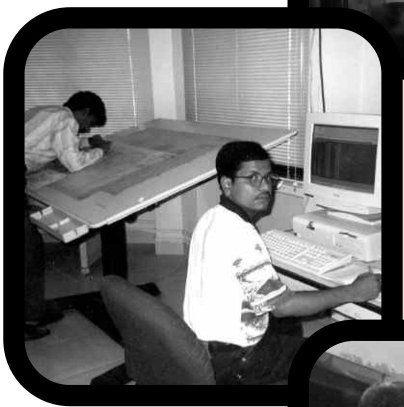
Foundation Course on
Air Quality Management in Asia



# Urban Air Pollution in Asia

Edited by
**Gary Haq** and **Dieter Schwela**

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SEI STOCKHOLM ENVIRONMENT INSTITUTE

## Editors

Dr Gary Haq, Stockholm Environment Institute, University of York
Dr Dieter Schwela, Stockholm Environment Institute, University of York

## Module Contributors

Professor Bingheng Chen, School of Public Health, Fudan University, Shanghai
Dr Dilip Biwas, Former Chairman, Central Pollution Control Board, New Delhi
Dr David L. Calkins, Sierra Nevada Air Quality Group, LLC, San Francisco Bay Area, CA
Dr Axel Friedrich, Department of Transport and Noise at the Federal Environment Agency (UBA), Berlin
Mr Karsten Fuglsang, FORCE Technology, Copenhagen
Dr Gary Haq, Stockholm Environment Institute, University of York, York
Professor Lidia Morawska, School of Physical and Chemical Sciences, Queensland University of Technology, Brisbane
Professor Frank Murray, School of Environmental Science, Murdoch University, Perth
Dr Kim Oanh Nguyen Thi, Environmental Technology and Management, Asian Institute of Technology, Bangkok
Dr Dieter Schwela, Stockholm Environment Institute, University of York, York
Mr Bjarne Sivertsen, Norwegian Institute for Air Research, Olso
Dr Vanisa Surapipith, Pollution Control Department, Bangkok
Dr Patcharawadee Suwanathada, Pollution Control Department, Bangkok
Mr Harry Vallack, Stockholm Environment Institute, University of York

## Production Team

Howard Cambridge, Web Manager, Stockholm Environment Institute, University of York, York
Richard Clay, Design/layout, Stockholm Environment Institute, University of York, York
Erik Willis, Publications Manager, Stockholm Environment Institute, University of York, York

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**Stockholm Environment Institute**
Kräftriket 2B
Stockholm
Sweden SE 106 91
Tel: +46 8 674 7070
Fax: +46 8 674 7020
E-mail: postmaster@sei.se
Web: www.sei.se

# Foundation Course on Air Quality Management in Asia

The Foundation Course on Air Quality Management in Asia is for adult learners studying the issue without the support of a class room teacher. It is aimed at students with some basic knowledge of environment and air pollution issues, acquired in a variety of ways ranging from conventional study, working in an environmental related field or informal experience of air pollution issues.

The course provides you with an opportunity to develop your understanding of the key components required to develop a programme to manage urban air pollution and to achieve better air quality. By working through the six modules you will gradually achieve a higher level of understanding of urban air pollution and the measures taken to monitor air quality and to prevent and control urban air pollution.

Clean air is recognised as a key component of a sustainable urban environment in international agreements and increasingly in regional environmental declarations in Asia. National and local governments have begun to develop air quality management strategies to address the deterioration in urban air quality. However, the scope and effectiveness of such strategies vary widely between countries and cities.

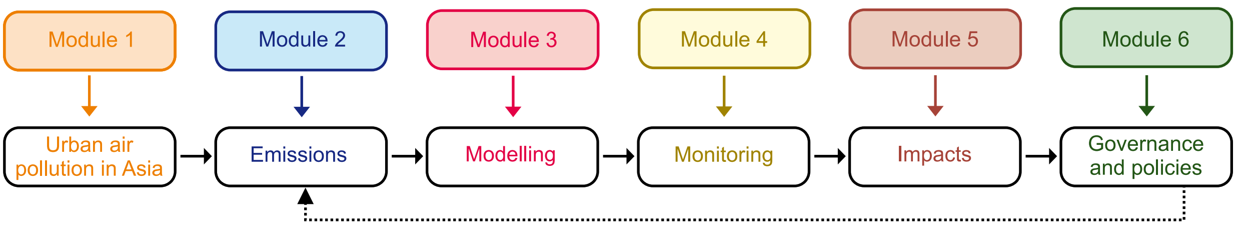
The aim of air quality management is to maintain the quality of the air that protects human health and welfare but also to provide protection for animals, plants (crops, forests and vegetation), ecosystems and material aesthetics, such as natural levels of visibility. In order to achieve this goal, appropriate policies, and strategies to prevent and control air pollution need to be developed and implemented.

## Urban Air Pollution in Asia

Urban air pollution affects the health, well-being and life chances of hundreds of million men, women and children in Asia every day. It is responsible for an estimated 537,000 premature deaths annually with indoor air being responsible for over double this number of deaths. It is often the poor and socially marginalized who tend to suffer disproportionately from the effects of deteriorating air quality due to living near sources of pollution.

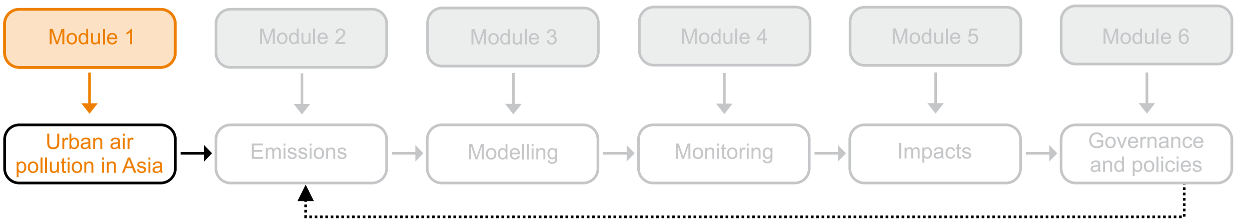
## Module Structure

The foundation course consists of six modules which address the key components of air quality management. An international team of air pollution experts have contributed to the development of the course. Each module is divided into a number of sections each devoted to a different aspect of the issue, together with examples and key references.




*A simple air pollution pathway*

# Module I - Urban Air Pollution In Asia



*A simple air pollution pathway*

## Learning objectives

In Module 1 *Urban Air Pollution in Asia* you will examine the causes of air pollution, the different types of air pollution which exist as well as the basic stages in air quality management system. At the end of the module you will have a better understanding of the:

- causes of air pollution
- range of air pollutants and their impact
- differences between indoor, outdoor and transboundary air pollution
- concept of air quality management.

# List of Acronyms and Abbreviations

| | |
|---|---|
| ABC | Atmospheric brown cloud |
| ACFA | Asian Clean Fuels Association |
| ACS | American Cancer Society |
| ADAC | Automatic data acquisition system |
| ADB | Asian Development Bank |
| ADORC | Acid Deposition and Oxidant Research Center |
| AirQUIS | Air quality information system |
| ALAD | Aminolaevulinic acid dehydrase |
| AMIS | Air quality management information system |
| APHEA | Air Pollution and Health, A European Approach |
| API | Air pollution index |
| APINA | Air Pollution Information Network |
| APMA | Air pollution in the megacities of Asia project |
| APNEE | Air Pollution Network for Early warning and on-line information Exchange in Europe |
| AQG | Air quality guideline |
| AQM | Air quality management |
| AQMS | Air quality management system |
| AQO | Air quality objective |
| AQSM | Air quality simulation model |
| As | Arsenic |
| ASEAN | Association of South East Asian Nations |
| ASG | Atmospheric Studies Group |
| ATD | Arizona test dust |
| AWGESC | ASEAN Working Group on Environmentally Sustainable Cities |
| AWS | Automatic weather station |
| BaP | Benzo[a]pyrene |
| BBC | British Broadcasting Corporation |
| BMR | Bangkok Metropolitan Area |
| BRT | Bus rapid transit |
| BS | Black smoke |
| BTEX | Benzene, toluene, ethylbenzene and xylenes |
| CAI-Asia | Clean Air Initiative for Asian Cities |
| CAIP | Clean air implementation plan |
| CARB | Californian Air Resources Board |
| CAS | Chemical Abstract Service |
| CBA | Cost benefit analysis |
| Cd | Cadmium |
| CD | Compact disc |
| CDM | Clean development mechanism |
| CEA | Cost-effectiveness analysis |
| CER | Certified emissions reduction |
| CMAS | Institute for the Environment, Chapel Hill |
| CMB | Chemical mass balance |
| CNG | Compressed natural gas |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| COHb | Carboxyhaemoglobin |
| COI | Cost of illness |
| COPD | Chronic obstructive pulmonary disease |
| CORINAIR | CORe INventory of AIR emissions |
| CPCB | Central Pollution Control Board |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| CVM | Contingent valuation method |
| DALY | Disability-adjusted life years |
| DAS | Data acquisition system |
| DDT | Dichloro-Diphenyl-Trichloroethane |
| DETR | Department for Transport and the Regions |
| DQO | Data quality system |
| DQO | Data quality objective |
| DWM | Diagnostic wind model |
| EB | Executive board |
| EC | European Commission |
| EEA | European Environment Agency |
| EGM | Eulerian Grid Module |
| EIA | Environmental impact assessment |
| ETS | Environmental tobacco smoke |
| EU | European Union |
| FID | Flame ionisation detector |
| FOE | Friends of the Earth |
| FST | Foundation for Science and Technology |
| GBD | Global burden of disease |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| GIS | Geographic information system |
| GTF | Global Technology Forum |
| HAP | Hazardous air pollutant |
| HC | Hydrocarbon |
| HCA | Human capital approach |
| HCMC | Ho Chi Minh City |
| HEI | Health Effects Institute |
| HEPA | Ho Chi Minh City Environmental Protection Agency |
| Hg | Mercury |
| HIV/AIDS | Human immunodeficiency virus/ Acquired Immunodeficiency Syndrome |
| I&M | Inspection and maintenance |
| IBA | Ion beam analysis |
| ICCA | International Council of Chemical Associations |
| IFFN | International Forest Fire News |
| IPCC | Intergovernmental Panel on Climate Change |
| IQ | Intelligent quotient |
| IR | Infrared |
| ISO | Organization for Standardization |
| IT | Interim target |
| IUGR | Intrauterine low growth restriction |
| IUPAC | International Union of Pure and Applied Chemistry |
| IVL | Swedish Environmental Research Institute |
| km | kilometre |
| LBW | Low birth weight |
| LCD | Less developed country |
| LPG | Liquid petroleum gas |
| LPM | Lagrangian particle module |
| MAPs | Major air pollutants |
| MCIP | Meteorology-Chemistry Interface Processor |
| MMS | Multimedia messaging service |
| MOEF | Ministry of Environment and Forests |
| MOPE | Ministry of Population and Environment |
| MT | Meteo-Technology |
| MW | Molecular weight |
| NAA | Neutron activation analysis |
| NAAQS | National Ambient Air Quality Standards |
| NASA | National Aeronautics and Space Administration |
| NDIR | Non-dispersive Infrared |
| NILU | Norwegian Institute for Air Research |
| NKBI | Neutral buffered potassium iodide |
| NMMAPS | National Morbidity and Mortality Air Pollution Study |
| NO | Nitric oxide |
| $NO_2$ | Nitrogen dioxide |
| $NO_x$ | Nitrogen oxides |
| NYU | New York University |
| $O_2$ | Oxygen |
| $O_3$ | Ozone |
| OECD | Organization for Economic Cooperation and Development |
| PAH | Polycyclic aromatic hydrocarbons |
| PAN | Peroxyacetyl nitrate |
| Pb | Lead |
| PbB | Level of blood lead |
| PCB | Polychlorinated biphenyl |
| PCD | Pollution Control Department |
| PDR | People's Democractic Republic |
| PESA | Proton elastic scattering analysis |
| PID | Photo ionisation detector |
| PIGE | Particle induced gamma ray emission |
| PILs | Public interest litigation |
| PIXE | Particle induced X-ray emission |
| PM | Particulate matter |
| $PM_{10}$ | Particulate matter less than 10 microns in diameter |
| $PM_{2.5}$ | Particulate matter less than 2.5 microns in diameter |
| PMF | Positive matrix factorisation |
| POP | Persistent organic pollutant |
| PPM | Parts per million |
| PRC | People's Republic of China |
| PSAT | Particulate matter source apportionment technology |
| PSI | Pollutant standard index |
| PSU/NCAR | Pennsylvania State University / National Center for Atmospheric Research |
| PVC | Polyvinyl chloride |
| QA/QC | Quality assurance/quality control |
| QEPA | Queensland Environmental Protection Agency |
| ROS | Reactive oxygen species |
| RBS | Rutherford backscattering spectrometry |
| SA | Source apportionment |
| SACTRA | Standing Advisory Committee on Trunk Road Assessment |
| SAR | Special Administrative Region |
| SMC | San Miguel Corporation |
| SMS | Short message service |
| $SO_2$ | Sulphur dioxide |
| $SO_x$ | Sulphur oxides |
| SPCB | State Pollution Control Board |
| TAPM | The Air Pollution Model |
| TEA | Triethanolamine |
| TEAM | Total Exposure Assessment Methodology |
| TEOM | Tapered element oscillating microbalance |
| TSP | Total suspended particulate |
| UAM | Urban airshed model |
| UCB | University of California at Berkeley |
| UF | Ultra fine |
| UK | United Kingdom |
| UNDESA | United Nations Department of Economic and Social Affairs |
| UNDP | United Nations Development Programme |
| UNECE | United Nations Economic Commission for Europe |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations framework on climate change |
| UN-Habitat | United Nations Habitat |
| US | United States |
| USEPA | United States Environmental Protection Agency |
| UV | Ultra violet |
| UVF | Ultra violet fluorescence |
| VOC | Volatile organic compound |
| VOSL | Value of statistical life |
| VSI | Visibility Standard Index |
| WAP | Wireless Application Service WHO World Health Organization |
| WMO | World Meteorological Organization |
| WRAC | Wide ranging aerosol collector |
| WTP | Willingness to pay |
| XRF | X-ray fluorescence |
| YLD | Years of life with disability |
| YLL | Years of life lost |

