EARTHWATCH

GLOBAL ENVIRONMENT MONITORING SYSTEM

City Air Quality Trends

(GEMS/Air Data)

Volume 1

BANGKOK	SHANGHAI
BEIJING	TEHRAN
BOMBAY	TOKYO
LONDON	WROCLAW
SAO PAULO	ZAGREB

UNEP
United Nations
Environment Programme

World Health
Organization

Contents

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Preface

This report is the first volume of a series presenting data on levels and trends of urban air pollutants in selected cities participating in the GEMS/AIR programme. The data from the GEMS/AIR global database are presented in a common format for every city, providing a synoptic view of a city's major urban air pollution problems.

In this report, monitoring data for sulphur dioxide (SO_2) and particulate pollutants (Suspended Particulate Matter and Smoke) are given for a first selection of ten cities which were chosen to illustrate a wide range of climatic and socio-economic conditions, as well as different levels of industrial development and air pollution control. These first cities are Bangkok, Beijing, Bombay, London, Sao Paolo, Shanghai, Tehran, Tokyo, Wroclaw, and Zagreb. Further reports dealing with other GEMS/AIR cities will follow. Cities already covered in earlier reports will be regularly revisited to show any changes in their air quality trends. This report complements other GEMS/AIR assessments[a] and is based on the holdings of the GEMS/AIR global database and other available relevant information.

The aim of this new report series, to be issued on a time-to-time basis, is to draw attention to the seriousness of the urban air problem at the global scale, and to increase awareness for the need to introduce better control and abatement strategies. It must be stressed, however, that pollutant levels in different cities vary widely, even though emission levels may be very similar. Location, topology and meteorology greatly affect the way in which pollutants are dispersed. In addition, some cities suffer from high levels of natural emissions - such as wind-blown dust - which cannot be controlled at present.

The report contains an introductory chapter which gives background information on the global urban air pollution problem, and on the GEMS/AIR programme. The air quality guidelines applied in the report are explained and the potential health risks of urban air pollution are summarized. The chapter containing the GEMS/AIR monitoring data is at the core of the report. Each city is presented in three sections. The *Situation Analysis* section briefly describes the city in terms of population, air pollution sources, and, if available, emission data and control actions. The *GEMS/AIR Results* section analyses SPM and SO_2 levels and trends, based on data from GEMS/AIR stations provided by cities to the global database. Comparisons of these results with the WHO guideline values indicate the potential for health effects. Graphs show the yearly average pollution concentrations at all monitoring sites. For each city, the daily mean values from the site with the highest annual average for the most recent year of data are also given. The *Recommendations* section suggests some possible options for further control measures aimed at the reduction of ambient concentrations of the air pollutants monitored within the GEMS/AIR programme. The report concludes with a synoptic chapter in which the data are analyzed with respect to their global significance.

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[a] such as: Urban Air Pollution in Megacities of the World. Basil Blackwell Publ., Oxford 1992
Assessment of Urban Air Quality. UNEP and WHO, Nairobi 1988
Urban Air Pollution 1973-1980. WHO and UNEP, Geneva 1984

I. Introduction

Urban Air Pollution

Air pollution constitutes an ominous threat to human health and the environment. Increasing urban populations and growing levels of industrialization have led to a series of environmentally-related problems in many of the world's cities, not least of which is worsening of air quality. A 1988 GEMS/AIR assessment report showed that some 1,200 million people worldwide may be exposed to levels of sulphur dioxide above WHO guidelines and 1,400 million people to levels of suspended particulates and smoke above WHO guidelines.

Data and information on air quality in urban agglomerations are required to identify levels and trends in air pollution; assess the impact of air pollution on human and ecosystem health; encourage compliance with air quality standards; promote the implementation of control strategies; and assess the effectiveness of pollution control efforts. These data can also be used to determine the geographical spread of air pollution; its effect on regional and global atmospheric issues, and to establish early warning systems.

GEMS/AIR

WHO and UNEP initiated in 1975 a world-wide programme to monitor and assess urban air quality in major cities. This programme is widely referred to as GEMS/AIR. GEMS/AIR is a component of the United Nations system-wide "Global Environment Monitoring System (GEMS)", and is jointly operated by UNEP and WHO. Its major objectives are:

- to provide a framework for global assessments of urban air quality;
- to improve the validity and comparability of air quality monitoring data;
- to compile, analyze and disseminate information on urban air quality world-wide; and
- to strengthen monitoring capabilities in participating countries and cities.

At present, 48 countries around the globe, with different climates, levels of socio-economic development and pollution situations participate in the monitoring programme. Fifty-five cities in 33 countries provide data on sulphur dioxide (SO_2) and suspended particulate matter (SPM) to the GEMS/AIR data bank. These two pollutants were selected at the onset of the programme because of their importance with respect to respiratory illness and because they were the two pollutants most often measured. Generally, GEMS/AIR data are collected from at least three different stations within cities, one each in an industrial, commercial and residential area. Many cities, however, now operate more stations, often as a result of the catalytic effect of the GEMS/AIR programme. However, due to different sampling methodologies and siting characteristics, GEMS/AIR data might be different from the data measured in other city monitoring networks.

Although GEMS/AIR provides information on the extent of air pollution in various cities worldwide, a direct city-to-city comparison of pollution levels is not useful. This is so because monitoring methods might differ and, even more serious, because the contribution of natural large-size dust particles to the overall SPM concentrations in a city is not always sufficiently differentiated in the monitoring process.

To further strengthen GEMS/AIR for the next decade, the programme will in the future integrate information from GEMS/AIR stations with information from other monitoring networks, include other major air pollutants (mainly nitrogen oxides and carbon monoxide) and better characterize particulate pollutants.

Air Quality Guidelines

In this report, urban air pollution is assessed by comparing air quality information with established WHO air quality guidelines. Where air contaminant levels exceed these guidelines, air quality may have deteriorated to such an extent that it is probably affecting health and welfare.

The results presented in this report are compared with two sets of guidelines. The annual mean guidelines are set to protect the population from regular exposure to high levels of pollution. By ensuring that the *average* concentrations remain low, long-term chronic effects on health are minimized. There is also a need to control the short-term effects which result when abnormally high levels of pollution persist for short periods. A second set of guidelines, therefore, places limits on the number of days in a year that pollution can exceed specific daily values. These guidelines, are referred to as the 98-percentile guidelines.

The guidelines are described in the following terms:

Annual Mean The annual arithmetic mean of daily averages should be at or below this value. The annual mean is calculated as the sum of each daily mean divided by the number of days measurements were taken. This guideline is shown on *Figures 1* and *3* for each city. Values falling within the shaded area have met the guideline.

98-Percentile Ninety eight percent (98 %) of all daily means should be at or below this value. Where measurements are taken on 365 days a year, values should not rise above the 98 percentile on more than 7 days. Where fewer measurements are made, the number of days in which levels are allowed to exceed this guideline falls proportionally. On *Figures 2* and *4* for each city, values above the shaded area have exceeded the guidelines.

The guidelines applied within this report are taken from Environmental Health Criteria 8, Sulfur Oxides and Suspended Particulate Matter, WHO, Geneva, 1979. The 1987 WHO Air Quality Guidelines for Europe are not referenced here as no guideline is given for long term exposure to total suspended particulate matter (TSP):

Guideline Values WHO/EHC 8, 1979	Total Suspended Particulate Matter (TSP) [b] (µg/m³)	Suspended Particulate Matter (Smoke) [b] (µg/m³)	Sulphur Dioxide (µg/m³)
Annual Mean [a]	90	60	60
98 - Percentile	230	150	150

a) The guidelines for annual arithmetic means are given as ranges, e.g. 60-90 µg/m³ for TSP and 40-60 µg/m³ for Smoke and SO_2. The thought behind this is that highly developed countries that can afford larger safety factors could choose to promulgate standards in the low range, and developing countries could set interim standards in the higher portion of the range. In this report, only the upper guideline values are applied for all cities.

b) In most cities, *Suspended Particulate Matter* is determined by collecting the total mass of a range of non-respirable (10-100 µm aerodynamic diameter) and respirable (< 10 µm) particles (TSP). In other cities, only *Smoke* is monitored, which makes only a part of the total suspended particles. Thus, different guidelines have been established for total SPM and Smoke.

Health Risks

High levels of suspended particulate matter (SPM) and sulphur dioxide (SO_2) cause significant health hazards. The effect on health depends largely on the length of exposure and the sensitivity of the individuals exposed. Moreover, it should be noted that the effects of these pollutants in combination may be more serious than the sum of their individual effects.

Short-term exposure to very high levels of SO_2, i.e. more than 1,000 micrograms per cubic metre ($\mu g/m^3$) for one hour, affects the respiratory tract, causes coughing and deterioration of lung functions, especially in susceptible individuals (children, elderly people and asthmatics).

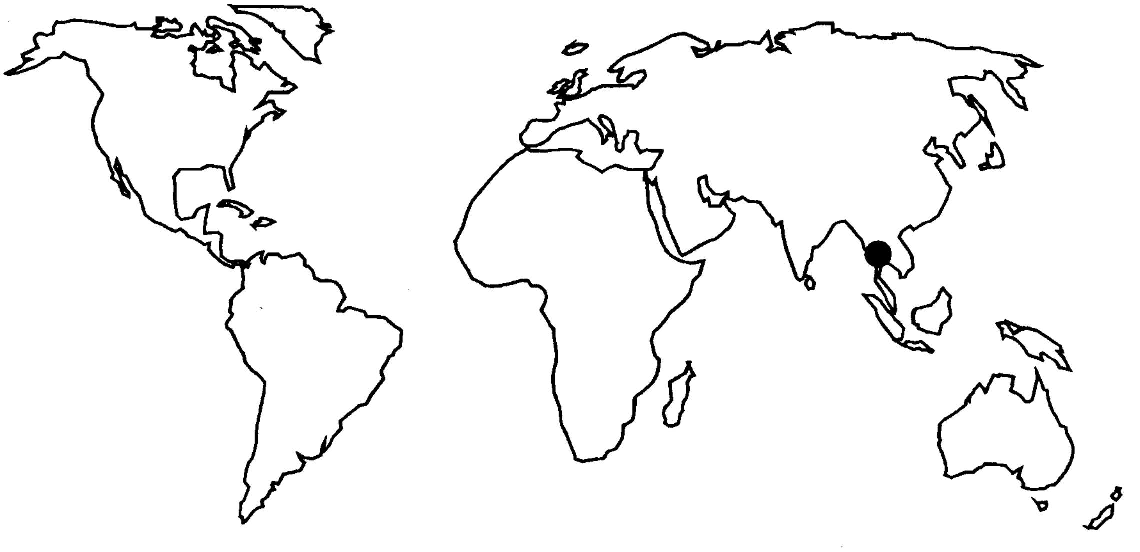
In combination with SPM and smoke above 500 $\mu g/m^3$, exposure to lower levels of SO_2 for a longer period (more than 500 $\mu g/m^3$ for 24 hours) results in increased respiratory illness and death rates. Long-term exposure to SO_2 and smoke increases the prevalence and frequency of respiratory diseases, including chronic bronchitis.

When assessing health risks, SPM data must be interpreted carefully. The effects of SPM exposure depend largely on the size distribution and chemical composition of the collected particles, but these are not sufficiently characterized in the current GEMS/AIR monitoring network. Natural dust is generally of larger particle size and significantly less irritating or toxic than particles produced by industrial sources and fossil fuel combustion.

Generally, anthropogenic SPM may irritate mucous membranes and may initiate a variety of respiratory diseases. There is a strong correlation between long-term exposure to suspended particulates (more than 100 $\mu g/m^3$ smoke or 200 $\mu g/m^3$ total suspended particles for one year) and community illness rates. Furthermore, since several carcinogenic substances are part of or are adsorbed on the particulates, usually as a result of incomplete combustion, high concentrations of particulates can increase the cancer risk, particularly lung cancer, among exposed populations.

II. GEMS/AIR Data

Bangkok



Situation Analysis:

Bangkok, the capital of Thailand, is a city of 6.5 million people. The main sources of inhalable suspended particulate matter (SPM) emissions are diesel engine exhausts, and emissions from light industry. Road dust and wind-blown soil particles are physically larger in size and so cause less health problems. In suburban areas, only 30 % of SPM might be of man-made sources. In city centre and roadside locations, however, 70-90 % of SPM is thought to be man-made. Sulphur dioxide (SO_2) emissions are thought to be relatively small due to absence of domestic heating and heavy industry. Generally, the main pollution problem is the heavy motor vehicle traffic, caused by over one million motor vehicles. Burning of rubbish might be a significant source of local pollution problems.

GEMS/AIR Results:

GEMS/AIR has three monitoring stations in Bangkok: one in an industrial zone, and two in suburban residential areas. In addition to the GEMS/AIR stations, there are eight automated stations operated by the national environmental protection authorities.

The levels of annual mean concentrations show the following trends:

SPM	1978-1989:	slight upward trend at two sites *(Figure 1)*
SO_2	1980-1989:	horizontal trend at low 1980 levels *(Figure 3)*

SPM values exceed the long-term guidelines in all sites, with values of more than 200% of the guideline at the industrial site and one of the residential sites. SO_2 levels are low and well below the guidelines.

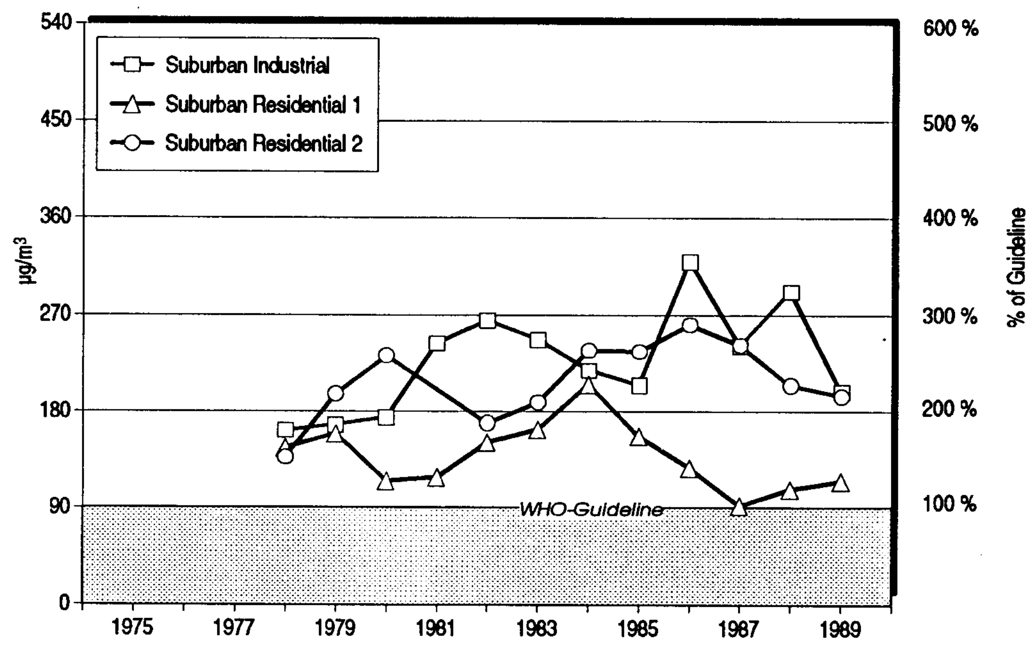
With respect to daily mean concentrations, most SPM values in the industrial site are close to the short-term guidelines, with values of more than 200% of the guideline during several days per year *(Figure 2)*.

However, the proportion of natural dust particles, which are probably larger in size and thus pose a lesser health risk, cannot be quantified with the monitoring methods used.

Recommendations:

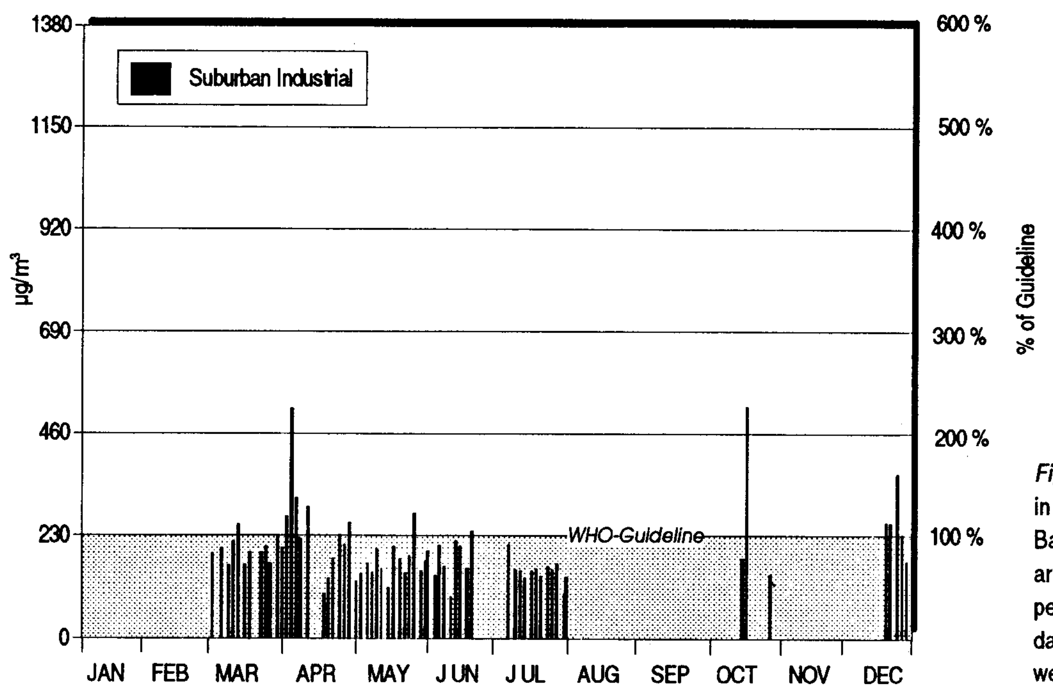
It is recommended that existing control measures be enforced. Possible additional control options include:

- Application of urban planning instruments to minimize traffic in the city;
- Introduction of a strict emission control legislation for new motor vehicles;
- Installation of a mandatory inspection and maintenance programme for the existing fleet of motor vehicles;
- Better enforcement of existing emission control legislation for small business and industrial sources.



