Foundation Course on
Air Quality Management in Asia

Monitoring

Edited by
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SEI STOCKHOLM ENVIRONMENT INSTITUTE

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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.

Urban Air Pollution in Asia

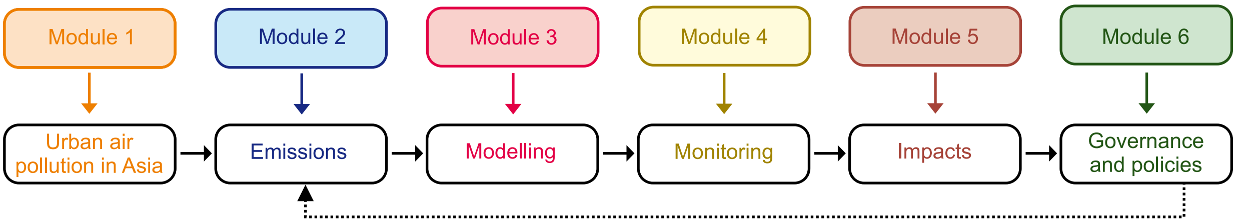
Urban air pollution affects the health, well-being and life chances of hundreds of million men, women and children in Asia every day. It is responsible for an estimated 537,000 premature deaths annually with indoor air being responsible for over double this number of deaths. It is often the poor and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

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.

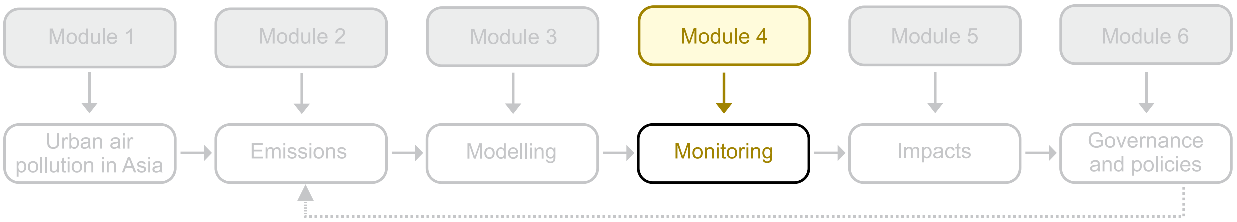
Module Structure

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.