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# Introduction

Air pollution is a term used to describe the contamination of the air with harmful or poisonous substances. Emissions of unwanted chemicals or other materials, which exceeds the capacity of natural processes to convert or disperse them, can result in the degradation of air quality. Polluting emissions may result from direct air emissions or through the production of secondary pollutants as a result of chemical reactions which take place in the air (AEAT, 1997).

Air pollution occurs both indoors and outdoors. Outdoor air pollution is often called ambient air pollution. In urban areas air pollutant levels sometimes exceed World Health Organization (WHO) air quality guideline values by a factor of three or more (WHO, 2000; 2005a). Worldwide, WHO estimates as many as 1.4 billion urban residents breathe air pollutant concentrations exceeding the WHO guideline values (WHO, 2002). Various lessons can be learnt from the experiences in developed countries to avoid or mitigate the serious air pollution that occurs in developing countries during the development process.

This module examines the causes of air pollution and the different types of air pollution which exist such as outdoor, indoor, and transboundary. It will examine the issue of urban air pollution in Asia, current trends and capabilities of Asian cities to cope with deteriorating air quality. It outlines the key stages in an air quality management system.

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## Section 1 Focus on Urban Air Pollution

Urban air pollution is not a new problem. In antiquity the effects of stale air in causing diseases were noted by the Greek physician Hippocrates, and wealthy Romans tried to escape "the smoke, the wealth, the noise of Rome" (EHT, 2001). Since the thirteenth century air pollution was recognised as a public health problem in cities and large towns in the United Kingdom (UK). Coal burning was identified as the principal source of polluting air emissions (Met Office, 2007). Coined in 1905, the term smog - a combination of the words smoke and fog - was originally used to describe the cloud of noxious fumes that arose from the chimneys and smokestacks of UK factories (Urbinato, 1994). Sulphurous smog (carbon particles and sulphur dioxide ($SO_2$) mixed with fog) in London became a significant problem when extensive coal burning was practised at the height of the Industrial Revolution in the ninetieth and early twentieth centuries (Brimblecombe, 2003; Met Office, 2007). The smog was frequently observed during winter due to additional emissions from domestic space heating and the special urban meteorological conditions during this time of the year. It is also known as winter smog.

The 1952 Great London Smog is the most notorious episodic smog event. It resulted in more than 12,000 premature deaths in Greater London (Bell and Davis, 2001). Mortality from bronchitis and pneumonia increased more than sevenfold as a result of the fog (Met Office, 2007) (see Figure 1.1).

**Figure 1.1: Dangerous driving during the Great London Smog**

Source: Met Office (007)

A different phenomenon is the photochemical smog pollution in Los Angeles that became known during the Second World War. Photochemical smog is a mixture of ozone ($O_3$) and other oxidants as well as tiny particles emitted from vehicles (UCB, 2002). This smog is formed when hydrocarbons (HC) and nitrogen oxides ($NO_x$) emitted into the atmosphere undergo complex reactions in the presence of sunlight. It is also called summer smog. It causes respiratory and eye irritation, damages plants and materials, and greatly reduces visibility. Figure 1.2 shows a typical image of Los Angeles smog.

**Figure 1.2: Smog envelopes the skyline of Los Angeles in 2003**

Source: Photo AFP/Getty Images/David McNew

Due to the continuous efforts to improve air quality, smog has become a rare occurrence in London and Los Angeles. In developing countries, however, urban air pollution has worsened in most large cities, a situation driven by population growth, industrialisation, and increased vehicle use. Despite pollution control efforts, air quality has approached dangerous levels in a number

**Figure 1.3: Smog in Beijing**

Source: AP (2007)

of megacities (with a population of more than 10 million) such as Beijing, New Delhi, Jakarta, and Mexico City (see Figure 1.3).

## 1.1 Causes of Urban Air Pollution in Asia

Fuel combustion is a key air pollution source in Asian cities which tends to increase with population size and economic activities. Fuel type is a useful indicator of potential emissions with coal and biomass as high emitting solid fuels, gasoline/diesel and kerosene as medium emitting liquid fuels, and liquefied petroleum gas (LPG) and natural gas as low emitting gaseous fuels. Burning low quality fuels in inefficient combustion devices with limited flue gas control is the main cause of air pollution in many Asian cities.

### Stationary source emissions

Many Asian cities have relied heavily on coal as a cheap fuel to meet the rapid growth in energy demand. This has resulted in a significant increase in polluting air emissions such as sulphur oxides ($SO_X$), particulate matter (PM) and $NO_X$. The relocation of industry and large power plants outside cities and the introduction of stricter emission regulations has reduced the relative contribution to urban air quality from big stationary sources. Other important stationary sources of air pollution are residential heating and cooking which emit high amounts of carbon monoxide (CO), hydrocarbons (HCs), $SO_X$ and soot.

### Traffic emissions

The steady growth in road traffic has resulted in the increasing contribution from traffic to urban air pollution, especially volatile organic compounds (VOCs), CO, $NO_X$ and PM. Uncontrolled motor vehicles, particularly those with diesel and two-stroke engines are the most important sources of air pollution in most urban areas in Asia. Asia has the largest motorcycle fleet in the world. This is because motorcycles provide the cheapest mode of individual motorized transportation for the expanding working class. Also, many Asian cities are too crowded to allow further expansion of the car fleet. This results in large emissions per passenger-kilometre (pkm) travelled, especially where two stroke engines are used. On average, a two-stroke motorcycle has a PM emission rate of the same order of an uncontrolled truck or a bus, a HC emission rate of 5-10 times of an uncontrolled car, and almost the same CO emission rate as an uncontrolled car. Where leaded gasoline is still used, the organic lead emitted with the unburned fuel from two-stroke motorcycles is more toxic than the inorganic lead formed in the combustion. Exposure to traffic emissions is high due to its proximity to the population, especially when emitted in street canyons with poor dispersion conditions.

The situation is worse for the many old and poorly maintained vehicles used in Asian cities. Of particular concern are the old diesel-powered buses which are a source of PM and $NO_X$. Frequent traffic congestion adds another dimension to urban air pollution which results in high emission per unit of fuel consumed and per km travelled. Urban congestion is seen as a high-priority in many countries such as China, India, Indonesia, Pakistan, Philippines and Thailand.

High VOC emissions from the incomplete combustion of reformulated unleaded gasoline in old engines without catalytic converters is also an issue. VOCs are toxic and may be cancerous. They also serve as precursors for $O_3$ formation.

### Other sources

In Asia, large cities are often surrounded by agricultural land. The open burning of agricultural waste may also contribute directly to urban air pollution. In poorer cities of developing Asia, backyard burning of refuse (garbage and biomass) still creates noticeable and perhaps considerable air pollution. Another source of concern is street cooking which may be important in many urban areas. Table 1.1 presents a summary of sources of urban air pollution in developing countries in Asia.

### Air pollution source control status

Due to poor enforcement of emission reduction measures, control techniques for emission sources are either missing or only focus on easy/cheap-to-treat pollutants. For example, particle removal techniques used are more effective at removing the coarse, rather than fine, inhalable particles. More effort is spent on $SO_x$ than $NO_x$ or VOC emissions. These control efforts can reduce total suspended particulate (TSP) and $SO_x$. However, problems with fine particles still remain and are likely to increase with fuel consumption. The incidence of photochemical smog pollution is likely to increase due to the emissions of $NO_x$ and VOC.

