of its role in the formation of photochemical oxidants, the most familiar being ozone. Although not discussed in detail in this report, there are worrying indications that levels of ozone are increasing in many European and North American cities. This pollutant is of particular concern because commonly recorded levels cause damage to crops and pose a health threat to city population at large; because of the nature of the photochemical processes, resulting oxidants are not confined to the immediate areas of emission of the precursor pollutants (NO_x and hydrocarbons).

Motor vehicle emissions of carbon monoxide and lead are also major issues of concern in developing countries. Careful urban planning is needed, both in order to minimize the buildup of these pollutants and to locate housing away from areas of high traffic density. However, the question of controlling these emissions in the ways being done in Europe and North America poses problems of cost in many developing countries. Another major issue in need of urgent attention is the question of particulate emissions from diesel powered vehicles. This source can make an important contribution to the urban suspended particulate matter burden. Furthermore, diesel vehicle densities are increasing in cities worldwide, but very few countries currently apply controls of any kind to this source.

Suspended particulate matter has been shown to be present at unacceptably high levels in many cities around the world. This class of pollutant is actually a highly complex and variable mixture of different sized particles with many chemical components from different sources. There is an urgent need to characterize both the inhalable portion and chemical composition of urban particulate loadings in different parts of the world. The high levels of organics, particularly PAHs, present on suspended particulate matter is of continuing concern because of the carcinogenicity of many of these compounds.

Problems of indoor pollution are discussed further in Appendix I, but it is appropriate to note here that the right perspective needs to be maintained in each situation in order to achieve the greatest benefits to health. Thus, in countries where it is seen that there are problems of indoor pollution that far outweigh the current ones outdoors, attention might need to be directed to them first.

Where large gaps in the data base for both emissions and ambient concentrations have been identified in this report, notably in respect of developing countries, it may be possible to fill some of them in relatively simple ways. The information gathered to date has already indicated links, albeit somewhat incomplete, between types of source, emissions, inventories, control measures (or the lack of them) and ambient concentrations. The starting point in areas where little information is as yet available need not be an extension of the monitoring network: the above features can be examined in sequence, looking first and foremost at the types of source, which will then indicate whether there could be problems in relation to human health, leading on to decisions about making emission inventories or considering control measures. Some pilot measurements of relevant pollutants could be helpful at that stage, but there may not be an immediate need to implement a monitoring programme.

Finally, the information in the present report should not be seen in isolation, but should be viewed as an integral part of the GEMS programme. Thus human intakes of some pollutants, such as lead, are influenced by ingestion as well as inhalation, and sources such as food and drink must be taken into account in assessing total uptake and in interpreting the impact of control measures on environmental concentrations and ultimate effects. Similarly, health is not the only outcome to consider for a wide range of pollutants. Increasingly, it is being recognized that damage to vegetation or other (indirect) effects such as acidification of lakes and rivers, to the detriment of fish stocks, can occur through the release of acid gases into the atmosphere. Resolution of these problems may create more stringent requirements for control than those based on health.

9. REFERENCES

9.1 General

The Associated Octel Company Limited 1976. Worldwide survey of motor gasoline quality.

The Associated Octel Company Limited 1985. Worldwide survey of motor gasoline quality.

CEC 1986. The air quality standard for SO_2 and particles (Directive 80/779/EEC) and its significance for the other main air pollutants. Commission of the European Communities, Luxembourg, EUR-10644 p.221.

Central Bureau of Statistics 1987. Environmental statistics 1987. Natural Resources and Pollution. Oslo, Norway.

DOE 1986. Digest of environmental and water statistics No. 9, 1986, HMSO, London.

ENDS 1987. Reducing the UKs acid emissions: a thinning mirage. ENDS Report 155:9-12 and 21.

Environment Agency 1986. The outline of air pollution control in Japan, The Government of Japan, Tokyo, Japan.

Environment Canada 1986. National urban, air quality trends 1974-1983. Conservation and Protection, Environment Canada, Ottawa, Canada, EPS 7/UP/1.

Environment Canada 1987. Clean air objectives, legislative and administrative practices in Canada, Canada's contribution to the International Union of Air Pollution Prevention Association's Proposed Compendium of Clean Air Objectives, Legislation and Administrative Practices Worldwide, Environment Canada, Ottawa.

EPA 1973. The national air monitoring program: air quality and emissions trends, Annual Report, Vol.1, Research Triangle Park, NC, US EPA Publication EPA-450/1-73-001.

EPA 1986. National air quality and emissions trends report 1984, Research Triangle Park, NC, US EPA Publication EPA-450/4-86-001.

EPA 1986. Air quality criteria for Lead, Research Triangle Park, NC, US EPA-600/8-83/028/af

EPA 1984. Air quality in Hong Kong, 1983/4, Hong Kong EPA/TRI/84.

EPA 1985. Air quality in Hong Kong, 1984/5, Hong Kong EPA/TR3/85.

Goldberg, E. D. (Ed.) 1982. Atmospheric chemistry, Springer Verlag, Berlin, Heidelberg, New York.

Highton, N.H. and Chadwick, M.Y 1982. The effects of changing patterns of energy use on sulphur emissions and depositions in Europe, Ambio 11: 324-329.

Jaffe, L. S. 1973. Carbon monoxide in the biosphere: sources, distributions and concentrations. J. Geophys. Res. 67:5,293-5,305.

Yaszay, T. and Bede, G. 1984. Energy and environment in Hungary. Ambio 13 (2): 107-108.

Logan, J.A., Prather, M.J., Wofsy, S.C. and McElroy, M.B. 1981 Tropospheric chemistry: a global perspective. J.Geophys. Res.86:7,210-7,254.

Laszlo,E. 1984. The state of the environment in Hungary. Ambio 13(2): 93-95.

MARC 1985. Historical Monitoring. Monitoring and Assessment Research Centre Report Number 31, University of London.

