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URBAN AIR POLLUTION

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Urban Air Pollution
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United Nations Environment Programme
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URBAN AIR POLLUTION

The UNEP/GEMS Environment Library

UNEP's Global Environment Monitoring System (GEMS) now has more than a decade of solid achievement behind it. In that time, we have helped make major environmental assessments of, for example, the greenhouse problem, the rate of degradation of the world's tropical forests and the numbers of threatened species— including the African elephant—in the world.

As is proper, the results of these assessments have been regularly published as technical documents. Until now, however, they have not been published in a form that can be easily understood by those without technical qualifications in the subjects concerned.

The aim of the UNEP/GEMS Environment Library is to rectify this omission.

This is the fourth volume in the series, and over the coming months and years we plan to publish many more. Only in this way can the result of UNEP's environmental assessments become widely known. And only if they are widely known is public opinion likely to become sufficiently vociferous to demand that everything possible be done to halt the deterioration of our environment, and preserve for future generations the possibility to survive and flourish as we have been able to do.

Michael D. Gwynne, Director
Global Environment Monitoring System

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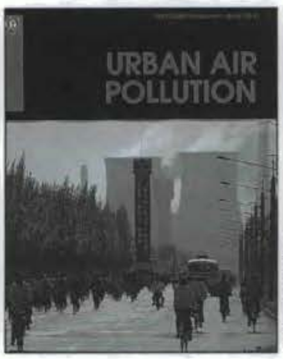


Panos Pictures

Cover picture shows urban air pollution in Baotou, China. In the background, the city's steel works disperse acidifying emissions, exposing the residents to unhealthy levels of air pollutants.

Foreword

The Global Environment Monitoring System has been monitoring air pollution in urban areas since 1974. Thanks to this diligent work, we have been able progressively to build up a picture of the state of the air in the world's major cities. In 1988, the World Health Organization (WHO) and UNEP together completed the second major GEMS assessment of urban air pollution.

Estimates of global figures, based on the GEMS data, are hardly reassuring. Some 1.2 billion city dwellers world-wide are exposed to excessive levels of sulphur dioxide. Even more are exposed to excessive levels of smoke and particles in the air. Nearly a third of the cities monitored within the GEMS/Air network have levels of nitrogen dioxide that exceed official WHO guidelines—and carbon monoxide levels in more than half the cities exceed WHO guidelines. Overall, only 20 percent of the world's 2.26 billion urban dwellers live in cities where air quality is acceptable. The health of many of the others is now being directly affected by high levels of airborne pollution.

Bad though this news is, the picture is not one of unrelenting gloom. In many of the developed countries, levels of urban air pollution—though high—are falling, and have been falling for some time. This success is due directly to improved pollution emission controls. It demonstrates that industrialization and urbanization do not lead inevitably to worse pollution.

Sadly, the same encouraging results are not coming in from the developing countries, nor from some of the poorer developed countries. There levels of urban air pollution are still increasing. The implications for the future are frightening.

By the year 2000, it is estimated that 4 out of 10 people in developing countries will live in cities. While in 1990 there were 68 cities housing over three million people, by 2000 there will be 66 cities housing more than four million people; by 2025 there will be 135 such cities. These statistics do not augur well for the future of the air that we must breathe. Without determined efforts to control pollution, the smogs of Victorian England may be reproduced world-wide. The effects on human health would be severe.

Mostafa K. Tolba

Mostafa K. Tolba
Executive Director
United Nations Environment Programme

Overview

...much of the world's population lives in cities where pollution levels exceed recommended WHO guidelines...

... controlling pollution is expensive, and presents governments with a challenge: how to encourage industrial development while imposing tighter pollution control regulations.

Urban air pollution has been growing since the Industrial Revolution. Rapid industrialization, burgeoning cities, and greater dependence on fossil fuels have brought in their wake increased production of harmful pollutants, making life in many cities more and more unpleasant and unhealthy.

Among the most common and most virulent of air pollutants are sulphur dioxide (SO_2), suspended particulate matter (SPM), nitrogen oxides (NO_x), carbon monoxide (CO) and lead. In addition, there is evidence of a growing threat to human health from indoor pollutants such as radon, formaldehyde, asbestos, mercury and organic substances.

Thanks to growing public demand—and increasingly certain evidence of a link between pollution and threats to health and environmental damage—many industrialized countries have controlled and reduced the most toxic pollutants. But in others—particularly in the Soviet Union and Eastern Europe, and less industrialized Western countries—the problems continue.

In almost all developing countries, meanwhile, urban air pollution is worsening. Rapidly growing cities, more traffic on roads, use of dirtier fuels, reliance on outdated industrial processes, growing energy consumption, and the lack of industrial zoning and environmental regulations are all contributing to reduced urban air quality and deteriorating public health.

In response to this, the World Health Organization (WHO) and the United Nations Environment Programme (UNEP) have been collaborating since 1974 on a project to monitor urban air quality. Known as GEMS/Air, the project has assessed the levels and health effects of five of the most common and ubiquitous air pollutants, drawing data from 50 countries. This publication summarizes the assessment's results.

The data show that much of the world's population lives in cities where pollution levels exceed recommended WHO guidelines, thereby exposing inhabitants to substantial health threats. For instance, more than 1200 million people may be exposed to excessive levels of sulphur dioxide; 1400 million people to excessive levels of SPM and smoke; and 15–20 percent of North American and European urban residents could be exposed to excessive levels of nitrogen dioxide. The air in half of the world's cities contains excessive levels of carbon monoxide; and people in up to a third of all cities may be exposed to excessive lead levels.

Panos Pictures

There are many different pollution control options available: using cleaner fuels, cleaning fuels before and during combustion, purifying emissions, encouraging energy conservation and, perhaps most important, planning carefully. But controlling pollution is expensive, and presents governments with a challenge: how to encourage industrial development while imposing tighter pollution control regulations.

GEMS/Air reached four main conclusions on pollutant levels:

- that pollution-control strategies are beginning to take effect in many industrialized countries, where trends in SO_2, SPM and lead emissions have been generally downward;
- that controls on CO and NO_x have been less effective, mainly because both pollutants are produced by road traffic, which is increasing almost everywhere;
- that data from developing countries are incomplete, but indicate that emissions of all five pollutants are growing;
- and that there are many cities—particularly in developing countries—where pollution levels still exceed WHO guidelines.

By the year 2005, every second person on Earth will be an urban resident, and by 2025, the total urban population in developing countries will have more than doubled to 4050 million. Against a prevailing background of rapid urban growth and variable treatment of pollution problems, the future health of the majority of the world's urban residents is in jeopardy.

By the year 2005, every second person on Earth will be an urban resident, and 8 out of 10 people will live in a developing country.

The scientific background

Historical overview

In London, for example, smog caused 500 and 2000 deaths in 1873 and 1880, respectively.

Air pollution has been a steadily growing problem since the Industrial Revolution began 300 years ago. The revolution was started by the invention of technology that could use new sources of energy —particularly coal, oil and gas—and that enabled increasingly large-scale industry to develop. The combustion of fossil fuels releases a number of pollutants into the air, notably soot, smoke and sulphur dioxide, and as industry spread, so did the pollution caused by the new industrial processes. Air and water quality deteriorated in some areas to the extent that human health was threatened.

In the large cities that grew up in the 19th century, where industry and workers' dwellings were in close proximity, the problems of air pollution were most acute. Most people relied heavily on coal for domestic heating and the smoke from this source—as well as from industry—led to increasingly dense and harmful smogs in cities during the late 19th century. In London, for example, smog caused 500 and 2000 deaths in 1873 and 1880, respectively.

However, relatively little was done to control any type of pollution or to promote environmental protection until the mid-20th century. The tremendous growth in the use of petroleum products at this time, particularly in petrol-driven road vehicles, made air pollution more and more difficult to avoid. Emissions of nitrogen oxides, carbon monoxide, hydrocarbons and lead often severely reduced the quality of urban life.

The turning point in public and political attitudes came in the 1940s and 1950s, when a number of severe pollution episodes in Europe and North America finally drew wider public attention to the problem. Although London had long suffered from smog, the 1952 incidence was particularly severe, and caused the deaths of 4000 people. This led directly to the passage of the 1956 Clean Air Act, which provided a model for similar legislation in other countries.

Since the 1950s, knowledge about the causes and effects of air pollution has grown, as have public demands for control measures. As we better understand the interaction of environmental systems, it has become clear that air pollution is extremely complex, and that it cannot be dealt with effectively simply as a local problem near major emission sources.

Today, many air pollutants originate in industrial processes, such as smelting. The most common pollutants are known to have a range of effects on human health, including respiratory illness and aggravation of heart problems, blood changes leading to reduced oxygen-carrying capacity, hyperactivity and neurobehavioural effects.

The release of toxic substances into the atmosphere as a result of major industrial accidents, such as Bhopal, has renewed calls for stricter preventive controls of industrial plants that pose a potential pollution threat.

Economic and technological developments since World War II have brought considerable and positive changes to the quality of human life. At the same time, though, these changes have often cost a deterioration in environmental quality. Regulation itself poses difficult questions about who should bear the costs of pollution control—polluting industries, the government, or society? For many environmentalists, it has become clear that a holistic and preventive approach to pollution control is essential. Only by seeing pollution problems in the long term, and as part of wide-ranging industrial development, can the overall costs of pollution control be adequately assessed.

Causes and effects of pollution

Air pollution has been exacerbated by four particular developments that typically occur as countries become industrialized: growing cities; increasing traffic; rapid economic development; and higher levels of energy consumption.

Petrol and diesel combustion in vehicles are major sources of air pollution, releasing a number of pollutants into the air that then build up to harmful levels in cities with high-density traffic.

Air pollution may affect areas outside national boundaries and is known to be threatening global environmental conditions. Because pollutants can be transported long distances in the atmosphere, the original solution of building tall smoke-stacks to disperse emissions has only spread pollution away from the original source. Some pollutants, once in the atmosphere, are converted to acidic compounds that destroy forests, acidify lakes and rivers, corrode materials, and cause human health problems.

Increases in the level of carbon dioxide and other pollutants (mainly from industrial processes and fossil-fuel combustion) have been shown to cause global warming, which may lead to a major long-term impact on climate, agriculture, and sea and groundwater levels.

Chlorofluorocarbons used in aerosols, refrigerants, solvents and foam plastics have destroyed much of the Earth's ozone layer, which shields organisms from damaging ultraviolet radiation.

Attention has also recently turned to indoor air pollution, which is caused by substances such as radon in building materials, the nitrogen dioxide given off by cooking and heating appliances, formaldehyde from insulation materials, asbestos from fire retardants, and tobacco smoke.

Air pollution has been exacerbated by four particular developments ... growing cities; increasing traffic; rapid economic development; and higher levels of energy consumption.

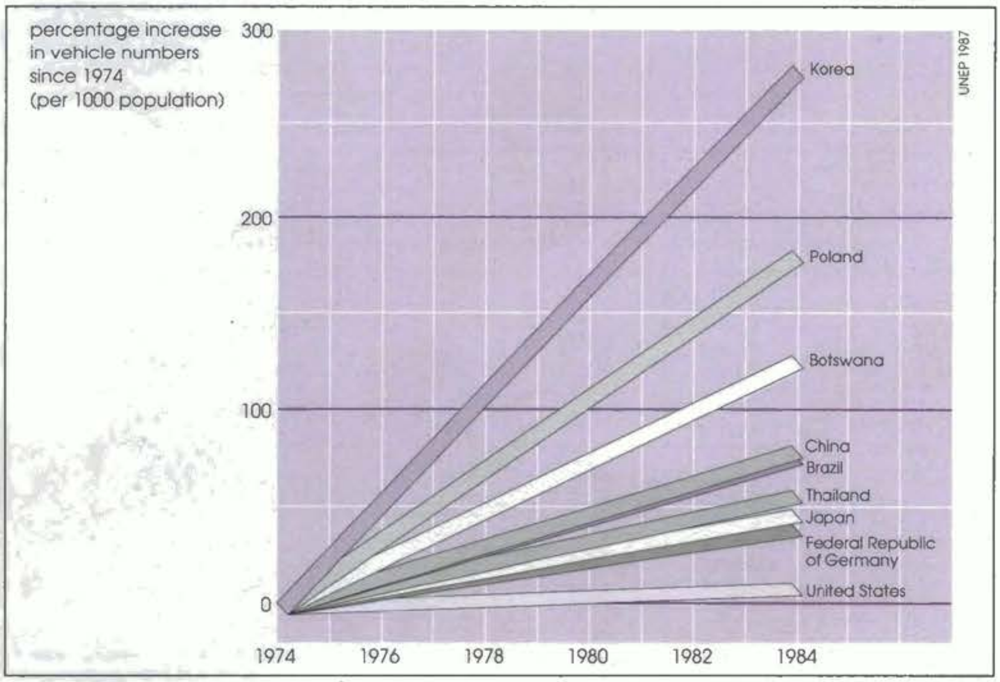


Figure 1 The number of vehicles (per 1000 population) increased particularly sharply in developing countries during 1974–84.

Pollution in developing countries

The number of cities with more than 4 million inhabitants grew from 13 to 35 between 1950 and 1980. It is projected that there will be 66 such cities by the year 2000, and 135 by the year 2025. The majority of these will be in developing countries, where the most rapid urbanization and industrialization in the world is occurring. Much of this expansion has resulted from high population growth and continuing migration from rural areas. If current trends continue, Mexico City and São Paulo—both in developing countries—will be the two largest cities in the world by the year 2000.

To improve economic and social well-being, many developing countries give priority to rapid industrial development. Although such development can lead to progress and improved quality of life, it can also produce serious environmental deterioration if not carefully controlled.

In many developing cities, the growth of both industrial and residential areas is unplanned, unstructured and unzoned. This leads to housing being built alongside factories and industries, increasing the human danger risk of industrial accidents.

The results of such rapid and unplanned development are growing levels of air pollution, more pollution-related health problems, lost working days and economic dysfunction. More people now live in an unhealthy, if not hazardous, environment.

Urban growth is accompanied by increased traffic and energy consumption. Use of motor vehicles is growing rapidly in developing countries. Since 1979, the greatest increases have been in Asia and South America, where vehicle ownership has more than doubled. Though growth rates have slowed in North America and Europe, these regions still have the greatest traffic density.

While North America and Western Europe account for 43 percent of global

Figure 2 shows 1950 and 1980 populations in the developing world living in cities of 1 million or more inhabitants and projects the figure for the year 2000. By then, South Asia's urban population will be nearly 20 times greater than in 1950.