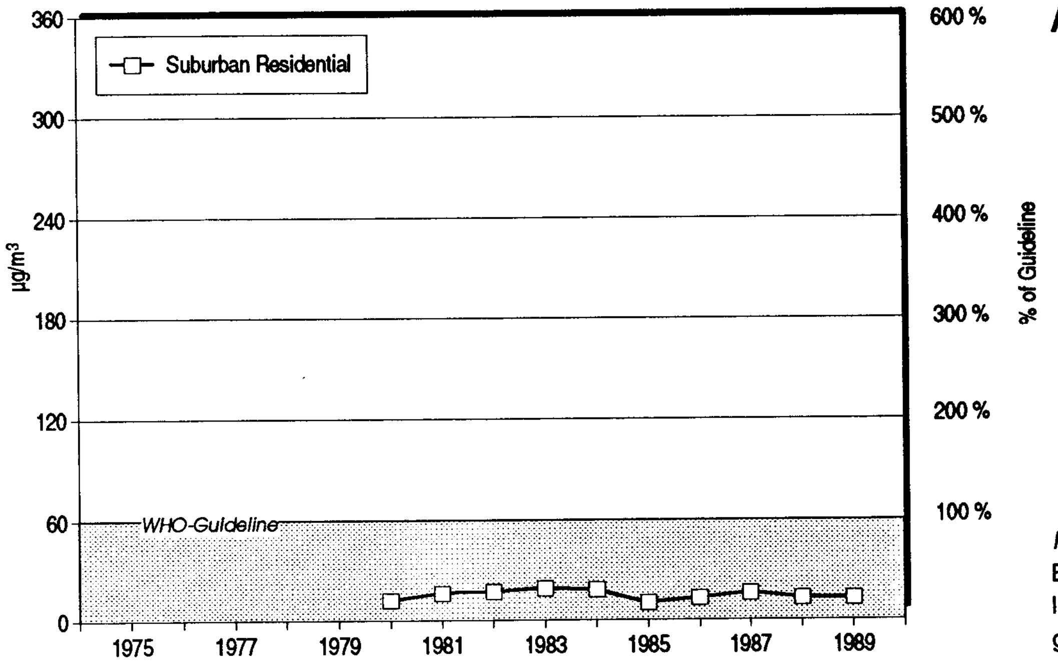
ANNUAL MEAN SPM
Bangkok

Figure 1: Annual mean SPM in Bangkok. Long-term guidelines are exceeded in all three monitoring stations.



DAILY MEAN SPM
Bangkok

Figure 2: 1989 daily mean SPM in a suburban industrial site in Bangkok. Short-term guidelines are exceeded during a few days per year. Zero levels indicate days where no measurements were taken.

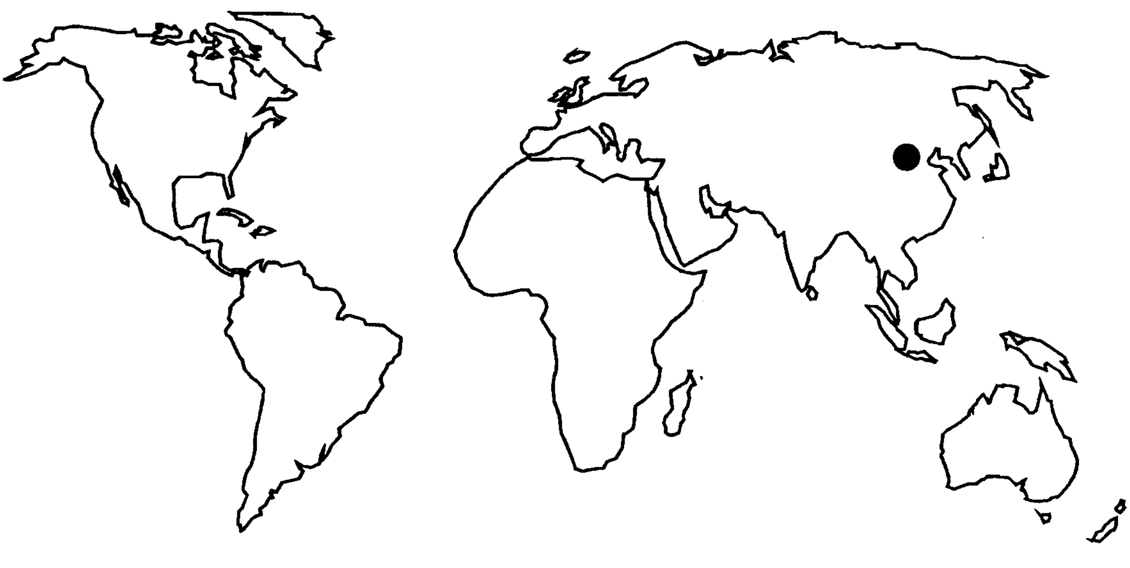


ANNUAL MEAN SO_2
Bangkok

Figure 3: Annual mean SO_2 in Bangkok. Very low pollution levels well below long-term guidelines.

The graph presenting daily mean SO_2 concentrations is omitted because of the low values which are near the technical limit of the analytical method used.

Beijing



Situation Analysis:

Beijing, the capital of China, has a population of about 10 million people. The main sources of sulphur dioxide (SO_2) are heavy industry, power plants, and domestic heating during the winter. Sources of suspended particulate matter (SPM) are domestic combustion, industry, dust from urban construction, and wind-blown dust, particularly from the *loess* plateau. As bicycles are currently the main mode of transport, motor vehicles probably provide a rather low contribution to the emission inventory at the present time.

GEMS/AIR Results:

GEMS/AIR has four monitoring stations in Beijing; one each in a suburban industrial zone, suburban residential area, residential city centre, and commercial city centre.

The levels of annual mean concentrations show the following trends:

SPM	1981-1985:	downward trend
	1985-1989:	stabilization at 1985 levels *(Figure 1)*
SO_2	1981-1983:	upward trend
	1983-1989:	stabilization at 1983 levels *(Figure 3)*

Although levels of air pollution are quite high in Beijing, the stabilization over recent years indicates that emission controls have been effective in offsetting the city's growth in industry and population. Residential SPM levels are lower than levels in industrial and commercial areas. Suburban SO_2 levels are lower than levels in the city centre sites.

Long-term annual average guidelines for SO_2 are exceeded in the city centre by a factor of two. The situation for SPM is more serious: SPM annual average values are almost 400% to 500% of the WHO guidelines in three of the four stations.

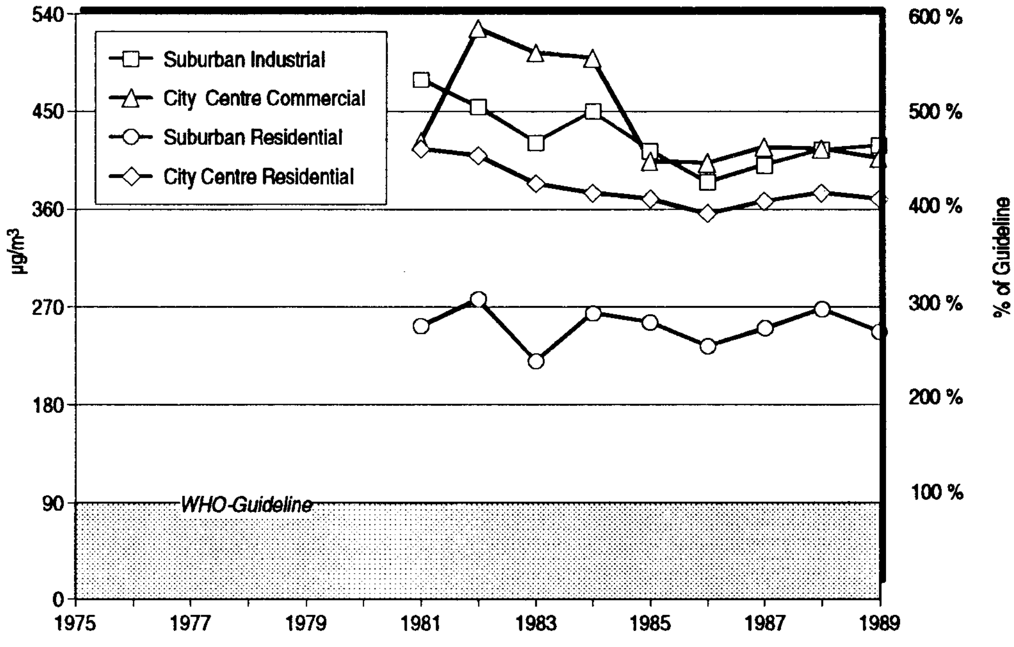
However, the proportion of natural dust particles, which are probably larger in size and thus pose a lesser health risk, cannot be quantified with the monitoring methods used.

Daily mean SO_2 concentrations are especially high during the winter period from November to January, when SO_2 in the industrial area exceeds short-term guidelines from time to time (*Figure 4*). The short term guideline for SPM is exceeded in an industrial site on almost all days of the year (*Figure 2*).

Recommendations:

It is recommended that existing control measures be enforced. Possible additional control options include:

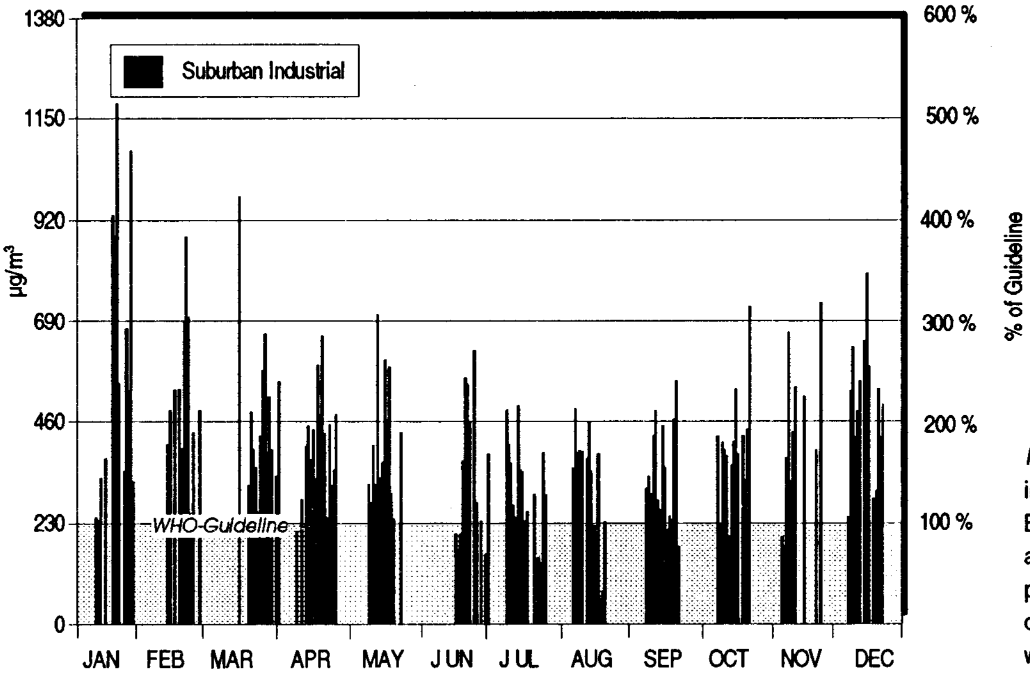
- Source identification for SPM emissions as a basis for the introduction of control measures;
- Reduction of the sulphur content of coal by washing the coal;
- Reduction of domestic coal combustion by provision of alternative low-sulphur fuels (e.g. gas, coal-gas) or through the provision of low-emission domestic heating alternatives (e.g. electricity);
- Prevention of high dust concentration by specifically controlling anthropogenic sources;
- Control of industrial pollution emissions on an industry-specific basis;
- Introduction of pollution control legislation for small sources.



ANNUAL MEAN SPM

Beijing

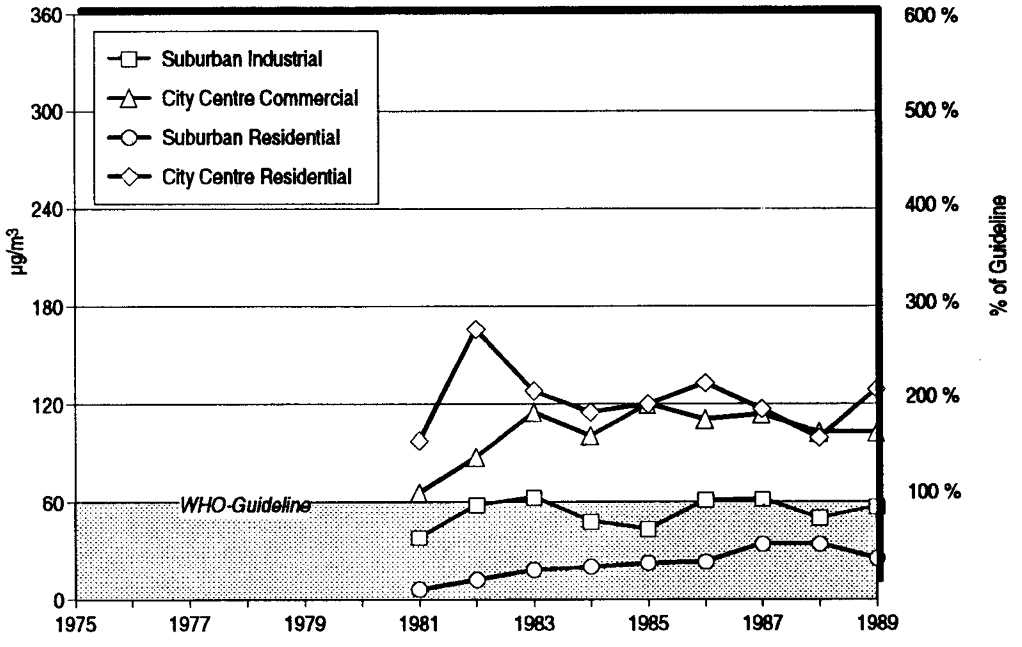
Figure 1: Annual mean SPM in Beijing. Long-term guidelines are exceeded in all four monitoring stations.



DAILY MEAN SPM

Beijing

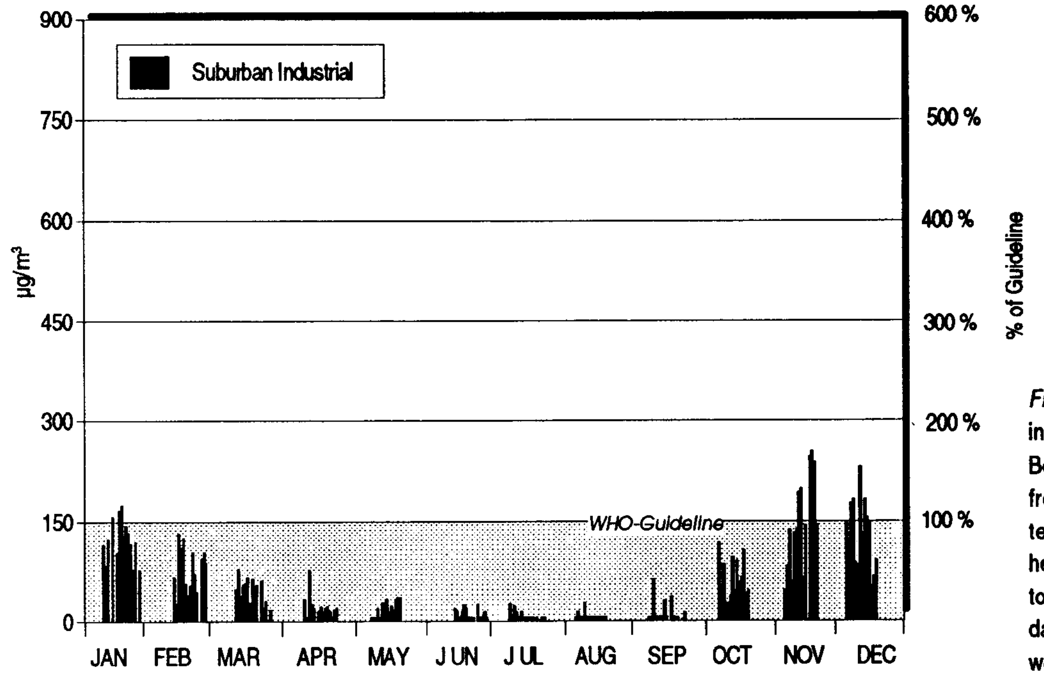
Figure 2: 1989 daily mean SPM in a suburban industrial site in Beijing. Short-term guidelines are exceeded on almost all days per year. Zero levels indicate days where no measurements were taken.