## 1.2 Air Pollutants

Air pollutants in urban air can be divided into two groups: the traditional/key/criteria/ major air pollutants (MAPs), for which air quality standards normally exist, and hazardous air pollutants (HAPs). The traditional air pollutants comprise $NO_2$, $SO_2$, CO, PM, $O_3$ and lead. The HAPs consist of chemical, physical and biological

**Table 1.1: Emission sources and primary pollutants in urban areas of developing countries in Asia**

| Source types | Pollutant emitted | | | | | |
|---|---|---|---|---|---|---|
| | $SO_2$ | $NO_2$ | CO | PM | HC | Pb[b] | Heavy metals |
| **Stationary sources:** | | | | | | | |
| Coal/heavy oil burning in small industry and homes | 2 | 2 | 1-2 | 2 | 1-2 | | 2 |
| Biomass burning in small industry and homes | 1 | 1 | 3 | 2 | 2 | | |
| **Traffic, and traffic-related sources:** | | | | | | | |
| Diesel-powered vehicles | 1-2 | 2-3 | 1 | 3 | 2-3 | | |
| Gasoline car (without catalyst) | 1 | 1 | 3 | 1 | 2 | 3 | |
| Gasoline car (with catalyst) | 1 | 1 | 1 | 1 | 1 | | |
| 4-stroke motorcycle | | | 3 | 1 | 2 | 3 | |
| 2-stroke motorcycle | | | 3 | 3 | 3 | 3 | |
| Gasoline station, solvents | | | | | 2 | | |
| **Other sources:** | | | | | | | |
| Backyard/open burning | | | 2 | 2 | 2 | | |
| Manufacturing process[a] | | | | 1-3 | 1-2 | | 1-3 |

Note: the relative importance as urban air pollution sources is indicated: 1- less important, 2-important, 3-very important

(a) the degree of importance varies with the manufacturing processes; (b) lead emissions are not important for cars with catalytic converters as unleaded gasoline is a prerequisite for catalyst application.

Source: CAI-Asia (2006)

**Table 1.2: General classification of gaseous air pollutants based on chemical composition**

| Class | Primary | Secondary |
|---|---|---|
| S-containing | $SO_2$, $H_2S$ | $SO_3$, $H_2SO_4$, **M**$SO_4$ |
| Organic | HC compounds | Ketones, aldehydes, organic aerosols (fine particles) |
| N-containing | NO, $NH_3$ | $NO_2$, **M**$NO_3$ |
| Oxides of carbon | CO, $CO_2$ | None |
| Photochemical oxidants | VOC, $NO_x$, etc. | $NO_2$, $O_3$, $H_2O_2$, **PAN** |

**M**$SO_4$ :sulphates; **M**$NO_3$: nitrates; **M** = Na, K, etc.

**PAN**: peroxyacetyl nitrate, a photochemical oxidant

Source: Adapted from Wark et al. (1998)

agents of different types (see Table 1.2). They are present in the atmosphere in much smaller concentrations than MAPs. HAPs often appear more localized, but are toxic or hazardous in nature. Examples of HAPs include a range of hydrocarbons (e.g. benzene, toluene and xylenes,) and other toxic organic pollutants (e.g. polycyclic aromatic hydrocarbons (PAHs), pesticides and polychlorinated biphenyls (PCBs)).

Air pollutants can also be classified into primary and secondary pollutants, according to their origin. Primary pollutants are those emitted directly to the atmosphere (e.g. $SO_2$, CO and soot) while secondary pollutants (e.g. $O_3$) are those formed by reactions involving other pollutants. Table 1.3 presents examples of common gaseous air pollutants and related secondary pollutants found in urban areas.

## 1.3 Urban Air Pollutants and Climate Change

Many urban air pollutants can also contribute to global climate change. Polluting air emissions from transport, power generation, industry, and domestic sectors contain both noxious pollutants which are deleterious to human health and greenhouse gases (GHGs) which contribute to climate change. Carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and three groups of fluorinated gases (sulphur hexafluoride ($SF_6$), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs)) are the major GHGs and the subject of the Kyoto Protocol, which entered into force in 2005.

Emissions of air pollutants and GHGs have direct (e.g. visibility) and indirect (e.g. acidification, ozone depletion, climate change) effects on air quality with a wide range of impacts on human health, ecosystems, agriculture and materials. Table 1.4 outlines the contribution of urban air pollutants to climate change.

In air quality management GHGs have often not been considered because they do not lead to direct health and environmental impacts. Indirect health effects include impacts of heat waves and cold spells on mortality and morbidity, vector-borne diseases and diarrhoeal illness, malnutrition, and mental health effects related to disasters caused by extreme weather and sea level rise (WHO, 2003).

**Table 1.3: Focus on air pollutants**

| | |
|---|---|
| **Particulate Matter (PM)** | PM or atmospheric aerosols is the term used to indicate any solid or liquid particles suspended in the atmosphere. Atmospheric particles vary widely in their physical parameters such as size and chemical composition. In general, airborne particle sizes range from 0.002 to 500 µm. Most of the suspended particles, however, are less than 100 µm because larger particles will settle rapidly by gravity. PM is generated from a wide variety of natural and anthropogenic processes. Natural sources of PM include dust storms, ocean/seas (sea salt), fugitive dust erosion by the wind, forest fires, volcanic eruptions, and the release of biogenic PM (e.g. plant wax). Man-made sources include traffic, non-combustion and combustion industrial processes, power plants, construction activities, agricultural activities (including agricultural waste burning).<br><br>Severity of effects of particles on human health, atmospheric visibility and climate depend on particle size, the smaller the size the more serious the effects. Several parameters are used to characterise the PM pollution, which include particle size. |
| **Total Suspended Particulate (TSP) Matter** | TSP is commonly monitored and reported in developing countries. TSP is measured by the high volume sampler method (sampling rate of ~1 m$^3$/min). The majority of TSP, as measured by mass, consists of particles with the size below 20-50 µm.<br><br>$PM_{10}$ and $PM_{2.5}$: $PM_{10}$ (particles with aerodynamic diameter less than 10 µm) are respirable particles (i.e. they are small enough to enter the human respiratory system). Particles larger than $PM_{10}$ may be filtered out through the airways' natural mechanisms. $PM_{10}$ is divided into two fractions, the fine fraction or $PM_{2.5}$ (particles with the aerodynamic diameter less than 2.5 µm) and the coarse fraction or $PM_{10-2.5}$ (particle size less than 10 µm but larger than 2.5 µm). The coarse particles, in general, are generated from mechanical processes. They usually contain earth crustal materials and dust from road vehicles and industries. The fine particles mainly consist of the secondary aerosols, combustion particles, and re-condensed organic and metallic vapours. In the urban environment, most secondary PM occurs as sulphates and nitrates (formed in reactions involving $SO_2$ and $NO_x$) and organic aerosols.<br><br>PM may be seen as the most critical of all pollutants from the perspective of health effects. Particles may consist of toxic chemicals and may carry surface-absorbed substances, including carcinogenic compounds, into the lungs. PM in diesel exhaust has been cited as a probable human carcinogen by several agencies. Respirable particles ($PM_{10}$) can enter the human respiratory system and so potentially pose significant health risks. Fine particles can be carried deep into the lungs where they can cause inflammation and worsen conditions of people with heart and lung diseases. Increase in $PM_{10}$ and $PM_{2.5}$ levels is associated with increased daily mortality and increased rates of hospital admissions due to respiratory diseases (WHO, 2005a).<br><br>Beside health effects, particles, especially fine particles, effectively reduce atmospheric visibility. Acid particles can be deposited dry or wet on the earth surface causing detrimental effects for terrestrial and aquatic life. Some particles (e.g. soot) absorb solar radiation while others (e.g. sulphate particles) reflect solar radiation and contribute to global warming and climate change. |
| **Sulphur dioxide ($SO_2$)** | $SO_2$ is an acidic gaseous pollutant. $SO_2$ in ambient air can affect human health, particularly in those suffering from asthma and chronic lung diseases even at levels well below 100 µg/m$^3$. $SO_2$ is known to be associated with increased daily mortality and hospital admissions from respiratory and cardiovascular disease. $SO_2$ is considered more harmful when particle and other pollution concentrations are high. In the atmosphere, $SO_2$ is transformed into sulphuric acid and sulphate particles, which can cause a wide range of effects including visibility reduction and acid deposition.<br><br>The principal source of $SO_2$ is the combustion of sulphur-containing fossil fuels in industry and power stations, and for domestic heating. When large industry and power stations with tall stacks are located away from urban areas, $SO_2$ emissions may still affect air quality in both rural and urban areas. $SO_2$ emissions can be successfully reduced using fuels with low sulphur content (e.g. natural gas or oil instead of coal). The flue gas desulphurisation technique, which uses a basic solution to scrub flue gas, can also significantly reduce $SO_2$ from emissions. |
| **Oxides of Nitrogen ($NO_x$)** | $NO_x$ are formed mainly by oxidation of atmospheric nitrogen during combustion at high temperature. The majority of $NO_x$ emissions are in the form of nitrogen oxide (NO), which is subsequently oxidized in the atmosphere to the secondary pollutant $NO_2$. $NO_2$ is the major form of nitrogen oxides in the atmosphere.<br><br>$NO_2$ can irritate the lungs and lower resistance to respiratory infections such as influenza. Continued or frequent exposure to high concentrations may cause increased incidence of acute respiratory illness in children.<br><br>The principal source of $NO_x$ is road traffic, power stations, heating plants and industrial processes. $NO_x$ emissions can be reduced by optimization of the combustion process, for example low $NO_x$ burners in power plants, or by removal of $NO_x$ from the exhaust gas, for example, through three-way catalytic converters for mobile sources which transform $NO_x$ into nitrogen gas. |