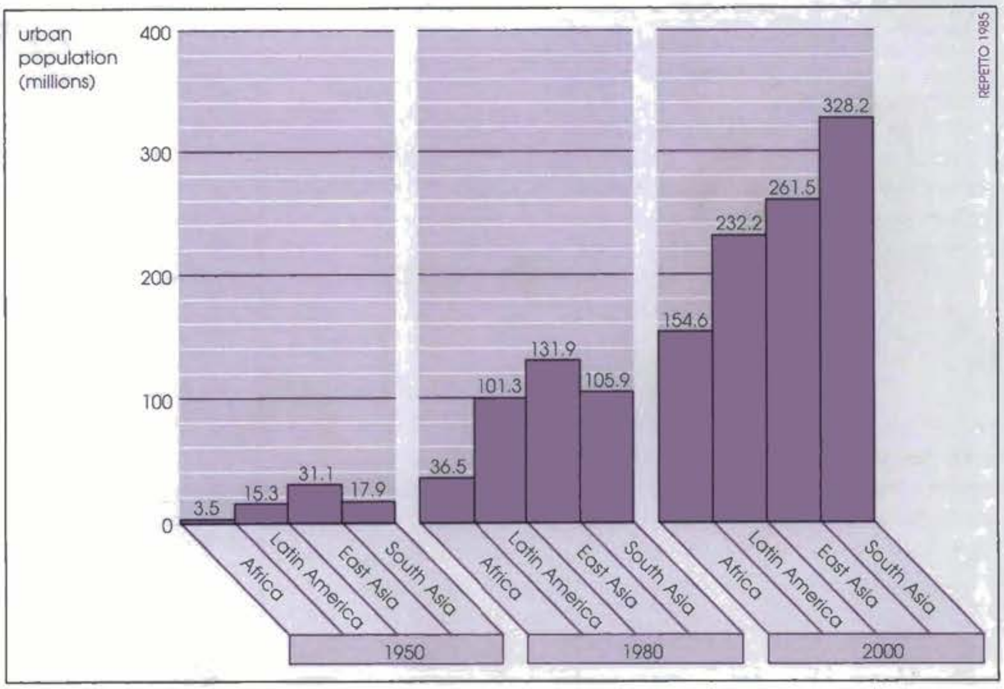


Figure 3 While generally stabilizing in Western Europe and North America, primary energy consumption rose steeply in developing countries and the Soviet Union during 1965–85.

commercial energy consumption, and the centrally planned economies for another 35 percent, the proportion consumed by developing countries has been growing rapidly. As those countries expand their economic and industrial base, so their consumption of coal, oil and other fossil fuels grows. This growth is rarely accompanied by pollution control laws, which leads to worsening environmental conditions in the largest urban centres of the developing world.

In developing countries particularly, indoor pollution is also a serious health problem, caused mainly by dependence on wood and animal residues for fuel. These are often burnt in confined and unventilated spaces, where they give off large amounts of harmful substances.

petrol-powered motor vehicles ... account for nearly all the CO emitted in some urban areas.

About two-thirds of the world's total consumption of refined lead is concentrated in just eight countries in the northern hemisphere ...

Sources of pollution

Sulphur dioxide

The sulphur present in the atmosphere comes from both natural and man-made sources. Natural sources of sulphur dioxide (SO_2) include microbial activity and volcanic activity; and sea-salt spray adds to atmospheric sulphate. Natural emissions account for about half of all atmospheric SO_2; these are not increasing as natural sulphur is simply recycled. But man-made emissions are increasing, especially in the northern hemisphere, where an estimated 90 percent of all man-made SO_2 is created.

Most man-made SO_2 is formed when fossil fuels are burned, and the sulphur naturally stored in coal, oil and natural gas is released into the atmosphere. About 10 percent is formed through metal-smelting and sulphuric acid production. This sulphur may return to Earth as dust, but taller smoke-stacks have meant that sulphur can be carried over hundreds of kilometres by the wind. The sulphur reacts with moisture in the atmosphere to form particulate sulphates and droplets of sulphuric acid. Sulphur dioxide is thus the major cause of acid rain.

Suspended particulate matter

Suspended particulate matter (SPM) consists of solid and liquid particles emitted from numerous natural and man-made sources. SPM is a complex and variable mixture of different-sized particles with many chemical components. Larger particles may come from wind-blown and industrial dust, volcanic particles and plant pollen; finer particles tend to be formed by combustion and gas-particle conversions (chiefly from SO_2). The constituents can vary, although in urban areas they typically include carbon particles and polynuclear aromatic hydrocarbons (PAHs) produced by incomplete fuel combustion.

Sulphur dioxide and the particulates are 'traditional' urban pollutants because they were found in the sulphurous, coal-induced smogs that characterized the first industrial cities. Modern-day SPM problems are aggravated by the lack of emission regulations on the increasing number of diesel-powered vehicles being used for freight transport.

Nitrogen oxide

Almost the same amounts of nitrogen oxides (NO_x) are emitted by natural and man-made sources. Natural sources include lightning, forest fires, volcanic activity and microbial processes in soil. Because natural emissions occur all over Earth, they are diluted and have little impact on concentrations in a specific area.

Man-made sources, by contrast, are concentrated in centres of population in the northern hemisphere. Combustion oxidizes both the nitrogen in fuel and some of the nitrogen naturally present in the air, producing several oxides of nitrogen. However, the only two known to have adverse environmental or biological effects are nitrogen oxide (NO) and nitrogen dioxide (NO_2). About 75 percent of man-made NO_x comes from vehicular emissions and burning fossil fuels in power stations. In countries such as Sweden, which use a lot of nitrate-based fertilizer, about 30–40 percent of man-made nitrogen compounds come from agriculture.

Carbon monoxide

Carbon monoxide (CO) is one of the most widely distributed of all air pollutants—global emissions probably exceed the combined emissions of all other major air pollutants. A colourless, odourless gas, it is naturally formed by biological and oxidation processes, but much is man-made. By far the largest source of man-made emissions is petrol-powered motor vehicles, which account for nearly all the CO emitted in some urban areas. (Properly adjusted diesel engines produce little CO.)

Local CO concentrations can be high near

Table 1 shows the most important sources of indoor and outdoor pollutants. Some sources contribute to both types of pollution.

POLLUTANTS	SOURCES
predominantly outdoor	
sulphur oxides	coal and oil combustion, smelters
ozone	photochemical reactions
lead, manganese	automobiles, smelters
calcium, chlorine, silicon, cadmium	soil particulates and industrial emissions
organic substances	petrochemical solvents, vaporization of unburnt fuels
indoor and outdoor	
nitrogen oxides	fuel combustion
carbon monoxide	incomplete fuel combustion
carbon dioxide	fossil fuel combustion, metabolic activity
suspended particulate matter	resuspension, condensation of vapours and combustion products
organic substances	petroleum products,combustion, paint, metabolic action, pesticides, insecticides and fungicides
ammonia	metabolic activity, cleaning products and agriculture
predominantly indoor	
radon	building materials (concrete, stone), water and soil
formaldehyde	particleboard, insulation, furnishings, tobacco smoke
asbestos, mineral wools, synthetic fibres	*fire-retardant, acoustic, thermal or electric insulation*
organic substances	adhesives, solvents, cooking, cosmetics
aerosol of nicotine and other 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	infected organisms
allergens	*house dust, animal debris*

power stations, oil refineries, iron foundries, steel mills and refuse burners. Other man-made sources include forest clearing, fuelwood and savannah burning, and the oxidation of man-made sources of hydrocarbons (mainly methane).

Lead

Lead occurs naturally in wind-blown dust and volcanoes but most is man-made. The biggest single source (60 percent of man-made lead emissions) is road traffic. Alkyl lead—used as an anti-knock agent in petrol—is released into the atmosphere as fine particles when the petrol is burnt.

Other sources include smelting and refining lead, coal combustion, refuse incineration, and producing batteries, cables, solder, paint. Like many pollutants, about two-thirds of the world's consumption is concentrated in eight countries in the northern hemisphere.

Indoor air pollution

Air pollution is not restricted to outdoor air. Although relatively little is known about the hazards of many substances found in indoor air, because people may spend as much as 80–90 percent of their time indoors, the need to understand this environment is obvious.

The sources of indoor pollution are different for developing and industrialized countries. In the former, the main pollutant sources are human activities (such as cooking and smoking) and certain types of building materials. Key pollutants in the latter include nitrogen dioxide, carbon monoxide, radon (from building materials, water and soil), formaldehyde (from insulation), asbestos, mercury, man-made mineral fibres, volatile organics, allergens and tobacco smoke—as well as health-damaging organisms such as bacteria. There are currently few comprehensive monitoring programmes for any of these indoor pollutants (though the US Environmental Protection Agency has a major research department), but individual studies have suggested many potential adverse health effects.

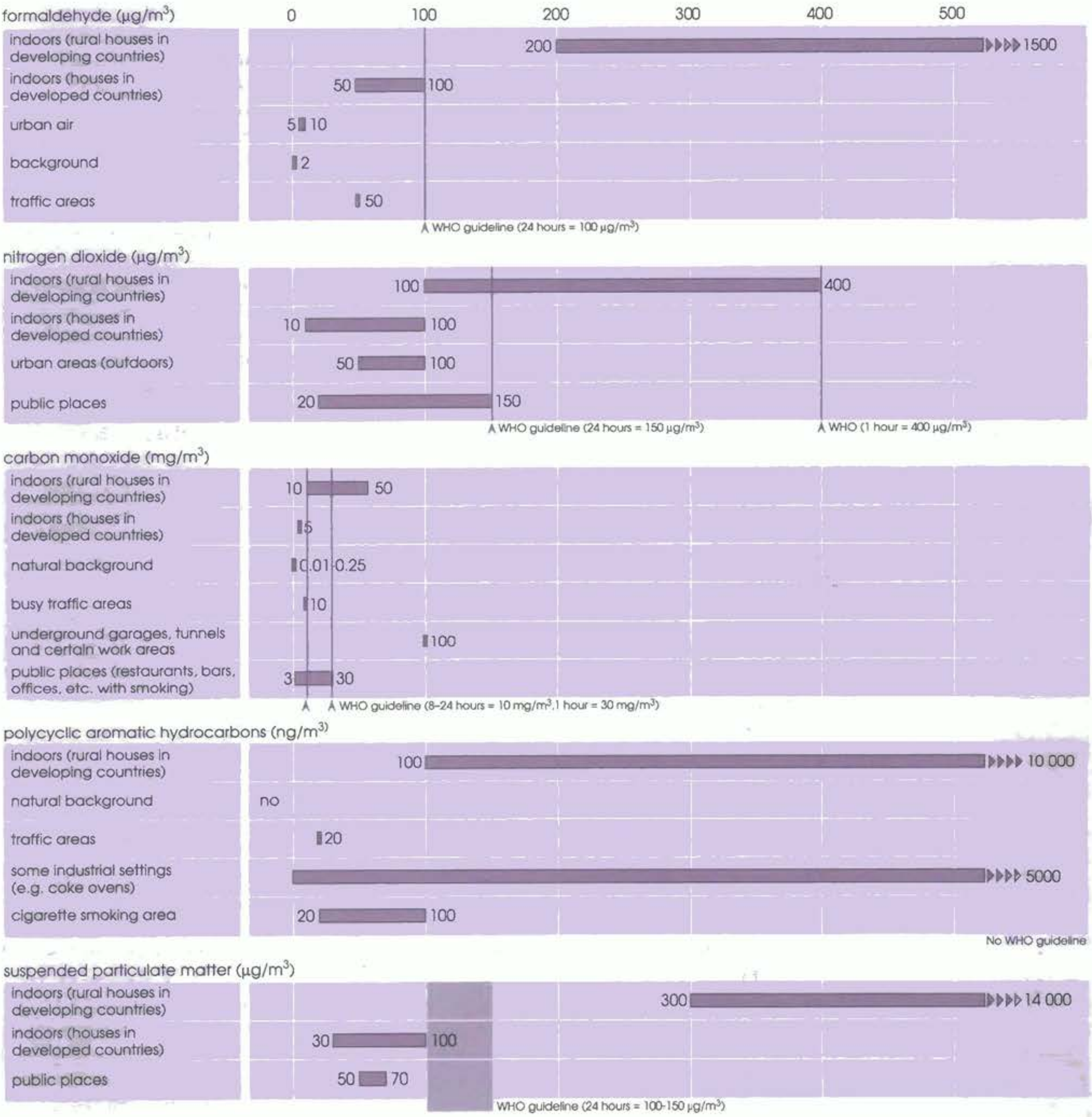
Most of these health effects arise in buildings made from materials that give off radon, asbestos particles, formaldehyde and volatile organic compounds. These pollutants are often recirculated indefinitely in houses and offices with energy-efficient ventilation. Legionnaire's disease is a form of bacterial pneumonia linked to air-conditioning systems, for example, and the rather ambiguous affliction known as 'sick building syndrome'—which can include ear, nose and throat irritations, fatigue, nausea, headaches and dizziness—is usually associated with new or remodelled buildings.

In developing countries, indoor pollution comes mainly from using biomass fuels (wood, agricultural waste, dung, and so on) for cooking and heating. The fuel is often burnt inefficiently, in rooms that are poorly ventilated. Biomass smoke contains numerous substances, the most hazardous of which include suspended particulate matter, nitrogen dioxide, sulphur dioxide, and carbon monoxide; it also releases a number of aldehydes, including formaldehyde. The smoke has also been shown to contain quite high levels of polycyclic aromatic hydrocarbons (PAHs), many of which are known carcinogens.

High exposure to these indoor pollutants can lead to lung and heart disease; cancer of the lungs and nasopharynx; acute respiratory infections, particularly in children; and low birth weights if the mothers have been exposed to indoor pollution. Because two-thirds of the world's people depend on biomass fuels for most of their energy supply, as many as 400–500 million people—mainly in the rural areas of developing countries and primarily house-bound women and children—may be adversely affected by indoor pollution.

Table 2 Ranges of air pollution for five important pollutants are shown for indoor and outdoor environments. Indoor levels of four of them are much higher than outdoor levels. Note the different units of measurement per cubic metre (m^3) for different pollutants: 1 milligramme (mg) is 10^{-3} g; 1 microgramme (µg) is 10^{-6} g; and 1 nanogramme (ng) is 10^{-9} g.