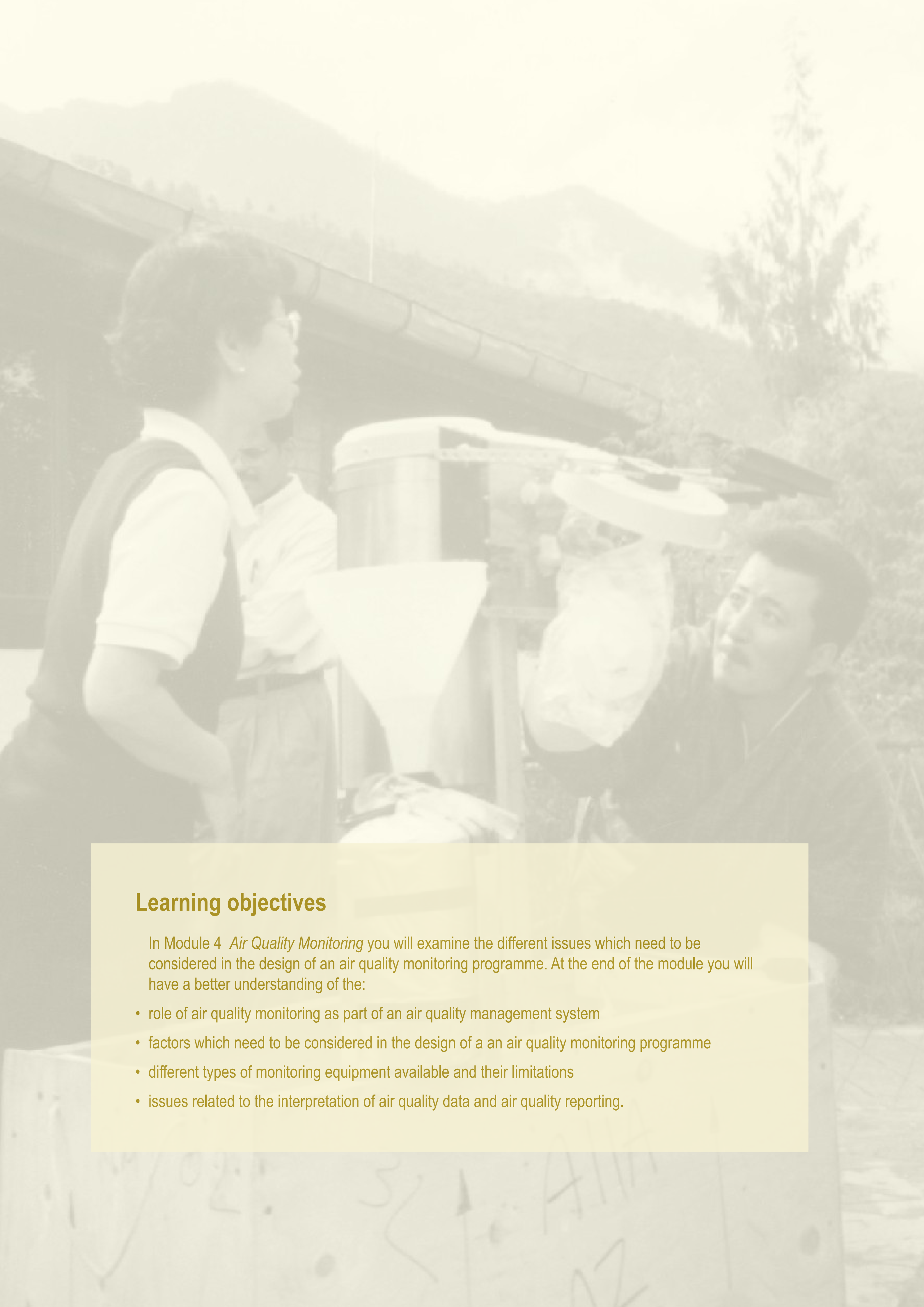


A simple air pollution pathway

Module 4 - Monitoring



A simple air pollution pathway



Learning objectives

In Module 4 *Air Quality Monitoring* you will examine the different issues which need to be considered in the design of an air quality monitoring programme. At the end of the module you will have a better understanding of the:

- role of air quality monitoring as part of an air quality management system
- factors which need to be considered in the design of a an air quality monitoring programme
- different types of monitoring equipment available and their limitations
- issues related to the interpretation of air quality data and air quality reporting.

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

List of Tables, Figures and Boxes

Introduction

One of the main challenges in air quality management (AQM) is to have timely and appropriate access to air quality data which are relevant and of known quality. Air quality monitoring is one key element to allow effective decision-making on air quality issues. The monitoring of air quality provides the data required to assess compliance with current ambient air quality guidelines and standards and to assess trends in air pollutant concentrations. It can also be used to determine the effectiveness of existing and proposed policies.

Due to improvements in air quality monitoring and capability in AQM, the status of air quality in Asian cities is becoming increasingly well documented. For example, China has been active in expanding and further developing its capacity to monitor air pollution. In 2004, it had 2,289 monitoring stations including 688 automated monitoring stations in 234 cities. Singapore, Hong Kong SAR, and Thailand have also developed sophisticated air quality monitoring systems providing data of high quality (CAI-Asia, 2006).

Most large Asian cities have some air quality monitoring in place, with varying levels of sophistication and quality assurance. In contrast, some countries in the early stages of industrial development need to further develop an adequate system for measuring air quality.

The variation in air quality monitoring approaches means that considerable differences remain in the methodology, site selection, frequency and reliability (quality assurance/quality control) of monitoring of air quality and air quality standards. These differences explain why air quality levels and trends for one city cannot be directly compared with that of other cities in Asia.