McCormick, J. 1985. Acid Earth: a global threat of acid pollution. International Institute for Environment and Development, London and Washington, DC.

Möller, D. 1984. Estimation of the global man-made sulphur emission. Atm. Env. 18 (1): 19-27.

NAS 1981. Indoor air quality. National Academy Press, Washington, D.C.

Nasralla, M.M.N. 1986. An investigation of some motor vehicle exhaust pollutants in Yeddah streets. Int. J. Env. Studies, 226: 217-222.

Nriagu, 1979. Global inventory of natural and anthropogenic emissions of trace metals to the atmosphere. Nature 279: 409-411.

OECD 1983. Environmental policies in Greece. Organization for Economic Cooperation and Development, Paris, France.

OECD 1986. Environmental effects of automotive transport. The OECD Compass Project, p.172, Organization for Economic Cooperation and Development, Paris, France.

Pattenden, N.Y. and Branson, Y.R. 1987. Relation between lead in air and in petrol in two urban areas of Britain. Atm.Env. 21 (11): 2481-2483.

Repetto, R. (Ed.) 1985. The global possible resources, development and the new century, Yale University Press, New Haven and London.

Robinson, E. and Robbins, R. C. 1972. Emissions, concentrations and fate of gaseous atmospheric pollutants. In: Strauss, W. (Ed.) Air Pollution Control, Part II, Wiley Interscience, New York, 1-93.

Settle, D. M. and Patterson, C. C. 1980. Lead in albacore: Guide to lead pollution in Americans. Sci. 207: 1,167-1,176.

Shrivastava, J. P., Desai, H. T. and Shah, R.K. 1984. Lead in the environment of Ahmedabad City. Indian J. Air Poll. Contr. 5 (1): 9-15.

Staatsuitgeverij 1985. Statistical yearbook 1985. CBS publication. The Hague, The Netherlands.

UN 1980. Urban, rural and city populations, 1950-2000 Assessed in 1978, United Nations Department of International, Economic and Social Affairs, Population Division, New York, Doc ESA/P/WP.66.

UN 1984. Energy statistics yearbook 1982. Department of International Economic and Social Affairs, UN, New York.

UN 1985. Estimates and projections of urban, rural and city populations, 1950-2025: The 1982 Assessment. United Nations Department of International, Economic and Social Affairs, New York, Doc. ST/ESA/SER.R/58.

UN 1986. Energy statistics yearbook 1984. Department of International Economic and Social Affairs, UN, New York.

UN/ECE 1987. National strategies and policies for air pollution abatement. UN, New York, E.87 II. E.29.

UNEP 1987. Environmental data report. Basil Blackwell, Oxford, UK, P. 52.

Vahter, V. 1982 (Ed.). UNEP/WHO Assessment of human exposure to lead and cadmium through biological monitoring. National Swedish Institute of Environmental Medicine and Karolinska Institute, Stockholm, Sweden, P.136.

Varhelyi, G. 1985. Continental and global sulphur budgets-I. Anthropogenic SO_2 emissions. Atm. Env. 19 (7): 1,029-1,040.

Wetstone, G.S. and Rosencranz, A. 1984. Acid Rain in Europe and North America. Environmental Law Institute, Washington, D.C.

WHO 1979. Sulphur oxides and suspended particulate matter. Environmental Health Criteria Document No.8. World Health Organization, Geneva.

WHO 1985. Urban air pollution in the People's Republic of China, 1981-1984. World Health Organization, Geneva.

WHO 1987. Air quality guidelines for Europe. World Health Organization, Regional Office for Europe, Copenhagen. WHO Regional Publications, European Series No. 23.

World Resources Institute 1986. World Resources 1986. Basic Books, New York, p.351.

Williams, M.L. 1987. The impact of motor vehicles on air pollutant emissions and air quality in the UK - an Overview. Sci. Total Env. 59:47-61.

Yuanjun, H. and Zhongxing, Z. 1987. Environmental pollution and control measures in China. Ambio 16 (5): 257-261.

Zhao, D. and Sun, B. 1986. Atmospheric pollution from coal combustion in China. J.A.P.C.A.36 (4): 371-374.

9.2 GEMS/Air

Selected methods of measuring air pollutants
WHO Offset Publication No. 24, 1976 (E, F, S, C)*

Air monitoring programme design for urban and industrial areas
WHO Offset Publication No. 33, 1977 (E, F, S, C)

Analysing and interpreting air monitoring data
WHO Offset Publication No. 51, 1980 (E, F, C)

Estimating human exposure to air pollutants
WHO Offset Publication No. 69, 1982 (E, F, C)

Air quality in selected urban areas - 1973-1974
WHO Offset Publication No. 30, 1976 (E)

Air quality in selected urban areas - 1975-1976
WHO Offset Publication No 41, 1978 (E)

Air quality in selected urban areas - 1977-1978
WHO Offset Publication No. 57, 1980 (E)

Human exposure to carbon monoxide and suspended particulate matter in Zagreb, Yugoslavia
WHO Internal Document EFP/82.33 (E)

Air quality in selected urban areas - 1979-1980
WHO Offset Publication No. 76, 1983 (E)

Urban air pollution, 1973-1980
World Health Organization, Geneva, 1984 (E, F, S)

Human exposure to suspended particulate matter and sulfate in Bombay, India
WHO Internal Document EFP/84.66 (E)

Urban air pollution in the People's Republic of China
WHO Internal Document EHE/PEP/85.5 (E, C)

Human exposure to carbon monoxide and suspended particulate matter in Beijing, China
WHO Internal Document PEP/85.11 (E, C)

Air quality in selected urban areas, 1981
WHO Internal Document PEP/86.4 (E)

Air quality in selected urban areas, 1982
WHO Internal Document PEP/86.5 (E)

Global pollution and health
World Health Organization, Geneva, 1986 (E)