Air pollution concentrations in different environments



The GEMS assessment

WHO and UNEP have been collaborating since 1974 on a programme to monitor air quality in urban areas. The programme—GEMS/Air—is part of the Global Environment Monitoring System, established in 1974 and coordinated by UNEP. Related WHO/UNEP GEMS monitoring and assessment programmes are also being carried out for fresh water quality, and (together with FAO) food contamination.

The GEMS/Air assessment concentrated on the five most common and serious air pollutants:

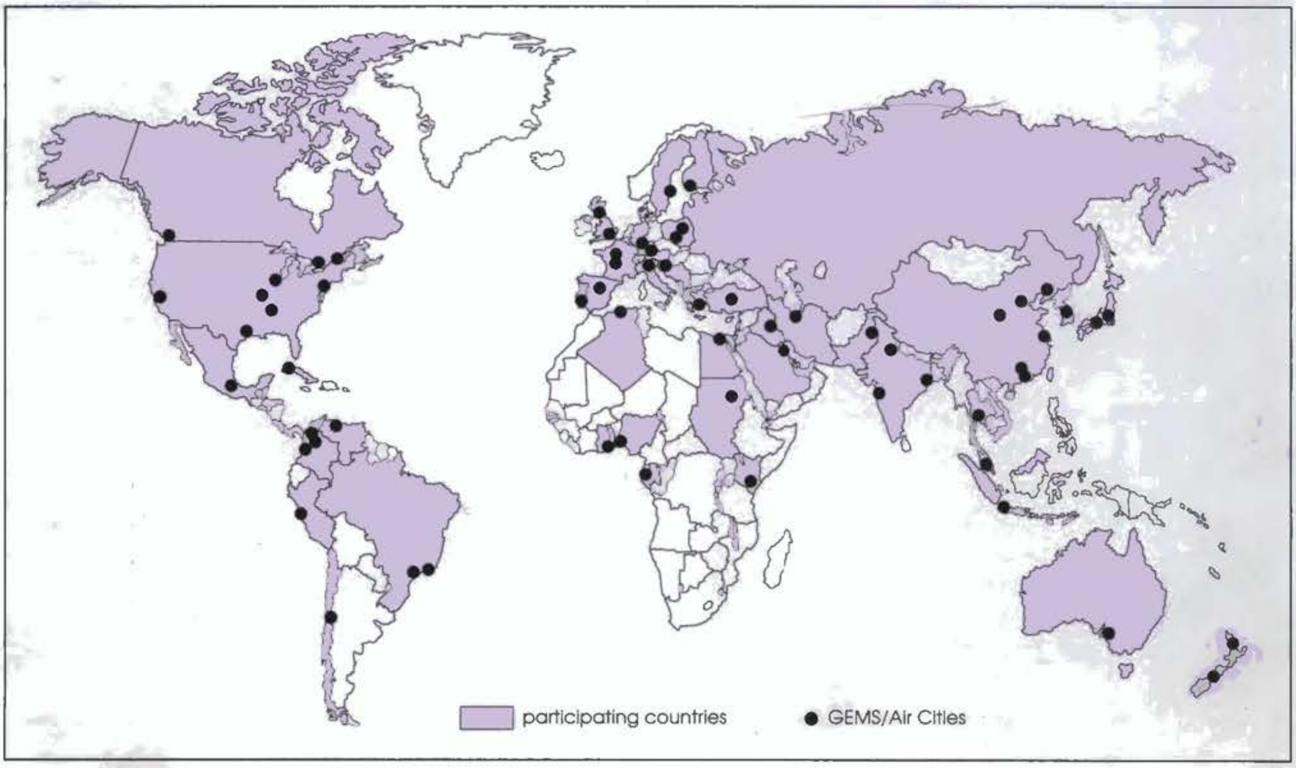
- sulphur dioxide,
- suspended particulate matter,
- lead,
- nitrogen oxides, and
- carbon monoxide.

These were chosen because they are ubiquitous pollutants, emitted in large quantities; originate in different industries and processes; and are known to affect human health in their current concentrations. Although not yet part of the monitoring programme, indoor pollution, a growing problem in industrialized and developing countries alike, was covered in the GEMS assessment.

The GEMS/Air assessment involved collecting information from 50 countries. Of those, 35 have provided representative data sets on sulphur dioxide and suspended particulate matter for major urban areas. Data on lead, nitrogen oxides and carbon monoxide were culled from national reports, open literature, and from questionnaire results.

Using data from the period 1973–1984,

Figure 4 GEMS/Air has 50 monitoring cities world-wide. Most GEMS/Air cities include three monitoring stations: one in an industrial zone, one in a commercial area, and one in a residential area.



trends in pollutant emissions and the quality of urban air were assessed and levels were measured against WHO guidelines on recommended pollutants (where those guidelines exist).

The cities of the GEMS/Air network were chosen to provide the broadest global coverage possible, and to represent different climatic conditions, levels of industrial and urban development, and pollution situations. Most of the GEMS/Air cities have three monitoring stations: one in an industrial zone, one in a commercial area, and one in a residential area. The data collected from these stations made possible a reasonable evaluation of minimum and maximum pollutant levels, and long-term trends of average concentrations.

The assessments had two main goals: to continue the ongoing process of producing periodic evaluations of global urban air pollution; and to keep developing and refining the techniques used for evaluating air pollution monitoring data, particularly to advance understanding of the risks air pollution poses to human health.

In 1988, the information collected under GEMS/Air (supplemented with other reliable international data) was compiled and analysed. Global and regional levels and trends were assessed for each pollutant. This information was endorsed by a meeting of government-designated experts in Geneva in 1988, and is summarized in the following pages.

POLLUTANT	**POSSIBLE EFFECTS**	**WHO GUIDELINE** *annual mean*
sulphur dioxide	worsening respiratory illness from short-term exposure, increased respiratory symptoms, including chronic bronchitis, from long-term exposures	40–60 μg/m^3
suspended particulate matter	as for SO_2 combined exposure to SO_2 and SPM are associated with pulmonary effects	*black smoke* 40–60 μg/m^3 *total SPM* 60–90 μg/m^3
lead	blood enzyme changes, anaemia, hyperactivity and neurobehavioural effects	0.5–1μg/m^3
		WHO GUIDELINE *not to be exceeded*
nitrogen dioxide	effects on lung function in asthmatics from short-term exposures	150 μg/m^3 (for 24 hr)
carbon monoxide	reduced oxygen-carrying capacity of blood	10 mg/m^3* (for 8 hr)

*US National Air Quality Standard for annual mean exposure is set at 100 μg/m^3

Table 3 lists recommended WHO guidelines for maximum exposure to the major pollutants and some possible health effects if these recommendations are exceeded.

Sulphur dioxide

Annual global emissions of sulphur dioxide (SO_2) currently stand at about 294 million tonnes, of which 160 million tonnes are anthropogenic. Total emission figures are calculated mainly from estimates of the production or consumption of fossil fuels, the sulphur content of fuels, and mean emission factors. Although the quality and validity of national and global emissions estimates is improving, there are still enough discrepancies to leave questions about trend assessments.

About half the world's SO_2 emissions come from natural sources (mainly volcanic activity). The other half is the product of human activity, mainly fuel combustion in coal- or oil-fired power stations. Man-made emissions have been rising about four percent annually—the same rate as global energy consumption.

About 90 percent of these emissions come from the northern hemisphere (the United States and the Soviet Union are the two biggest sources, although actual emission figures for the Soviet Union are still unclear); but developing countries are contributing more as they develop their industrial base. SO_2 pollution is becoming particularly evident in countries such as China, Mexico and India.

The dispersal area, the amount of acid produced, and the polluting effects of SO_2 depend on factors such as weather conditions (wind, cloud cover, humidity and sunlight), the presence of other pollutants, the height at which SO_2 is released, and the length of time it stays in the atmosphere.

SO_2 that returns to Earth immediately can be dry-deposited as oxides on plants or buildings, it can enter the stomata of plants, or it can be breathed in by humans and animals. SO_2 remaining in the atmosphere can be converted into acid within as little as an hour through reactions with moisture.

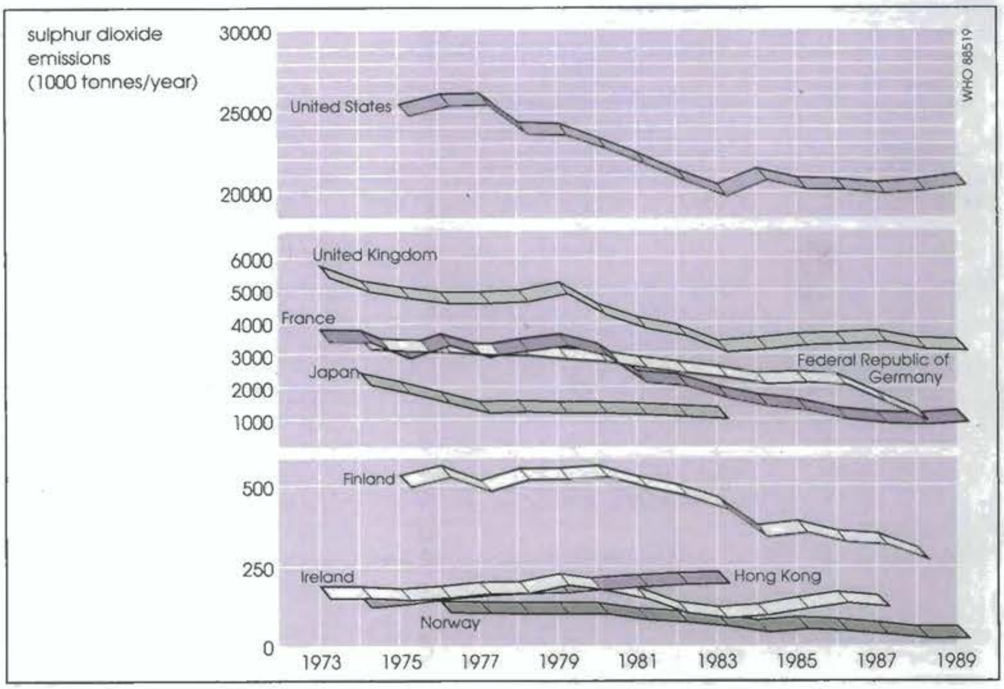


Figure 5 SO_2 emissions have been significantly reduced in many developed countries over the past 15 years. The wide difference in SO_2 emissions from certain countries is emphasized by a discontinuous vertical scale.

SO_2 has a number of adverse health effects, and is linked to bronchitis, tracheitis and respiratory problems. Sulphurous smogs—one of the most infamous of all being London's smog of 1952—have caused many deaths and health problems in large cities. After 4000 people died in 1952, the UK government rapidly passed new legislation to clean the air over Britain's cities. In other cities, such as Athens, Dublin, Beijing and Mexico City, atmospheric SO_2 still threatens human health.

Environmental effects of SO_2 include acidification of soils, lakes and rivers; and damage to plants and crops. Hypotheses about how this happens involve factors such as climatic stress, slow changes in the soil, and attacks by pests and diseases. Acidic deposition may release the aluminium in soils, or it may reduce the availability of other chemicals, such as magnesium and calcium. Aluminium released by acidification can enter rivers and lakes, where it poisons fish, and can be ultimately ingested by humans through drinking water.

Finally, SO_2 is responsible for corroding buildings, monuments and works of art in, and downwind of, major industrial centres. Sulphur can react with the calcium carbonate in limestone or sandstone to form gypsum, which sticks to the stone like icing on a cake, causing the surface of the stone to break up into small flakes that are then washed away by rain. Sulphur can also create salts in the stone, which then expand or contract, bringing on fatigue or disintegration. Stained glass windows throughout Europe are thought to be affected, as are buildings such as Westminster Abbey in London, Cologne Cathedral in Germany, the Acropolis in Athens, the Coliseum in Rome, and Rheims Cathedral in France.

There are several different ways to control

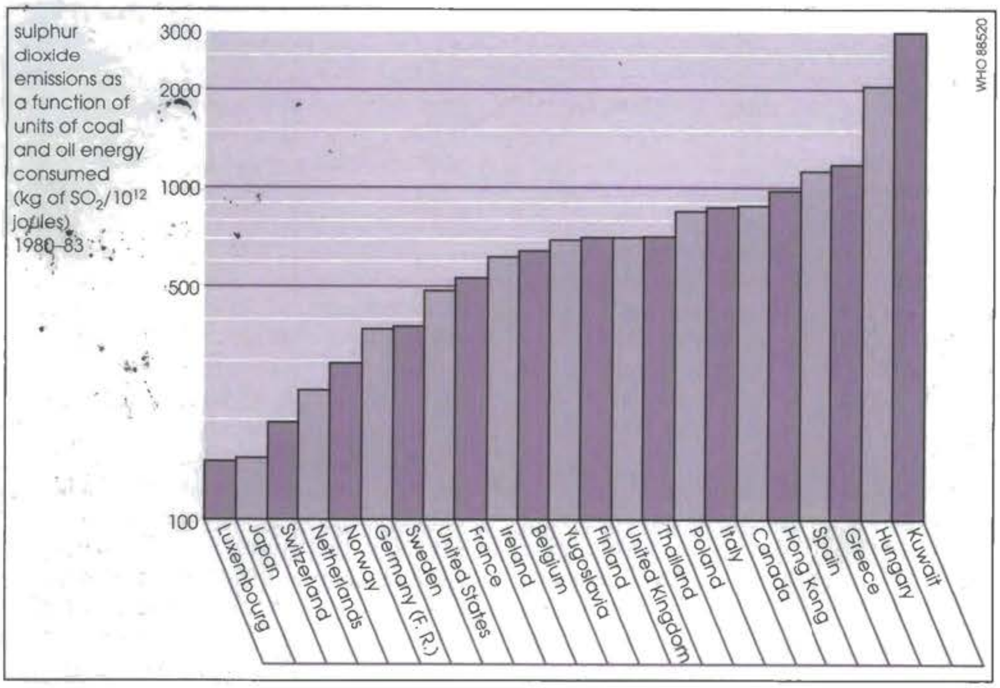


Figure 6 SO_2 emissions per unit of energy consumed. Overall outputs reflect stringent emission controls in developed countries such as Luxembourg and Japan. For every 10^{12} joules of energy produced, different countries emit different amounts of SO_2 relative to the type of energy source and processing method. Note the logarithmic vertical scale.