This module examines the different factors that need to be taken into consideration in the design of an air quality monitoring programme. This includes setting monitoring objectives, selecting monitoring equipment and determining the number of monitoring sites and frequency of monitoring. It provides an understanding of the interpretation of monitoring data collected and how this can be used to feed into policy development and inform the public.

Section 1 Designing Air Quality Monitoring Programmes

Any air quality monitoring programme is a key component of an AQM (see Module 6 *Governance and Policies*). The design of the air quality monitoring network involves determining the number and location of air quality stations and using monitoring methods appropriate with respect to objectives, costs and available resources (Larssen, 1999).

The typical approach to designing a national or city-wide air quality monitoring network involves placing monitoring stations or sampling points at carefully selected locations representative for population exposure. These locations are chosen on the basis of required information and known emission/dispersion patterns of the pollutants under study. This scientific approach will produce a cost-effective air quality monitoring programme. In addition, modelling and other objective assessment techniques may need to be used to ''fill in the gaps'' in information.

Another consideration in the basic approach to network design is the scale of the air pollution problem.

- If air pollution is of predominantly local origin, the air quality monitoring is mainly within the urban area (e.g. nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter (PM_{10}), carbon monoxide (CO) and benzene).
- If there is a significant regional contribution to the air pollution problem then more emphasis will be on the regional pollutants (e.g. ozone (O_3) and PM).
- If large-scale phenomena (e.g. winter or summer smog episodes in Europe or the Asian dust cloud) occur then the focus should not be on local impacts.

This module addresses monitoring in relation to urban air pollution problems. The number of sites will depend upon the size and topography of the urban area, the complexity of the source mix and again upon the monitoring objectives. In Europe a European Union (EU) Directive specifies a minimum number of stations to be established dependent upon the population, and indicates what types of areas should be monitored (EC, 2005).

1.1 Monitoring in Air Quality Management

The air quality monitoring programme will often have to be designed as a part of an air quality management system (AQMS). Generally, the users will have individual requirements ranging from simple measurement to full-scale land-use planning and air pollution abatement programmes. A modern AQMS integrates air quality monitoring, source apportionment and emissions inventories, dispersion modelling, health and environmental impact assessment, land-use planning, cost-benefit analysis, control options and actions, legislation and implementation (see Module 6 *Governance and Policies*).

Air quality monitoring is that part of an AQMS relating to areas in which air quality is required to comply with air quality standards or guidelines and/or population exposure or exposure of the environment to air pollution has to be estimated.

1.2 Monitoring Programme Design

The design of the air quality monitoring programme will depend upon the monitoring objectives, the measuring strategy and the pollutants to be assessed. For the relevant air quality parameters or selected indicators the concentration of an air pollutant and associated averaging time need to be specified. Specifications are also needed on where, how, and how often measurements should be taken.

In the initial design phase a screening study would have to estimate the:

- magnitude and variation of pollutant concentrations in space and time;
- availability of supplementary information such as topographical data, population density and spatial distribution, background concentrations, air quality standards or guidelines, sources, emission estimates (see Module 2 *Emissions*), wind speed and direction distribution, dispersion modelling capacity (see Module 3 *Modelling*), and others;
- required accuracy of the estimated concentrations.

The screening study may consist of some simple, inexpensive measurements (e.g. using passive samplers) and simple dispersion models for estimating the magnitude of average and the locations of maximal concentrations on the basis of rapid emission estimates (see Modules 2 and 3). The estimates will give some information on the expected air pollution levels, high impacted areas and general air pollution background levels. It will usually be possible to derive, in quantitative terms, a measuring strategy from this information.

The indicators to be measured at a certain station and the number of monitoring stations in the final permanent network may then be decided upon based on the results of the screening study.

Once the objective of air sampling is well-defined and results of the screening study are available, an operational sequence has to be followed. The best assessment of the extant air pollution problem together with an analysis of available personnel, budget and equipment represents the basis for the decision. A number of questions would need to be addressed in the site studies and in the selection of sites (see Box 4.1). The answers to these questions will vary according to the particular need in each case.