ANNUAL MEAN SO_2

Beijing

Figure 3: Annual mean SO_2 in Beijing. Long-term guidelines are exceeded in two city centre monitoring stations.

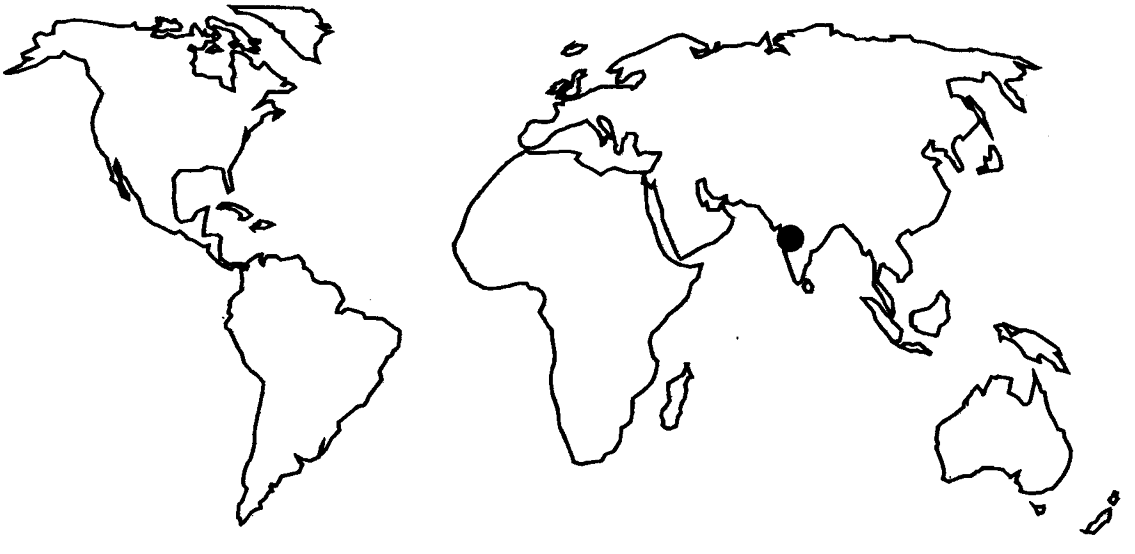


DAILY MEAN SO_2

Beijing

Figure 4: 1989 daily mean SO_2 in a suburban industrial site in Beijing. Marked seasonality with frequent exceedances of short-term guidelines in the winter heating period from November to January. Zero levels indicate days where no measurements were taken.

Bombay



Situation Analysis:

Bombay is the major industrial and commercial centre in Western India with an estimated population of 11 million.

The most important emission sources of suspended particulate matter (SPM) and sulphur dioxide (SO_2) are light and heavy industry; there is also one thermal power station as a major point source. In 1990 total anthropogenic emissions were estimated to be about 60,000 tons per year for SPM and about 150,000 tons per year for SO_2. Emissions of SPM have increased by about 30% from 1970 to 1990. SO_2 emissions remained stable since 1980 due to emission control measures and the introduction of natural gas.

GEMS/AIR Results:

During the last 15 years, there have been six GEMS/AIR monitoring sites in Bombay in residential and commercial areas. However, not all sites have been operated during the overall period and reporting to the GEMS/AIR global database discontinued after 1985.

The levels of annual mean concentrations show the following trends:

SPM	1977-1985:	no overall trend: upward trend at residential sites downward trend at commercial sites *(Figure 1)*
SO_2	1977-1982:	downward trend at the highly polluted sites slightly upward trend at low-polluted sites
	1982-1985:	stabilization at 1982 levels at all sites *(Figure 3)*

SPM annual means are above long-term guidelines at all monitoring sites. SO_2 does not exceed the long-term guidelines since 1982.

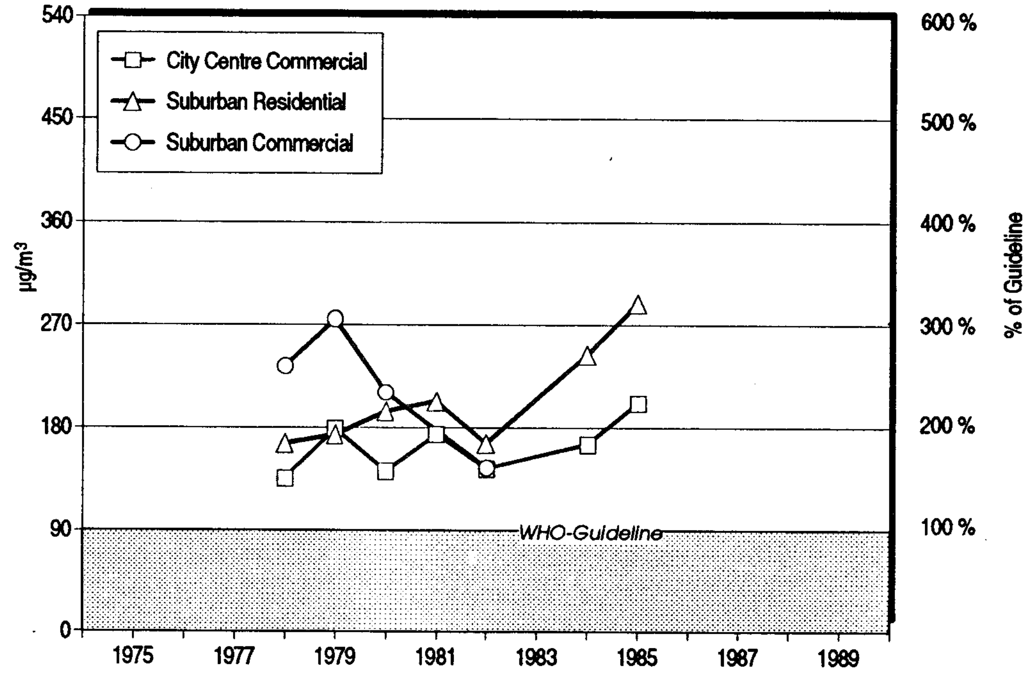
Daily mean concentrations show no trends throughout the year. SO_2 daily mean concentrations are well below the guidelines, but the majority of daily mean SPM values exceed short-term guidelines, despite the fact that the monitoring site is a residential area.

However, the proportion of natural dust particles, which are probably larger in size and thus pose a lesser health risk, cannot be quantified with the monitoring methods used.

Recommendations:

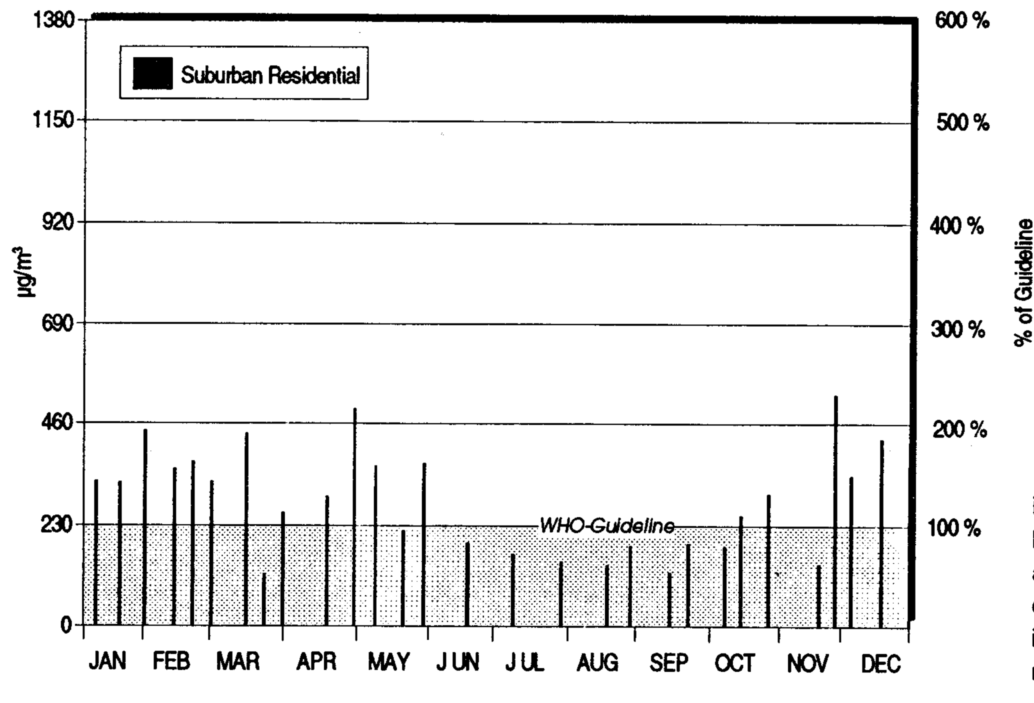
It is recommended that existing control measures be enforced. Possible additional control options include:

- Source identification for SPM emissions as a basis for the introduction of control measures;
- Encouragement of further use of natural gas, especially in industry;
- Introduction and enforcement of tighter emission standards for motor vehicles.



ANNUAL MEAN SPM
Bombay

Figure 1: Annual mean SPM in Bombay. Long-term guidelines are exceeded in all monitoring stations.
Note: Suburban Residential data averaged from two sites.
City Centre Commercial data averaged from three sites.



DAILY MEAN SPM
Bombay

Figure 2: 1985 daily mean SPM in a suburban residential site in Bombay. Short-term guidelines are exceeded on the majority of days per year. Zero levels indicate days where no measurements were taken.

ANNUAL MEAN SO_2
Bombay

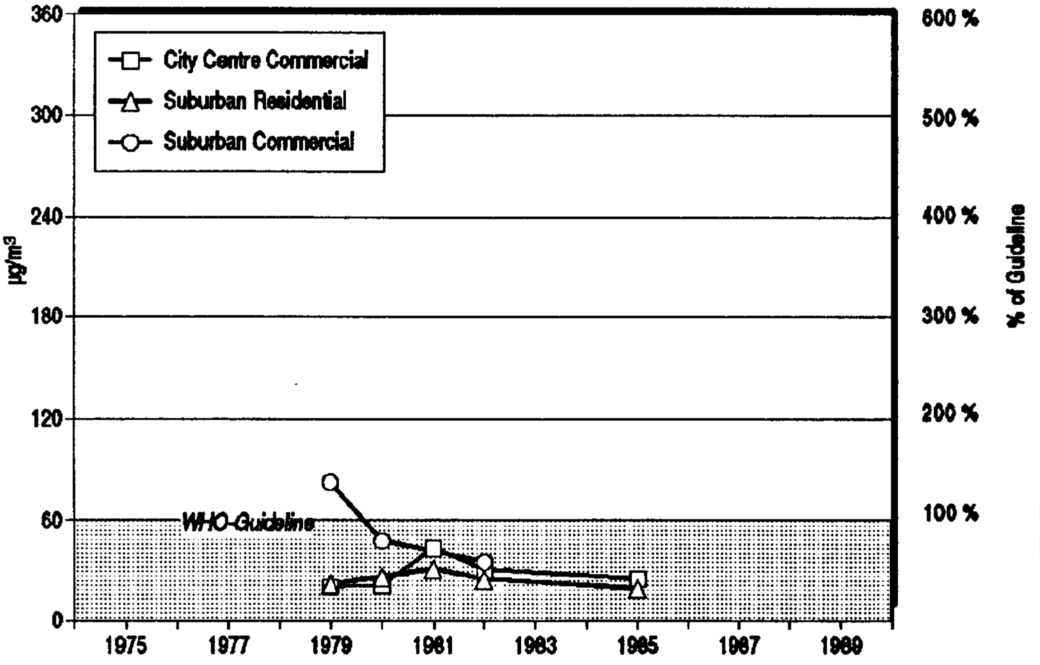


Figure 3: Annual mean SO_2 in Bombay. Long-term guidelines have not been exceeded since 1981.
Note: City Centre Commercial data averaged from two sites.

DAILY MEAN SO_2
Bombay

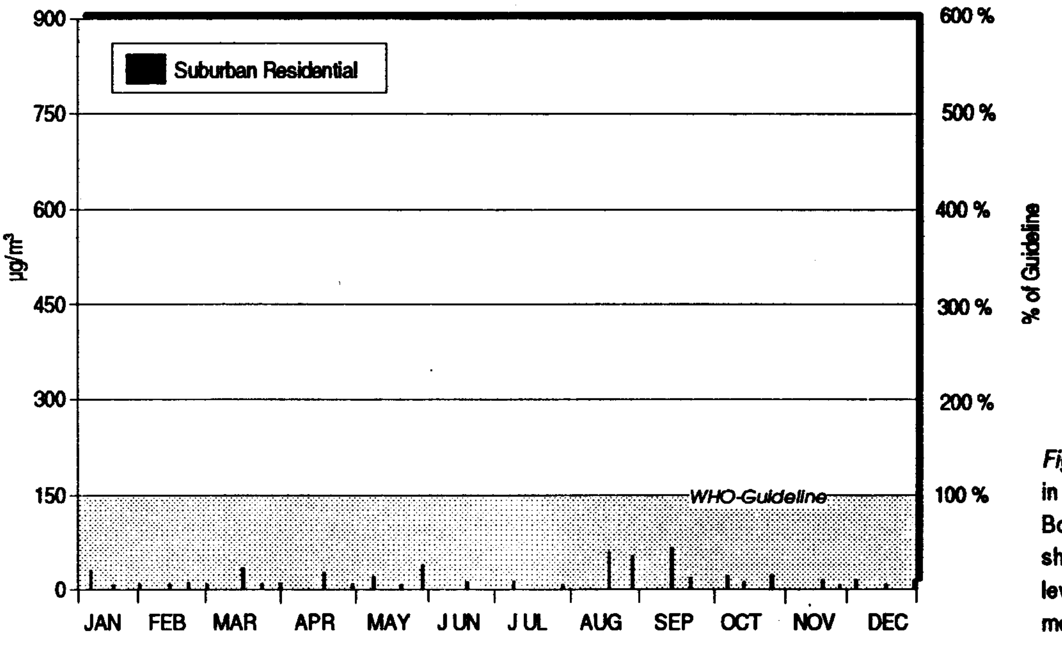


Figure 4: 1985 daily mean SO_2 in a suburban residential site in Bombay. No exceedances of short-term guidelines. Zero levels indicate days where no measurements were taken.

London

Situation Analysis:

London is the capital of the United Kingdom and is the most populous city in Europe, with an estimated population of 10.5 million.

Emission sources of suspended particulate matter (SPM) are mainly light industry and motor vehicles. Sources of sulphur dioxide (SO_2) are fuel oil and coal combustion in the domestic, commercial and industrial sector. There are also three thermal power stations in the London area. With easterly winds power stations from outside London account for occasionally high ambient air SO_2 concentrations.

Emissions of SO_2 have decreased by 70% from 1976 to 1984 due to strict control legislation. Similarly, there was a decrease in SPM emissions from stationary sources, but SPM emissions from motor vehicles have increased by 30%.

GEMS/AIR Results:

There are three GEMS/AIR monitoring sites in London: one each in the commercial city centre, in a suburban residential area and in a suburban industrial area. Data for SPM are determined by the smoke shade reflectance method and are thus not directly comparable to other cities where total suspended particulates are monitored. Reporting of monitoring data was discontinued after 1985.

The levels of annual mean concentrations show the following trends:

SPM	1975-1982:	slight downward trend
	1982-1985:	slight downward trend in suburban site; slight upward trend in city centre site *(Figure 1)*
SO_2	1975-1985:	steadily downward trend to 30-50% of 1975 levels *(Figure 3)*

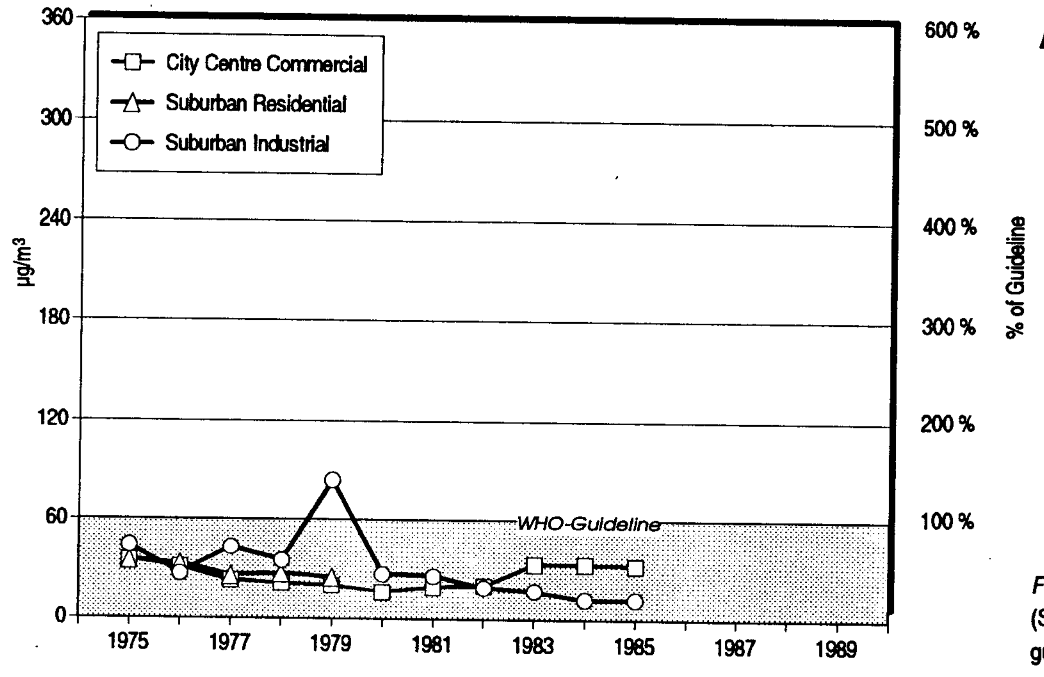
The general decrease of pollutant levels reflects the positive results of emission control measures. For example, since 1972 the maximum allowable concentration of sulphur in fuel oil has been reduced to 1%, and there has been a general shift away from fuel oil and coal to natural gas. Perhaps the lack of a trend of SPM (smoke) in the city centre site reflects the increasing motor vehicle SPM emissions. Current annual mean levels of SPM (Smoke) and SO_2 are well below the long-term guidelines.