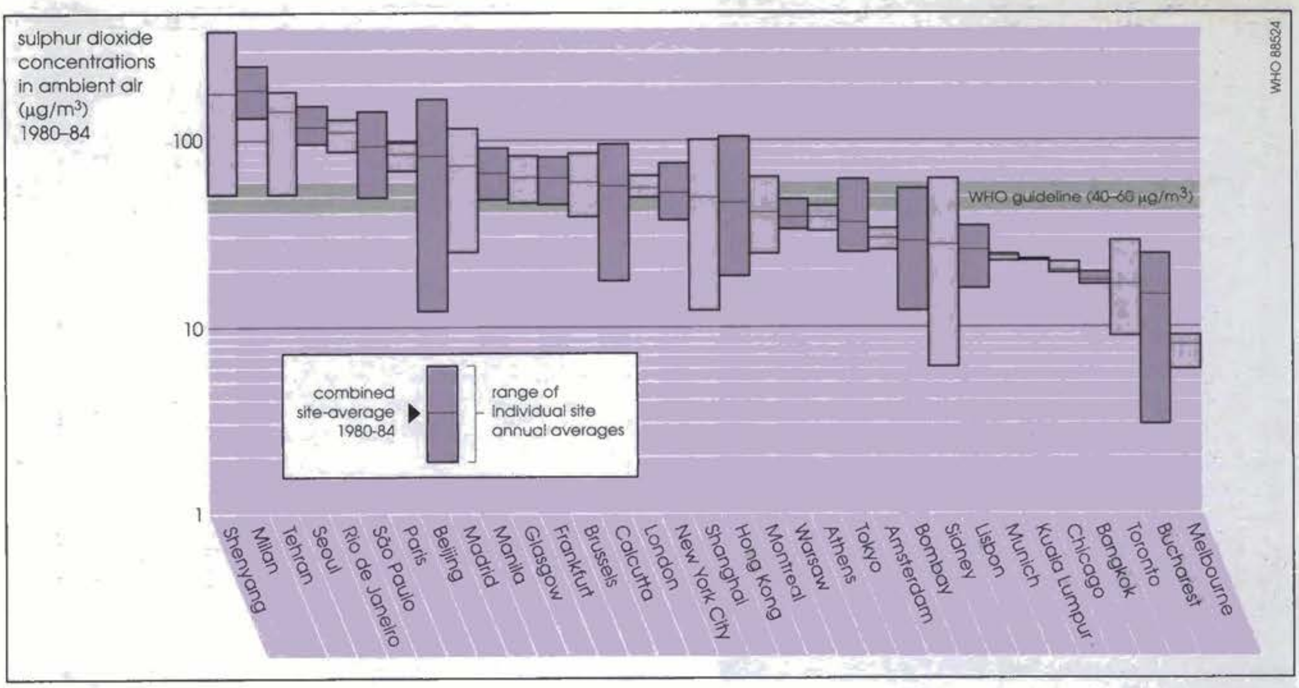


Figure 7 There are large variations in SO_2 levels in the world's major cities, but WHO recommended guidelines are exceeded in many of them. Note the logarithmic scale.

or reduce SO_2 emissions. One of the most obvious is to use low-sulphur fuel. However, coal and oil containing less than one percent sulphur are in short supply, and many of the regions producing (and relying on) high-sulphur coal could suffer economic dislocation and unemployment problems if industry changed to low-sulphur coal from other regions. An alternative is to continue using high-sulphur fuels, but to wash coal and desulphurize oil before use.

SO_2 pollution can also be reduced by extracting the sulphur from fuel during combustion. Injecting limestone into the firebox during combustion, for example, causes a reaction that converts much of the sulphur into gypsum.

Alternatively, SO_2 can be absorbed after combustion through the process of flue gas desulphurization (FGD). This involves fitting scrubbers to smoke-stacks to 'clean' emissions before they enter the atmosphere. More than 500 coal-fired power plants (mainly in Japan and the United States) already use this method, and wider FGD use is planned in many European countries.

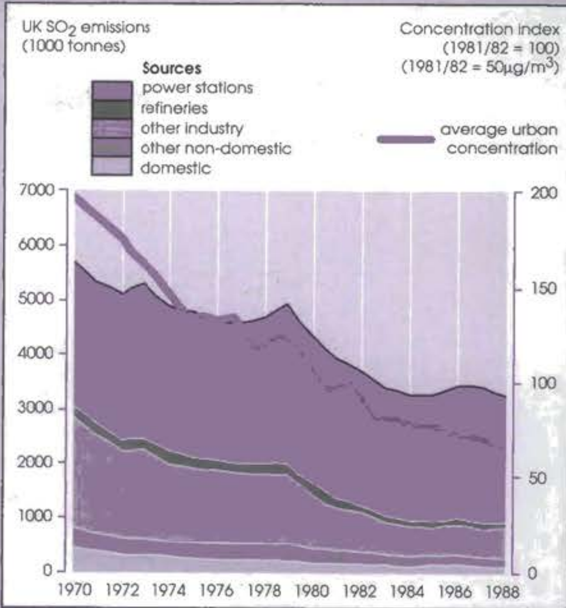
Encouraging energy conservation and improving energy generation efficiency is another option. This would reduce energy consumption, thus reducing the amount of fossil fuels burnt to generate energy.

Emission levels are being restricted in some countries. Japan and the United States have applied the most rigorous SO_2 pollution controls to date. Japan was the first country to embark on an FGD programme in the 1960s, and helping to reduce its SO_2 emissions by nearly 40 percent between 1974 and 1983. By the end of 1986 it was operating 1755 FGD units, mainly in small, oil-fired industrial burners and smelters, though all sources including coal-fired power plants have been included in the programme. The United States has 100 FGD units in operation on coal-fired plants, and reduced SO_2 emissions by 18 percent between 1974 and 1985. New legislation proposed by the Bush administration in 1989 committed the United States to a further 50 percent reduction by the end of the century.

To comply with European Community legislation, and specifically the 1979 UN/ECE (Economic Commission for Europe) Convention on Long-Range Transboundary Air Pollution, most major Western industrial countries have now committed themselves to substantial SO_2 reductions. The main objective has been to reduce acid pollution, not urban SO_2 levels. Many countries, such as Austria, France, Sweden and Switzerland, have already reduced SO_2 by more than 40 percent. Germany—where acid pollution damage to forests has been particularly obvious and widespread—is planning the largest FGD programme in Europe. The United Kingdom—one of Europe's most prolific

SO_2 in the United Kingdom

As the first industrial nation, the United Kingdom was also the first to experience widespread air pollution. A British scientist, Robert Angus Smith, identified the process of acid pollution in the 1850s, but little was done to reduce SO_2 emissions. It was only after London's smog of 1952 that controls were introduced, leading to a substantial fall in urban SO_2 levels. The 'pea-soup' fogs for which London and other major cities were famous became increasingly rare. During the 1970s, Sweden and Norway, two of the main recipients of UK SO_2 emissions, pressured Britain to introduce further controls. By the early 1980s, Britain was the fourth biggest producer of SO_2 in the world, but only agreed to substantial national controls in 1988. Under EC law, UK emissions must be cut by 60 percent of 1980 levels by the year 2003. This will be done by using low-sulphur coal, switching to gas and fitting some of Britain's largest power plants with FGD scrubbers.



producers of SO_2—has agreed under the terms of EC legislation to reduce SO_2 emissions by 60 percent of 1980 levels by the year 2003.

Despite these reductions, global SO_2 production continues to grow. Of the 33 cities assessed by GEMS/Air between 1973 and 1985, 27 showed a downward trend (3 percent per year or more) of annual average SO_2 concentrations, while 6 showed an upward trend. The greatest improvements were mainly in developed countries, often due to the building of taller smoke-stacks, which simply disperse emissions further afield. The greatest increases in annual SO_2 levels were found in New Delhi (20 percent per year, averaged over 8 years), Tehran (10 percent per year, over 10 years), and Wroclaw and Hong Kong (8 percent per year, over 8 and 9 years, respectively).

WHO has established two guidelines for SO_2 concentrations based on scientific findings and epidemiological studies, which should apply simultaneously. One relates to safe long-term exposure by recommending an average annual level of SO_2, the other to safe levels of daily exposure, which are higher as it is assumed that such exposure will not be prolonged. The recommended annual mean level is 40–60 µg/m^3, where 1 microgramme (µg) is 10^{-6} g. This is intended to eliminate any risk of respiratory illness in children, or of respiratory symptoms in children and adults as a result of long-term exposure to SO_2. The 100–150 µg/m^3 limit for 98 percent of daily averages is designed to ensure that even particularly sensitive members of the population be protected from short-term adverse effects. Many cities continue to exceed the guidelines, in some cases by large margins.

Based on the results from GEMS/Air cities, 625 million people around the world live in urban areas where average SO_2 levels exceed the WHO annual guideline, and 975 million (nearly one-fifth of the world's population) live in cities where the the short-term guideline is exceeded on more than 7 days a year. Of cities contributing to the GEMS/Air database, only 30 percent of their populations live in urban areas where annual average ambient SO_2 levels are below WHO guidelines.

Suspended particulate matter

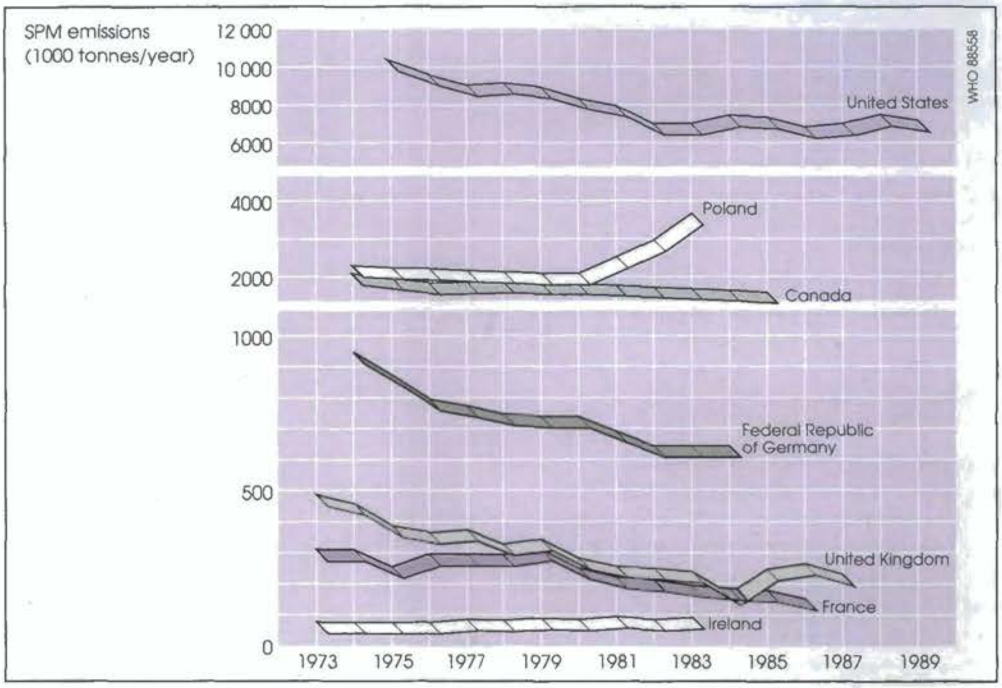
Research on global man-made emissions of suspended particulate matter (SPM) is still incomplete, making it difficult to establish trends. Available data for the period 1982–84 show emissions of about 27 million tonnes per year, but the global total is probably closer to 135 million tonnes.

Particles enter the atmosphere from many natural and man-made sources; they are also formed when gases and vapours condense. Direct SPM emissions arise from many human activities, including combustion, industry and agriculture. One of the difficulties in assessing the health effects of SPM is that different monitoring methods and terminology are widely used. SPM may be monitored using a variety of techniques. In the United States, SPM is measured by weight (gravimetric, total suspended particulates). Alternatively, many countries use the black smoke reflectance method (darkness of stain obtained on a white filter paper through which air has been passed).

Respirable particles in urban areas contain lead, other metals and organic compounds. Sulphuric acid and other sulphates can make up as much as 20 percent of such particles, so the health effects are similar to those for SO_2. SPM was present in the more serious London and New York smogs of the 1950s and 1960s, which led to several thousand deaths. Long-term exposure to sulphates and particles can cause or aggravate respiratory diseases (especially asthma and pulmonary emphysema), and may damage lungs. The organic compounds present in SPM are worrying because many are known to be carcinogenic.

The elderly, the young and people with chronic pulmonary and heart diseases are particularly susceptible to SPM. Deaths in the 1952 London smog mainly involved those suffering from bronchitis, impaired breathing and heart disease (aggravated by

Figure 8 Despite increased coal combustion, particulate emissions have decreased in many industrialized countries because of cleaner burning techniques. Note the split vertical scale.



SPM). Continuous exposure of young children is particularly serious as early respiratory illnesses may develop into chronic ailments later in life.

SPM can also damage the vital photosynthetic systems of plants by covering leaves, plugging stomata, and reducing absorption of CO_2 and sunlight.