1.3 Monitoring Objectives

As stated above, the design of an air quality monitoring programme will be dependent upon the specific monitoring objectives specified for AQM in the selected urban area. Two general questions arise:

Box 4.1

Questions to be Addressed in Developing an Air Quality Monitoring Programme

1 Which spatial density of sampling stations is required?
2 How many sampling stations are needed?
3 Where should the stations be located?
4 What kind of equipment should be used?
5 How many samples are needed, during what period?
6 Which should be the sampling (averaging) time and frequency?
7 Which additional background information is needed?
    - Meteorology
    - Topography
    - Population density
    - Emission sources and emission rates
    - Effects and impacts
8 What is the best way to obtain the data (configuration of sensors and stations)?
9 How shall the data be accessible, communicated, processed and used?

- Which problems need to be addressed?
- What are the expected outputs of the monitoring activity?

Defining the problems and expected output as clearly as possible will influence the design of the air quality monitoring network and optimise resources used for monitoring. It will also ensure that the network is specially designed to optimise information for the air pollution issue being addressed.

There might be different objectives for the development of the environmental monitoring and surveillance system. Ideally, the system will have to provide on-line data and information transfer with direct/automatically/online quality control of the collected data. Several monitors, sensors and data collection systems may be applied to make on-line data transfer and control possible. For less developed countries (LDCs), however, it does not make sense to request on-line data transfer to start with. For example, in order to find out if there is a significant air pollution problem with respect to certain compounds, it would be logical to start monitoring with cost-effective diffusive samplers for gaseous compounds and simple monitors for estimating PM concentrations such as DustTraks and Minivol samplers. The reason for this is that the use of sophisticated automatic telemetric systems is a waste of funds if the result of the monitoring is that a significant air pollution problem in the city does not exist.

A general objective for the air quality measurement programme (monitoring, sampling and analysis) is to characterise air pollution for a particular area with minimal time and financial cost. The measurement and sampling techniques to be used will be dependent upon a complete analysis of the problem (emission source, dispersion conditions and the current air pollution situation).

The main objectives stated for the development of an air quality measurement and surveillance programme might be to:

- facilitate background concentrations measurements;
- monitor current levels as a baseline for assessment;
- check the air quality relative to standards or limit values;
- detect the importance of individual sources;
- enable comparison of air quality data from different areas and countries;
- collect data for AQM, traffic and land-use planning purposes;
- observe trends (related to emissions);
- develop abatement strategies;
- determine exposure and assess effects of air pollution on health, vegetation or building materials;
- inform the public about air quality and raise awareness;
- develop warning systems for prediction of air pollution episodes;
- facilitate source apportionment and identification;
- supply data for research investigations;
- develop/validate management tools (such as dispersion models);
- develop and test analytical instruments;
- support legislation in relation to air quality limit values and guidelines.

The relationships between the data collected and the information to be derived from them must be taken into account when a monitoring programme is planned, executed and reported. This emphasises the need for users and potential users of the air quality data to be involved in planning surveys, not only to ensure that the surveys are appropriate to their needs but also to justify committing the resources.

1.4 Site Selection

The urban air quality monitoring programme should normally provide information to support and facilitate air quality assessments in selected areas and to meet the objectives stated by the users.

In designing a monitoring programme in a certain region several monitoring stations are normally needed to characterise air quality in different areas. The areas are generally divided into urban, suburban and rural areas. Measurements should be undertaken in different micro-environments within these areas, where people are living, staying and moving. In a typical urban air pollution measurement programme the micro-environments selected are often classified as:

- urban traffic
- urban commercial
- urban industrial
- urban background
- suburban (traffic and industrial)
- rural sites (background areas).

When considering the location of individual samplers, data collected should be representative for the site and type of area without undue influence from the immediate surroundings. On the other hand, sampling data should also be representative for a certain area around the site. When measuring air quality or analysing results from measurements it is important to bear in mind that the different sources contribute to the concentrations of interest.