With respect to daily mean values, SPM (Smoke) concentrations are very small throughout the year. SO_2 concentrations show a seasonal variation with highest values during the winter period. In 1985 some exceedances of short-term guideline values were recorded for SO_2 at the city centre monitoring site.

Recommendations:

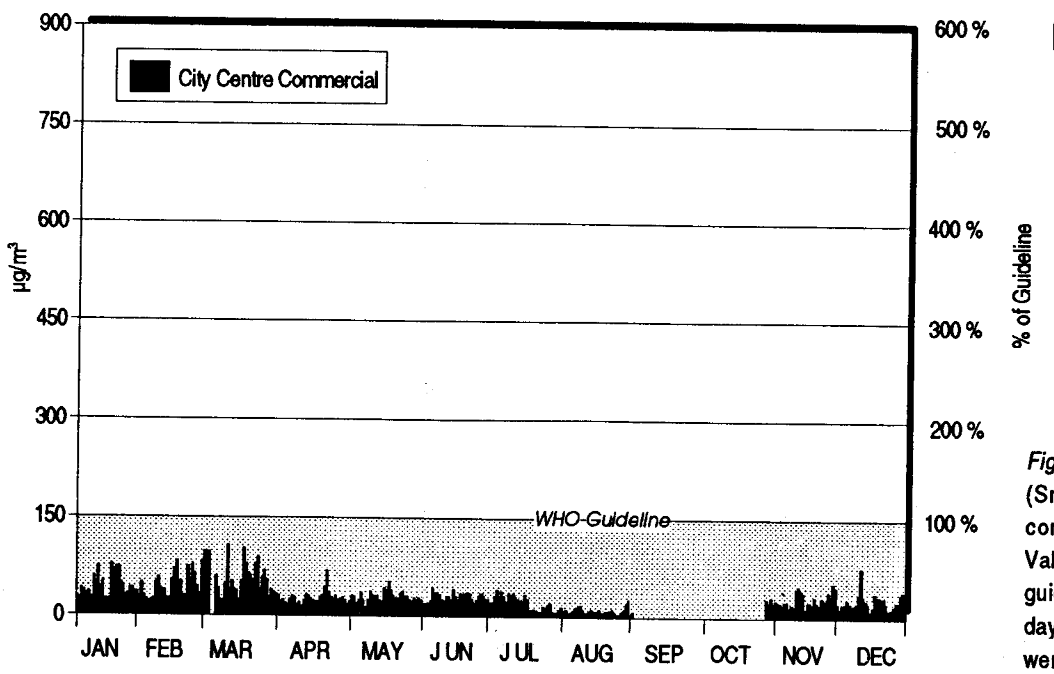
It is recommended that existing control measures be enforced. Possible additional control options include:

- Introduction and enforcement of tighter emission standards for motor vehicles;
- Retrofitting of existing power stations in and around London with fuel gas desulphurization equipment.



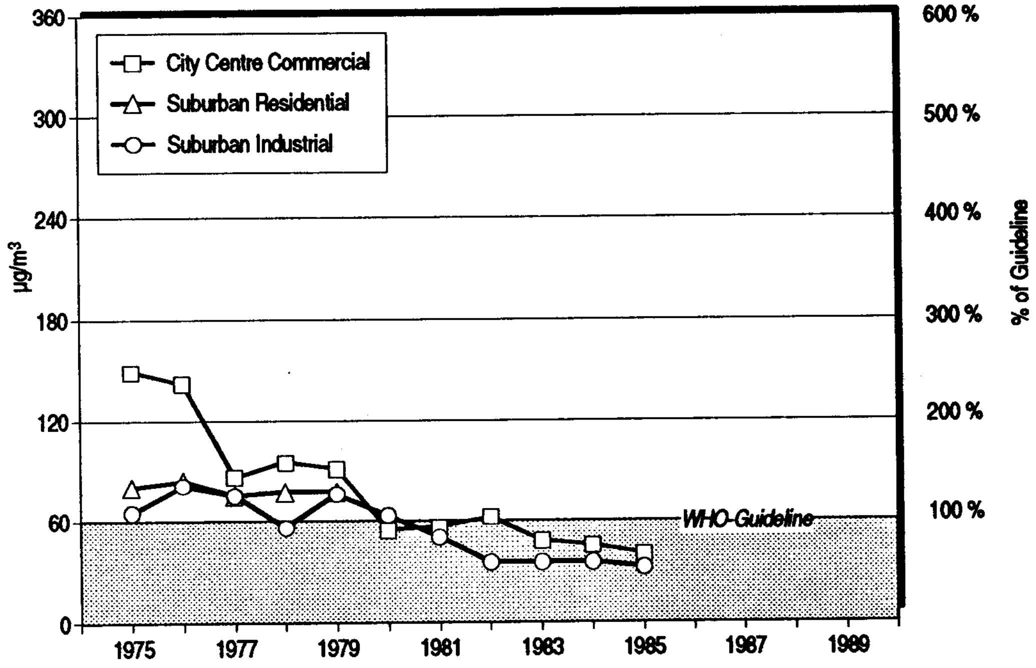
ANNUAL MEAN SPM (SMOKE)
London

Figure 1: Annual mean SPM (Smoke) in London. Long-term guidelines are not exceeded.



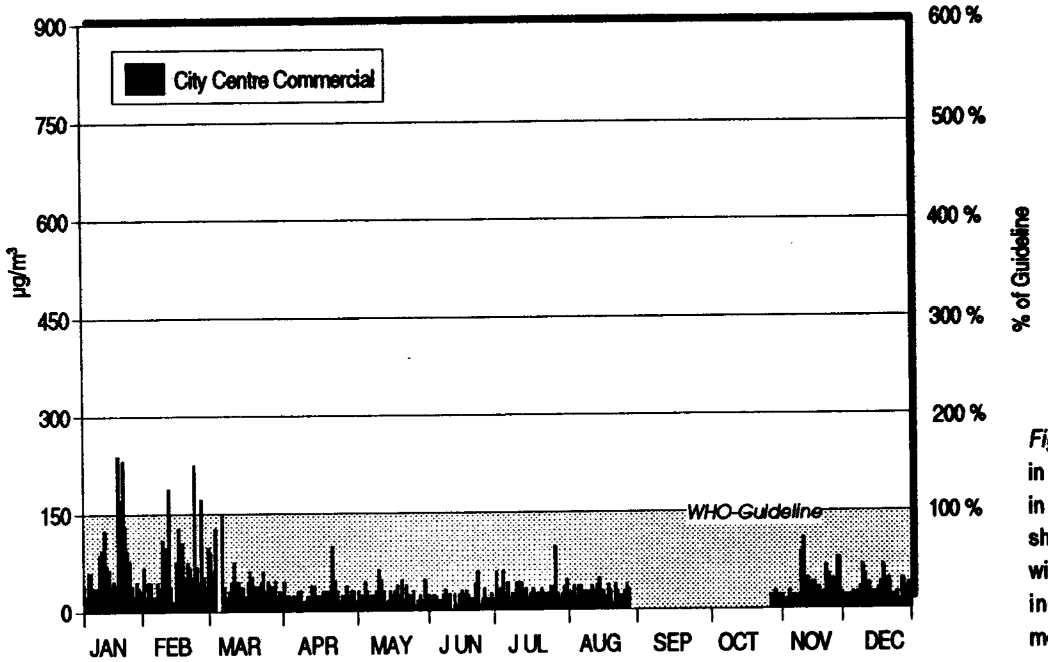
DAILY MEAN SPM (SMOKE)
London

Figure 2: 1985 daily mean SPM (Smoke) in a city centre commercial site in London. Values are well below short-term guidelines. Zero levels indicate days where no measurements were taken.



ANNUAL MEAN SO_2
London

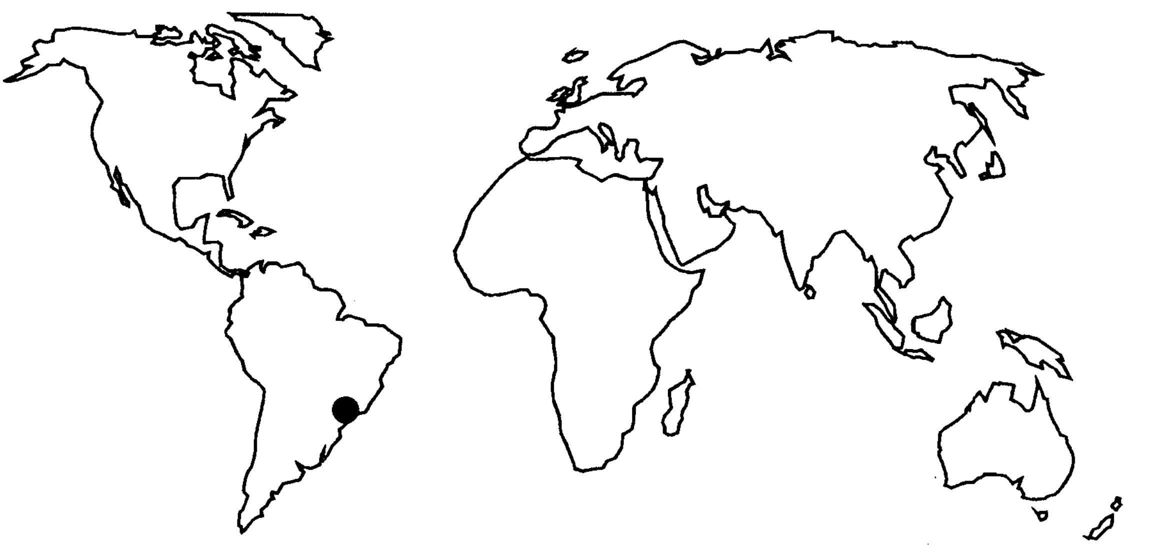
Figure 3: Annual mean SO_2 in London. Remarkable downward trend since 1975 due to emission control legislation. Long-term guidelines have not been exceeded since 1981.



DAILY MEAN SO_2
London

Figure 4: 1985 daily mean SO_2 in a city centre commercial site in London. Few exceedances of short-term guidelines during the winter heating period. Zero levels indicate days where no measurements were taken.

Sao Paulo



Situation Analysis:

Sao Paolo is the economic centre of Brazil and contributes about 50% to the country's GNP. The Sao Paolo urban region has about 17 million people and it is estimated that its population will be 21-24 million by the year 2000. As 95% of power generation is hydroelectric, this pollution source is probably negligible. The sources of sulphur dioxide (SO_2) emissions are mainly diesel vehicles and, to a much lesser extent, light and heavy industry. The sources of suspended particulate matter (SPM) are motor vehicle emissions and industrial activities.

Generally, the four million motor vehicles are thought to be the major air pollution problem. Emission control legislation and the introduction of alcohol fuels have probably cut the emissions considerably despite the immense growth of the city's population and economy since the 1970s.

GEMS/AIR Results:

Sao Paulo operates an automated network of 27 urban air monitoring stations. Three additional stations report to GEMS/AIR, two of which are located in city centre areas. At the GEMS/AIR stations, SPM is monitored as smoke shade reflectance, thus ambient concentrations are not comparable to other cities reporting total suspended particulates.

The levels of annual mean concentrations show the following trends:

SPM	1976-1986: downward trend, decreasing about 40% 1986-1988: stabilization *(Figure 1)*
SO_2	1976-1979: upward trend 1979-1985: downward trend 1985-1988: stabilization *(Figure 3)*

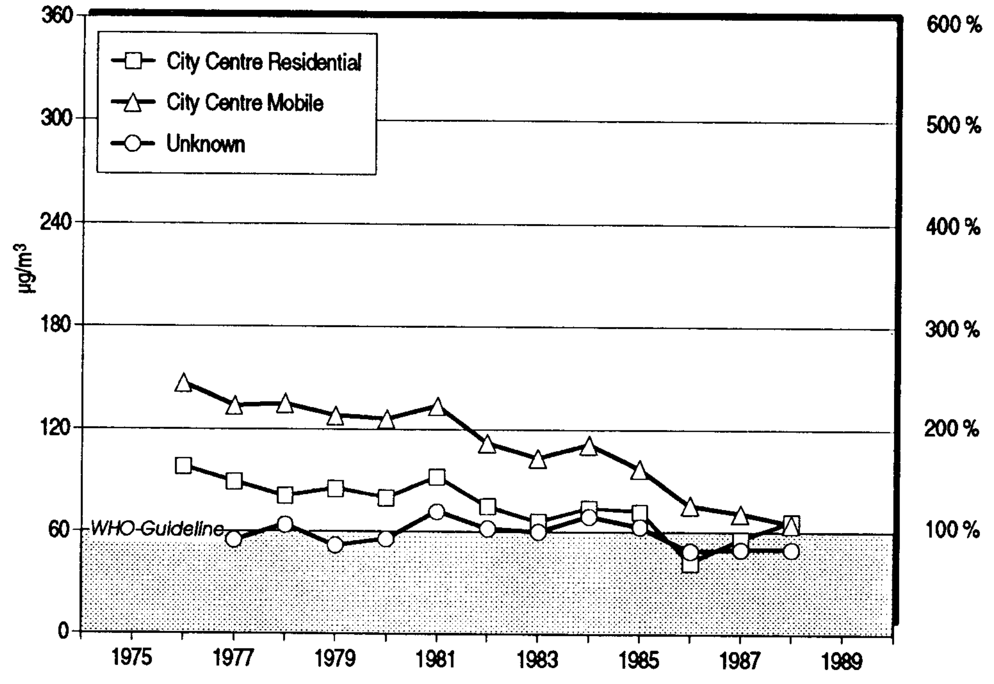
Generally, air quality is at or below WHO guidelines. The SO_2 and SPM pollution problem experienced during the 1970s has been corrected and is now under control, mainly through strict enforcement of existing legislation.

With respect to daily mean values, there is a slight trend towards higher pollution in the colder period. SO_2 daily means do not exceed guidelines, but a few exceedances of SPM occurred in 1988 in a city centre residential site.

Recommendations:

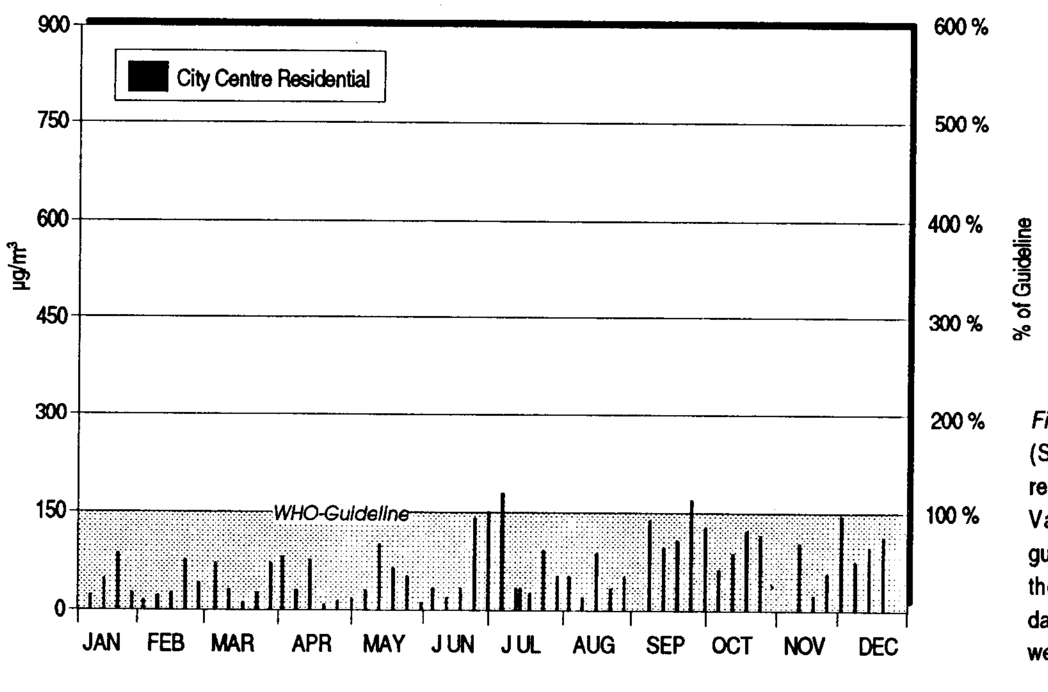
It is recommended that existing control measures be enforced. Possible additional control options include:

- Identification of sources or conditions which contribute to high SPM episodes;
- Implementation of further emission control measures, especially with respect to motor vehicle emissions.



ANNUAL MEAN SPM (SMOKE) *Sao Paulo*

Figure 1: Annual mean SPM (Smoke) in Sao Paulo. Long-term guidelines were met in 1988.