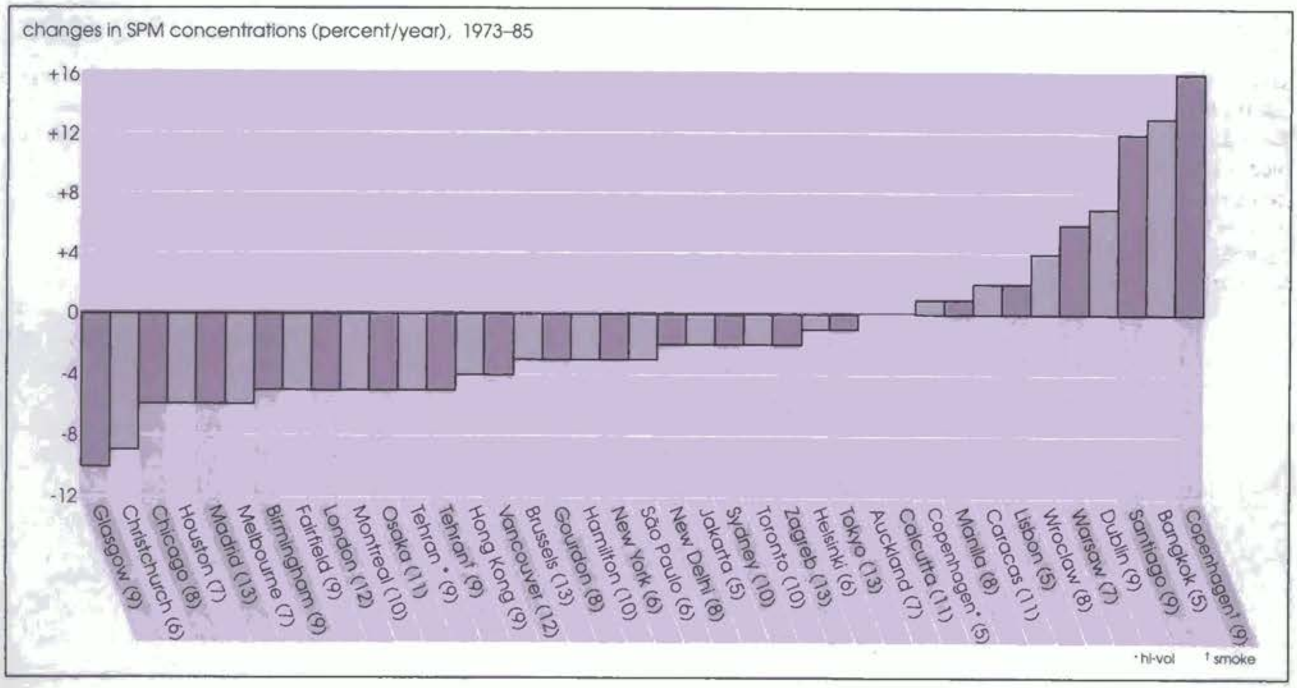
Like sulphates, particles can stain fabrics, painted surfaces and buildings, reducing the life of materials and surface finishes. The blackening of buildings by SPM is one of the more visible effects of urban air pollution. Such effects are particularly evident in London, where decades of pollution are now being cleaned off major public buildings, such as the Houses of Parliament and Westminster Abbey.

In countries for which there are records, SPM emissions have often been reduced (despite increased power generation) by coal washing; switching to smokeless fuel and natural gas for domestic heating; energy conservation; and using more efficient combustion and particle-removal equipment at power stations.

Particulate emissions may be increasing, however, in Eastern Europe and some developing countries, mainly because coal washing is less common, and abatement equipment is poorly maintained (or absent altogether). Smoke emissions from diesel engines are increasing in Western Europe and North America. Diesel engines can generate 10 times more particles than petrol engines and can account for up to 70 percent of urban smoke emissions.

The United Kingdom nearly halved its smoke emissions between 1973 and 1985, thanks mainly to the Clean Air Acts of 1956 and 1968, which created urban smokeless-fuel zones and obliged all industries to operate without producing smoke. Issuing more than 6000 smoke-control orders has regulated smoke emissions in half the country's urban areas. Average smoke

Figure 9 Trends in annual average SPM concentrations in cities—values in brackets refer to the number of sampling years—suggest these levels are falling in many of the world's cities.

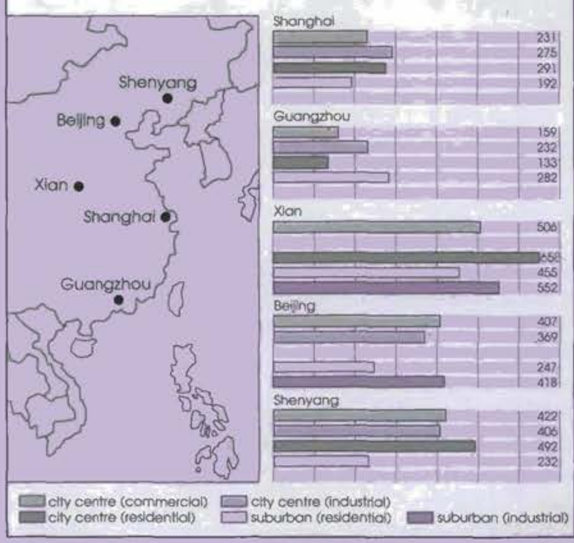


SPM in China

The main source of SPM in China is coal-burning, which accounts for over 70 percent of total Chinese energy production. Much of the coal is burnt in medium- to small-sized furnaces with low smoke-stacks, and in outdated and inefficient domestic stoves. SPM control equipment is either inefficient or non-existent, with the result that most major Chinese cities are characterized by hazy, polluted air; and inhabitants suffering from respiratory and heart diseases.

SPM emissions can be cut by cleaning up industrial processes, making them more energy-efficient. The prosperous steel and petrochemical industries have made the most progress to date. Reducing emissions from domestic stoves is more difficult because it involves using non-traditional fuels such as gas and electricity. Progress is being made however—between 1980 and 1985 the number of urban households using gas for cooking rose from 15 to 22 percent.

SPM annual mean concentrations in Chinese cities, 1989 (µg/m³)



concentrations in most urban areas have fallen by more than 60 percent since 1973, and are currently below WHO guidelines. Coal-fired power stations contribute little to British SPM levels, thanks to the high efficiency of the electrostatic particle precipitators in power plants.

The United States reduced its SPM emissions by a third between 1975 and 1984, partly through using more efficient emission-control equipment. Since 1984 emissions have remained relatively constant.

At the same time, though, some of the reductions occurred not as the result of deliberate policy changes, but because of declining industrial activity, and others (especially in 1982 and 1983) were due to greater-than- average precipitation. Rain can reduce the amount of dust getting into the atmosphere and wash particles out of the air. Ambient SPM levels increased in 1984 when rainfall levels returned to normal, and increased still further in urban areas during the hot, dry summer of 1988. Emissions from transport, fossil-fuel combustion and other sources have meanwhile remained constant.

Of the 37 cities assessed by GEMS/Air for SPM, 19 showed downward trends, 12 stationary trends, and 6 upward trends. The highest annual average increases were in Bangkok (13 percent per year, averaged over 5 years), Copenhagen (18 percent a year over 5 years), Dublin (12 percent a year over 9 years) and Wroclaw (4 percent over 8 years).

WHO has recommended guidelines for annual and daily levels of both SPM and smoke concentrations. Recommended SPM levels are an annual mean of 60–90 $\mu g/m^3$ and and a daily average of 150–230 $\mu g/m^3$. The majority (54 percent) of GEMS/Air cities exceeded the guidelines on particulates —the most serious offenders being Beijing, Calcutta, New Delhi and Xian. Only 12 percent of cities in the programme showed SPM levels below both the annual and daily WHO guidelines.

WHO smoke concentration levels are set at 40–60 $\mu g/m^3$ for the annual mean, and 100–150 $\mu g/m^3$ for daily levels of exposure. Almost one-third of cities, including Tehran, Santiago, Madrid and São Paulo, commonly exceeded these guidelines.

Although the figures initially appear worse than those for SO_2, most of the cities with the highest concentrations of particulates are in areas with high levels of natural wind-blown dust (in Beijing, for example, it accounts for 60 percent of particulates). Dust is less harmful to human health than respirable particles containing potentially toxic pollutants.

The GEMS data indicate that less than 20 percent of urban dwellers could be breathing air of acceptable quality. More than 1250 million people probably live in urban areas where particulate and smoke levels exceed the WHO guidelines.

Nitrogen oxides

One 1980 estimate puts total natural and man-made emissions of nitrogen oxides (NO_x) at 150 million tonnes per year, just over half of that from natural sources. Natural emissions are caused by lightning, forest fires and microbial activity in soils. Being globally distributed, they create only low background values. In the industrial regions of Europe and North America, however, man-made NO_x outweighs natural NO_x by 5–10 times.

In Western Europe, about 30–50 percent of man-made emissions come from motor vehicles, and another 30–40 percent from power plants, mainly those fired by coal. In 1989, 40 percent of NO_x emissions in the United States came from road transport. In 1985, 64 percent of Canadian NO_x emissions were attributable to road transport. In Sweden, about 30–40 percent of man-made nitrogen compounds come from agriculture and forestry, which both rely extensively on the use of nitrogen-based fertilizers.

The quantity and composition of nitrogen oxides formed by industrial processes depend on how combustion occurs, and at what temperatures. Burning normally oxidizes 5–40 percent of the nitrogen in coal, 40–50 percent of that in heavy oil, and nearly 100 percent of that in light oil and gas. The higher the temperature, the more nitrogen oxides are formed.

High temperature combustion produces nitrogen oxide (NO), which is then transformed in the atmosphere through photochemical oxidation into nitrogen dioxide (NO_2). These oxides are important elements in producing other pollutants, such as ozone—a major constituent of smog. NO_2 can also be a significant indoor pollutant, produced by gas-fired heaters, boilers, cookers, and tobacco.

Because much of the NO_x from stationary sources, such as power plants, is discharged through tall stacks, it can be carried large distances in the atmosphere.

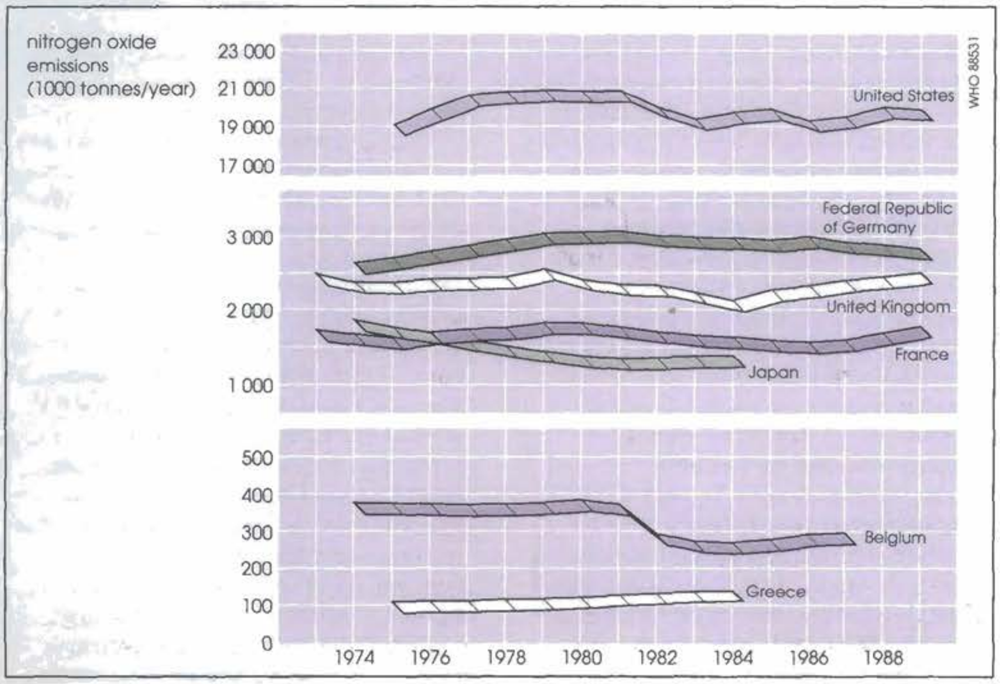


Figure 10 Despite increased energy consumption, NO_x emissions remained fairly constant in many developed countries during 1973–87. Note the discontinuous vertical scale.

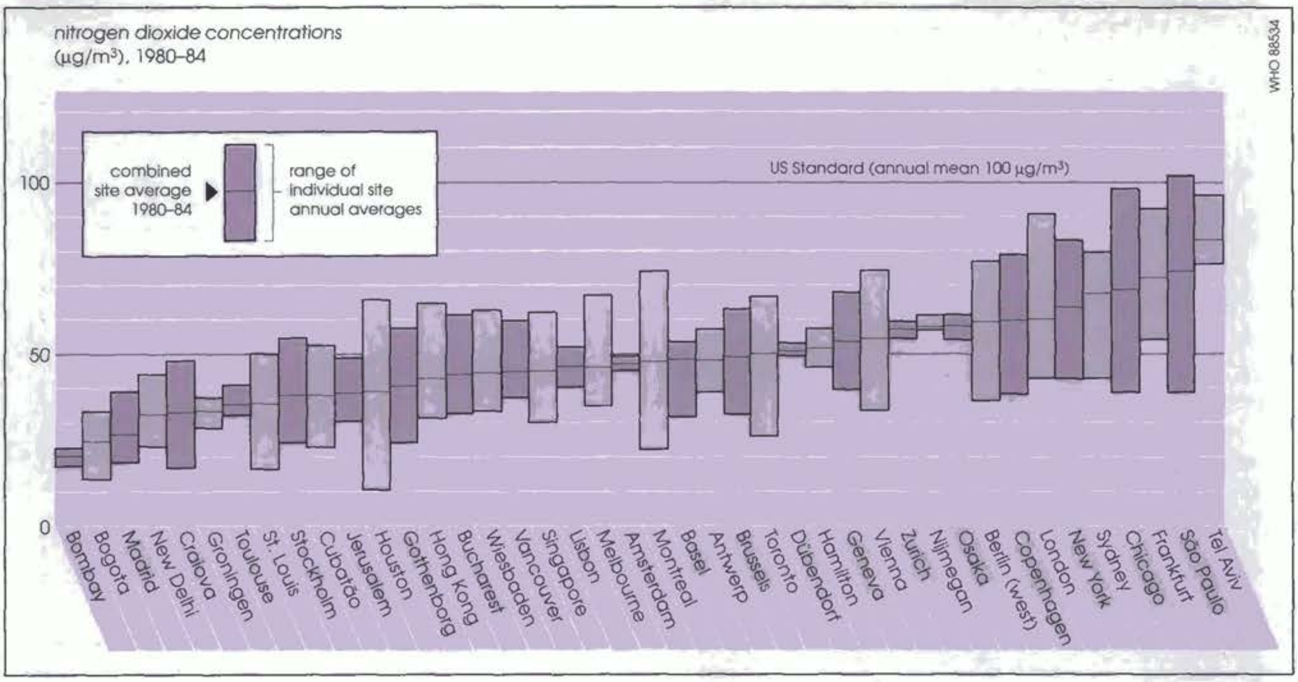


Figure 11 Annual NO_2 averages in cities 1980–84. Presumably Bombay and New Delhi have among the lowest values because of low-density traffic. The horizontal line represents the National Air Quality Standard for NO_2 in the United States and Canada.

Reacting with atmospheric moisture, it can return to Earth as nitric acid, contributing to acidic deposition in areas far from the source.

Atmospheric NO_x plays a key role in reducing visibility and contributes to acid aerosol formation. Nitrous oxide (N_2O) can absorb infra-red radiation and may enhance global warming. Although N_2O levels are being held steady by biological decay and natural conversion processes in the soil and the oceans, increased use of nitrate-based fertilizers could lead to higher levels of N_2O, possibly contributing to a rise in global surface temperatures and the destruction of the Earth's ozone layer.