| | |
|---|---|
| **Carbon monoxide (CO)** | CO is a toxic gas which is produced as a result of incomplete combustion. Once emitted, CO can remain in the atmosphere for a few months and is eventually oxidized to carbon dioxide ($CO_2$).<br><br>CO interferes with the oxygen-carrying capacity of blood because of its high affinity for red blood cells, which is more than 200 times higher than that of oxygen. This gas therefore can lead to a significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease. A range of symptoms can be expected from CO exposure, such as headaches, dizziness, weakness, nausea, confusion, disorientation, and fatigue in healthy people, and episodes of increased chest pain in people with chronic heart diseases. Exposure to high CO levels is lethal, but the normal concentrations found in the urban area are much lower than the lethal level.<br><br>In urban areas, CO is produced almost entirely (~90 per cent) from road traffic emissions. Other sources of CO such as open fires may be significant in local areas. The emissions can be reduced by optimizing the combustion conditions to burn more completely, but with the risk of increasing the formation of $NO_x$. Most effective reductions are achieved by catalytic converters which oxidize CO to $CO_2$. |
| **Ozone ($O_3$)** | $O_3$ is the main component of the photochemical smog that is formed in the atmosphere. High levels of $O_3$ are generally observed during hot and sunny weather of summer. Once formed, $O_3$ is destroyed by NO which is normally high at traffic sites, and therefore $O_3$ is normally higher at a distance from busy traffic areas such as rural suburb areas than in the city centres.<br><br>While the stratospheric $O_3$ is useful as it protects the life on the Earth from harmful ultraviolet radiation, ground level $O_3$ is a toxic air pollutant. $O_3$ irritates the airways of the lungs, increasing the symptoms of those suffering from asthma and lung diseases. It may increase the lung's reaction to allergens and other pollutants. $O_3$ also affects materials and plants, which leads to forest damage and reduction of agricultural productivity. |
| **Lead (Pb)** | Lead is a toxic heavy metal that is normally present in particle form in the air. Even small amounts of lead can be harmful, especially to infants and young children. Exposure has also been linked to impaired mental function and neurological damage in children. In addition, lead taken in by the mother can interfere with the health of the unborn child.<br><br>Tetraethyl lead has been used for many years as an additive in gasoline to reduce knock and to boost the octane number. Most airborne emissions of lead therefore originated from gasoline-powered vehicles. Lead is also emitted from metal processing industries, battery manufacturing, painted surfaces, and waste incineration.<br><br>Leaded gasoline has been phased out rapidly in almost all countries which has resulted in a drastic reduction in lead emissions and ambient air concentrations of lead. |
| **The Hazardous Air Pollutants (HAPs)** | HAPs, also known as toxic air pollutants or "air toxics" in the USA, are those pollutants that are known or suspected to cause cancer or other serious health effects. A large number of HAPs are found in urban air. HAPs are difficult to manage due their low concentrations and also because in many cases they are not identified. In December 2005, USEPA listed 187 compounds or groups of compounds as the air toxics, including a range of the VOCs.<br><br>VOCs are released from fuel combustion as the product of incomplete combustion or fuel evaporation, typically from vehicles. They are also emitted by the evaporation of solvents used in industry and motor fuels from gasoline stations. In urban air the most important compounds are benzene and a series of PAHs.<br><br>As leaded gasoline has been phased out, unleaded gasoline has to be reformulated to boost the octane number. If there are no adequate exhaust gas control devices, the higher aromatics content in reformulated gasoline increases the VOC emissions, in particular, benzene. MTBE (methyl-tetra-butyl ether) has been found to be a good alternative additive. However, MTBE is also an air pollutant that causes both immediate eye and respiratory irritation, and long-term risk of cancer. It may contaminate soil and groundwater, especially around petrol filling stations (Welsh, 2005).<br><br>The toxic organic pollutants such as PCBs, DDT, furans and dioxins are some of the most well known persistent organic pollutants (POPs) that are listed as HAPs. These substances are known to decay slowly and they can be transported over long distances through the atmosphere. These are carcinogenic pollutants hence there is no "threshold" dose and the tiniest amount can cause cell damage.<br><br>People exposed to toxic air pollutants may have an increased risk of developing cancer or experiencing other serious health effects. These health effects include damage to the immune system, as well as neurological, reproductive, developmental, respiratory and cardiovascular health problems. PCBs, pesticides, dioxins, and some heavy metals can accumulate in body tissues and undergo the bio-magnification through the food chain. As a result, people and animals at the top of the food chain are exposed to concentrations that are much higher than the concentrations in water, air, or soil. |

### Table 1.4: Urban air pollutants and climate change

| Pollutant | Main sources | Major effects on air quality and climate change |
|---|---|---|
| Sulphur dioxide ($SO_2$) | Burning fossil fuels, e.g., domestic, industrial combustion, shipping, electricity generation. | Affects human health.<br>Forms secondary aerosol (sulphates), which affects health and causes cooling of the atmosphere.<br>Contributes to acidification of sensitive ecosystems. |
| Nitrogen oxides ($NO_x$) [nitric oxide, NO, and nitrogen dioxide, $NO_2$] | Burning fossil fuels, e.g., road transport, shipping, electricity generation. | $NO_2$ affects human health.<br>Promotes formation of ozone ($O_3$), which affects human and ecosystem health and is a greenhouse gas.<br>Forms secondary particulate matter (nitrates), which affects health and causes cooling of the atmosphere.<br>Contributes to acidification and eutrophication of sensitive ecosystems. |
| Ammonia ($NH_3$) | Agriculture, mainly from the production and management of manure and slurry in livestock farming. | Promotes the formation of secondary nitrate and sulphate aerosol, which affects human health and causes cooling of the atmosphere.<br>Contributes to acidification and eutrophication of sensitive ecosystems. |
| Nitrous oxide ($N_2O$) | Biomass burning, nitrogen fertilisers, sewage. | Greenhouse gas. |
| Particulate matter (PM) | Combustion processes from industries and transport, dust- and sandstorms. | Affects human health.<br>Provides a negative contribution to radiative forcing. |
| Ozone ($O_3$) | Chemical reactions in the atmosphere of nitrogen oxides and hydrocarbons. | Affects human health and agriculture.<br>Greenhouse gas. |
| Carbon dioxide ($CO_2$) | All combustion processes. | Greenhouse gas. |

Source: DEFRA (2007); WHO (2005a); IPCC (2007)

# Section 2 Types of Air Pollution

Different types of air pollution exist. As well as outdoor or ambient air pollution in urban and rural areas there is indoor air pollution, transboundary air pollution and greenhouse gas emissions.

## 2.1 Rural Air Pollution

It is often assumed that ambient air quality in rural areas is better than that in towns and cities. While this may be true for some primary gaseous air pollutants emitted directly from urban sources, it is not necessarily true for fine PM. For ground level $O_3$, a secondary air pollutant that is formed in the atmosphere through photochemical reactions, the levels are very often lower in urban areas than in suburban areas and the surrounding countryside.

People living in large cities are often exposed to higher concentrations of most air pollutants than those living in small villages. Exposure to urban air pollution has resulted in significant adverse effects on human health. On a global scale it is estimated that 800,000 deaths (approximately 1.5 per cent of the total deaths) occur each year due to exposure to outdoor air pollution (WHO, 2002). In urban areas of developing countries, 2-5 per cent of total deaths are estimated to be caused by the exposure to high PM levels alone. High urban air pollution also has impacts on the gross domestic product (GDP) due to increases in mortality and morbidity, as well as damage to properties, and crops and tourism.

## 2.2 Indoor Air Pollution

Indoor air pollutants can be grouped into four categories:

1. **Combustion contaminants** comprise a large group of gaseous and particulate pollutants that may potentially be emitted from all types of combustion processes, including tobacco smoke. The composition and magnitude of the emission of combustion contaminants depend on the combustion efficiency. Smoke from combustion processes may contain thousands of substances, many of which damage human health. If the temperature in the combustion zone is not sufficiently high, the combustion will be incomplete, and the emission of airborne pollutants will increase dramatically.
2. **Volatile organic compounds** may be emitted to indoor air from many sources. Some of the most typical sources are the evaporation of VOCs from building materials, household products, paints, or from contaminated soil.
3. **Biological agents** are typically mildew, moulds, fungi, or bacteria. Furthermore, biological allergens such as dust mites may cause an allergic reaction in vulnerable people.
4. **Other contaminants** are specific groups of chemicals such as pesticides or asbestos.

According to WHO approximately half of the world's population rely on biomass fuels and coal for domestic energy needs. Smoke from biomass fuels (e.g. wood, animal dung, and crop residues) and coal contains a range of health-damaging pollutants including small soot particles that are able to penetrate deep into the lungs. In poorly ventilated dwellings, indoor smoke can exceed 100-fold acceptable levels for small particles, which are set for outdoor air (WHO, 2005b). Exposure is particularly high among women and children in rural areas, who spend more time indoors. On a global scale, indoor air pollution is responsible for the death of 1.6 million people every year – that is equal to one death every 20 seconds (WHO, 2002).

In urban areas in Asia, the use of cleaner fuels for cooking such as LPG or kerosene is more common. However, the poorest sections of society are often still dependent on low grade energy resources. Biomass and solid fuels such as locally-produced coal are also used for cooking in urban areas in some Asian countries. The solution to such a complex set of problems is not simple, because with low income levels, most households both in the urban slums as well as in rural areas find that they are unable to purchase superior fuels such as kerosene or LPG, even if these were available. The poorest often use the most polluting fuels, whilst more wealthy urban communities have moved to LPG or electricity.

Even when cleaner energies are used for cooking and heating, indoor air quality is a cause of concern because people tend to spend more of their time indoors (e.g. up to 90 per cent of the time in cold climate countries). In some urban areas in Asia lifestyles are quickly approaching those in developed countries. In addition, the issue of indoor air pollution from building materials and consumer products is becoming increasingly important.

Another source of combustion contaminants in indoor air is tobacco smoke. The significant health impact from tobacco smoke is well known. Tobacco smoking has an impact not only on smokers, but also on passive smokers that are exposed to environmental tobacco smoke (ETS). As the economies of Asia improve, so do sales of tobacco products. In China alone, it is estimated that there were 350 million tobacco smokers and 540 million passive smokers in 2007. An estimated one million people die in China each year from smoking-related illness, and the forecast is for this figure to triple in the next 50 years (GTF, 2007).

Other indoor air problems may occur in modern buildings. This may be due to construction materials and furnishing of buildings, to more air-tight buildings with poor ventilation, and to the wrong use of air conditioning. Such challenges have occurred in many developed countries, causing the so called "sick building syndrome". Indoor air in more air-tight buildings can have increased humidity, causing mildew, moulds, fungi, or bacteria. Evaporation of chemical vapours from building materials or furniture is a potential cause of indoor air problems in modern buildings. CO and $NO_2$ emissions from gas stoves can also pose a problem.

When the impact of air pollution on human health is assessed there is a strong tendency to focus mainly on outdoor air pollution. However, indoor air pollution has a significant impact on human health in many Asian countries, in particular in areas where the use of solid fuels for cooking and heating is prominent in households.

In many countries, the tendency to focus mainly on outdoor air pollution is seen not only in governmental regulations, but also in the scientific community. One of the main reasons for this situation is probably due to exposure to air pollution in private homes (e.g. cooking or heating) not being regulated by law. Indoor air pollution is therefore often considered beyond the scope of urban air quality management and it has yet to become a central focus of research, development aid and policy-making.

## 2.3 Regional and Transboundary Air Pollution

The transboundary movement of air pollution across borders may cause adverse effects in countries other than the country of origin. Regional and transboundary air pollution has been a topic of scientific research for several decades and its importance has become increasingly recognised. With advanced monitoring and modelling technology there is more evidence that pollution emitted in one part of the world can create adverse effects in other parts.