DAILY MEAN SPM (SMOKE) *Sao Paulo*

Figure 2: 1988 daily mean SPM (Smoke) in a city centre residential site in Sao Paulo. Values are below short-term guidelines during most days of the year. Zero levels indicate days where no measurements were taken.

ANNUAL MEAN SO_2

Sao Paulo

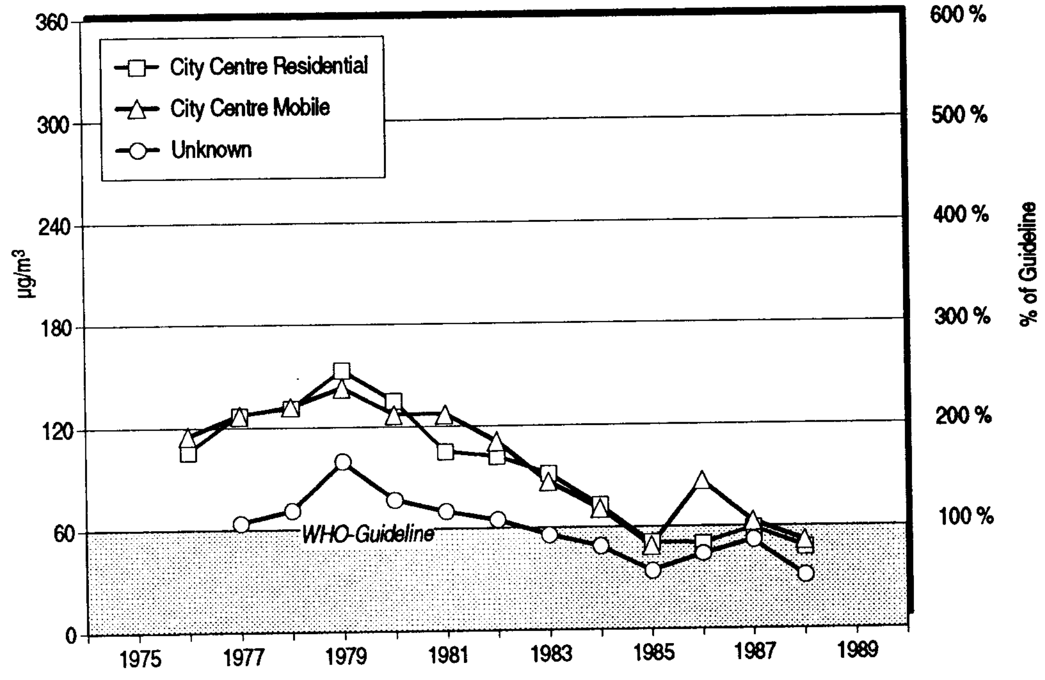


Figure 3: Annual mean SO_2 in Sao Paulo. Remarkable downward trend since 1979. Long-term guidelines were not exceeded in 1988.

DAILY MEAN SO_2

Sao Paulo

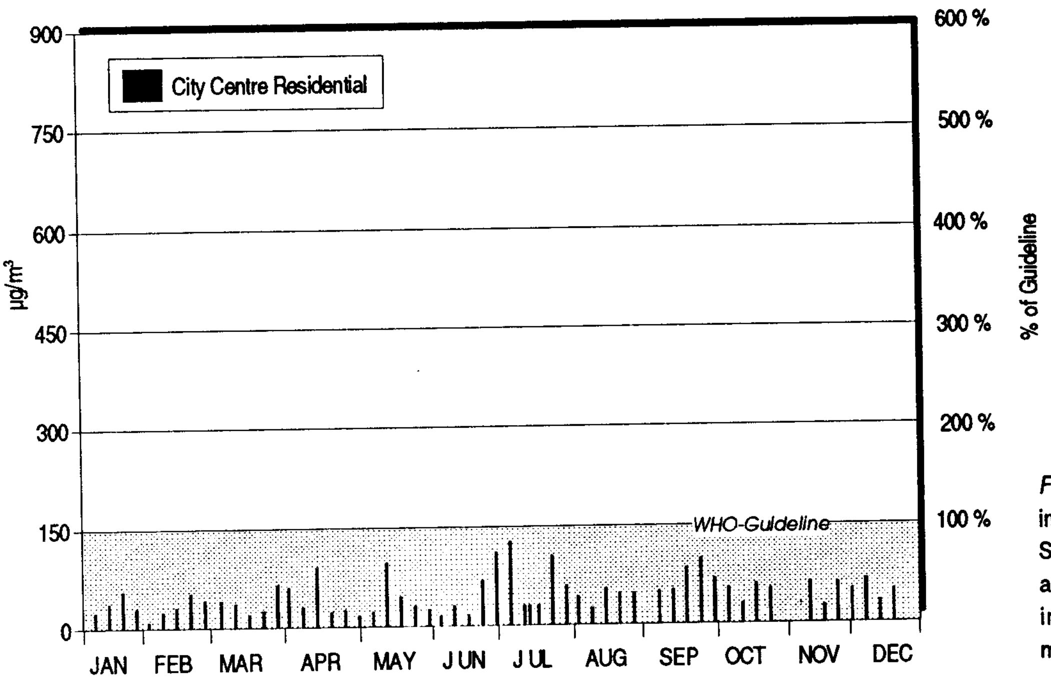


Figure 4: 1988 daily mean SO_2 in a city centre residential site in Sao Paulo. Short-term guidelines are not exceeded. Zero levels indicate days where no measurements were taken.

Shanghai

Situation Analysis:

Shanghai is a city of approximately 12 million people, located on the East Coast of China. The climate is subtropical but winter temperatures can reach as low as -8 °C. There are many small industries which are frequently located in residential regions, with people living right next to them. The main sources for anthropogenic suspended particulate matter (SPM) and sulphur dioxide (SO_2) are industrial and domestic combustion processes. 70% of the coal is used for industry, the remainder being for domestic use. Major sources of air pollution are coal-fired power plants with a total capacity of 500 megawatts. To control SO_2 pollution, Shanghai has recently introduced the use of low sulphur coal.

GEMS/AIR Results:

GEMS/AIR has four monitoring stations in Shanghai: one each in a suburban industrial zone, a suburban residential area, a city centre residential and a commercial city centre.

The levels of annual mean concentrations show the following trends:

SPM	1981-1983:	Slight downward trend
	1983-1988:	Upward trend to about 150% of 1983 levels
	1988-1989:	Downward trend *(Figure 1)*
SO_2	1981-1984:	Slightly upward trend, especially in city centre sites
	1984-1989:	Stabilization at 1984 levels *(Figure 3)*

Current annual mean values of SPM are approximately 250% to 350% of WHO guidelines at all city centre monitoring sites. At the suburban site, values are approximately 200% of the guideline.

However, the proportion of natural dust particles, which are probably larger in size and thus pose a lesser health risk, cannot be quantified with the monitoring methods used.

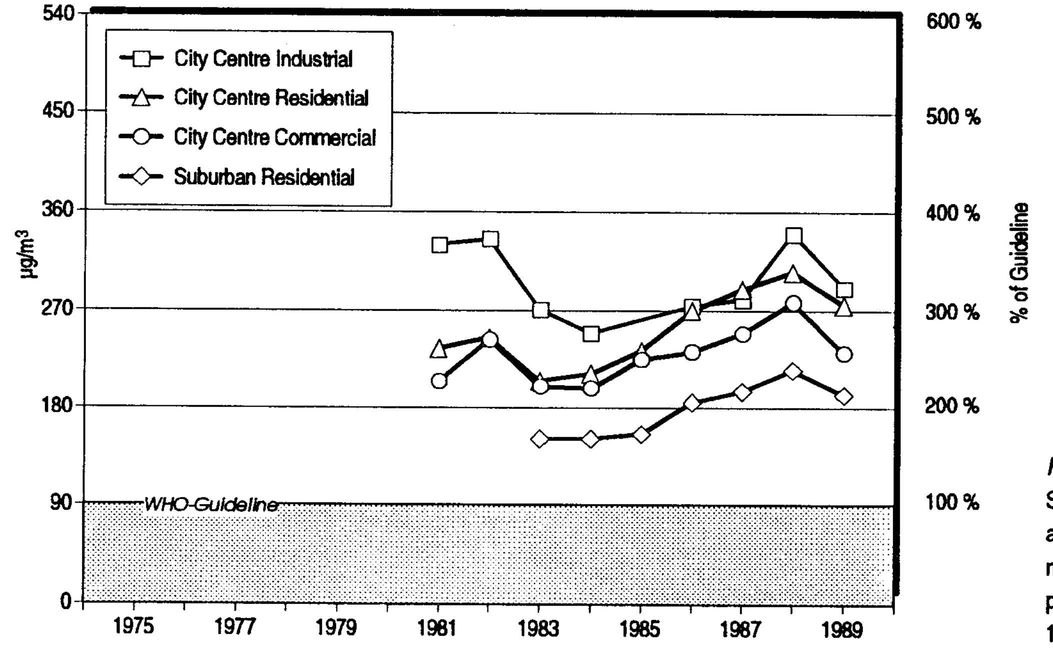
Annual mean values of SO_2 are close to the long-term guidelines or exceed them in the city centre, but not in the suburban areas.

Daily mean values of SPM exceed short-term guidelines regularly throughout the year with values up to 300% of the guideline in the city centre residential site. For SO_2, the situation is much better with only a few violations of short-term guidelines, mainly in the winter heating period. However, there are some days of very severe air pollution with SO_2 levels as much as 200% of the WHO guideline in 1989.

Recommendations:

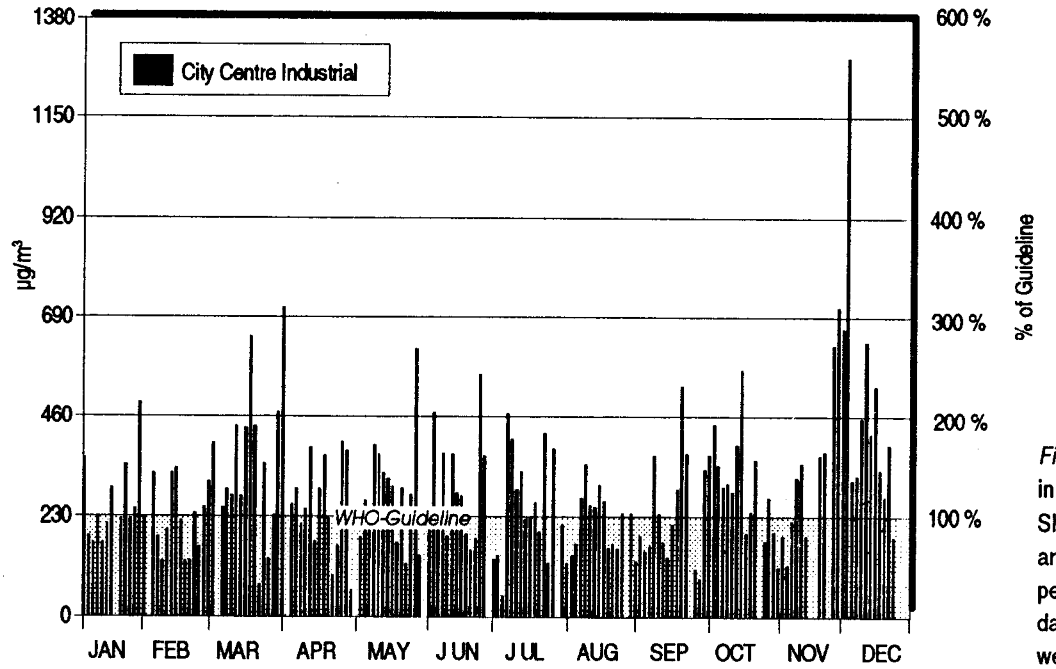
It is recommended that existing control measures be enforced. Possible additional control options include:

- Further substitution of high SPM emitting fuels (coal briquettes) with cleaner fuels (e.g. coal gas, coke);
- Relocation of industries from residential areas to specific industrial zones leeward of the city, and installation of new industries in areas outside the city;
- Reduction of wind-raised dust by cultivation of bare surfaces.



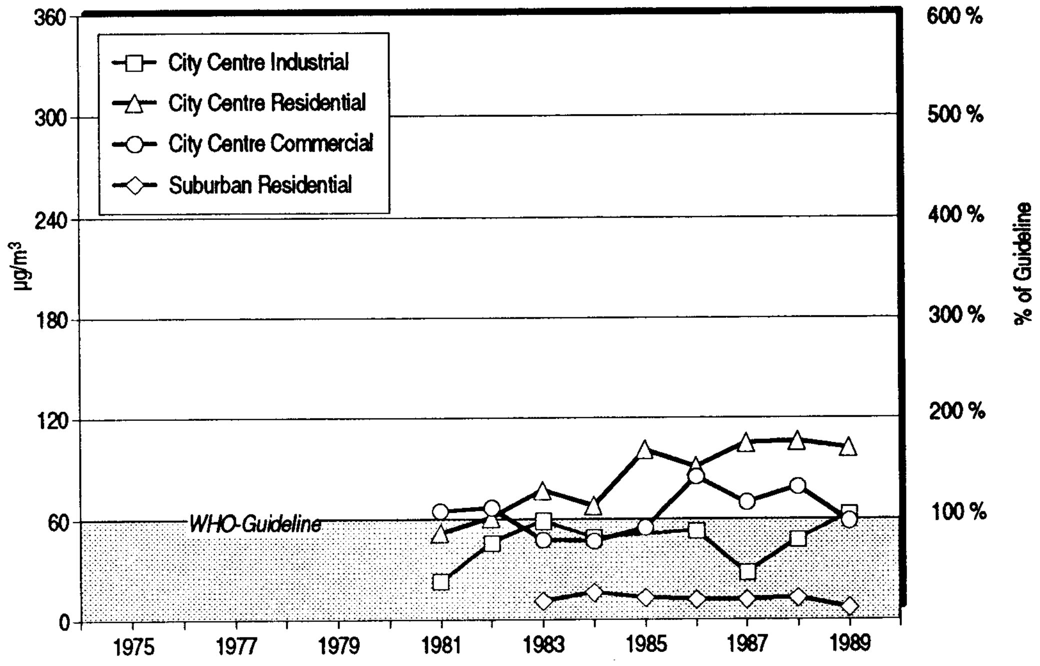
ANNUAL MEAN SPM
Shanghai

Figure 1: Annual mean SPM in Shanghai. Long-term guidelines are exceeded in all four monitoring stations. High pollution still increasing since 1984.



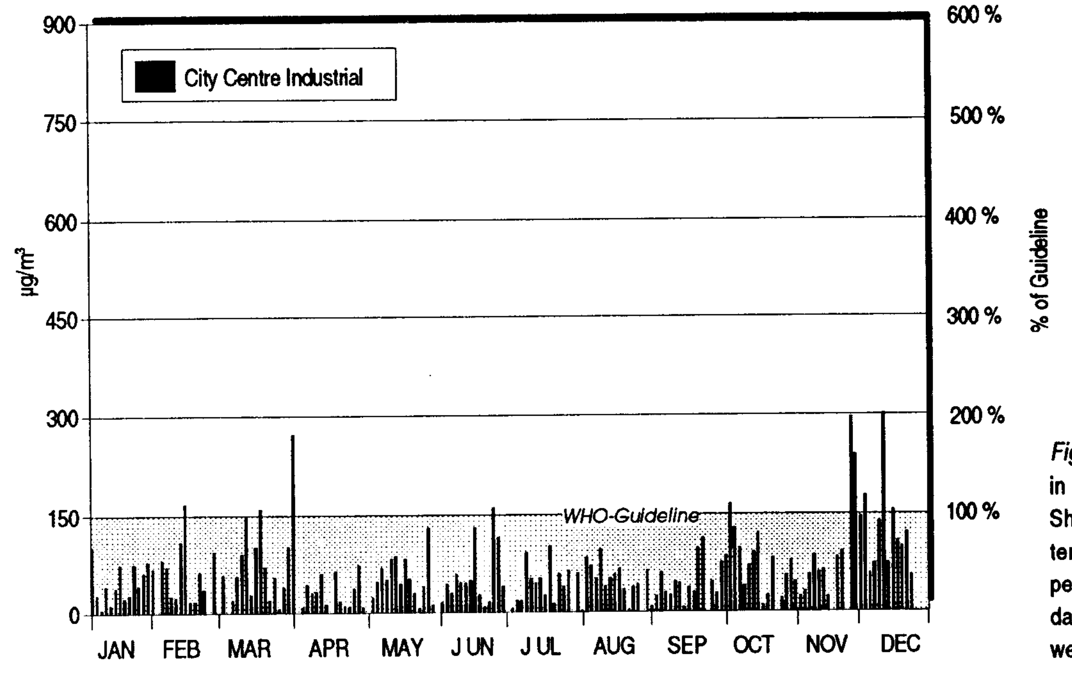
DAILY MEAN SPM
Shanghai

Figure 2: 1989 daily mean SPM in a city centre industrial site in Shanghai. Short-term guidelines are exceeded on almost all days per year. Zero levels indicate days where no measurements were taken.



ANNUAL MEAN SO_2
Shanghai

Figure 3: Annual mean SO_2 in Shanghai. Values are close to the long-term guidelines or even exceed them in city centre sites but not in suburban sites.



DAILY MEAN SO_2
Shanghai

Figure 4: 1989 daily mean SO_2 in a city centre industrial site in Shanghai. Exceedances of short-term guidelines on several days per year. Zero levels indicate days where no measurements were taken.