Practical application of liquid sodium sulfite-TCM samples as reference standards for SO_2 measurements
WHO Internal Document EFP/81.13 Rev. 1 (E)

Report of a meeting of government-designated experts on health-related monitoring, Geneva, 8-12 March 1982
WHO Internal Document EFP/82.28 (E)

Report of a meeting on quality assurance in air quality monitoring, Mol 17-20 October 1982
WHO Internal Document EFP/84.63 (E)

Report of a meeting to review the air monitoring project operation, London, 12-15 June 1984
WHO Internal Document EFP/8467 (E)

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*Languages: E = English F = French S = Spanish and C = Chinese

APPENDIX I

INDOOR AIR QUALITY

1 Nature of the Problem

The indoor environment has become an issue for the public, government, scientists and industry because of four factors:

- outdoor air quality in many developed countries has improved substantially, highlighting indoor sources that remain uncontrolled
- energy conservation efforts which may aggravate an indoor pollution problem
- the realization that little is known about the hazards of many substances commonly found in indoor air, including some derived from household products
- the need to understand total exposure which includes both the outdoor and indoor environment where people may spend 80-90% of their time

The last point is illustrated in the table below where the weight given to indoor concentrations in estimates of total exposures is based on the amount of time spent there. With regard to indoor pollution only those pollutants for which there are significant sources indoors need generally to be given consideration (third category in Table 2.1).

Table 1 Daily intakes of some air pollutants from indoor and outdoor environments (total respiratory volume taken as 15 m^3/d: 1.5 m^3/d outdoors and 13.5 m^3/d indoors)[1]

Pollutant	outdoor concentration ug/m^3	outdoor intake ug/d	indoor concentration ug/m3	indoor intake ug/d	total intake ug/d
Formaldehyde	3	4.5	50	675	679
Toluene	5	7.5	75	1012	1020
Resp. Particulates	30	45.0	80	1080	1125
NO2	5	7.5	20	270	278

[1]The determination of health effects of indoor air pollution, J.A. Stolwijk in Proc. 4th Int. Conf. Indoor Air Quality and Climate, Berlin, 1987.

The indoor pollution problems that are of major importance differ considerably in industrialized countries and developing countries. In industrialized countries many of them are associated with energy-saving tightening of buildings and houses and the resulting build-up of pollutants. In developing countries, on the other hand, the most significant indoor air pollution problem is associated with the burning of so-called biomass fuels in unflued open fires indoors in many rural houses. The remainder of this section is divided into three parts, the first describes indoor problems in industrialized countries, the second deals with indoor air pollution in rural areas of developing countries and the third illustrates typical concentrations of indoor pollutants both in developing and industrialized countries.

2. Indoor air pollution in industrialized countries

Pollutants and groups of pollutants that are of major importance include NO_2, CO, Radon, formaldehyde, asbestos, man-made mineral fibres, volatile organics and allergens. Another important source of indoor pollution is tobacco-smoking which introduces many organic substances into the atmosphere. There is, at present, no ongoing monitoring programme for any of the substances mentioned but in each case many individual studies and surveys have been carried out, the results of which have been summarized below.

Also, the number of studies which have specifically addressed adverse effects of indoor pollution is relatively small and the results in many cases have been far from conclusive with regard to their impact on human health.

Indoor pollutants are mostly either produced by human activities, such as smoking and cooking, or from building materials, such as those used for insulation and from furnishings, such as carpets. The overiding problem is, however, that because of energy considerations, ventilation of buildings and houses is reduced causing a gradual increase of various pollutants liable to result in adverse effects of health.

Radon: Building materials, domestic water, underlying soil and groundwater can release substantial amounts of radon into the indoor atmosphere in certain regions. The radon decays to "daughter products" that are themselves radioactive and that become attached to other particulate matter in the indoor air. Indoor concentrations are affected by various factors, the most important of which is the ventilation rate. Data from several studies carried out in the USA and Scandinavia showed a high proportion of homes with levels at which there is concern for the health of the inhabitants. Epidemiological studies of workers in atmospheres containing relatively high concentrations of radon indicate that the most serious and likely health risk is increased incidence of bronchogenic carcinoma.

Asbestos: Because of its desirable insulating and fire-resistant properties, asbestos has been used widely in the construction of homes and public buildings. The use of asbestos, has been shown to have adverse health effects ranging from asbestosis to bronchogenic carcinoma, especially in cigarette smokers. Streneous efforts should be made to avoid all exposure to asbestos-fibre releasing materials and workers involved in the removal of asbestos from buildings or during demolition of buildings should be protected. There is also a need to investigate any adverse health effects of other inorganic fibrous materials such as glass fibre or rockwool.

Formaldehyde: Concentrations of formaldehyde are almost always higher indoors than outdoors. Sources include building materials (particle board and plywood), insulation materials (urea formaldehyde foam), cigarette smoking and home and office furnishings. The main acute adverse health effects of formaldehyde are irritation of the eyes and respiratory tract. A number of countries have adopted or recommended guideline values for indoor formaldehyde concentrations.

Nitrogen dioxide: Indoor sources of NO_2 are gas appliances, such as cooking stoves and unflued heaters and portable kerosine heaters. As ventilation rates fall, increased indoor concentration of NO_2 are likely. Exposure to NO_2 may have adverse effects such as increase in respiratory illness particularly among young children who spend much time in the home and changes in pulmonary function. The effects appear to be more related to peak values than to long-term averages.

Tobacco smoking: Smoking of cigarettes, pipes and cigars is a major and widespread source of contaminants in indoor air. The effects of this on non-smoking occupants (passive smoking), include increased exposure to CO, acrolein, aldehydes, NO_2 and the aerosol of tobacco "tar" containing substances that are carcinogenic. The effects of environmental tobacco smoke are of particular concern with regard to children. For example, children of parents who smoke compared with children of parents who do not smoke show increased prevalences of respiratory symptoms. Evidence has also accumulated indicating that non-smoking pregnant women exposed to environmental tobacco smoke on a daily basis for several hours are at increased risk of producing lowbirth-weight babies. Many studies indicate an increased risk of increased lung cancer among non-- smokers regularly exposed to environmental tobacco smoke.