Nitrogen dioxide is a respiratory irritant, and long-term exposure can lead to irreversible lung damage. It can cause chest tightness, burning of the eyes and headaches, particularly in asthmatics and bronchitics. Repeated exposure to intermittently high concentrations of NO_2 is more toxic than more regular exposure to lower-level concentrations.

Despite increases in energy consumption, particularly by vehicles, NO_x emissions in many developed countries have remained steady. Japan achieved a 21 percent decline in emissions between 1974 and 1983; it was the first country to set emission standards for NO_x from stationary sources. By 1986, Japan had installed more than 320 flue gas denitrification units in power plants and other industrial units.

Catalytic converters for road vehicles were first introduced in the late 1970s, and are now compulsory on new cars in Australia, Canada, Japan and the United States. As a result, emissions of NO_x from new cars in Japan were cut by 92 percent between 1972 and 1978. The United States cut emissions from new petrol-engine cars by 75 percent between 1972 and 1978.

However, in many areas these reductions in emissions have been largely offset by increases in the volume of road traffic. Between 1973 and 1983, the number of vehicle kilometres travelled increased by 28 percent in the United States, and by 54 percent in Japan.

In Canada, the number of road vehicles increased by more than a third between 1973 and 1984; despite the use of emission controls on new cars, NO_x emissions grew almost 7 percent in the same period. Emissions from stationary sources in Canada, meanwhile, grew by 20 percent between 1970 and 1980, mainly as a result of rising emissions from electric utilities. These increases were partly offset by a 15 percent decrease in emissions from residential and commercial combustion sources, caused by changes in fuel use patterns (such as increased use of electricity in domestic heating).

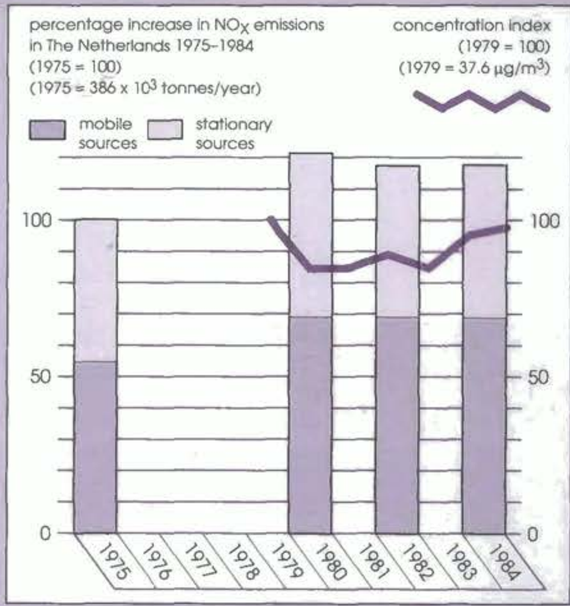
Several European cities, including London, Frankfurt and Amsterdam, have seen increases in NO_x, mainly from vehicles. Few European countries have

NO_x in The Netherlands

Nitrogen oxides in The Netherlands increased by 18 percent over the 10 years between 1975 and 1984, largely because of the rise in emissions from mobile sources, which rose 27 percent during the same period. In a number of individual cities, such as Amsterdam and Maassluis, levels are still rising.

However, The Netherlands is committed to a 20 percent reduction in NO_x by 1993, and to a 40 percent reduction by 1998 (from 1980 figures). Prospects for success may have improved since October 1988, when emission limits stricter than the current EC regulations were introduced for passenger cars.

Stationary-source emissions of SO_2 and NO_x have also fallen over the past two decades—despite the lack of emission controls—because of increased reliance on natural gas instead of coal and oil.



stringent emission standards. Some have relied on lean-burn technology, and the European Commission has proposed NO_x emission standards for vehicles, but it remains to be seen how effective these measures will eventually prove.

Data for developing countries are scarce, but urban NO_x levels are probably rising in rapidly industrializing countries, such as Brazil, Chile, Hong Kong and India (despite decreasing in Singapore). Emissions are probably high in these countries because of the many old and poorly maintained vehicles on the road.

The health effects of NO_x and other pollutants can be exacerbated, especially in certain developing countries, by local weather conditions and wind patterns, which will often recirculate air pollutants. For example, many South-east Asian cities experience 'heat islands', when the cities are several degrees warmer than the surrounding countryside. This phenomenon produces a circular air flow above cities, preventing air pollutants from being dispersed. Malaysia's Kelan valley, which includes the city of Kuala Lumpur, has estimated pollution levels two or three times greater than those of equivalent US cities. Between 1970 and 1982, the number of road vehicles in peninsular Malaysia grew by 400 percent.

The WHO recommended guidelines for NO_2 are 400 $\mu g/m^3$ 1-hour mean and 150 $\mu g/m^3$ 24-hour mean. The 1-hour guideline is designed to provide a margin of protection for asthmatics, and the 24-hour guideline to protect against chronic exposure.

For the 42 cities assessed by GEMS/Air for NO_2, overall mean concentrations were 20–90 $\mu g/m^3$. Cities in developing and developed countries are found at both extremes. Some of the lowest concentrations are found in New Delhi and Bombay, presumably because traffic levels are—surprisingly—relatively low. Similar concentrations were found in St Louis and Houston in the United States, where traffic levels are high. The 24-hour and 1-hour WHO guidelines were exceeded in 25–30 percent of the cities surveyed.

Ambient levels can be affected by several local characteristics, such as the 'canyon effect' of tall buildings, meteorological conditions (temperature inversions can increase levels), and photochemical conversion. The location of monitoring stations also determines the concentrations measured.

Because the data (where they exist) come mainly from the developed world, it is difficult to estimate the number of people exposed to potentially harmful levels of nitrogen dioxide. GEMS/Air estimates that 15–20 percent of the urban residents of North America and Europe (70–90 million people) are at increased risk of high short-term NO_2 exposure.

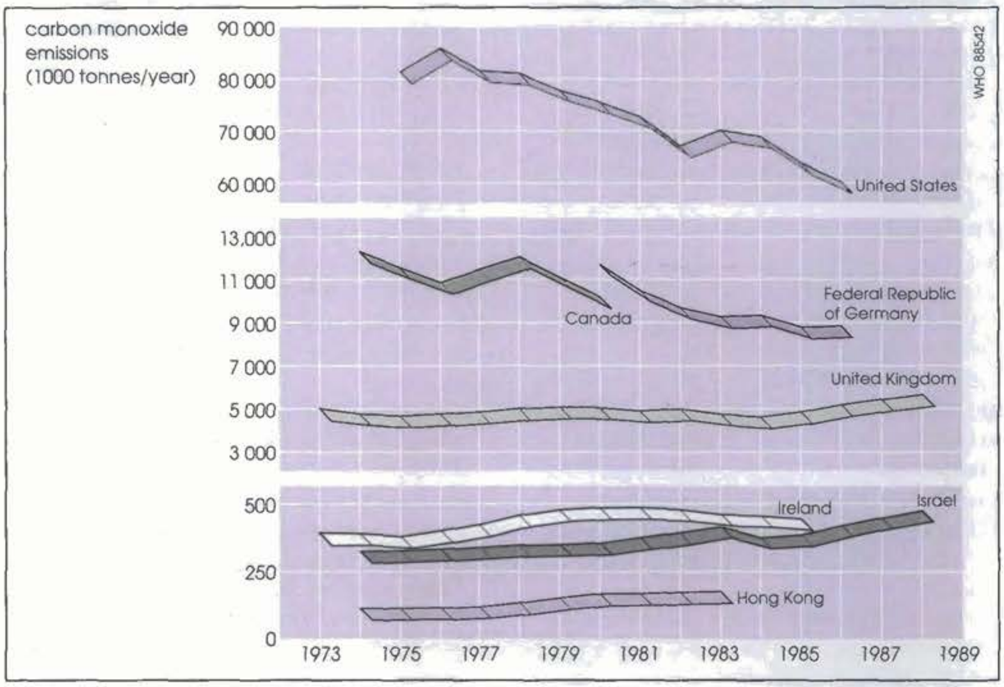
Carbon monoxide

Carbon monoxide is one of the most widely distributed air pollutants. Global emissions, estimated at an annual average of 2600 million tonnes, probably exceed the combined emissions of all other major air pollutants. Man-made emissions account for about 60 percent of the global CO production, and are estimated at 1600 million tonnes per year, the latter figure including emissions caused by human activities such as burning fuelwood, clearing forests by fire, savannah burning and the oxidation of man-made sources of hydrocarbons (mainly methane).

Road traffic is by far the largest source of man-made CO emissions, accounting for virtually all the emissions in some urban areas. CO emissions have increased with the rapid growth in vehicle numbers since the 1940s. In the United States, the number of vehicles increased fourfold between 1940 and 1970, while annual CO emissions rose from 73 to more than 100 million tonnes over the same period. Road transport now accounts for more than two-thirds of US CO emissions, and increases in road traffic continue. Between 1977 and 1988, the number of vehicles on American roads grew by 25 percent, and the number of kilometres travelled per person in private cars grew by 21 percent.

Daily CO concentrations in urban areas rise and fall with traffic density and changes in weather conditions. For example levels are highest during morning and evening rush-hours; and the highest concentrations are often found in confined spaces such as tunnels, garages, loading bays, and underpasses. 'Thermals' or temperature inversions may also cause a buildup of high local concentrations of pollutants at very low altitudes. During a thermal, the layer of warm air usually found near the earth's surface and the cooler air higher in the atmosphere are inverted. Under such conditions air that

Figure 12 More stringent vehicle exhaust controls over the past 15 years have led to steep CO reductions in countries such as in the United States Elsewhere, where controls were less stringent—as in Ireland and Hong Kong—levels continued to rise. Note the split vertical scale.



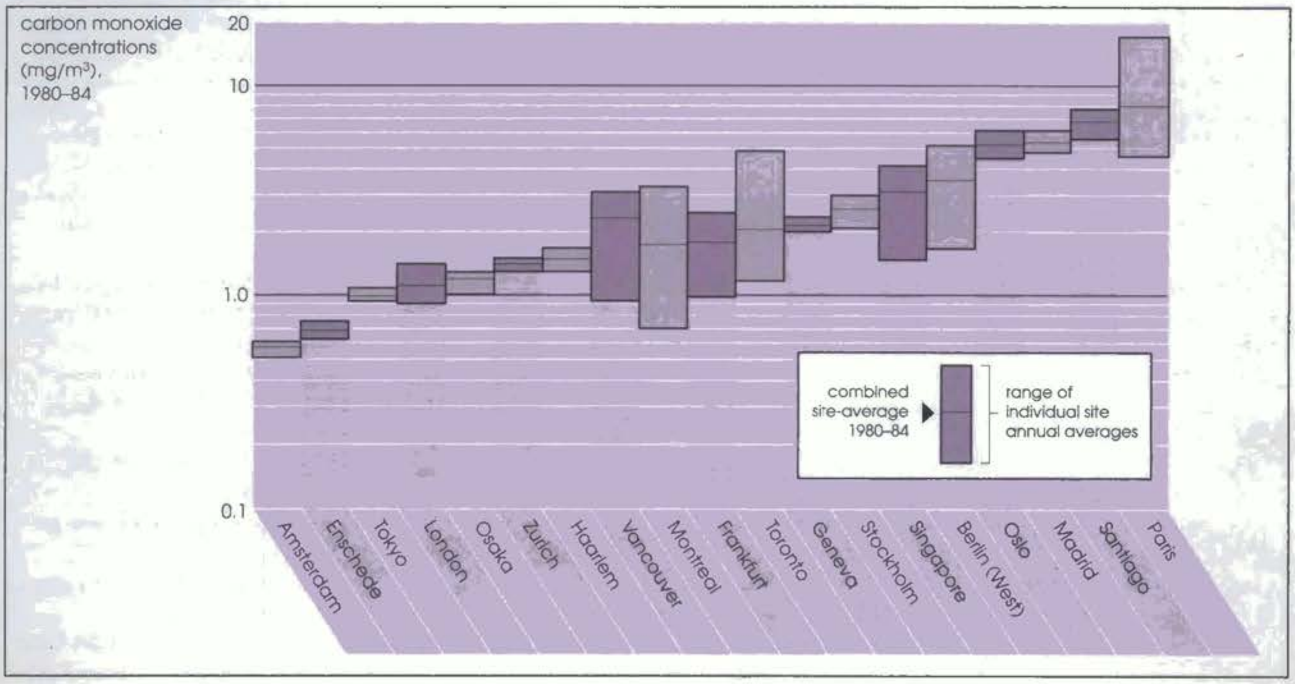
would usually rise is trapped near ground level. Normally a thermal disperses in the morning as rising temperatures break up the different air temperature boundaries. However, under certain meteorological conditions, inversions may remain stable for several days. Such conditions are typical at sites where there are long calm periods and little turbulence.

At existing concentrations, CO has no known effects on vegetation or materials. Its effects mainly relate to human health. Absorbed through the lungs, CO reacts with haemoproteins, particularly the haemoglobin in blood. Inhaled CO can turn haemoglobin into carboxyhaemoglobin (COHb), restricting oxygen binding and the transport of oxygen in the blood. (Tobacco smoking is the most common cause of high COHb concentrations in people.) Inhaled CO can lead to adverse neurobehavioural and cardio-vascular problems. Moderate exposure leads to short-term and reversible effects, but high exposures in closed or open environments can lead to permanent health damage, or even death.

Particularly dangerous is indoor CO pollution caused by domestic combustion appliances, especially where air supply is inadequate. People in developing countries who rely on biomass, such as wood and residues, for cooking and heating, are likely to be exposed to higher levels of CO. Such materials burn at an average 7– 8 percent efficiency, producing large amounts of CO.