Tehran

Situation Analysis:

Tehran, the capital of Iran, is a city of 9 million people. There are no emission inventories, but it is estimated that the sources of sulphur dioxide (SO_2) and suspended particulate matter (SPM) are mainly coal and oil burning for industrial and domestic use, power generation, industrial processes, and motor vehicles exhaust. Wind blown dust is an additional source of SPM.

GEMS/AIR Results:

GEMS/AIR has three monitoring stations in Tehran: one in an industrial zone, one in a residential area, and one in the commercial city centre.

The levels of annual mean concentrations show the following trends:

SPM	1978-1981: downward trend, decreasing about 50% *(Figure 1)* 1981-1983: upward trend, 1983-1989: stabilization at 1979/80 levels
SO_2	1976-1979: downward trend, decreasing about 50% *(Figure 3)* 1979-1981: sharp upward trend, increasing about 300% 1981-1987: downward trend to approximately 1976 levels 1985-1988: light upward trend

The long-term variations of the pollution levels reflect the changes in the socio-economic situations. The slight increases of SO_2 levels in recent years indicate that emission controls could only partly offset the increased industrial activities. Long-term annual average guidelines are exceeded for SPM as well as for SO_2 at all stations. Values are especially high in the city centre and at the industrial sites.

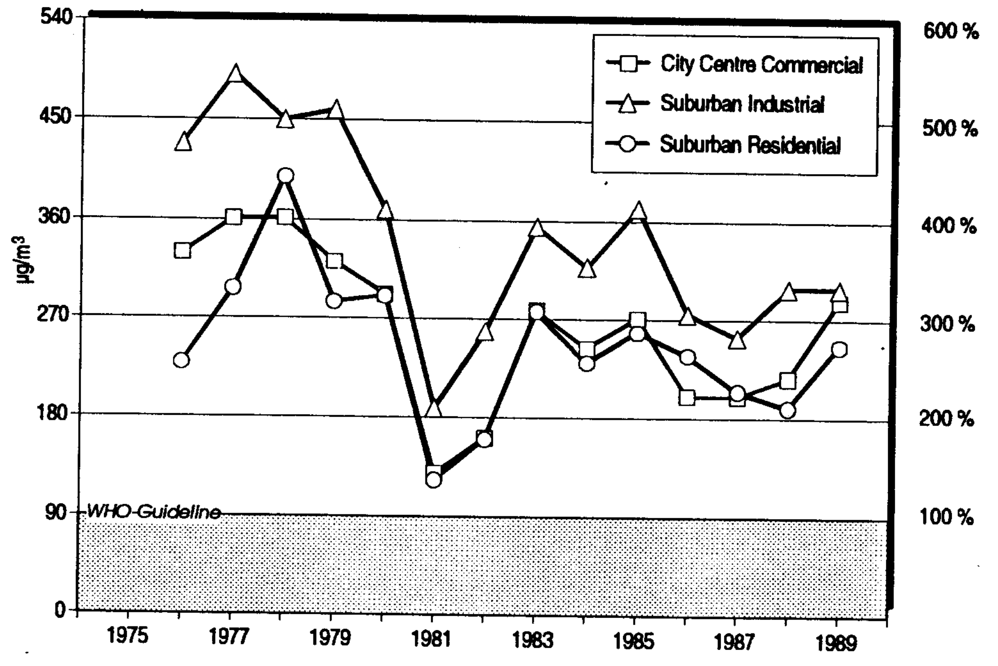
However, the proportion of natural dust particles, which are probably larger in size and thus pose a lesser health risk, cannot be quantified with the monitoring methods used.

With respect to the daily mean concentrations, the short term guidelines for SPM and SO_2 were exceeded at the industrial site on most days of the year 1989.

Recommendations:

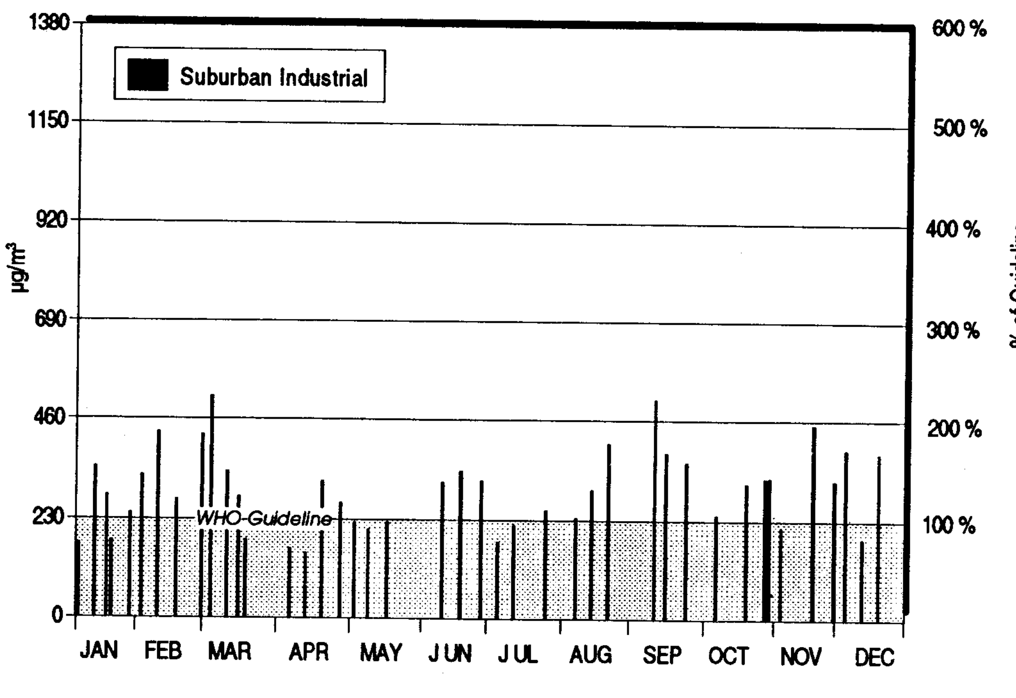
It is recommended that existing control measures be enforced. Possible additional control options include:

- Source identification for SPM emissions as a basis for the introduction of control measures;
- Elaboration of general emission reduction plans;
- Implementation and enforcement of source oriented pollution control legislation;
- Introduction of SO_2 control measures at industrial emission sources and power plants;
- Improvement of road pavement to reduce SPM generation.



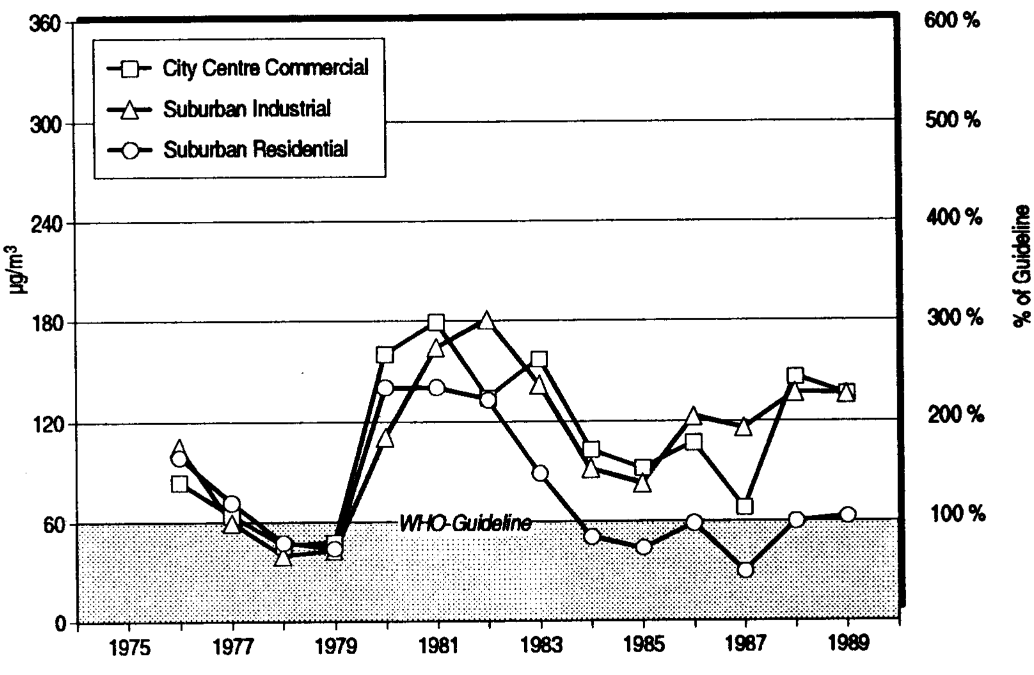
ANNUAL MEAN SPM
Tehran

Figure 1: Annual mean SPM in Tehran. Long-term guidelines are exceeded in all three monitoring stations.



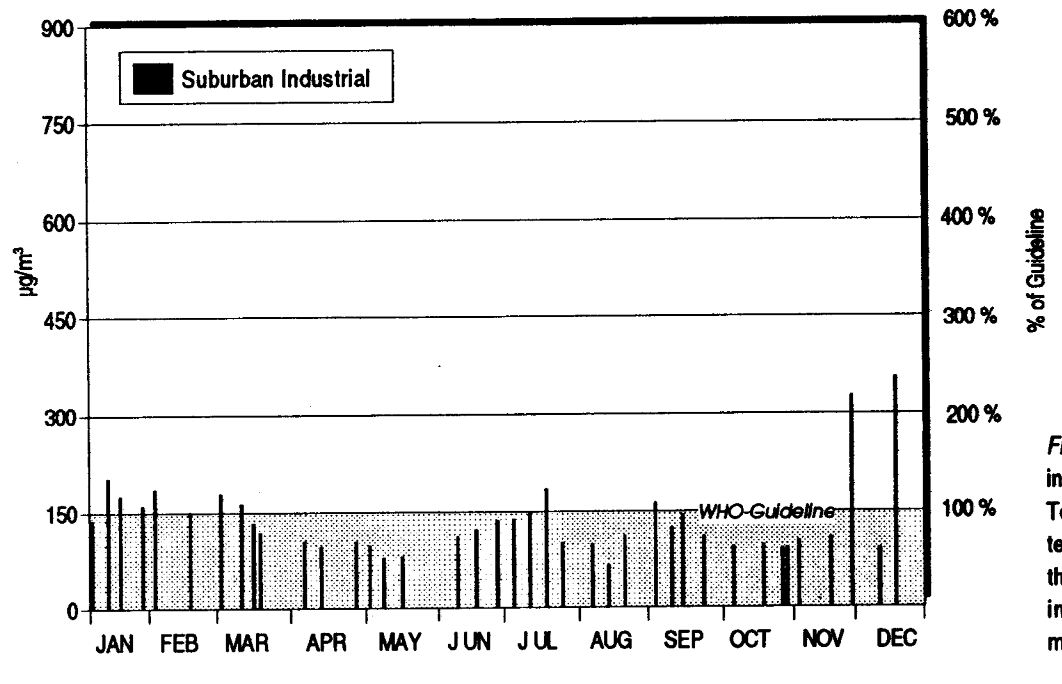
DAILY MEAN SPM
Tehran

Figure 2: 1989 daily mean SPM in a suburban industrial site in Tehran. Short-term guidelines are exceeded on almost all days per year. Zero levels indicate days where no measurements were taken.



ANNUAL MEAN SO_2
Tehran

Figure 3: Annual mean SO_2 in Tehran. Long-term guidelines are exceeded in all three monitoring stations, especially in the industrial and commercial sites.



DAILY MEAN SO_2
Tehran

Figure 4: 1989 daily mean SO_2 in a suburban industrial site in Tehran. Exceedances of short-term guidelines on about 25 % of the days per year. Zero levels indicate days where no measurements were taken.

Tokyo

Situation Analysis:

Tokyo is the capital of Japan. At present, Tokyo is the largest city in the world with an estimated population of 18 million in the greater metropolitan area.

The main suspended particulate matter (SPM) emission sources are small scale combustion and motor vehicle emissions. Sulphur dioxide (SO_2) emissions result mainly from fossil fuel combustion for domestic purposes. Japan was one of the first countries to introduce stringent air pollution control legislation. These measures have been effective in reducing national SO_2 emissions by approximately 70% from 1975 to 1986.

GEMS/AIR Results:

There are three GEMS/AIR monitoring sites in Tokyo: one each in the commercial city centre, in a city centre industrial area and in a suburban residential area. The GEMS/AIR monitoring sites were selected from the 35 ambient air monitoring stations operated by the Tokyo Municipal Government. In addition, the Tokyo Municipal Government operates also 32 traffic air pollution monitoring sites, a tower station and a background monitoring station.

The levels of annual mean concentrations show following the trends:

SPM	1984-1989:	slight downward trend *(Figure 1)*
SO_2	1975-1981:	downward trend, especially at the commercial and the industrial sites to 50% of 1975-1977 levels
	1981-1989:	slightly downward trend *(Figure 3)*

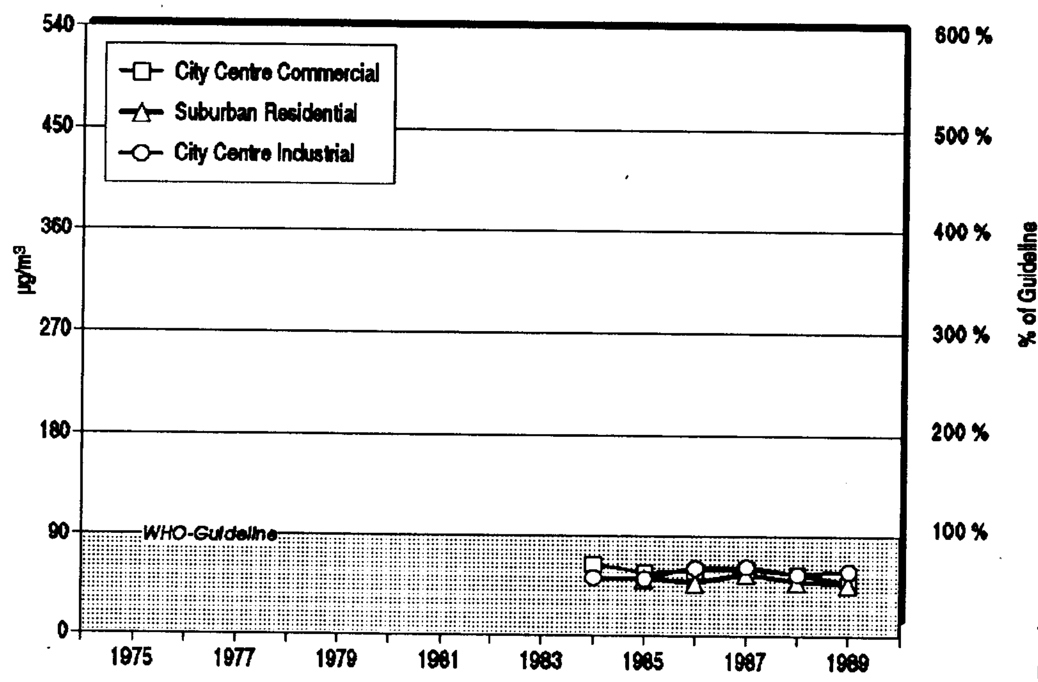
The decrease of SO_2 pollution levels, especially during 1977-1981, reflects the implementation of tight emission control measures. The main measure to cut SO_2 emissions was the reduction of sulphur content in fuel oil, followed by flue gas desulphurization devices at power stations.

Due to the pollution control efforts, both SPM and SO_2 levels are well below the long-term and the short-term guidelines at all monitoring sites.

Recommendations:

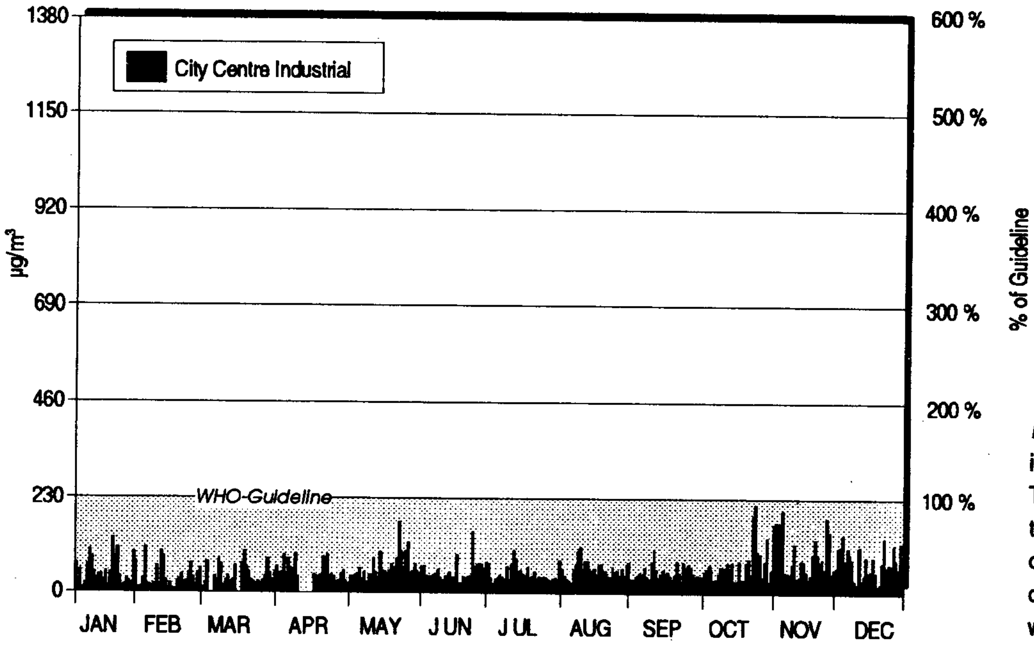
Pollution control legislation in Tokyo has resulted in a reduction of SPM and SO_2 ambient air concentrations, so there are no violations of WHO guidelines.