Volatile Organic compounds: Generally, volatile organic compounds (VOCs) arise indoors from furnishings and consumer products such as personal grooming items, various household cleaning products, paints and solvents, etc. No well-defined health effects have been associated with this type of indoor pollution. There may, however, be individual substances included in this group, such as benzene for example, which may have clear and well-defined health risks associated with them (occupational exposures to benzene are associated with an increased risk of leukaemia).

Viable particles and odours: Ventilation systems, humidifiers, and air conditioners can be sources of viable particles in the form of bacteria, viruses, fungi and parasites. Such particles can produce infectious diseases, parasitic diseases and allergic ailments. For example, "legionaires disease" appears to be associated with air conditioning systems. The perception of odours is not considered a health effect in itself. Annoyance caused by inappropriate odours however can lead to stress and behavioural change.

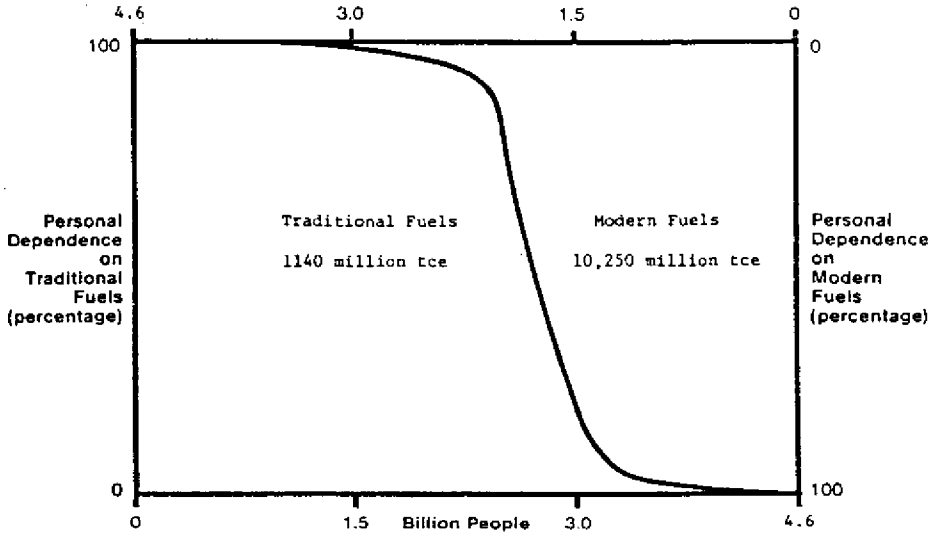
Sick Building Syndrome: This is the name given to a rather unspecified state affecting wellbeing that is associated with the occupancy of rather large and often recently constructed or remodelled buildings. Such buildings are almost always found to have a forced ventilation system with partial recirculation of the air. Often the walls and floors are covered by textiles and the windows cannot be opened. The effects on health include eye, nose and throat irritation, mental fatigue, headaches and nausea and dizziness.

3. Indoor air pollution in developing countries

In this section, the indoor air pollution problem is described which occurs widely in rural agricultural communities and in some urban areas also in the developing regions of the world. The indoor air pollution problem arises from the primitive combustion of biomass fuels indoors for cooking and heating. Biomass fuels are wood, agricultural waste, dung, etc. In some countries, particularly China, coal is used widely for cooking and heating, with inadequate flues or none at all producing also severe indoor air pollution in many instances.

Although biomass fuels today supply a relatively small proportion (10 percent) of global energy requirements, they provide the largest fraction of energy in terms of numbers of people using them. As shown in Figure 1 about two thirds of the world population depends on these traditional fuels for most of their energy supply.

Figure 1. Global personaL use of traditional fuels[1]



Biomass smoke contains a mixture of many hundred substances. In addition to the major constituents, such as particulate matter which is made up of many organic and inorganic constituents, nitrogen dioxide, sulfur dioxide, various aldehydes and carbon monoxide, there are a large number of other gases and organic vapours contained in biomass smoke. Studies of the composition of biomass smoke generally show quite high levels of polycyclic aromatic hydrocarbons (PAH), many of which have been shown to be carcinogenic.

[1] Biomass fuel combustion and health, WHO 1984.

Table 2 shows the results of an analysis of some 20 air samples for a number of polynuclear hydrocarbons. The samples were collected inside rural houses in Maragua, Kenya[1]

Table 2. Concentrations of polynuclear hydrocarbons

	Compound	n	Air concentration* Mean (ng/m^3)	Max. (ng/m^3)	Min. (ng/m^3)
1.	Fluoranthene	20	254	779	34
2.	Pyrene	20	779	2387	103
3.	Benz(a)anthracene	20	273	838	36
4.	Chrysene	20	262	801	34
5.	Benzo(b)fluoranthene	20	106	324	14
6.	Benzo(k)fluoranthene	20	36	109	5
7.	Benzo(a)pyrene	20	86	263	11
8.	Benzo(ghi)perylene	18	252	771	33
9.	Dibenz(a,h)anthracene	18	143	438	19
10.	Indeno(1,2,3-cd)pyrene	19	51	158	7

*The air concentrations were calculated on the basis of the mean PAH content of the 20 filters and the mean, maximum and minimum of the complete data set.

4. Indoor concentrations of pollutants, as reported from developing and developed countries

Table 3 presents ranges of different pollutants found inside houses in developing and developed countries. The data have been collected from different sources and mainly serve to give an approximate indication of indoor levels alongside guidelines as recommended for outdoor air, which may assist in the evaluation of the indoor air pollution situation.