Pollutants with a potential for regional and intercontinental transport include:

- fine particles;

- acidifying substances ($SO_2$, $NO_x$);
- $O_3$ and its precursors (VOC and $NO_x$);
- heavy metals (mercury);
- persistent organic pollutants (POPs).

Pollutant levels at a location are determined by a combination of processes, including the intensity of local source emissions, the atmospheric capacity to dilute the emission, the natural removal processes, the physical and chemical transformation of pollutants, and the amount transported from upwind regions (see Figure 1.4).

Atmospheric, oceanic and ice transport as well as ecological factors, all contribute to the high concentrations of PCBs found in polar bears (Norstrom *et al*., 1998). High concentrations of 16 polychlorinated biphenyl congeners (sigma PCB) as well as others chlorinated compounds were found in bears from Svalbard, East Greenland, and the Arctic Ocean near Prince Patrick Island in Canada. Concentrations of PCBs in bears in these areas were significantly higher than in most other areas (Norstrom *et al*., 1998).

Dust from the Sahara regularly causes a number of high PM events in Europe and even reaches Central and South America, and occasionally the State of Florida. Smoke from Central American and southern Mexican forest fires reached as far north as the Great Lakes and north-central Ontario. Emissions from human activities in populated cities may be transported over large distances. Air pollution from Asia, the dark sooty clouds containing $O_3$ and fine particles, was observed on the west coast of the USA in summer 2004 (USA TODAY, 2005). The yellow dust from Gobi desert in China and Mongolia has been reported to affect levels of PM in other parts of China, Hong Kong, Taiwan, Korea, Japan, and even North America (Husar, 2004).

Significantly enhanced $O_3$ concentrations have been found in the European upper troposphere. These high concentrations could be attributed directly to the transport of air pollution from North America. In August 1998, boreal forest fires

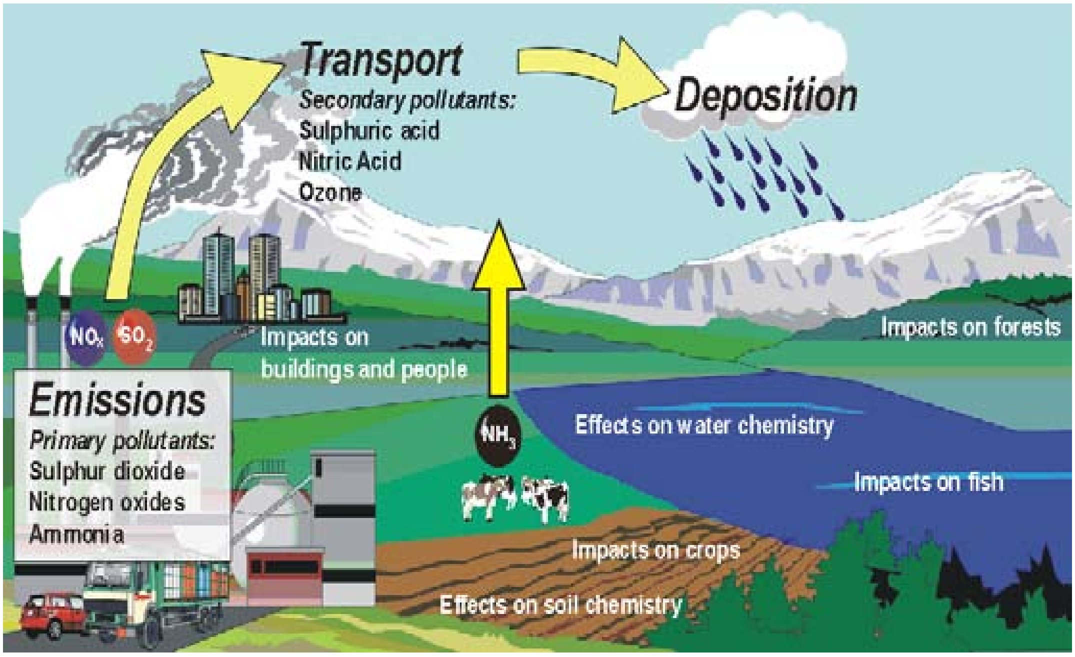



**Figure 1.4: Atmospheric pathway of air pollution**

in Canada had a strong influence on European air chemistry (Stohl and Trickl, 2001). However, there is little evidence that North American anthropogenic emissions exert a strong influence on the concentrations of air pollutants at European surface sites. Some episodes have been identified, but still lack unequivocal attribution to North American sources.

Indonesian forest fires often cause haze pollution in the neighbouring countries (BBC, 2004). The haze is a recurrent problem caused by the burning of farm land and forest clearance. In Malaysia and Singapore, the haze regularly reduces visibility and causes respiratory problems.

Intensive coal burning in East Asia has a high potential to cause acid deposition in downwind regions. According to a pollution inspection report to the Standing Committee of Parliament published in 2006, one third of China is suffering from acid rain caused by rapid industrial growth. The report found that 25.5 million tonnes of $SO_2$ were emitted mainly from the country's coal-burning factories in 2005 – an increase of 27 per cent since 2000 (BBC, 2006).

Several of the world's most polluted cities are located in Asia with notoriously high PM levels. Satellite images show high $SO_2$ and $NO_x$ concentrations over several locations in East Asia (e.g. Wang *et al*., 2007). Models to simulate concentrations show pollution plumes flowing out from megacities in Asia and spreading to downwind locations. A number of intensive source regions in Asia emit large amounts of $SO_2$, $NO_x$, VOC, PM and CO. The regional monsoon phenomenon enhances the long range transport of air pollution (Lin *et al*., 2007). The understanding of long-range transport will help formulate optimal air pollution abatement strategies on a regional or national scale.

Within the Asian continent, the major transboundary air pollution issues of concern, which are discussed here, include:

- regional haze from forest fires
- atmospheric brown cloud (ABC)
- regional dust
- acid deposition.

In addition, trace elements from coal combustion, particularly mercury (Hg), have a high potential for long range transport (UNEP, 2003, Pottinger *et al*., 2004).

## Regional haze from forest fires

Haze is the suspension of extremely small (dry) particles in the atmosphere which are invisible to the naked eye. However, they are numerous enough to give the atmosphere an appearance of opalescence together with reduced visibility (ISO, 1994). Sub-micron particles effectively scatter and absorb sunlight and affect cloud formation, which may introduce a range of effects from visibility reduction to climate change.

Smog is fog which has a high content of air pollutants (WMO, 1992). Smoke is an aerosol originating from combustion, thermal decomposition or thermal evaporation. Its particles may be solid (magnesium oxide smoke) or liquid (tobacco smoke) (IUPAC, 1997). The International Standard definition of smoke is that of a visible aerosol usually resulting from combustion (ISO, 1994) or as a suspension in the atmosphere of small particles produced by combustion (WMO, 1992).

Uncontrolled forest fires in Southeast Asia cause haze almost every year. Transboundary haze pollution from forest fires is one of the most severe air pollution problems in the ASEAN region. The haze from forest fire causes deleterious effects to human health, nature, and material property. The incomplete combustion nature of forest fires emits smoke containing large amounts of toxic gases (CO, HC) and fine particles, which can be transported over a great distance. The toxic effects of these compounds are described in Module 5 *Impacts*. Exposure to haze air pollution can be substantial as it involves a large number of people over a large region. Haze also can cause transport disruption and accidents due to visibility reduction, which may result in life and economic losses.

**Fire episodes in 1996-1998** A fire episode occurred in the ASEAN region during the El Niño drought of 1997–1998. It was the most damaging ever recorded in ASEAN countries. It started with burning of land for clearing and developed into a large forest fire in Sumatra and Kalimantan, Indonesia. Approximately 10 million hectares of forests were destroyed. The smoke from the fires affected all neighbouring countries with Java, Indonesia, and Malaysia being the most affected. At the peak of the haze, PM levels in ambient air reached unprecedented levels in the region. The PM levels observed in Sarawak, Malaysia in July 1997,were up to 15 times above the normal levels. During the haze episode in late September to early October 1997, Thailand experienced $PM_{10}$ above 200 $\mu g/m^3$ for the maximum 24-hr average. Emergency mitigation measures were taken including closing of schools and kindergartens. It was reported that approximately 70 million people in Southeast Asia were exposed to the poisonous smoke. The haze was blamed for several deaths in Indonesia, where more than 40,000 people were reported to suffer from respiratory and eyes problems. Due to reduced visibility, traffic accidents occurred including an aircraft, tanker collision, and sinking of a ferry in the Barito River. The total costs have been estimated to be several billion US dollars. In 1996 and 1997 forest and steppe fires which occurred in Mongolia destroyed approximately 10.7 and 12.4 million hectares, respectively. In these two years alone more forested areas burned than were harvested over the last 65 years (IFFN, 1998).

**Fire episode in August 2005** More recently, fires occurred in August 2005 on the Indonesian island of Sumatra which resulted in haze. Some areas in Malaysia were more seriously affected by the haze with the air pollution index reading above the hazardous level (300) and even above the emergency level (500). Visibility in some areas was reported to be less than 400-500 m. A sharp rise in complaints of eye and respiratory ailments was reported. Authorities ordered schools to be closed, flights were cancelled and people were advised to stay indoors. When the haze reached Southern Thailand the $PM_{10}$ levels peaked sharply with hourly levels reaching above 200 $\mu g/m^3$, and the 24-hour levels of $PM_{10}$ were also much higher than normal but still within the national ambient air quality standards of 120 $\mu g/m^3$.

## Atmospheric Brown Cloud

An atmospheric phenomenon, known as Atmospheric Brown Cloud (ABC) or South Asia haze has generated interest and concern among scientific community and policy makers (UNEP, 2004). The scientific study of the phenomenon has estimated the brownish cloud to be a 3 km thick blanket of pollution, which is composed of black carbon, organic carbon, sulphates, nitrates, mineral dust and fly ash. Anthropogenic sources are estimated to contribute approximately 75 per cent to this haze. Fossil fuels and biomass burning in South Asia (Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka,) and the entire Asian region are the main causes for this haze.

The ABC is transported far from the source regions. Hence it is not only a threat for South Asia but also to the entire Asian continent and beyond. It is reported that the haze is responsible for hundreds of thousands of deaths a year from respiratory diseases. Aside from potential health impacts, the haze also reduces the sunlight reaching the earth surface by 10 to 15 per cent, altering the region's climate, cooling the ground while heating the atmosphere. A reduction in photosynthesis resulting in a reduction in agricultural productivity is another potential effect. Erratic weather patterns and flooding in Bangladesh, Nepal and North Eastern India and drought in Pakistan and North Western India are some of the serious environmental consequences which have been associated with the ABC.