In any measurement point in the urban area the total ambient concentration is a sum of contributions from:

- natural, city neighbourhood and regional sources;
- traffic along streets and roads;
- small area sources like open air burning (waste and cooking); and,
- large point sources such as industrial emissions and power plants.

To obtain information about the importance of these different contributions it is necessary to locate monitoring stations so that they are representative of the contributions. In addition to air pollution data, meteorological data will often be needed to identify and quantify the sources contributing to the measurements. More than one monitoring site will also be needed to characterise air quality in the urban area. It is important to carefully characterise the representativeness of the monitoring sites, and to specify the kind of stations which report data.

In each of the areas – urban, suburban and rural - there may be four types of stations: traffic, industrial, residential/commercial and background. The background stations are divided into near-city background, regional and remote background stations. Table 4.1 provides a description of the different areas.

Information concerning networks, stations and measurement techniques is presented in two European Commission Decisions (EC, 2001a; 2001b). Information on these issues which have been specifically adapted to the needs of developing countries can be found in the GEMS/AIR Methodology Review Series (UNEP/WHO 1994a, 1994b) and in the AMIS Methodology Review Handbook (Schwela, 2003).

1.5 Air Intake Design

In the design of an urban air quality monitoring programme it is also necessary to consider the immediate surroundings around the air intake to the monitoring stations. Small-scale site considerations are important to ensure

Table 4.1: Typical area classification of micro-environments for air quality monitoring programmes

Type of area	Description	Type of station
Urban	Continuously built-up area	Traffic Industrial Residential/commercial Background : - Near city - Regional - Remote
Suburban	Largely built-up area: continuous settlement of detached buildings mixed with non-urbanised areas	
Rural	Areas that do not fulfil the criteria for urban/suburban areas	

meaningful and representative measurements. If baseline concentrations are to be assessed, then monitoring sites should be adequately separated from local pollutant sources (for example, roads or small boilers) or sinks (such as dense vegetation). The following general guidelines should be considered:

- All stations (more specifically the air intakes) should be located at the same height above the surface; a typical elevation in residential/suburban areas is 2 to 6 m above ground level.
- Constraints to the ambient airflow should be avoided by placing the air intake at least 1.5 metres from buildings or other obstructions.
- The intake should be placed away from micro-scale or local time-varying sources.

A free airflow around the sampling inlet is necessary to ensure representative sampling. For this reason, sampling in a stagnant or highly sheltered micro-environments should also be avoided. For the purpose of health impact assessment, sampling heights need to approximate, as far as is practicable, to the breathing zone of relevant population subgroups.

1.6 Number of Sites

The number of stations needed to answer the objectives of the air pollution sampling, depends on many factors such as:

- types of data needed;
- required mean values and averaging times;
- the need for frequency distributions;
- geographical distributions;
- population density and population distribution;
- meteorology and climatology of the area;
- topography and size of area; and
- location and distribution of industrial areas.

In consequence, the minimum number of sampling sites needed is a function of these parameters which can only be determined pragmatically. Recent literature suggests significant intra-city variability in air quality. Therefore, it is critically important to monitor data at a sufficiently large number of locations within a city. The goals of site selection are to: (a) identify the minimum number of sites required for capturing intra-city variability, and (b) optimize site locations by maximizing variability and minimising spatial autocorrelation.

The proposal for an EU Air Quality Directive (EU, 2005) presents criteria for the determination of the minimum numbers of sampling points for fixed *in situ* measurements of NO_2, SO_2 and

PM in ambient air. The number of sites given in Table 4.2 is for permanent sites designed to assess compliance with limit values for the protection of human health in zones and agglomerations where measurements is the only source of information.

In addition to the number of sites given in Table 4.2 at least one background station should be added. The selection of site locations should take into account the spatial distribution and variability of gaseous and particulate pollutants within the urban environment. For example, concentrations of primary traffic pollutants such as CO are highest at roadside locations, whereas $PM_{2.5}$ and O_3 levels are more uniformly distributed over the city. O_3 concentrations are normally lowest in near-road locations because of scavenging of O_3 due to the formation of NO_2 from NO emissions from cars. Taking this into consideration it is clear that it may not be necessary to measure all pollutants at all sites.