[1] Indoor air pollution study, Maragua, Kenya, WHO 1987.

Table 3. Air pollution concentrations in different environments

	Conc. range	WHO Guideline (see also Table 2.7)
Suspended particulate matter (ug/m^3)		
Indoors in rural houses of developing countries	300-14,000	100-150
Indoors in houses in developed countries	30-100	
Public places	50-70	
Formaldehyde (ug/m^3)		
Indoors in rural houses of developing countries	200-1500	100
Indoors in houses in developed countries	50-100	
Urban air	5-10	
Background	2	
Traffic areas	50	
Nitrogen dioxide (ug/m^3)		
Indoors in rural houses of developing countries	100-400	400 (1 hr) 150(24 hrs)
Indoors in houses developed countries	10-100	
Urban areas - outdoors	50-100	
Public places	20-150	

Carbon monoxide (mg/m^3)		
Indoors in rural houses of developing countries	10-50	
Indoors in houses in developed countries	5	
Natural background	0,01-0,25	30 (1 hr) 10(8-24 hrs)
Busy traffic areas	10	
Underground garages, tunnels and certain work areas	100	
Public places (restaurants, bars, arenas, theatres, offices, public transportation, with smoking	3-30	

Polycyclic aromatic hydrocarbons (ng/m^3)		
Indoors in rural houses of developing countries	100-10,000	
Natural background	NO	
Traffic areas	20	No guideline
Some industrial settings (coke ovens)	Up to 5,000	
Smoky room	20-100	

The table shows that especially for suspended particulate matter and polycyclic hydrocarbons in indoor environments in developing countries the situation is quite serious and definitely presents a health hazard. For the other pollutants, carbon monoxide, nitrogen dioxide and formaldehyde, the levels are quite high, but not orders of magnitude higher as they are for suspended particulate matter.

Regarding the particulate matter concentrations, a parallel can be drawn with tobacco smoke, the effects of which on children were briefly described in the previous section. Two smokers contribute about 40 ug/m^3 of additional particulate matter to indoor air levels and this is associated with certain effects in children[1]. Based on this information, the health impact of indoor air pollution in rural houses in developing countries must be expected to be very significant.

[1] Environmental tobacco smoke, measuring exposures and assessing health effects, National Research Council, Washington, 1986.

The health impact of indoor air pollution in developing countries was recently reviewed[1]. At present, the full dimensions of the health problems attributable to the toxic fumes and smoke have only been roughly delineated. There are four major categories of ill-health that are identified with high exposures to biomass combustion products:

- chronic obstructive lung disease;
- heart disease, particularly cor pulmonale caused by pulmonary damage;
- cancer, particularly of lung and nasopharynx;
- acute respiratory infections, particularly in children.

Respiratory diseases are not the only health problem brought about by the current practice of biomass fuel combustion. There are other health problems caused to an extent by the inefficient burning and subsequent fuel wastage. They include:

- possible loss in nutrition due to limitation on the frequency of hot dishes, change to foods requiring little or no heat, etc.;
- food contamination due to limited possibilities of re-heating "left-overs", boiling water, etc;
- low birth weight due to maternal exposures to pollutants and associated with a range of perinatal and infant ill-health.

The over-use of biomass as fuel, as it is now in many areas, is also a major human and natural resource and environmental problem in terms of requiring more and more time to be spent in gathering of fuel, depletion of forests, wastage of valuable fertilizer material, land erosion, desertification, etc.

A conservatively estimated 400-500 million people worldwide, mostly in rural areas of developing countries are affected by these problems. The victims are most often pre-school children and women[1] who suffer from impaired health due to prolonged and repeated contact with these harmful pollutants. Also when the women are pregnant, they may also expose the developing foetus to the risk of birth defects. In developing countries, exposure to biomass fuel emissions is probably the single most important occupational health hazard of women.

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[1]Rural energy utilization and the health of children, H.W.de Koning, Adv. Int. Maternal and Child Hlth. 7: 130-137 (1987)

APPENDIX II

EMISSIONS TABLES FOR SO_2 SPM, NO_x, CO AND Pb

The emission tables were compiled based on data obtained from questionnaires and the open literature. In most cases the information was later verified and updated by the responsible agencies in the different countries.

The emission data have been grouped in 3-year time periods (1973-75, etc.). For each of these periods either one, two or three annual values have been used, according to availability of this information, to calculate the average.

Care should be taken in making comparisons between mission data from different countries since different procedures have sometimes been used to make the estimates.

APPENDIX II

Table 1 Estimated SO_2 emissions (thousand tonnes/ year)

Country	1973-75	1976-78	1979-81	1982-84	Reference
Australia[a]		1,480			1
Austria	-	-	330	140	35
Belgium	1,000	930	860	700	38
Bulgaria			1,030	1,140	3
Canada[b]	5,880	4,920	4,610	3,760	4,34
China			14,210	12,920	5
Czechoslovakia			3,100		3
Denmark	430		460	410	1
Finland	540	550	570	360	6
France	3,760	3,670	3,410	2,305	7
Germany, Fed. Rep.	3,600	3.450	3,300	2,750	8
Germany, Dem. Rep.			4,000	4,000	3
Greece	270	385	400	360	39
Hong Kong	160	200	220	240	2
Hungary	-	1,640	1,635	1,460	9,42
Iceland			6	6	3
India	1,610	1,890			10
Ireland	190	205	210	150	11
Israel[c]	230	255	290	275	12,41
Italy	-	3,250	3,210	2,230	1,32,33
Japan	2,620	1,680	1,640	1,610	2
Kuwait		200		450	13
Luxembourg			20	10	14
Netherlands[d]	320	330	390	260	15,37
New Zealand[a]		90			1
Norway	155	155	145	110	16
Poland	2,080	-	2,600	3,700	17,18,19,20
Portugal	180	195	260	305	40
Romania			200		3
Spain			2,670		2
Sweden	690	610	480	285	21,22,30,31
Switzerland	110	120	120	100	23,36
Thailand	-	-	120*	310	24
Turkey		710			1
UK	5,430	4,990	4,740	3,750	25
USA	25,600	25,670	23,330	21,100	26
Yugoslavia			820		27