## Acid Rain

Acid deposition includes both dry and wet deposition. The term 'acid rain' is normally used to address the wet acid deposition though it is sometimes used interchangeably with 'acid deposition'. Rain water is naturally slightly acidic due to the presence of $CO_2$ in the air. The "pure" rain's acidity is pH 5.6-5.7. A wide-range of pollutants in the atmosphere such as $SO_2$, $NO_x$, ammonia, organic compounds, and wind blown dust, can lower pH of rain water. Acid rain refers to all types of precipitation that has pH below 5.6.

Major man-made precursors of acid rain are $SO_2$ and $NO_x$. These are emitted primarily from fossil fuel combustion in stationary sources and vehicles. These gases may remain in the atmosphere for several days, during which they can travel over large distances, may be well beyond 500-1000 km. In the atmosphere they are transformed into acidic compounds by a complex series of chemical reactions, and deposited on the Earth's surface. The major anion in acid rain water is $SO_4^{2-}$ which, consequently, dominates the chemistry of acidified water.

Acid deposition is a serious environmental threat. The resulting effects depend on the amount of acid compounds deposited to particular receptor surfaces and on the sensitivity of these surfaces to acid deposition. In general, acid rain can kill aquatic life, can damage trees, crops and other vegetation, buildings and monuments, can corrode metals, can reduce soil fertility and can cause toxic metals to leach into underground drinking water resources. In addition, $SO_2$ and $NO_x$ and fine sulphate and nitrate particles may cause visibility reduction and adverse health effects.

Acid rain was one of the first transboundary issues of concern. It was observed in 1960-1970s in North America, Canada and Europe. Nowadays, most industrialised countries have effectively reduced $SO_2$ emissions. However, $NO_x$ emissions have remained constant or are rising due to the increasing emissions from mobile sources.

**Acid Rain in Asia -** Acid rain is now emerging as a major problem in developing countries in the Asia and the Pacific region with potentially widespread and severe impacts. In Asia and the Pacific region energy consumption and the use of sulphur-rich coal as a cheap fuel and oil are rapidly increasing. In 1990 the $SO_2$ emission from Asia was estimated at 34 million metric tons. Rapid economic growth in East Asia will triple the 1990 $SO_2$ emission levels by 2020 if no action is taken beyond current control actions. Acid deposition levels have been reported as being high in areas such as southeast China, northeast India, Thailand, and the Republic of Korea, which are near or downwind from major urban and industrial centres. Rain with a pH below 4.5 has been reported in Chinese cities (SEPA, 2005). Effects on agricultural crops and material assets have been reported in China and India. The economic loss due to acid rain could be significant but no figures for Asia are currently available (RSC, 2001).

Control strategies available to mitigate significant acid deposition and its ecological consequences address reductions in both $SO_2$ and $NO_x$ emissions, and mitigate effects on sensitive receptors. Use of low-sulphur fossil fuels (low sulphur coal and oil, and natural gas) and low $NO_x$ burners can help to reduce $SO_2$ and $NO_x$ generation during combustion. Flue gas desulphurisation and denitrification are post-combustion methods to remove the pollutants from flue gas. For vehicle emission reduction, low sulphur fuels and $NO_x$ control devices can be applied. Increased energy efficiency in production and in society as a whole will help to reduce overall energy demand leading to lower fuel consumption and lower emissions.

Emission control technologies may take many years to reduce $SO_2$ and $NO_x$ emissions in order to solve the challenge of acid deposition. Short-term measures, such as liming of acidified surface water bodies, are necessary to save or restore many important resources. Many alkaline materials, such as lime compounds, and soda ash, can be used for this purpose. However, the effects of acid deposition are long-lasting. If soil is chemically changed it may take many decades for all the linked ecosystems to recover.

### Asian dust

The "yellow-sand" phenomenon is the dust of natural origin that occurs in East Asia, mainly over arid desert areas of China and Mongolia and is observed as a distinct yellow cloud on satellite images. The highest frequency of occurrence is observed during spring (March-May) when the soil in the arid areas is not yet covered by vegetation. A dust storm occurs when strong winds sweep up large quantities of dust particles and suspend them in the air. Large particles (>10 µm) will settle near the source within the first day of transport and cause their greatest impact on the local and neighbouring regions. Finer dust particles may be lifted up as high as 1-3 km into the atmosphere. They can be resident in the atmosphere for a period of 5-10 days during which they are transported over large distances.

Dust storms affect not only China and Mongolia but can also have major impacts on areas in Japan, Korea, and the northern Pacific Ocean. Under special conditions, the dust storms can also affect areas to the south including Taiwan, Hong Kong and even the west coast of North America. As the dust storms move over urban centres they pick up particles from industrial pollution. The resulting dust clouds often obscure the sun, and reduce visibility. In consequence, traffic is slowed down, more accidents occur, and airports are closed. Dust storms have been reported to cause episodic PM concentrations within and beyond Asia. Downwind countries such as North Korea, South Korea, and Japan regularly report the occurrence of dust clouds.

**Desertification and dust storms -** Dust storms have occurred frequently during the last 50 years and especially during the last few years. This is believed to be a result of the severe desertification in China as well as drought and uneven rainfall caused by global climate change. The biggest factor leading to intense dust storms in recent years is inappropriate development. This has turned the northwest China's once-fruitful agricultural land into desert due to the overuse of the land for farming/over-ploughing and grazing. Only by decreasing the damage caused by human activity and restoring the natural environment will it be possible to fundamentally mitigate the problem.

## 2.4 Urban Air Pollution in Asia

Indicators of air quality in the largest cities of Asia show that although many of these cities are among the most polluted in the world, air quality in a number of cities has generally been improving over the past few years (Schwela *et al.*, 2006). To improve air quality further, Asian cities must respond to the combined pressures of rapid growth in urban population, transport, economic development, and energy consumption. Asia is expected to account for most of the growth in world economic activity up to 2025. Asia currently has approximately one billion people living in urban areas, and this number is growing at an average of 4 per cent per year.

The major sources of outdoor air pollution in cities in Asia are vehicles, large stationary sources such as power stations and major industries, small stationary sources such as domestic sources and small industries, and area sources such as open burning.

Fine particles with a diameter around 2.5 microns ($PM_{2.5}$) clearly present the greatest health risk from air pollutants. They are estimated to cause 520,000 premature deaths and more than 4 million years of lives lost annually in Asia (Cohen *et al.*, 2005). The projected increases in $O_3$ concentrations in East Asia may lead to substantial crop losses and damage to natural areas in the near future. Acid deposition and other pollutants present particular health and environmental challenges in some countries.

Despite these challenges, the strong economic growth of many Asian economies is providing the resources necessary to meet the costs of effective air quality management (AQM) which include fuel changes, emissions control technologies, industrial restructuring, and modernization of transport systems.

## Ambient Air Pollutant Concentrations

Ambient air quality data from Asian cities reveal a complex situation, with general air quality improving in many cities and deteriorating in others. Data from 20 large Asian cities show a general slow improvement in air quality, especially for TSP and $SO_2$ (see Figure 1.5). The greatest area of improvement has been in reducing levels of TSP and $SO_2$, while the levels of $PM_{10}$ - the most critical air pollutant - have shown a limited decline. Average concentrations of $PM_{10}$ in many Asian cities still exceed WHO guidelines for $PM_{10}$ annual average of 20 µg/m$^3$ (see Figure 1.6). None of the large Asian cities shown in Figure 1.6 meets the WHO guideline for $PM_{10}$. The mean concentration for the 20 large cities is approximately four times the WHO guideline value (CAI-Asia, 2006).

The average concentration of $PM_{10}$ of approximately 80 µg/m$^3$ has changed little in the selected cities since 1995. This illustrates the difficulty of probably

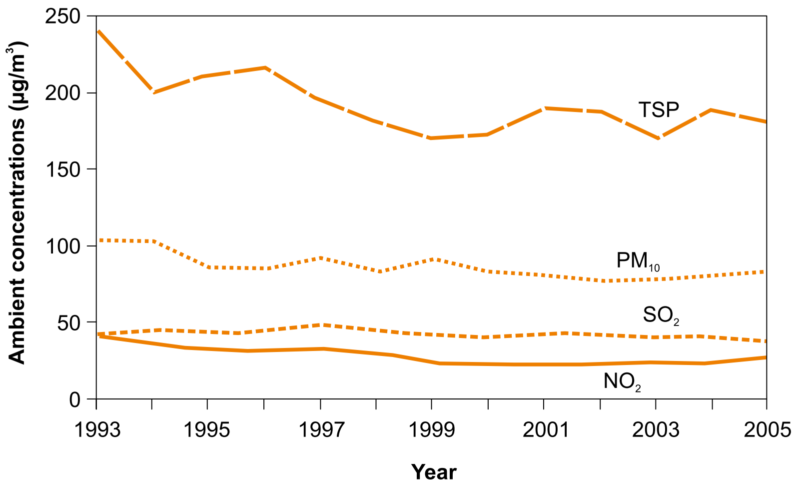



**Figure 1.5: Aggregated annual ambient air quality monitoring data for 20 selected Asian cities (1993–2005)**

$NO_2$ annual guideline value from WHO (2006): 40 µg/m$^3$; annual limit from USEPA (2006): 100 µg/m$^3$ ; annual limit from EU (2005): 40 µg/m$^3$

$PM_{10}$ annual guideline value from WHO (2006): 20 µg/m$^3$ ; limit from EU (2005): 40 µg/m$^3$

$SO_2$ guideline value from WHO (2006): 20 µg/m$^3$ for 24-hr average; WHO (2006) has no annual $SO_2$ guideline; annual limit from USEPA (2006): 78 µg/m$^3$; annual limit from EU (2005): 20 µg/m$^3$

TSP annual guideline value from WHO (1979): 60-90 µg/m$^3$

Source: CAI-Asia (2006)

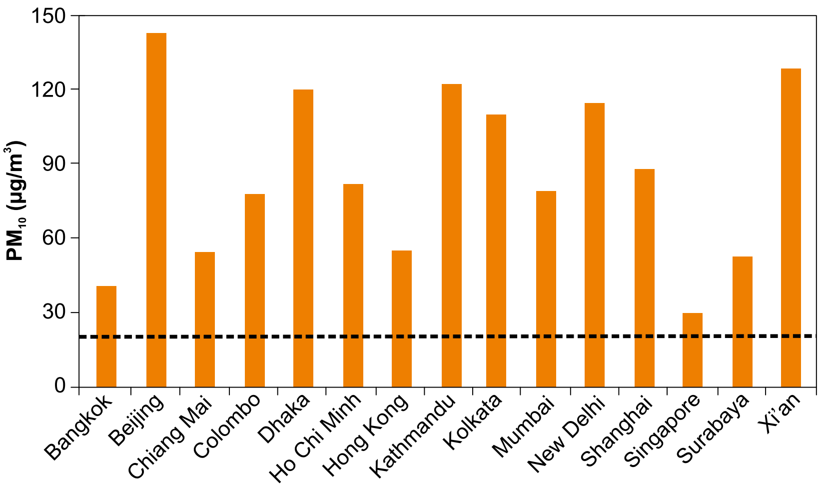



**Figure 1.6: Annual average ambient concentrations of $PM_{10}$ in selected Asian cities**

Note: WHO annual $PM_{10}$ guideline value is 20 µg/m³

Source: CAI-Asia (2006)

one of the most important challenges in air quality in Asian cities - the reduction in $PM_{10}$ levels. The enforcement of the WHO interim guidelines for $PM_{10}$ can provide interim targets for AQM in Asian cities. Achieving these targets is critically important if the health of Asian city dwellers is to be protected.