It is recommended that the municipal, provincial and national authorities provide the know-how for the planning, implementation, and enforcement of air pollution control to cities in developing countries.



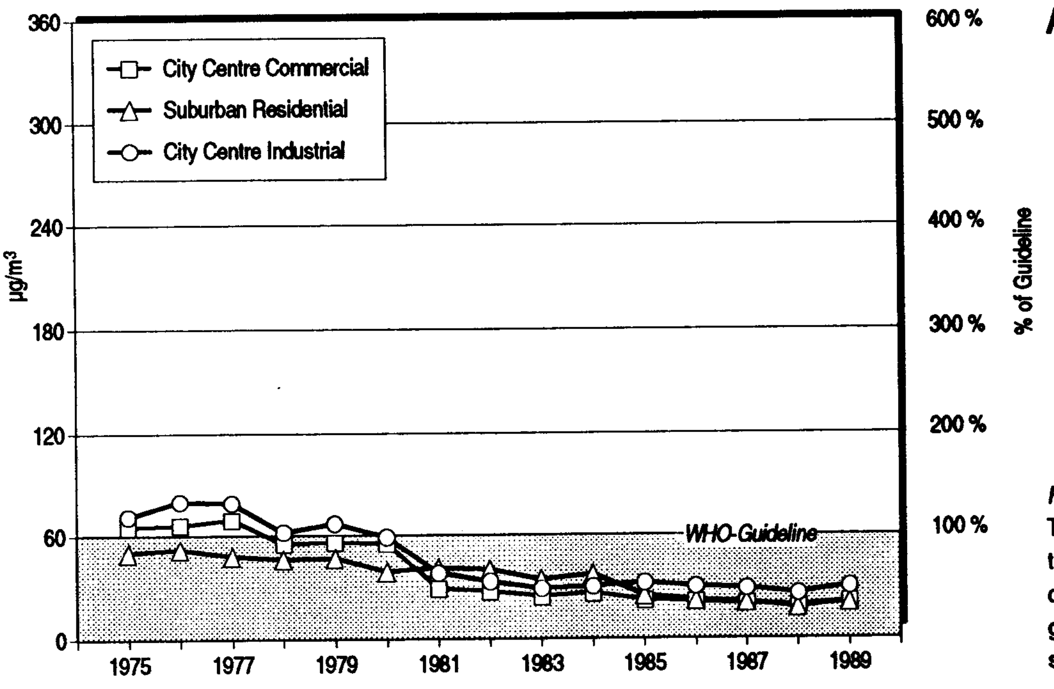
ANNUAL MEAN SPM
Tokyo

Figure 1: Annual mean SPM in Tokyo. Long-term guidelines are met in all years.



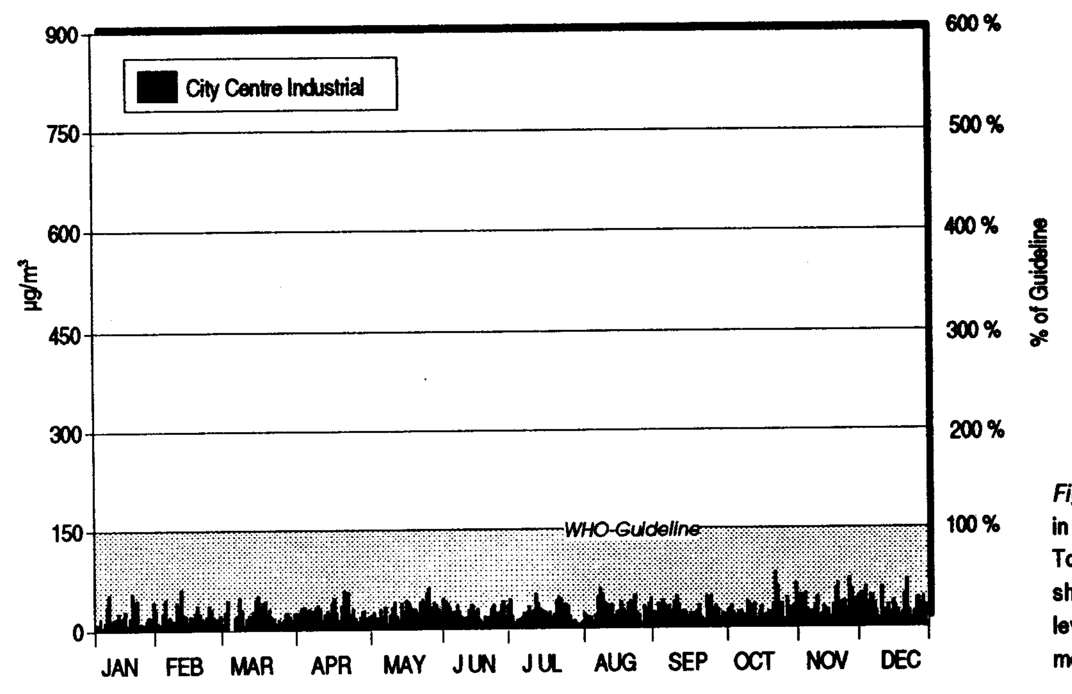
DAILY MEAN SPM
Tokyo

Figure 2: 1989 daily mean SPM in a city centre industrial site in Tokyo. Values are below short-term guidelines during all days of the year. Zero levels indicate days where no measurements were taken.



ANNUAL MEAN SO_2
Tokyo

Figure 3: Annual mean SO_2 in Tokyo. Remarkable downward trend since 1977 due to emission control legislation. Long-term guidelines are not exceeded since 1980.



DAILY MEAN SO_2
Tokyo

Figure 4: 1989 daily mean SO_2 in a city centre industrial site in Tokyo. Values are well below short-term guidelines. Zero levels indicate days where no measurements were taken.

Wroclaw

Situation Analysis:

Wroclaw is an industrial city in south-eastern Poland with about 650,000 inhabitants. The main energy source for power generation, heavy industry and domestic heating is low-grade coal. Emissions of suspended particulate matter (SPM) and sulphur dioxide (SO_2) are largely due to coal combustion processes. Greater use of coal in the winter heating season leads to a remarkable seasonality in the emission patterns.

GEMS/AIR Results:

GEMS/AIR has three monitoring stations in Wroclaw: one each in an industrial zone, in a residential area, and in the commercial city centre. Data for SPM are determined by smoke shade reflectance method and thus not directly comparable to other cities, where total suspended particles are measured.

The levels of annual mean concentrations show the following trends:

SPM	1978-1985:	no significant trend
	1985-1989:	slightly upward trend *(Figure 1)*
SO_2	1976-1981:	no significant trend
	1981-1987:	upward trend, increasing by 70-100 %
	1987-1989:	slightly downward trend *(Figure 3)*

The general long-term trend for SO_2 and SPM is upward. Ambient air concentrations of SO_2 and SPM were about 30% higher in 1989 than in the 1970s. SPM levels exceed long-term WHO guidelines in all stations. SO_2 concentrations are below the long-term average guidelines.

With respect to daily mean concentrations, there are strong seasonal trends: in the winter, daily mean concentrations of both SPM and SO_2 at the commercial city centre site frequently exceed short-term guidelines, especially during inversion episodes. Occasionally SPM reaches levels of about 300-500% of the WHO-guideline.

Recommendations:

It is recommended that existing control measures be enforced. Possible additional control options include:

- Reduction of domestic coal combustion by provision of low-sulphur fuels (e.g. washed coal, gas) or through the introduction of centralized combined heating-power facilities;
- Installation of SPM control equipment at industrial sources;
- Enforcement of pollution control existing legislation;
- Installation of an early warning system to prevent high pollution episodes during winter inversion episodes.

ANNUAL MEAN SPM (SMOKE) *Wroclaw*

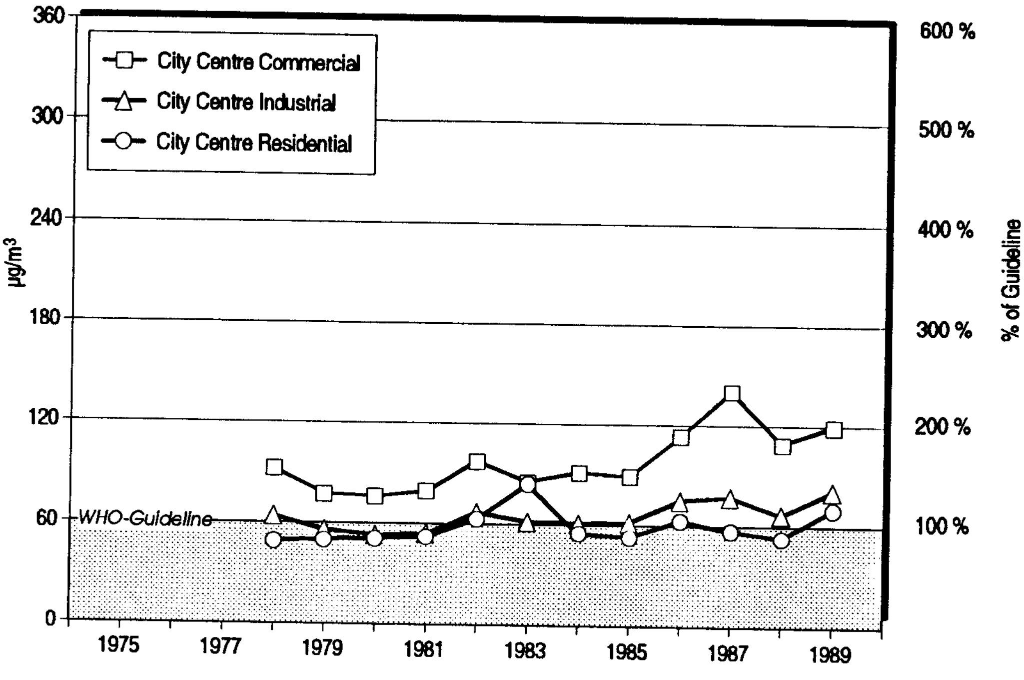


Figure 1: Annual mean SPM (Smoke) in Wroclaw. Long-term guidelines are exceeded in all three monitoring stations with a still upward trend.

DAILY MEAN SPM (SMOKE) Wroclaw

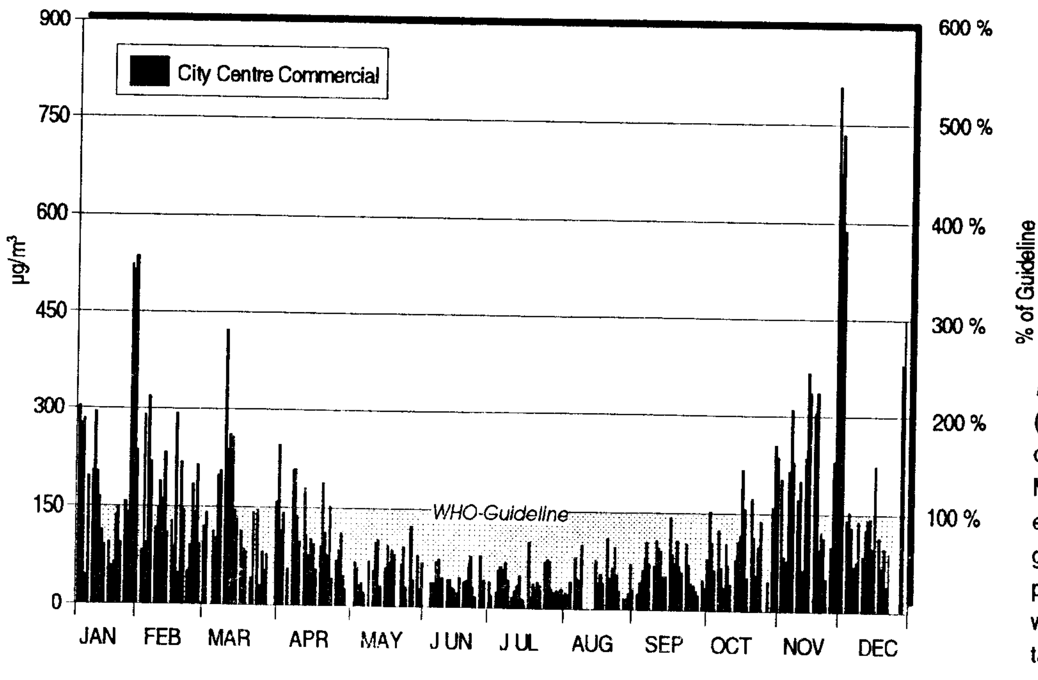
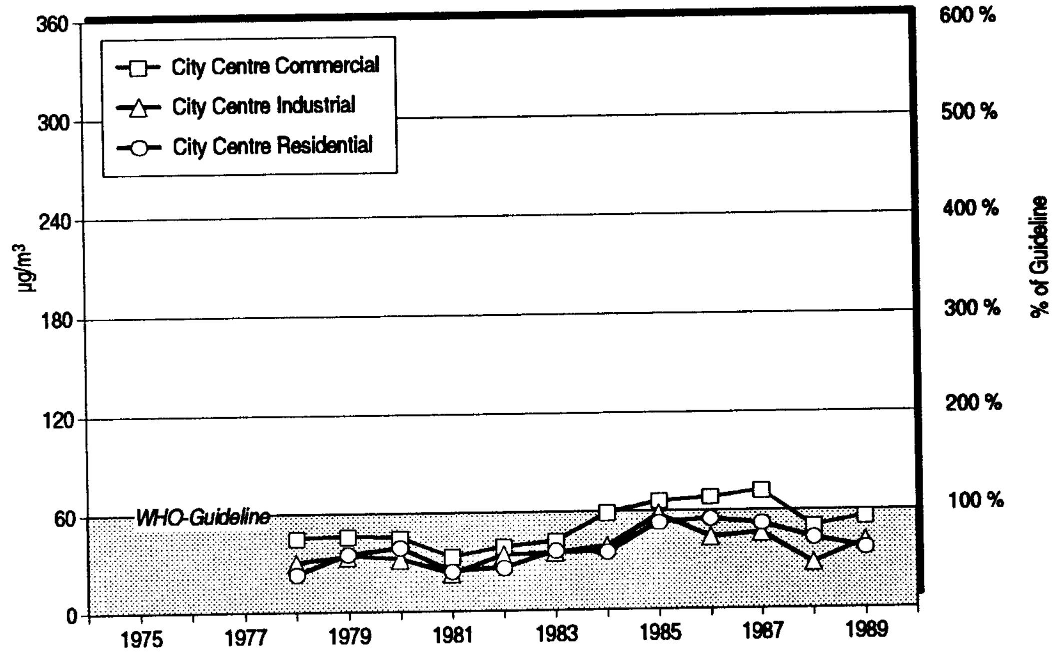
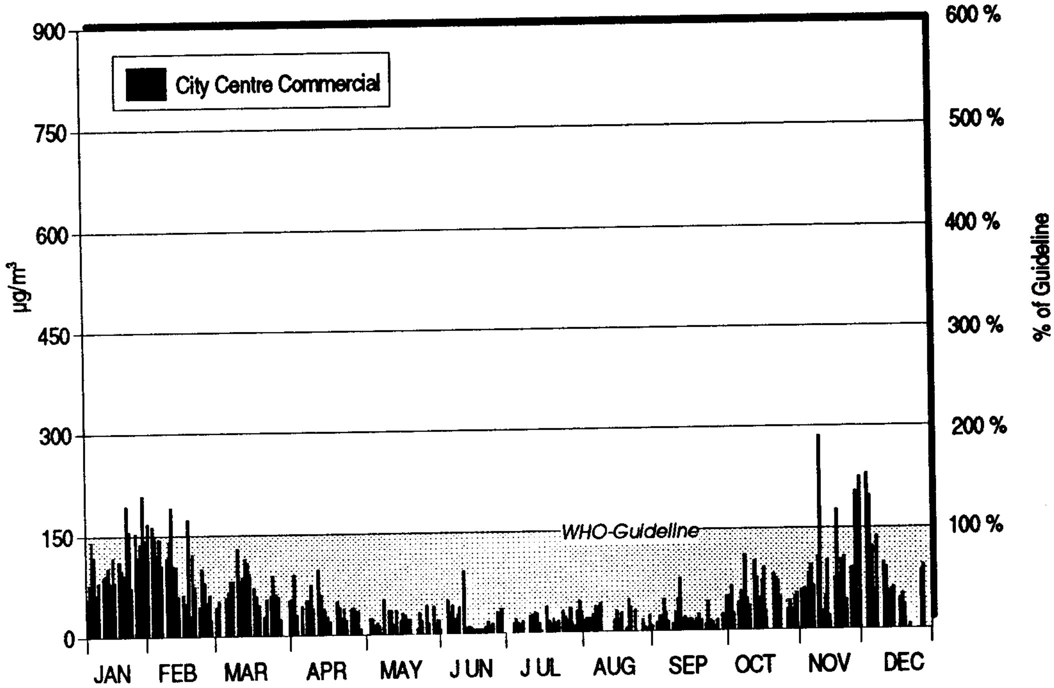


Figure 2: 1989 daily mean SPM (Smoke) in a city centre commercial site in Wroclaw. Marked seasonality with frequent exceedances of short-term guidelines in the winter heating period. Zero levels indicate days where no measurements were taken.