*Bangkok only

APPENDIX II

Table 2 Estimated suspended particulate particulate emissions (thousand tonnes/year)

Country	1973-75	1976-78	1979-81	1982-84	Reference
Australia[a]		70			1
Austria[a]	-	-	50	55	5
Belgium	175	150	140	125	38
Canada[b]	2,080	1,880	1,870	-	4,34
China[c]			16,200	13,740	5
Denmark	-	50	-	-	1
Finland		90			6
France	295	295	265	210	7,
Germany, Fed. Rep.	950	780	750	650	8
Greece[a]	155	165	170	185	39
Hong Kong	15	20	20	15	2
Hungary	-	540	550	500	9,42
Ireland	80	80	90	100	11
Israel[c]	16	18	20	19	12,40
Italy[a]	-	380	435	410	32,33
Kuwait		50		180	13
Netherlands[d]	30	35	40	35	15,37
New Zealand[a]		20			1
Norway[i]	30	30	30	25	1
Poland	2,230		2,120	3,350	17,18,19,20
Portugal	75	90	120	-	40
Spain			1,520		1
Sweden	170	170	-	40	21,30,31
Switzerland	30	30	30	20	36
Thailand	-	-	40*	230	24
Turkey[a]	-	140	-	-	1
U.K.[f]	450	360	300	230	25
U.S.A.	10,400	9,330	8,470	6,900	26

*Bangkok only

APPENDIX II

Table 3 Estimated NO_x emissions (thousand tonnes/year)

Country	1973-75	1976-78	1979-81	1982-84	Reference
Australia[a]		920			1
Austria	-	-	200	210	35
Belgium	380	380	390	340	28,38
Bulgaria				150	3
Canada[b]	1,750	1,800	1,910	1,870	4,34
China			4,400	4,130	5
Czechoslovakia			1,200		3
Denmark	200		240	250	1
Finland	160	170	280	250	6
France	1,675	1,795	1,855	1,730	7
Germany, Fed. Rep.	2,600	2,900	3,100	3,000	8
Greece	105	120	130	150	39
Hong Kong	40	45	50	80	2
Hungary	-	280	290	300	9,42
Iceland			10	10	3
Ireland	60	60	70	60	11
Israel[c]	95	100	110	125	12,41
Italy	-	1,300	1,510	1,530	32,33
Japan	1,800	1,550	1,340	1,420	2
Kuwait		100		100	13
Luxembourg			20	20	14
Netherlands[d]	390	420	470	450	15,37
New Zealand[a]		90			1
Norway	150	170	170	180	16
Poland	90	-	-	1,770	18,19,20
Portugal	105	170	210	190	40
Spain	620		810		1
Sweden	310	320	320	295	21,22,30,31
Switzerland	160	180	200	210	23,36
Thailand	-	-	30*	130	24
Turkey		380			1
U.K.	1,870	1,890	1,900	1,770	25
USA	19,200	20,870	20,670	19,500	26

*Bangkok only

APPENDIX II

Table 4 Estimated CO emissions (thousand tonnes/ year)

Country	1973-75	1976-78	1979-81	1982-84	Reference
Australia[a]		3,700			1
Austria[a]	-	-	1,130	1,070	35
Belgium	1,150	1,250	1,250	1,000	38
Canada[b]	10,700	10,650	9,930	-	4,34
Denmark[g]			600	250	1
Finland	-	-	600	-	6
France[a]	-	5,200	6,550	6,330	46
Germany, Fed. Rep.	11,700	9,850	9,000	7,400	8
Greece[a]	-	700	-	-	39
Hong Kong	110	120	165	180	2
Hungary	-	1,100	1,370	1,400	9,42
Ireland	390	430	490	480	11
Israel[c]	320	340	360	420	12,41
Italy[a]	-	4,795	5,480	5,420	32,33
Kuwait		500		620	12
Netherlands[d]	1,460	1,360	1,170	990	15,37
New Zealand[a]		570			1
Norway	540	605	605	595	16
Poland	590			3,300	18,19,20
Portugal	460	490	525	-	40
Spain			3,780		1
Sweden	1,400	-	1,390	1,600	21,22,30,31
Switzerland	740	720	710	640	36
Thailand	-	-	120*	-	24
Turkey			3,710		1
U.K.	4,820	4,920	5,090	5,180	25
U.S.A.	81,200	83,100	76,030	69,230	26

*Bangkok only

APPENDIX II

Table 5 Estimated lead emissions (thousand tonnes/year)

	1973-75	1976-78	1979-81	1982-84	1985	Reference
Belgium				1.4		43
Canada	14.5			11.5		29,44
Hungary[h]	0.6				0.5	44
Ireland	0.7	0.8	0.8	0.5	0.4	11
Mexico			19.6	8.4		43
Netherlands[d]			1.4	1.3		15,44
Norway		0.7	0.6	0.4		45
Sweden[h]	1.5	1.5	1.1	0.7	0.9	22,44
Switzerland			1.0		0.5	44
Thailand				1-5		24
UK[h]	7.9	7.4	7.2	7.0	6.5	25
USA	147.0	140.7	78.4	46.9	21.1	26

a excludes industrial processes
b excludes forest fires
c fossil fuel combustion only
d fossil fuel combustion in domestic stoves and automobiles only
e 'soot'
f smoke from coal combustion
g mobile sources only
h petrol-engined road vehicles only
i fossil fuels and wood