Ambient concentrations of $SO_2$ in most Asian cities - but not all - are below WHO guidelines. The picture for $NO_2$ varies, with some cities having ambient concentrations below WHO guideline values and some exceeding them. Data for $O_3$ are not comprehensive enough to make an assessment at this time.

## 2.5 Climate Change and Urban Air Pollution

Climate Change is considered to be one of the greatest challenges we face today. The effects of global climate change are becoming ever more evident (see Box 1.1). The Earth's surface temperature has increased by approximately 0.74°C since 1906. Most of the warming over the last century has occurred in recent decades (IPCC, 2007). The majority of the world's scientists now agree that it is at least 90 per cent certain that human emissions of GHGs rather than natural variations are warming the planet's surface (IPCC, 2007).

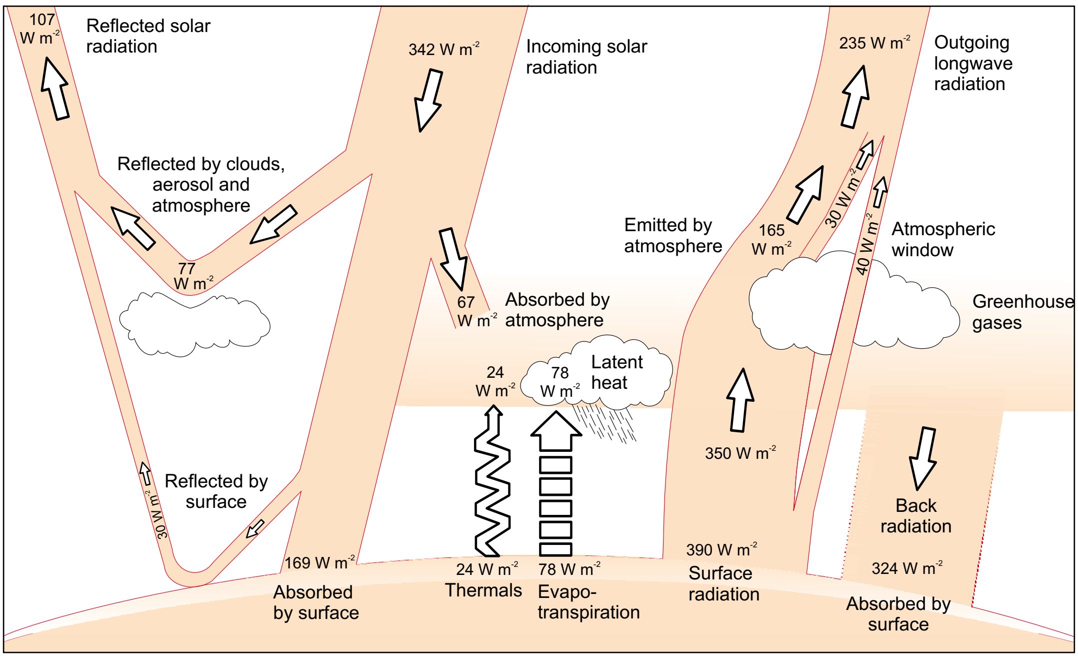
The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment of the evidence for climate change showed that (IPCC, 2007):

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

Box 1.1

## Global Climate Change

The planet is surrounded by a blanket of gases. Like a garden greenhouse the gases trap heat from the sun, which keeps the surface of the earth warm and able to sustain life. This is a natural process known as the greenhouse effect. The following figure shows the balance of incoming and outgoing radiation.




Human activity, rather than nature are increasing the level of greenhouse gases. The increasing use of fossil fuels such as oil, coal and gas since the industrial revolution over 200 years ago is the main source of GHGs such as $CO_2$. These gases stay in the atmosphere and add to the natural 'greenhouse effect'. They make the blanket of gases thicker by trapping the heat. As a result, the planet is beginning to warm up and our climate is starting to change.

### Natural Causes

Some changes to the earth's climate are caused by the effects on the sun, land, oceans and atmosphere. These often occur over very long periods of time.

### Human Causes

Human activity has changed the concentration of GHGs in the atmosphere. This has been due to burning more fossil fuels such as coal, oil and gas for energy together with cutting down forests to develop land for agriculture. Trees absorbs $CO_2$ so, with fewer trees, more carbon builds up on the atmosphere. Also, agricultural practices can be a source of GHG emissions.

$Wm^{-2}$ = watts per square metre

- Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.
- Global GHG emissions due to human activities have grown since preindustrial times, with an increase of 70 per cent between 1970 and 2004.
- Global atmospheric concentrations of $CO_2$, $CH_4$ and $N_2O$ have increased markedly as a result of human activities since 1750 and now far exceed preindustrial values determined from ice cores spanning many thousands of years.
- Most of the observed increase in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. It is likely there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica).
- Anthropogenic warming over the last three decades has likely had discernible influence at the global scale on observed changes in many physical and biological systems.
- There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades.

The IPCC (2007) predicts an increase of the global average temperature by 1.8 – 4 °C (3.2 – 7.2 °F) by the end of the century. This will affect the climate system and lead to an increase in the frequency and intensity of extreme weather events as well as sea level rise, which is expected to have adverse effects on natural and human systems (see Table 1.5). Some of the most serious effects of climate change are occurring in countries least prepared to adapt to and/or counter them. In Asia the predicted impacts of climate change include (IPCC, 2007):

- a decrease in freshwater availability in Central, South, East and South-East Asia, particularly in large river basins by the 2050s;
- greater flood risk to coastal areas from the sea and, in some deltas, flooding from the rivers, especially in heavily-populated delta regions in South, East and South-East Asia;
- compounding of existing pressures on natural resources and the environment, associated with rapid urbanisation, industrialisation and economic development;
- endemic morbidity and mortality due to diarrhoeal infections primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle;
- an increase in the spatial spread of vector-borne disease.

Many traditional urban air pollutants and GHGs have similar sources. Their emissions interact in the atmosphere and cause a variety of direct and indirect health and environmental impacts at the local, regional and global level. Air pollutants cause direct impacts while GHGs lead to climate change with indirect effects on human health and the environment. However, there is a clear difference in the spatial scales between urban air pollution and GHGs. Ambient air pollutants generally stay in the atmosphere for a short period (e.g. days or weeks). In contrast, $CO_2$ has a lifetime of approximately 150 years and methane approximately 12 years (DEFRA, 2007). These pollutants affect the climate of countries around the world.

**Table 1.5: Examples of possible impacts of climate change due to extreme weather and climate events**

| Phenomenon and direction of trend | Likelihood | Agriculture, forestry and ecosystems | Water resources | Human health | Industry, settlement and society |
|---|---|---|---|---|---|
| Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights | Virtually certain | Increased yields in colder environments; increased yields in warmer environments; increased insect outbreaks | Effects on water resources relying on snowmelt; effects on some water supplies | Reduced human mortality from decreased cold exposure | Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism |
| Warm spells/ heat waves. Frequency increases over most land areas | Virtually certain | Reduced yields in warmer regions due to heat stress; increased danger of wildfire | Increased water demand; water quality problems, e.g. algal blooms | Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated | Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor |
| Heavy precipitation events. Frequency increases over most areas | Very likely | Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils | Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved | Increased risk of deaths, injuries and infectious respiratory and skin diseases | Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructure; loss of property |
| Area affected by drought increases | Likely | Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildlife | More widespread water stress | Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water-and food-borne diseases | Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration |
| Intense tropical cyclone activity increases | Likely | Damage to crops; windthrow (uprooting) of trees; damage to coral reefs | Power outages causing disruption of public water supply | Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders | Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property |
| Increased incidence of extreme high sea level (excluding tsunamis) | Likely | Salinisation of irrigation water, estuaries and freshwater systems | Decreased freshwater availability due to saltwater intrusion | Increased risk of deaths and injuries by drowning in floods; migration-related health effects | Costs of coastal protection versus coasts of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above |

Source: IPCC (2007)

## 3.1 Air Quality Management in practice

The ultimate goal of AQM is to ensure that air pollution concentrations do not exceed defined target levels (e.g. air quality standards, target values for outdoor air quality), and that human health and the environment are essentially protected.

AQM comprises the process of monitoring and control of air emissions to eliminate or limit the impact on the population and the environment. AQM is a cross-cutting issue, and requires the support of numerous stakeholders from governmental institutions, research institutes, non-governmental organisations and private organisations. Figure 1.7 presents the basic steps involved in AQM .

AQM is a dynamic and iterative process which typically starts with the definition of ambient (outdoor) air quality standards or guidelines. In order to assess the levels of air pollution in a specific geographical area or region, the next steps will be to perform ambient air quality monitoring and derive emissions inventories. From the results of ambient air monitoring networks, the compliance with air quality standards and potential impacts can be assessed. The emissions inventory is one of the crucial components of AQM. An emissions inventory is a reasonable quantitative assessment of the emission loads from relevant sources/sectors that can be used to identify the most important sources and options for control. The quantification of emissions can also be used as an input to dispersion modelling to