In a topographically complex area with hills, valleys, lakes and mountains, there are considerable local spatial and temporal variations of meteorological parameters and dispersion conditions. More sampling stations may be needed in such areas than in flat homogeneous terrain. For a flat area spaced stations (as proposed by the German Federal regulations (TA Luft, 2002) or by the New York City's aerometric network (e.g. Goldstein *et al.*, 1979) normally average out spatial variations and can give net results representative for the area as a whole.

To be able to use the data for comparing air pollution levels between different environments, we may need specific information about the location for some of the stations (e.g. source vicinity, topography, elevation, sampling frequency and time).

1.7 Sampling Frequency and Sampling Time

The selection of sampling time is a function of the air pollutant characteristics (emission rate, lifetime) and time specifications of the air quality criteria. The ability of combining air quality data with meteorological data also sets requirements for the time resolution in the raw data.

As soon as air pollutant statistical parameters ("indicators") have been selected the measurement technologies used must be capable of time resolutions consistent with the pollutant averaging times specified by the limit values, standards or World Health Organization (WHO) air quality

Table 4.2: Minimum numbers of sampling stations for fixed in situ measurements of NO_2, SO_2 and PM in ambient air

Population of agglomeration or zone (1000x)	Number of sites if Conc. > UAT
0 – 250	1
250 – 750	2
750-1000	3
1000-1500	4
2000 – 2750	6
3750 – 4750	8
> 6000	10

UAT = Upper Assessment Threshold level (LV=limit value)

NO_2: UAT=0.8LV, SO_2: UAT=0.6LV, PM_{10}: UAT=14 µg/m^3

Source: EU (2005)

Box 4.2

Concentration Units

Concentration of gaseous air pollutants may be reported in the following units:

- parts per million (ppm) or parts per billion (ppb)

Conversion of µg/m^3 to ppm:

- µg/m^3 = ppm x 40.9 x molecular weight of pollutant (MW)

Example: Convert 0.120 ppm of O_3 to µg/m^3 when MW of O_3= 48

- 0.120 ppm x 40.9 x 48 = 236 µg/m^3

For particle concentrations the unit is always mg/m^3 or µg/m^3.

guideline values. Air pollutant concentrations should preferably be expressed in SI units, i.e. µg/m^3 or mg/m^3.

A minimum level of data evaluation could be the production of daily, monthly and annual summaries, involving simple statistical and graphical analysis. For some of the required statistics, (e.g. percentiles, maximum 8-hour moving averages) a time resolution of at least one hour in the raw data will be required for many of the indicators. The use of Geographical Information Systems (GIS) should be considered (if funds are available), especially for combining pollution data with meteorological data and with those from epidemiological and other geo-coordinated social, economic or demographic sources.

The WHO specified in a strategy for monitoring (WHO, 1999) that expert judgment and knowledge of local conditions and spatial patterns of concentrations have to be used to produce information that best represents the exposure of the population (see Module 5 *Impacts*).

WHO also presented criteria used to establish the minimum sample size from a monitoring station. These criteria are used to estimate:

- 1-hour average values from data with a smaller averaging time, at least 75 per cent of valid data should be available.
- An 8-hour moving average values from hourly data, the number of hours with valid measures must be at least 18 (75 per cent) per day.
- A 24-hour average values from hourly data, over 50 per cent of 1-hour valid data should be available. If less than 25 per cent of successive data values exist they should not be accepted for an evaluation of 24-hour averages.
- Seasonal and annual average values, at least 50 per cent of the valid data reported for the period should be available.

For the stations that comply with the validity criteria, the following indicators can be calculated:

- 1-hour averages for CO and NO_2, and from these several-hour moving averages over a certain time period (e.g. the maximum 8-hour running average over a day);
- maximum 1-hour average and a maximum 8-hour moving average over a day (24 hours) for O_3;
- daily (24-hour) average for SO_2, total suspended particulate (TSP), black smoke, PM_{10}, and $PM_{2.5}$;
- seasonal (e.g. winter period) and annual average for lead and benzo[*a*]pyrene.