REFERENCES

1. OECD 1985 Environmental Data Compendium 1985, Organisation for Economic Co-operation and Development, Paris.
2. Personal communication, Environmental Protection Department, Hong Kong.
3. UN ECE 1987 National Strategies and Policies for Air Pollution Abatement, United Nations, New York.
4. Environment Canada 1986 Emissions and Trends of Common Air Contaminants in Canada: 1970 to 1980, Report EPS 7/AP/17, Ottawa.
5. State Statistical Bureau 1985 Materials on Chinese Social Statistics, Zhongguo Tongi Chubanshe, Beijing.
6. Central Statistical Office of Finland 1986 Environmental Statistics 1985, Helsinki.
7. Ministère de l'Environnement 1985 L'Etat de l' Environnement 1985, La Documentation Francaise, Paris.
8. Umweltbundesamt 1986 Daten zur Umwelt 1986/87, Erich Schmidt Verlag, Berlin.
9. Hungarian Central Statistical Office 1981 Environmental Statistics 1975-1980, Budapest.
10. Kumar, S. and Prakash, C. B. 1980 Sulphur dioxide emission in India, In: Proceedings of the Fifth International Clean Air Congress, Buenos Aires.
11. An Foras Forbatha 1985 The State of the Environment, Dublin.
12. Environmental Protection Service 1979 The Environment in Israel, Ministry of the Interior, Jerusalem.
13. Ibrahim Hadi, Environmental Protection Council (personal communication).
14. Comite National pour la Protection de l'Environnement 1985 Stress Anthropique et Dommages Forestiers, Grand-Duche de Luxembourg.
15. Staatsuitgeverij 1985 Statistisch Zakboek 1985, CBS-publicatie, The Hague.
16. Central Bureau of Statistics of Norway 1986 Environmental Statistics 1986 Oslo.
17. Central Statistical Office 1984 Concise Statistical Yearbook of Poland, 1984, Warsaw.
18. Glowny Urzad Statystyczny 1984 Opracowania Statystyczne, Ochrona Srodowiska i Gospodarka Wodna 1984, Warsaw.
19. Glowny Urzad Statystyczny 1986 Ochrona Srodowiska i Gospodarka Wodna 1986, Warsaw.
20. Nowicki, M. 1984 Glowne zrodla emisji zanieczyszczen atmosfery, Ochrona Powietra No.4, Warsaw.
21. Boström, C. E. et al. 1982 Luftföroreningar i Sverige 1970-1980, Statens Naturvardsverk SNV PM 1521, Solna.
22. Jernelöv, M. and Lövblad, G. 1985 Luftföreningar fran vagtrafik i Sverige, Statens Naturvardsverk SNV PM 1671, Solna.
23. Rapport sur la Strategie de lutte contre la Pollution de l'Air, Septembre 1986, Berne, Suisse.
24. Limpaseni, W. 1986 Draft Paper on Air Quality and Noise Pollution Management, Thailand Development Research Institute (unpublished).
25. Department of the Environment 1987 Digest of Environmental Protection and Water Statistics No. 9 1986, HMSO, London.
26. U.S. Environmental Protection Agency 1986 National Air Quality and Emissions Trends Report 1984, US EPA, Washington. 450/4-86-001, Research Triangle Park, North Carolina.

27. Federal Administration for International, Scientific, Educational, Cultural and Technical Co-operation and Co-ordinating Committee for the Environment; Territorial Management, Housing and Public Utilities of the Federal Executive Council and the Executive Councils of the Socialist Republics and Socialist Autonomous Provinces 1983 National Report. The State of the Environment and the Environmental Policy in Yugoslavia, Belgrade.
28. De Rijck, I. T. and Van Hove, L. W. 1985 Raming van NO_x - uitworp in Belgie, Leefmilieu **3**, 78-81.
29. Environment Canada 1985 National Inventory of Sources and Releases of Lead, EPS 5/MA/3, Ottawa.
30. Statistiska Centralbyrian 1987 Sulphur and nitrogen oxide emission to air in Sweden 1985, Statistiska.
31. Statistiska Centralbyrian 1987 The Natural Environment in Figures. Year book of Environmental Statistics 1986-87.
32. Ministero dell'Ambiente 1987 Nota preliminaire alla relazione sullo stato dell'Ambienta, tabella 1, 7 elaborata da ENEA Direzione Centrale Studi.
33. Bocola, W. and Circillo, M. C. 1986 Le emissioni di inquinanti dell'aria dai processi di combustione un'analisi della situazione italiana, Energia **4**, 48-62.
34. Personal communication, Inventory Management Division, Environmental Analysis Branch, Environmental Protection Branch, Environment Canada, Ottawa, Canada.
35. Energie Bericht 1986 Bundesministerium für Handel, Gewerbe und Industrie, Wien, Ostereich.
36. Athropogene Schadstoffemissionen in der Schwyz 1950-2010 1984, Berne, Schwyz.
37. Netherlands Central Bureau of Statistics, Environmental Statistics of the Netherlands 1987 Voorburg, The Netherlands.
38. Hecq en Kayser, Emissies van luchtverontreinigende stoffen afkomstig van de verbranding in België. Een balans van tien jaar, Algemeen Gastijdschrift, nr. 2, 1986 blz. 69.
39. Personal communication, Ministry of Environment, Physical Planning and Public Works, Directorate of the Environment, Athens, Greece.
40. Personal communication, Ministry of Planning and Territorial Administration, Lisbon, Portugal.
41. Personal communication, Ministry of Health, Tel Aviv, Israel.
42. Personal communication, National Authority for Environment Protection and Nature Consortium, Budapest, Hungary.
43. UNEP/WHO 1985 Assessment of human exposure to lead: comparison between Belgium, Malta, Mexico and Sweden Karolinska Institute, Stockholm, 57pp.
44. UN ECE 1987 Environment Statistics in Europe and North America, UN New York, p.29.
45. Environmental Statistics 1987 Central Bureau of Statistics of Norway, Oslo, Norway.
46. Personal Communication, Ministry of Equipment, Housing, Land Management and Transport, Ministry of the Environment, France.
47. Kim, Y.S. 1984 Air pollution in the Republic of Korea, JAPCA 34(8):841-843.