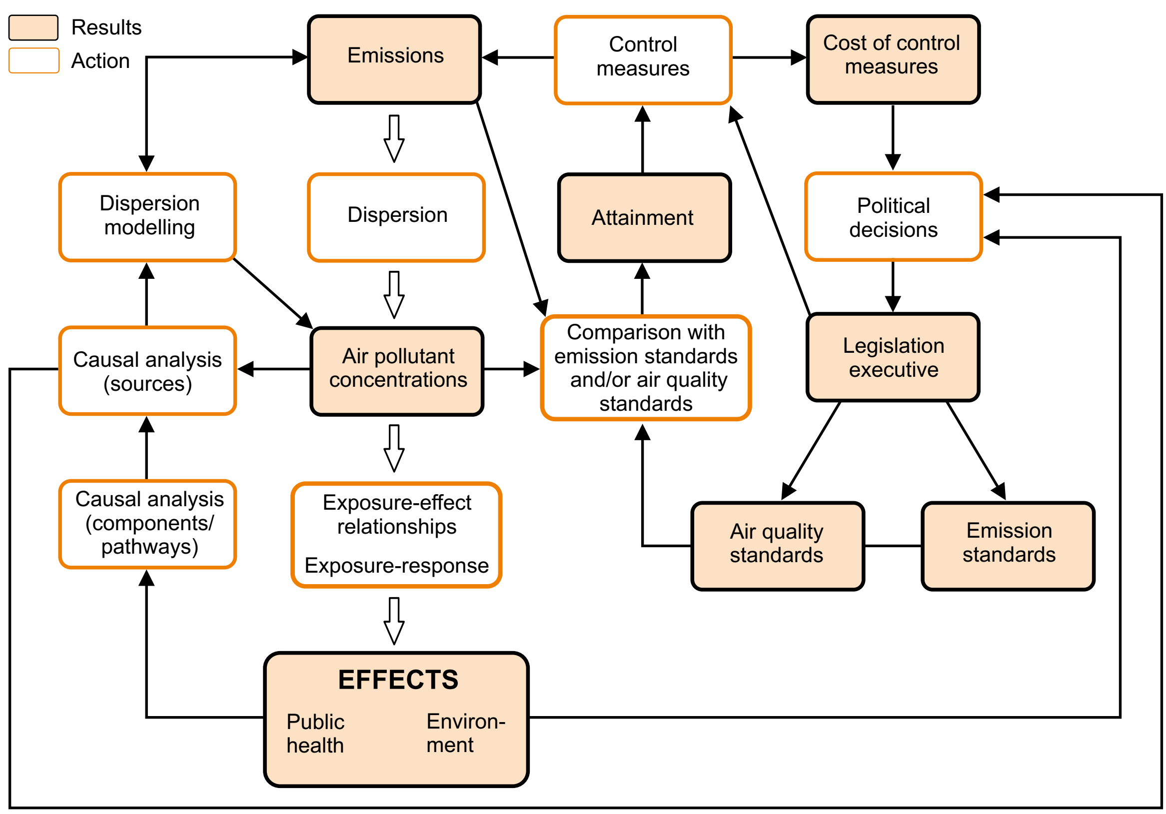



**Figure 1.7: Basic elements in the process of air quality management**

Box 1.2

**Air Quality Management: the Case of Kathmandu Valley**

Kathmandu Valley is surrounded by 500 -1000 m high hills. Low wind speeds in the Valley create poor dispersion conditions, predisposing Kathmandu to serious air pollution problems. Several studies have shown that the quality of the air in Kathmandu Valley has been deteriorating over the last two decades. The URBAIR Report for Kathmandu (Shah and Nagpal, 1997) suggested an AQM strategy for the city. In 2001, His Majesty's Government of Nepal (HMG/N) initiated an AQM programme in Kathmandu Valley with support from the Government of Denmark. The Ministry of Population and Environment (MOPE) has undertaken the programme which focuses on supporting initiatives that can contribute to a reduction in air pollution in Kathmandu Valley. Along with the introduction of the EURO 1 vehicle standards for imported vehicles in Nepal in 2000, and the ban of leaded petrol, a number of initiatives has been taken as part of the AQM programme, such as vehicle emission control training, introduction of national ambient air quality standards, implementation of an air quality monitoring system, and a ban on the most polluting vehicles (Sharma et al., 2004).

predict ambient air concentrations from different emission sources.

The data and information that is derived from these actions should be analysed and assessed by the scientific community and the relevant environmental agencies, and possible control options should be suggested. The next important step is to pass this information onto the stakeholders involved, and to ensure that the stakeholders – including policy-makers - understand the need for action plans as a response to the pressures and impacts of air pollution. In this process, public awareness raising is also important.

Many Asian cities have developed some form of AQM system to address the increasing levels of urban air pollution. One of the first co-ordinated initiatives was undertaken by the URBAIR project in the 1990s, resulting in the recommendation of action plans for Kathmandu, Jakarta, Manila and Mumbay (Shah *et al*., 1997). The implementation of a co-ordinated, integrated AQM strategy requires strong commitment from all stakeholders, and not least, an empowered environmental authority to take the leadership in this process. This seems to be the weakest link in AQM in many countries, especially in the least developed ones of Asia, where environmental ministries and agencies are relatively new, and often have limited political power.

## 3.2 Air Quality Management Capability in Asian Cities

Learning from current AQM practice through comparative analyses in cities can contribute to a better understanding and more effective implementation of environmental policies (UNEP/WHO, 1992; WHO/UNEP/MARC, 1996; BEST, 2000; 2003; OECD, 2002). Considerable interest among policy makers exists for international comparisons of urban air pollution trends and policy measures. By understanding the current stage of a city's development additional action can be outlined to effectively reduce pollutant emissions and achieve better air quality (Gudmundsson, 2003).

Schwela *et al*. (2006) assessed the AQM capabilities of twenty Asian cities (Bangkok, Beijing, Busan, Colombo, Dhaka, Hanoi, Ho Chi Minh City, Hong Kong, Jakarta, Kathmandu, Kolkata, Metro Manila, Mumbai, New Delhi, Seoul, Shanghai, Singapore, Surabaya, Taipei and Tokyo). The WHO/UNEP/MARC AQM capability index was used to assess AQM capabilities in the 20 Asian cities. The index had previously been applied to twenty major cities throughout the world and 64 major European cities (WHO/UNEP/MARC, 1996; EEA, 1998). The capability index consists of four sets of indicators (indices) to represent the key components of AQM capability were used:

1. **Air quality management capacity index**
   Assesses the ambient air monitoring taking place in a city and the accuracy, precision and representativeness of the data collected.

2. **Data assessment and availability index**
   Assesses how air quality data is processed to determine their value and how they are used to provide information in a decision-relevant format. It also assesses the extent to which there is access to air quality

information and data through different media.

3. **Emission estimates index**
   Assesses emissions inventories undertaken to determine the extent to which decision-relevant information is available about the sources of pollution in the city.

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

In order to determine the four indices and develop an overall score, city authorities in the twenty Asian cities were asked to complete a questionnaire with Yes or No answers for a number of the component indicators (Schwela *et al.*, 2006). An overview of the capacity of cities to formulate and implement AQM strategies is provided by combining the four component index scores of management capability out of 100. An assessment of AQM capabilities enables the identification of the strengths and omissions of a city's current capabilities. Figure 1.8 presents the result of this assessment.

A wide range of scores and capabilities exist within the twenty cities. Seven cities achieved an excellent rating (Bangkok, Hong Kong, Seoul, Singapore, Shanghai, Taipei and Tokyo). Beijing, Busan and New Delhi were rated with a good overall capability. A total of six cities were rated with overall moderate capacity in AQM (Colombo, Ho Chi Minh City, Jakarta, Kolkata, Metro Manila, and Mumbai). Dhaka, Hanoi, Kathmandu and Surabaya have limited AQM capability. None of the cities considered had a minimal capability. The assessment highlighted the level of progress the different cities have made in addressing urban air pollution.

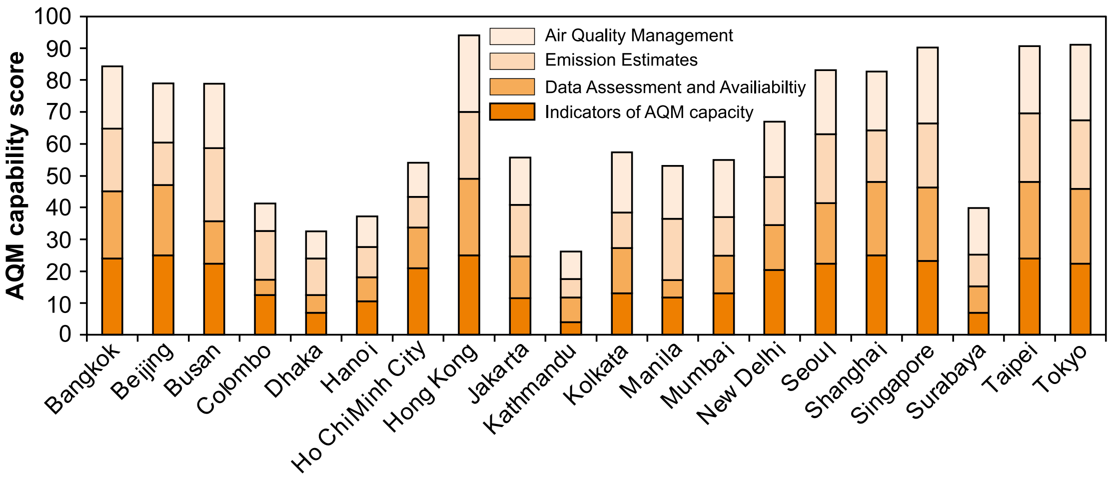



**Figure 1.8: Air quality management capability in selected Asian cities**

Source: Schwela et al. (2006)

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## Summary

In this module you have learnt about the causes of air pollution (emissions from transport, industries, power plants and uncontrolled fires) and the different types of pollution sources (stationary and mobile) as well as the key air pollutants (PM, $NO_2$, $O_3$, $SO_2$ and CO) and the key hazardous air pollutants (VOCs, PAHs and POPs). You have also gained an initial understanding of:

- outdoor air pollution;
- indoor air pollution;
- regional and transboundary air pollution;
- haze from forest fires;
- atmospheric brown cloud;
- acid rain;
- yellow-sand and dusts storms.

You have also learnt about the capability of Asian cities to manage air pollution, the magnitude of the outdoor air pollution concentrations and the link between urban air pollution and climate change. Finally, you have become familiar with the principles of AQM and the basic steps needed to develop a system to manage air quality.

The key messages you should take away from this module on urban air pollution in Asia are:

- ▶ Air pollution, including GHG emissions, is a complex phenomenon involving different types of pollution sources (industries, power plants, transport, transboundary dispersion).
- ▶ In AQM the relevant air pollutants have to be determined. The relevance of air pollutants is determined not only by the amount emitted but also by their potential of being hazardous to human health.
- ▶ There are links between air pollution and climate change. The extent of challenges due to air pollution and GHG emissions is substantial in Asia.
- ▶ AQM and GHG mitigation needs a multidisciplinary approach.
- ▶ Preventive action is less expensive than *a posteriori* measures.

Module 2 *Emissions* will examine the need for emissions inventories and the different sources of emissions. It will provide an overview of the different types of computer programs available from different agencies that can be used to compile an emissions inventory.

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The Foundation Course on Air Quality Management in Asia is for adult learners studying the issue without the support of a class room teacher. It is aimed at students with some basic knowledge of environment and air pollution issues, acquired in a variety of ways ranging from conventional study, working in an environment related field or informal experience of air pollution issues. It provides the opportunity to develop an understanding of the key components required to manage urban air pollution and to achieve better air quality.

The course consists of six modules which address the key components of air quality management. An international team of air pollution experts have contributed to the development of the course. Each module is divided into a number of sections devoted to a different aspect of the issue together with examples and key references.

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