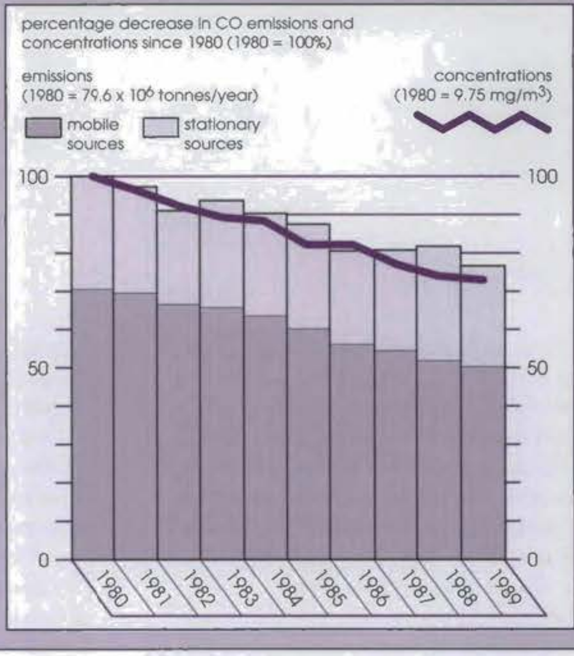
Traffic policemen, garage attendants, taxi and truck drivers, and others who spend extended periods in outdoor urban environments, may be exposed to high levels of CO. Increases in COHb levels of 1–2 percent can affect behaviour and aggravate cardio-vascular problems; there is evidence that people exposed to relatively low CO levels can experience COHb increases of up to 3 percent. COHb levels above 10 percent can lead to

Figure 13 Density of road traffic, number of control regulations, and proximity of monitoring stations to the road explain the large variation found in CO levels in the world's major cities. Note the logarithmic vertical scale.



CO in the United States

In 1989, transportation accounted for about two-thirds of total US carbon monoxide emissions, which fell by 23 percent between 1980 and 1989 (US Environmental Protection Agency figures). National average ambient CO levels fell by 25 percent over the same period, despite a 39 percent increase in number of vehicle miles travelled. The decrease reflects the siting of monitoring stations in urban areas, where the greatest CO reduction has been achieved, due mainly to stricter US exhaust emission controls (now among the most stringent in the world). In the same decade, vehicle emissions fell by 33 percent, while those from stationary fuel-combustion and other sources remained constant. Since 1975 oxidation catalysts to reduce CO and hydrocarbon exhaust emissions have been compulsory in new cars, as have three-way catalytic converters to remove nitrogen oxides since 1981. More than 90 percent of new 1990 vehicles were fitted with some form of emission control.



headaches, fatigue, drowsiness, reduced work capacity, coma, respiratory failure, and ultimately death.

Understandably, CO control strategies focus on vehicle emissions. The United States and Japan pioneered the first effective control strategies in the late 1960s by improving engine design and reducing exhaust emissions by developing a method of converting most of the CO content of exhaust into carbon dioxide. The oil crises of the 1970s also encouraged the design and use of more fuel-efficient vehicles with lower CO emission rates. More stringent controls have since been introduced in Canada and several European countries, including Austria, Sweden and Switzerland.

The result of CO controls has been a gradual decrease or stabilization of CO emission levels in North America and parts of Western Europe, despite increases in traffic density. In the United States, emissions from vehicles fell by 33 percent between 1980 and 1989 (though emissions from stationary sources, such as power stations and waste incinerators, have remained steady). In The Netherlands and West Germany, emissions fell by 32 percent and 37 percent respectively between 1975 and 1985. Emissions in Britain, Ireland and several East European countries, meanwhile, grew over the same period.

Dealing with CO emissions in developing countries will be more complex, mainly because new cars from the North are now increasingly fitted with NO_x and CO controls, demanding the use of unleaded petrol, which is not widely available in the developing world. CO emissions in newly industrialized countries are therefore expected to rise over the next few years.

There are few national networks for measuring CO, but monitoring vehicle emissions is now carried out quite widely in cities. Only 11 cities (mainly in Europe and North America) reported annual emission trends between 1973 and 1985, and all show annual decreases—ranging from 1.5 percent in Geneva to nearly 8 percent in West Berlin. Only three countries (Japan, Canada and The Netherlands) operate national CO monitoring networks, and all showed decreases over that time (Japan halved its ambient concentration levels).

WHO has set an 8-hour guideline of 10 mg/m^3 for concentrations of CO, where 1 milligramme (mg) is 10^{-3} g. All 15 cities assessed by GEMS/Air for CO exceeded this at some point during 1980–84. Eight out of the 15—mostly in North America—exceeded the guideline on average over the 5-year period.

Based on the relatively small sample of cities in the assessment, it seems that people living in as many as half the cities in the world may be exposed to concentrations of CO above the short-term WHO guideline.

Lead

Emissions of lead began in pre-Roman times with the smelting of non-ferrous metals, but the greatest growth in emissions has occurred since the Industrial Revolution. The greatest rate of increase has occurred since the 1940s, when alkyl lead compounds were first added to petrol. Their use grew steadily in the 1970s, after which increasingly stringent controls on lead in petrol led to steady reductions of lead in the atmosphere.

Relatively few countries report their lead emissions, so trends have to be based on the record in a few (mostly industrialized) countries. Human activity produces an estimated 332 000 tonnes of lead every year (natural sources—mainly wind-blown dusts and volcanoes—account for approximately 12 000 tonnes). Although lead in petrol accounts for just 10 percent of all refined lead production, it accounts for 60 percent of man-made lead emissions. In cities with heavy traffic and ineffective (or non-existent) controls, the proportion can be as high as 90 percent. Lead emissions also occur during the mining, smelting and refining of lead, and the processing of other non-ferrous metal ores containing lead.

About 10 percent of the lead emitted by motor vehicles is deposited within 100 metres of the road. The rest is more widely dispersed. Lead concentrations in urban areas can fluctuate widely, depending on meteorological conditions, traffic flow and density, and the configuration and layout of buildings. Thus the levels of airborne lead to which people are exposed vary according to time and place.

Human exposure to lead can occur not only through direct inhalation of atmospheric lead particles, but also through ingestion of drinking water supplied by lead pipes or eating contaminated food. Lead is most easily absorbed from water ingested independently of food.

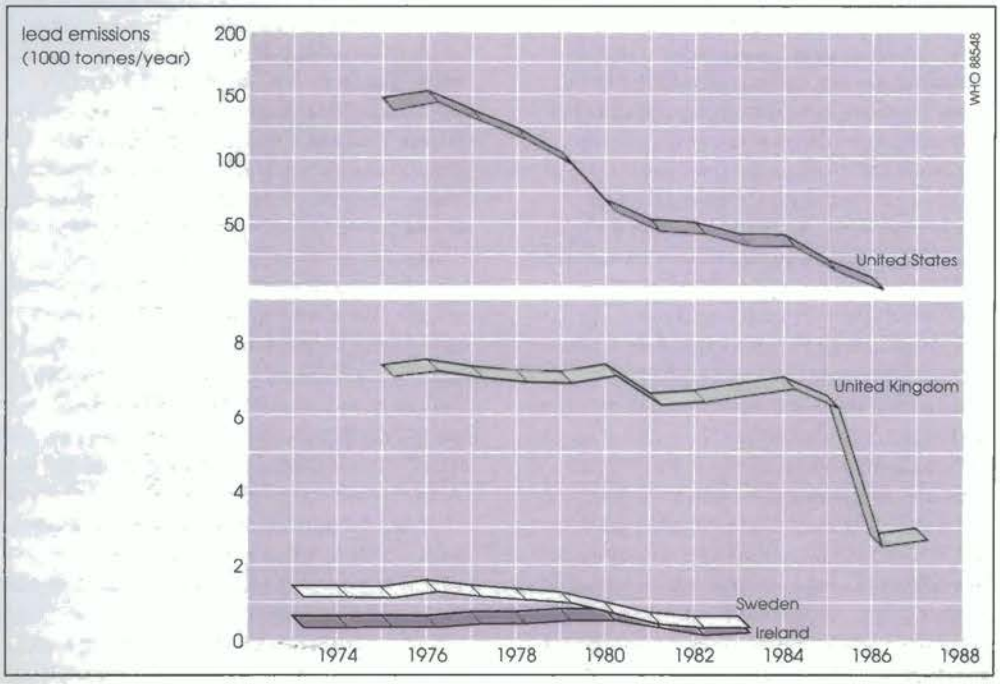


Figure 14 Lead emissions have declined in the few countries that report annual estimates—most notably in the United States, where unleaded petrol was introduced in 1973. Note the split vertical scale.

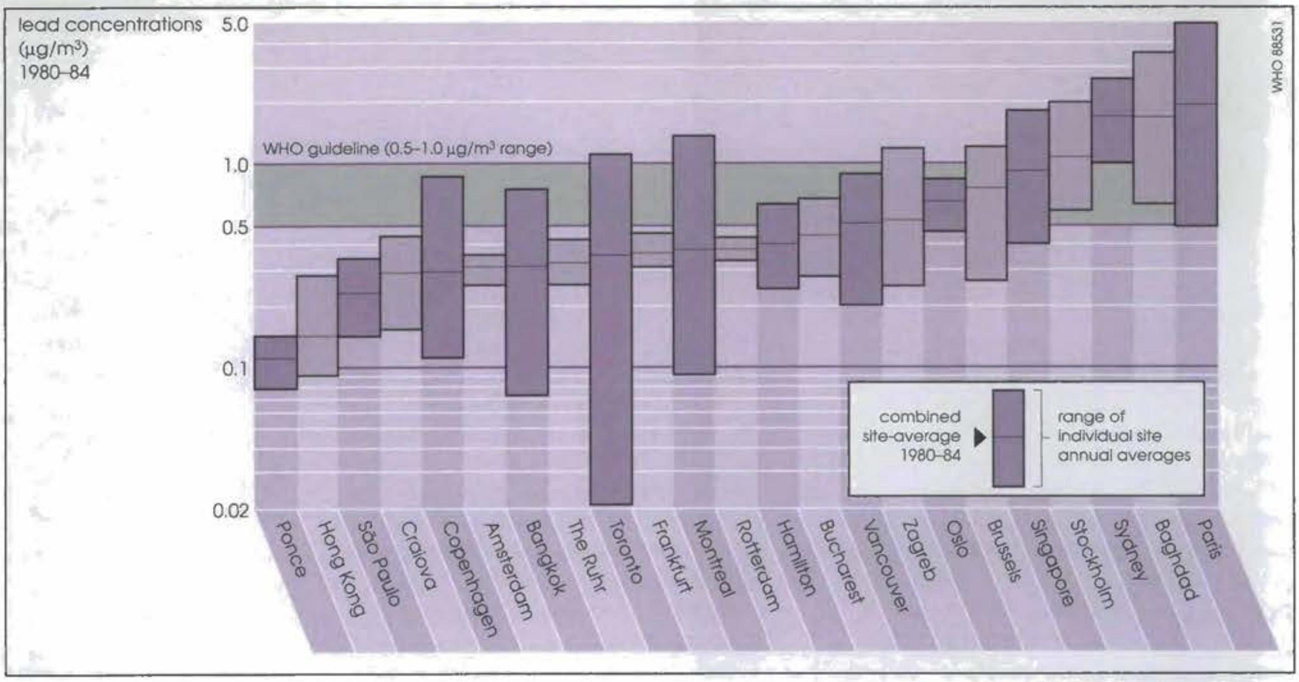


Figure 15 Annual average lead concentrations exceeded the WHO guideline in many cities during 1980–84. About one-third of the world's cities are estimated to have marginal or unacceptable lead levels. Note the logarithmic vertical scale.

Lead can adversely affect blood and the human nervous system. Anaemia is a common early toxic effect. Higher levels of lead in the blood, due to long-term exposure, can lead to brain dysfunctions, acute or chronic encephalopathy, and kidney damage.

Children are particularly susceptible to the dangers of lead because of their relatively higher rates of intake—they are more prone than adults to ingesting it from licking or eating objects containing lead. Their greater sensitivity to lead also makes children more likely to be affected by breathing in lead-contaminated dust; and in older houses, children may suffer from exposure to lead-based paints or water supplied through lead pipes. Inner-city children are particularly prone to high blood lead concentrations because they are exposed to emissions from heavy traffic.

The effects of low blood lead levels in children are less obvious, and more controversial. Even low levels may cause subtle neurological damage in more susceptible children, leading to behavioural and emotional problems.

There is also controversy about which sources of lead contribute most to total human lead intake. Mounting evidence in the last decade has, however, strengthened the assertion of anti-lead campaigners that reductions in the amount of lead in petrol produce corresponding decreases in blood lead levels.

Recognizing the health threat of lead, almost all industrialized countries have progressively reduced the lead content of petrol over the past decade. The United States was one of the first countries to begin the cutbacks in 1973. In 1975, it introduced unleaded petrol—with the additional stipulation that all new cars be fitted with catalytic converters. Unleaded petrol now accounts for about 90 percent of all US petrol sales; in parts of the country, leaded petrol is now almost impossible to find. In 1975, about 170 000 tonnes of lead were used in petrol in the United States; by 1989 the figure had fallen to 7200 tonnes. The United States has also achieved substantial decreases in lead emissions from stationary sources. The result of all these changes was a 90 percent drop in US lead emissions between 1980 and 1989.

Japan went even further, by making an almost complete switch to unleaded petrol in 1976. Of the seven countries for which there was GEMS data on national average annual lead levels, Japan had the lowest.