APPENDIX III

The tables in this Appendix were compiled as follows:

(a) For each representative yearly data set the number of days during which the measured SO_2 concentration exceeded 150 ug/m^3 was determined and, if required, extrapolated to a complete year of 365 or 366 days. This gave a set of year-site specific exceedances for each city.

(b) These were summarized on a city-wide basis by means of:

- the minimum value in that set corresponding to the year-site combination with the smallest number of days above 150 ug/m^3,

- the maximum value in that set corresponding to the year-site combination with the largest number of days above 150 ug/m^3, and

- the arithmetic average of all the available yearly exceedance figures;

(c) For the suspended particulate matter tables the same procedure was followed as described under (a) and (b) using the guideline value of 150 ug/m^3 for smoke and 230 ug/m^3 for SPM.

APPENDIX III

Table 1 Number of days per year with SO_2 levels above 150 ug/m^3

Country	City	Number of site-years	Number of days over 150 ug/m^3 min.	avg.	max.
Australia	Melbourne	13	0	0	0
	Sydney	12	0	2	11
Belgium	Brussels	13	0	12	32
Brazil	Sao Paulo	11	0	12	32
Canada	Hamilton	8	0	3	7
	Montreal	10	0	10	32
	Toronto	9	0	1	3
	Vancouver	5	0	0	0
Chile	Santiago	9	0	19	55
China	Beijing	8	0	68	157
	Guangzhou	12	0	30	74
	Shanghai	10	0	16	32
	Shenyang	7	43	146	236
	Xian	7	4	71	114
Colombia	Cali	1	0	0	0
	Medellin	3	0	0	0
Denmark	Copenhagen	3	0	0	0
Finland	Helsinki	8	0	2	7
France	Gourdon	4	27	46	64
Germany,	Frankfurt	6	8	20	38
Fed. Rep.	Munich	3	0	0	1
Greece	Athens	3	1	9	15
Hong Kong	Hong Kong	10	0	15	74
India	Bombay	13	0	3	32
	Calcutta	8	0	25	85
	Delhi	12	0	6	49
Iran	Tehran	15	6	104	163
Ireland	Dublin	6	0	1	3
Israel	Tel Aviv	9	0	3	24
Italy	Milan	8	66	29	167
Japan	Osaka	20	0	0	0
	Tokyo	15	0	0	0
Malaysia	Kuala Lumpur	1	0	0	0
Netherlands	Amsterdam	10	0	1	5
New Zealand	Auckland	12	0	0	0
	Christchurch	12	0	0	2
Philippines	Manila	4	3	24	60
Poland	Warsaw	13	3	10	19
	Wroclaw	15	1	8	22
South Korea	Seoul	6	5	87	121
Spain	Madrid	7	0	35	95
Thailand	Bangkok	3	0	0	0
U.K.	Glasgow	5	4	14	21
	London	6	0	7	17
U.S.A.	Illinois	4	0	1	2
	St Louis	3	1	3	8
	New York City	12	1	8	22
	Houston	3	0	0	0
Venezuela	Caracas	8	0	0	0
Yugoslavia	Zagreb	15	3	30	80

Table 2 Number of days per year with gravimetrically determined SPM levels above 230 ug/m^3

Country	City	Number of site-years	Number of days over 230 ug/m^3 SPM		
			Min.	Avg.	Max.
Australia	Melbourne	4	0	0	0
	Sydney	10	0	3	19
Brazil	Rio de Janeiro	6	0	11	35
Canada	Hamilton	10	0	8	14
	Montreal	15	0	0	6
	Toronto	14	0	1	7
	Vancouver	12	0	0	7
China	Beijing	08	145	272	338
	Guangzhou	10	7	123	283
	Shanghai	10	19	133	277
	Shenyang	13	117	219	347
	Xian	10	189	273	327
Colombia	Medellin	3	0	0	0
Denmark	Copenhagen	6	0	0	1
Finland	Helsinki	11	0	19	75
Germany, Fed. Rep.	Frankfurt	3	0	0	0
India	Bombay	12	23	100	207
	Calcutta	8	189	268	330
	Delhi	12	212	294	338
Indonesia	Jakarta	7	4	173	268
Iran	Tehran	15	8	174	347
Japan	Osaka	20	0	0	2
	Tokyo	15	0	2	4
Malaysia	Kuala Lumpur	5	10	37	59
Philippines	Manila	7	0	14	225
Portugal	Lisbon	7	4	12	28
Thailand	Bangkok	12	5	97	209
U.S.A.	Birmingham	9	0	7	28
	Fairfield	5	0	0	0
	Chicago	7	0	6	14
	New York City	12	0	0	0
	Chatanooga	16	0	1	17
	Houston	7	0	0	0
Yugoslavia	Zagreb	15	13	34	57

Table 3 Number of days per year with smoke levels above 150 ug/m^3

Country	City	Number of site-years	Number of days over 150 ug/m^3 smoke		
			Min.	Avg.	Max.
Belgium	Brussels	13	0	0	2
Brazil	Sao Paulo	11	16	31	52
Chile	Santiago	9	11	102	299
Denmark	Copenhagen	6	0	0	0
France	Gourdon	9	0	3	7
Hong Kong	Hong Kong	11	0	3	18
Iran	Tehran	15	12	122	249
Ireland	Dublin	6	0	6	15
New Zealand	Auckland	12	0	0	0
	Christchurch	12	0	8	25
Poland	Warsaw	14	4	17	33
	Wroclaw	15	9	30	73
Spain	Madrid	4	4	60	126
U.K.	Glasgow	5	2	6	8
	London	6	0	0	0
Venezuela	Caracas	8	0	0	0