ANNUAL MEAN SO_2
Wroclaw

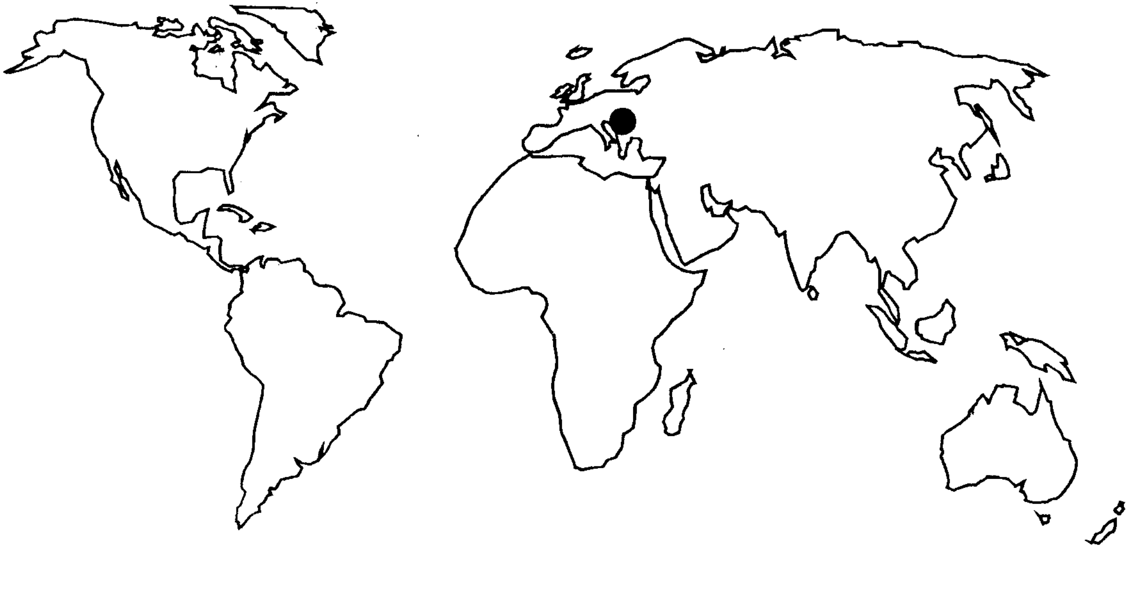
Figure 3: Annual mean SO_2 in Wroclaw. Values are at or below long-term guidelines.



DAILY MEAN SO_2
Wroclaw

Figure 4: 1989 daily mean SO_2 in a city centre commercial site in Wroclaw. Marked seasonality with frequent exceedances of short-term guidelines in the winter heating period. Zero levels indicate days where no measurements were taken.

Zagreb



Situation Analysis:

Zagreb is an industrial city in Croatia with over 800,000 people. The main sources of suspended particulate matter (SPM) are industrial processes, domestic combustion and motor vehicle emissions. The major sources for sulphur dioxide (SO_2) are coal and oil combustion processes in industry and power plants, and emissions from domestic fossil fuel usage during the winter heating period.

GEMS/AIR Results:

GEMS/AIR has three monitoring stations in Zagreb: one in an industrial zone, one in a residential area, and one in the commercial city centre.

The levels of annual mean concentrations show the following trends:

SPM	1975-1989:	slightly downward trend *(Figure 1)*
SO_2 :	1975-1989:	slightly increasing trend at industrial site; decreasing trend at commercial site *(Figure 3)*

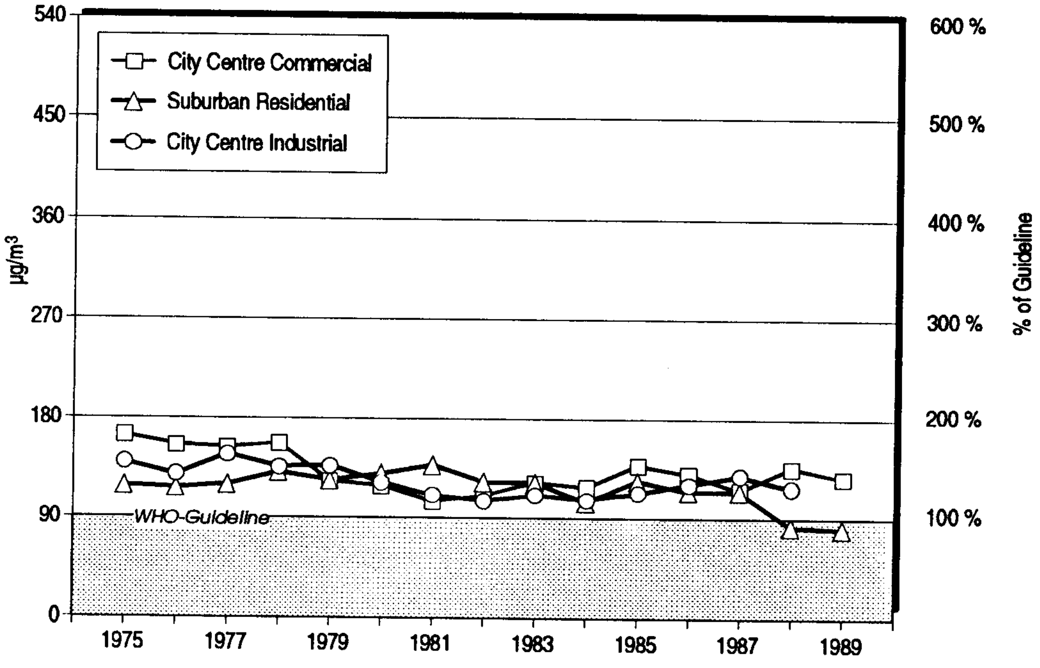
The slight downward trend in SPM and SO_2 concentrations relates most probably to an considerable increase in stack height at two thermal power stations, and a continuing slow conversion from coal and lignite to oil and gas for domestic heating. Annual mean values of SPM and SO_2 are above long-term guidelines at both city centre stations (commercial and industrial).

Daily mean concentrations show that there is a seasonal variation of SPM and SO_2, with maximum values occurring in the heating period. During the winter, daily mean values of SO_2 frequently exceed short-term guidelines in the commercial city centre. The seasonality is somewhat less with SPM, although similarly most guideline exceedances occur during the winter.

Recommendations:

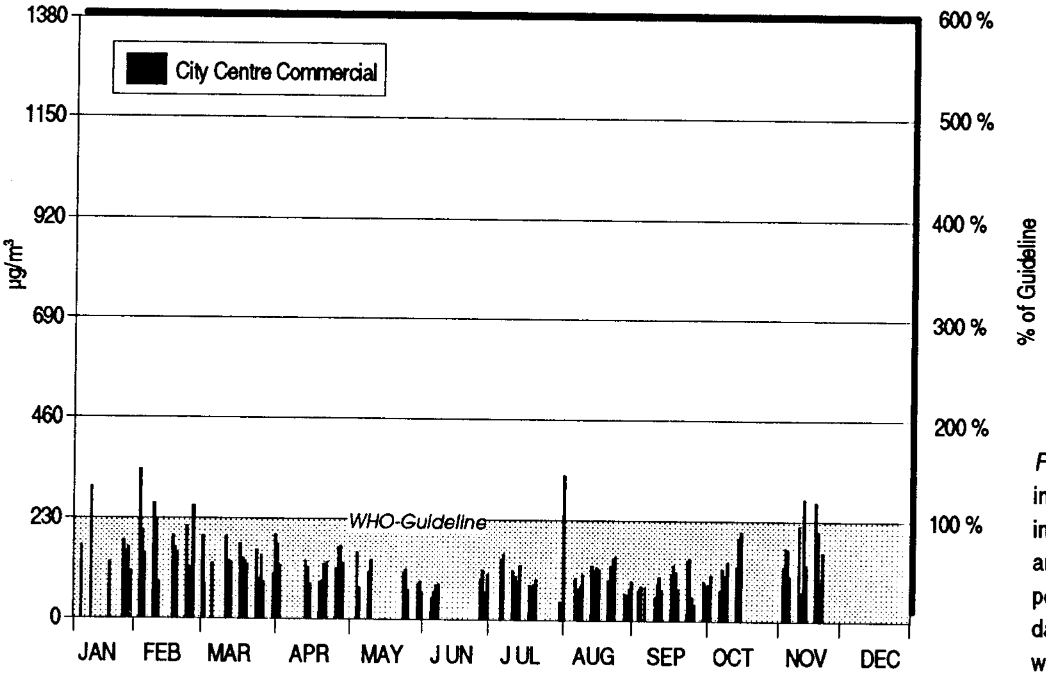
It is recommended that existing control measures be enforced. Possible additional control options include:

- Introduction and enforcement of emission control legislation for heavy industry and power stations, especially for those using low-grade coal and lignite;
- Reduction of domestic coal combustion by provision of low-sulphur fuels (e.g. washed coal, gas) or through the introduction of centralized combined heating-power facilities;
- Implementation of a mandatory inspection and maintenance programme for motor vehicle emission;
- Installation of an early warning system to prevent high pollution episodes during winter inversion episodes.



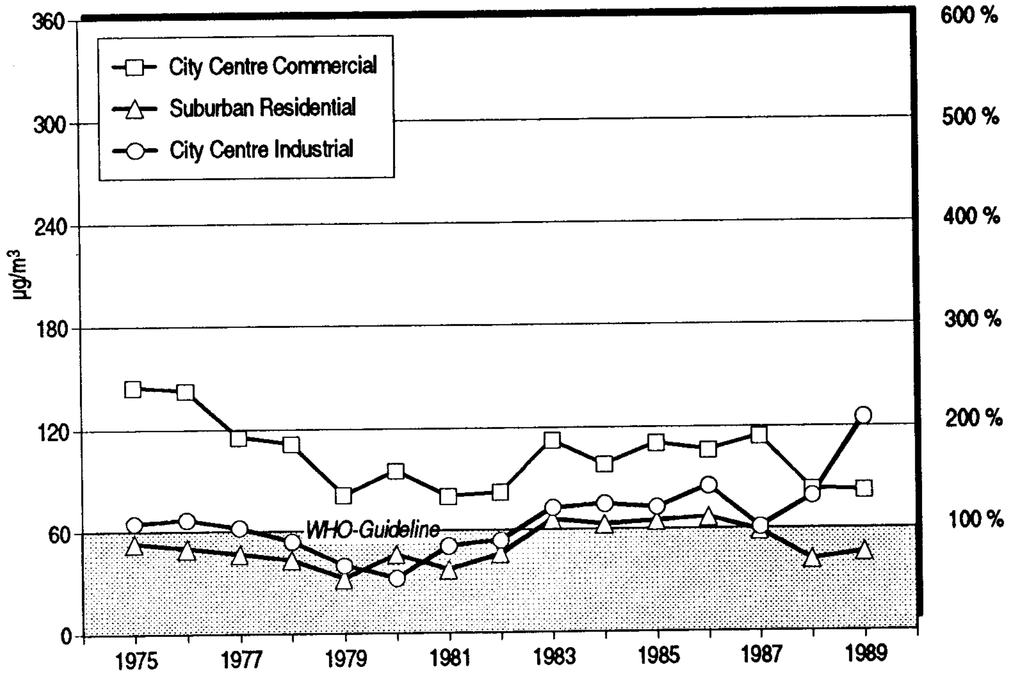
ANNUAL MEAN SPM
Zagreb

Figure 1: Annual mean SPM in Zagreb. Long-term guidelines are now met at the suburban residential site but not at the city centre sites.



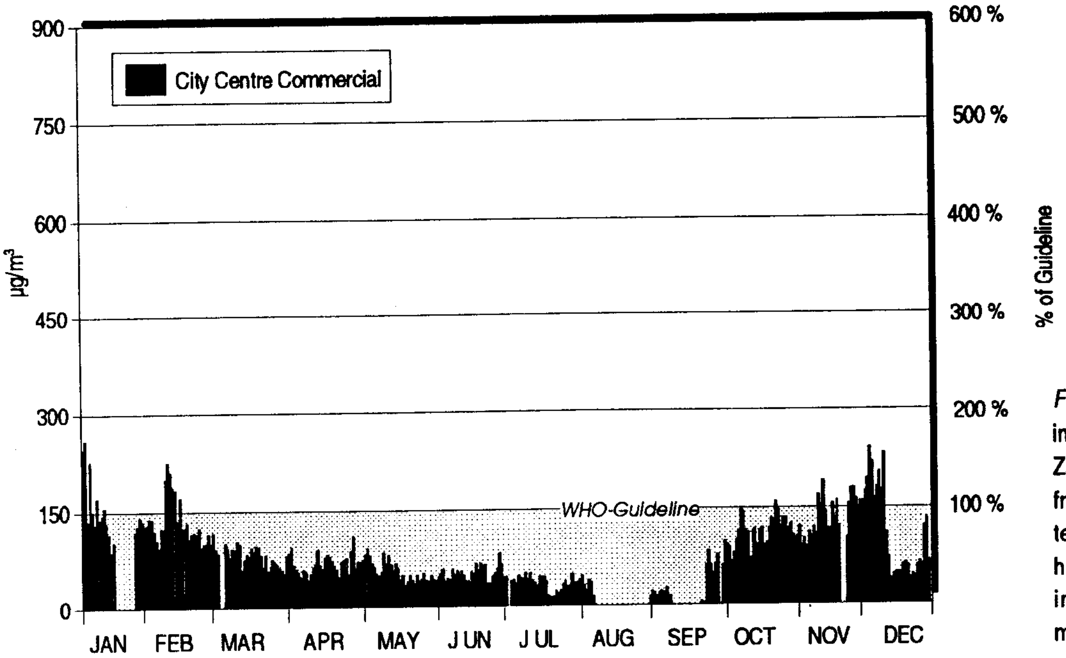
DAILY MEAN SPM
Zagreb

Figure 2: 1989 daily mean SPM in a city centre commercial site in Zagreb. Short-term guidelines are exceeded during a few days per year. Zero levels indicate days where no measurements were taken.



ANNUAL MEAN SO_2
Zagreb

Figure 3: Annual mean SO_2 in Zagreb. Long-term guidelines are now met at the suburban residential site but not at city centre sites.



DAILY MEAN SO_2
Zagreb

Figure 4: 1989 daily mean SO_2 in a city centre commercial in Zagreb. Marked seasonality with frequent exceedances of short-term guidelines in the winter heating period. Zero levels indicate days where no measurements were taken.

III. Synopsis and Conclusions

Synopsis and Conclusions

The cities presented in this report were chosen to illustrate a wide variety of climatic and socio-economic conditions, as well as different levels of industrial development and air pollution control. Thus, the conclusions cannot be regarded as fully representative for the GEMS/AIR network. Conclusions will be supported or might be changed when data from other cities are added to the further GEMS/AIR city air quality trends reports. Furthermore, direct city-to-city comparisons of pollution levels based only on the monitoring data are inadvisable in view of the different sampling methods and monitoring site characteristics of the GEMS/AIR stations for which data were reported. However, an aggregated synopsis seems useful to evaluate the potential global significance of the monitoring results.

Aggregated city pollution levels have been calculated[a] and evaluated in terms of exceedances of the WHO health guidelines. Aggregated city pollution trends have been calculated from individual city monitoring station trends[b] in order to identify the overall success of pollution control.

Levels and trends of SO_2

SO_2 levels are low in the two developed cities where pollution control was enforced in the 1970s. This is also the case for the two cities in tropical climates with no domestic heating and few industrial sources. However, in three of the ten cities presented here the average levels regularly exceed WHO long-term annual guidelines.

A downward trend of SO_2 pollution was noticed in three cities which already had low or moderate SO_2 levels; an upward trend was noted in two cities, and five cities showed horizontal trends.

Levels and trends of SPM

Levels of suspended particles are generally very high, especially in the cities from developing countries. In those cities with high SPM levels, substantial contributions may result from natural sources such as wind-blown dust, which can hardly be controlled. In eight of the ten cities presented here, average

a) The average levels were determined by averaging the available annual mean values for all monitoring stations in a given city for the last five years.

b) The average relative trends were determined by (i) assigning a base trend index of 100 to the annual mean values of each monitoring station for a city base year(the base year is the first year when data for all stations were available) and calculating relative trend indices for the subsequent annual means in every monitoring station, and (ii) averaging the trend indices of the monitoring stations in a given city for the last five years.

SPM/Smoke pollution levels exceeded long-term WHO guidelines, and in five cities, all of them in developing countries, the average levels were more than twice the guidelines. Three cities show a downward trend in SPM/Smoke levels, two cities an upward trend, and in five cities there was a horizontal trend.

General Conclusions

Only two of the ten cities presented here do not violate long-term WHO health guidelines for either SPM/Smoke or SO_2. Overall, air pollution is more severe in the eight cities in developing countries and newly industrialized countries than in the two developed cities. SPM pollution is certainly of greater concern than SO_2 pollution, with respect to the number of cities affected as well as with respect to the magnitude of the WHO guideline exceedances.

The analysis of pollution trends between 1985 and 1989 shows that pollution levels in the cities with a rather good air quality remained low or even decreased, but that pollution levels in the cities with already severe air pollution tended to remain high or even got worse.