In Britain, lead emissions fell by 58 percent between 1979 and 1988, despite a significant increase in petrol consumption over the same period. This fall in emissions resulted from decreases in the lead content of fuel which fell from a maximum permitted level of 0.84 g/l in 1972 to 0.4 g/l in 1981, and finally to 0.15 g/l in 1985. The effect was a drop of 60 percent in ambient lead levels in urban areas between 1976

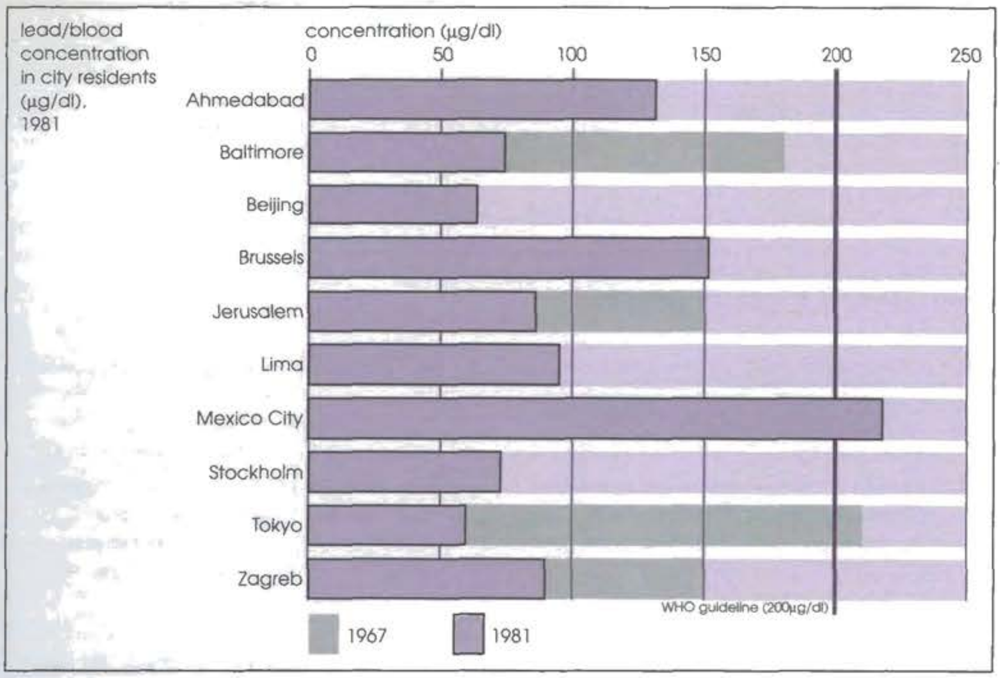


Figure 16 Average lead concentrations in city residents participating in the UNEP/WHO blood lead monitoring programme of 1979–81. Mexico City exceeds the WHO guideline of 200 µg/dl, where 1 decilitre (dl) is 10^{-1} litres. The lowest levels were found in Tokyo, where all petrol has been virtually lead-free since 1976.

and 1985; a further 50 percent drop was observed in 1986.

Emissions of lead from stationary sources (such as non-ferrous metal-smelting and battery plants) have also been reduced in countries using stack controls on particulate emissions. For developing countries, controls on stationary sources may be more important than controls on vehicular emissions. Severe lead pollution from a single plant can expose large numbers of people living in the area to excessive lead levels.

Ambient lead levels have been widely monitored for health reasons, but very rarely with the goal of monitoring trends. In countries such as Britain, Canada, The Netherlands and Japan, lead levels have been measured as part of urban air quality monitoring networks. In most areas, atmospheric lead levels are falling.

WHO has suggested 0.5–1 µg/m^3 as an annual average guideline for ambient lead. This is thought to be the maximum level for keeping blood lead levels below the threshold level at which adverse effects begin. Of the 23 cities assessed by GEMS/Air for lead, 15 were below the guideline level, 4 were within range, and 4 were above the recommended level.

While lead levels in petrol have been reduced in developed countries, very little has changed in developing countries. In Africa and South and Central America, levels of lead in petrol remain about the same as they were in the early 1970s. With more vehicles on the roads in developing countries, lead reduction in petrol has become a major priority. In Saudi Arabia, monthly average city-centre lead levels of up to 9 µg/m^3 were recorded in 1983–84; in Ahmedabad, India, annual average roadside levels of up to 15 µg/m^3 were reported in 1981.

The data available suggest that people living in about one-third of the world's cities are likely to be exposed to lead levels that are either only just within guidelines, or are unacceptably high. The problem is likely to be worst in cities in developing countries with dense traffic.

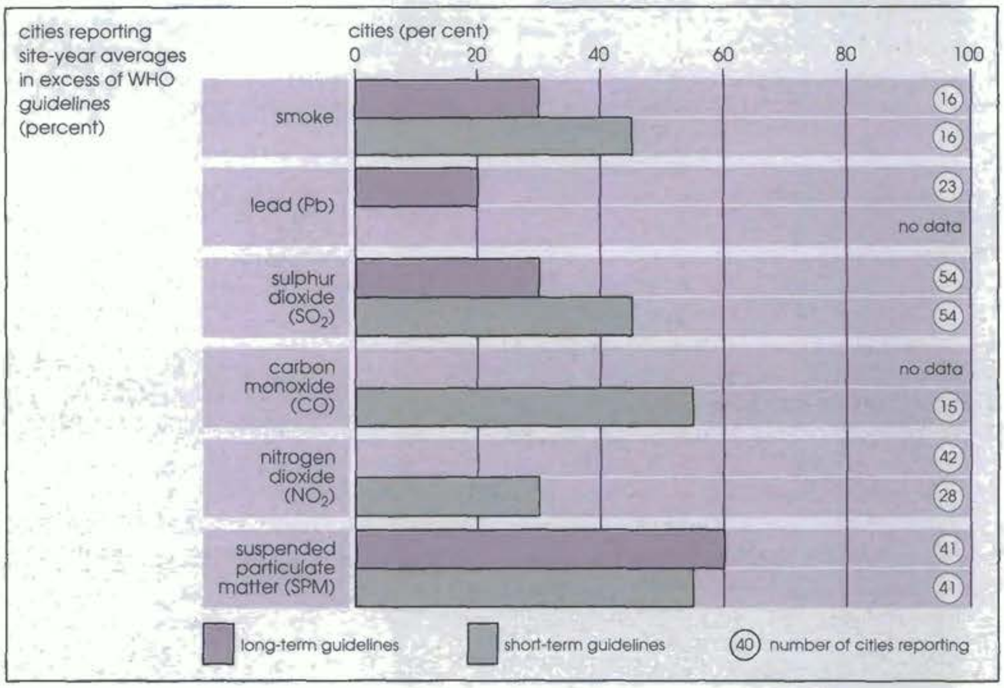
Conclusions and controls

The GEMS conclusions

After assessing data for the five main urban air pollutants, GEMS/Air concluded that:

- In industrialized Western countries (which produce well over half of all emissions of the five pollutants), control strategies are beginning to take effect, leading to generally downward trends in SO_2, SPM and lead levels.
- Data on pollutants in developing countries are incomplete, but indicate that emissions of all five are growing.
- Controls for CO and NO_x have been less widely applied; thus CO levels are rising in some countries and decreasing in others; NO_x emissions are increasing slightly. This may be partly because CO and NO_x are associated with road traffic, which is still increasing almost everywhere. Because there are so many sources (every vehicle on the road), controlling CO and NO_x is expensive and complex. Over half (55 percent) of the GEMS cities exceeded short-term WHO guidelines for CO, usually near high-density traffic areas.
- Nearly two-thirds of the world's 1.8 billion urban residents could already live in areas where annual average SO_2 levels fall at or above the WHO guideline; 20 percent of GEMS cities exceed 150 $\mu g/m^3$ for more than 30 days a year.
- For SPM, 1.4 billion urban residents (mainly in developing countries) may be exposed to marginal or unacceptable air; nearly 40 percent of the reporting cities exceed the short-term guidelines for more than 30 days a year.
- Although none of the 40 reporting cities exceeded the US annual standard of 100 $\mu g/m^3$ for NO_2 (there is no WHO long-term guideline), 10 percent approached that level at least once during 1980–84 and 30 percent exceeded WHO's short-term level.
- Lead levels were within or above the

Figure 17 Percentage of cities (rounded to nearest 5 percent) where average pollution concentrations exceed WHO guidelines.



WHO guideline in 30 percent of reporting cities (developed and developing). Reducing the lead content in petrol has significantly decreased blood-lead levels of urban populations.

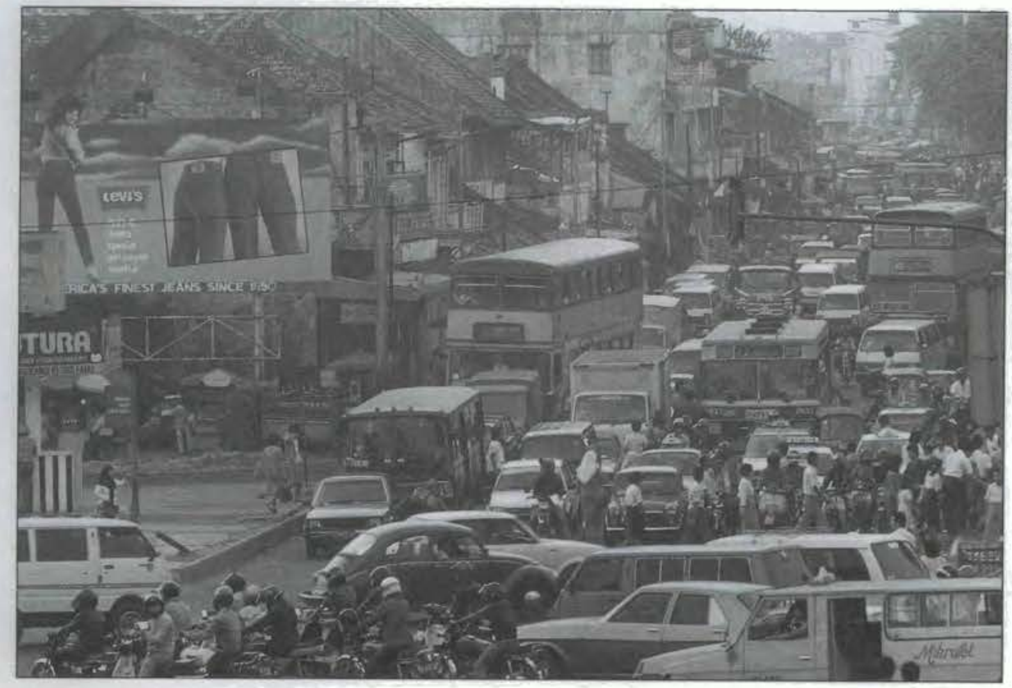
Ideally, urban air quality assessments should be based on comparable data collected from the cities or regions being monitored. However, GEMS had to rely on nation-wide estimates of emissions from developed countries, which made no allowance for local variations. Data were often limited or skewed by the lack of representative monitoring stations and the uncertain quality of analysis.

Although many developed countries have reduced SO_2 emissions and SPM, very few have reduced overall emissions of NO_x; in some, emissions have actually increased. Rapid industrialization and population growth will lead to more city traffic and more exposure to NO_2. Nitrogen oxides are worrying because of their role in forming photochemical oxidants, such as ozone.

Vehicular emissions of CO and lead are of growing concern, notably in developing countries. Careful urban planning is needed to minimize the build-up of these pollutants and to locate housing away from areas of dense traffic.

Although some industrialized countries have reduced some pollutant levels , they are increasing in others (mostly in southern and Eastern Europe). Worsening pollution in developing areas such as Latin America, China, India, South-east Asia, and Eastern Europe is particularly worrying.

By the year 2000, every second person will be an urban resident, and every third person will live in a city of at least 100 000 people. Eight out of 10 people will live in a developing country. Against this background, the GEMS/Air analysis suggests that—in terms of urban air quality—the future for the majority of the world's urban residents is cause for real concern.



Panos Pictures

Rush hour in Jakarta, Indonesia. Growing numbers of cars and lorries in cities in developing countries are a major threat to urban air quality, promising to raise CO and lead levels past recommended guidelines.

Control strategies

As the GEMS/Air assessments make clear, not only is much more work needed to assess air quality trends, but much more is also needed to design and implement workable control strategies, especially in developing countries.

Until the 1950s, the only air pollution control strategy used by industrialized countries was to build tall smoke-stacks to disperse industrial pollution and move it away from urban areas. This was a response to the prevailing view that air pollution was a local issue, and that the answer lay simply in dispersal. This did not remove pollution, but simply redistributed it. It soon became obvious that more stringent and wide-ranging controls were needed. The major target was fossil-fuel combustion, particularly in large stationary sources (power stations and industrial processes) and road vehicles.

Over the past 30–40 years, five main approaches have been developed to control air pollution:

- **pre-combustion controls**—including using low-sulphur oil and coal, fuel cleaning, switching to sulphur-free fuels (such as natural gas and nuclear power), and reducing lead additives in petrol;
- **combustion modification**—changing methods of fuel burning, for example by using low NO_x burners, and fluidized bed combustion, which reduce both NO_x and SO_2 emissions;
- **post-combustion control**—removing pollutants from flue gases and using catalysts in power stations to reduce NO_x and in vehicle exhausts to reduce NO_x, CO and hydrocarbon emissions;
- **new industrial processes**—several of which have been developed in recent years, such as the low-temperature hydrometallurgical techniques, now widely used in the production of several non-ferrous metals in developed countries, which reduce SO_2 emissions; and
- **energy conservation**—simply making better use of energy reduces energy demand and the need to generate as much energy, in turn reducing demand for fossil fuels and thereby cutting pollutant emissions.

Between them, these strategies have contributed to reducing air pollution in some parts of the world. But in developing these strategies, policy makers have been (and will continue to be) faced with two fundamental problems: the costs of pollution control and how they should be met; and the lack of scientific certainty involved in pollution control that would ensure that particular policy options have the predicted results and therefore gain the support of regulated industries.

Pollution control is not cheap, and there are repeated disputes about who should actually bear the costs of that control. For example, one of the most complicated aspects of acid pollution reduction has been how to compel polluting countries to invest heavily in controlling pollution that does little damage within their own borders, but is carried on the wind to other countries.

Similarly, there is the problem of deciding the proportion of pollutants produced by different sources, and fairly distributing the costs of control amongst the producers of pollution. In many free-enterprise systems, industry rails against the kind of central or local government regulation that is often essential for effective pollution control and environmental management. A variety of approaches to this problem have been attempted, including providing financial incentives to polluting industries, using tradeable pollution permits, and adopting cost-benefit strategies.

The second dilemma relates to the problem of scientific certainty. Not only are data on pollution emissions variable and incomplete, but so is our understanding of how pollutants interact with each other and affect plant, animal and human life.

Among the problems that have to be considered when designing air pollution control policies are that:

- air pollution is created by many different sources that will vary from location to location, from day to day, and often from hour to hour;
- the concentration of pollutants not only depends on the actual quantities emitted, but on the atmosphere's ability to absorb or disperse them;
- the effects of air pollutants on human health vary according to different life-styles, living conditions and levels of exposure.

It is becoming increasingly obvious that short-term, isolated and localized responses to urban air pollution do not sufficiently address the problem. Air pollution issues must be seen holistically; and as prevention is clearly preferable to cure, the costs of air pollution must be weighed against the long- and short-term costs of health problems caused by pollution. Most important is careful forethought and planning to minimize further environmental impact and damage to human health. The GEMS/Air assessment indicates worsening air quality problems in many parts of the world and emphasizes the problems inherent in existing control strategies.

Panos Pictures

Tall smoke-stacks were one of the few 'solutions' to urban air pollution until the 1950s. Future strategies must aim to eliminate pollution, rather than simply redistributing it.

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