The calculation of statistical parameters requires:

- for the mean (arithmetic): over 50 per cent of accepted data;
- for the 98-percentile: over 75 per cent of accepted data;
- an annual mean;
- SO_2, NO_2, TSP, PM_{10}, $PM_{2.5}$: valid winter and summer periods;
- O_3: a valid summer period of daily maximum 8-hour moving averages; and
- CO: a valid annual period of daily maximum 8-hour moving averages.

Table 4.3: Sample resolution needed to meet statistics requirements

Pollutant/Indicator	Unit	Sample resolution	Average needed
Carbon monoxide	mg/m^3	Hourly average	Hourly, maximum 8-hour running average, annual mean of daily 8-hour maximum values
Nitrogen dioxide	µg/m^3	Hourly average	Daily average, Annual average
Ozone	µg/m^3	Hourly average	Hourly, maximum 8-hour running average, annual mean of daily 8-hour maximum values
Particulate matter	µg/m^3	Daily average	Daily average, Annual average
Sulphur dioxide	µg/m^3	Hourly average	Daily average, Annual average.
Lead	µg/m^3	Annual average	Annual average
Benzene	µg/m^3	Annual average	Annual average

The time coverage has also to be defined. A year is normally a calendar year (1 January to 31 December). The seasons are defined as winter from October to March inclusive and summer from April to September inclusive. Table 4.3 provides a summary of the sampling time (sampling resolution) as well as averaging times needed for a selected number of indicators.

In most cases the arithmetic mean is used for calculating averages over a certain time period. This procedure assumes that the individual data constituting the mean are normally distributed. This is not necessarily the case as air pollutant data may follow a logarithmic, exponential or some other kind of distribution (e.g. Weibull). Other kind of averages may therefore better characterise the distribution (e.g. the geometric mean in case of a logarithmic distribution).

1.8 Air Quality Indicators

It is normally not possible to measure all the air pollutants present in the urban atmosphere. We therefore have to choose some indicators that should represent a set of parameters selected to reflect the status of the environment. They should enable the estimation of trends and development, and should represent the basis for evaluating human and environmental impacts. Furthermore, they should be relevant for decision-making, public awareness raising, and also be responsive as early warning systems.

The selected parameters for air quality are related to air pollutants for which air quality guideline values or standards are available (see Modules 5 and 6). The interrelationships between the indicators and other related compounds might vary from region to region due to differences in emission source profiles.

Local and regional authorities use the selected sets of environmental indicators as a basis for the design of monitoring and surveillance programmes and for reporting the state of the environment.

Air quality indicators should:

- provide a general picture;
- be easy to interpret;
- respond to changes;
- allow international comparisons;
- be able to estimate trends over time provided sufficient data are available.

Measurement techniques should be reasonably accurate and cost-effective. The quality of data should be ensured by a Quality Assurance/Quality Control (QA/QC) plan to which staff involved in the monitoring should adhere to.

If monitoring is performed to estimate health and environmental impacts, the relationships between indicators and health impacts, material damage such as building deterioration, and vegetation should be adequately documented. If control options are to be considered, suitably selected indicators should respond to mitigation actions to prevent adverse impacts on human health and the environment. Indicators should also be suitable to raise public awareness.

Air quality indicators have been selected for different environmental issues and challenges. Not all indicators are specific enough to address only one issue. Many indicators are related to several issues. Some of these issues include:

- climate change
- ozone layer depletion
- acidification
- toxic contamination
- urban air quality
- traffic air pollution.

As can be seen from this list, the indicators have to cover all scales of air pollution problems (in space and time) to address different types of impacts and effects.

The most commonly selected air quality indicators for urban and industrial air pollution are NO_2, SO_2, CO, PM_{10}, $PM_{2.5}$ and O_3.

The United States Environmental Protection Agency (USEPA) refers to the compounds listed above as the priority pollutants (USEPA, 1990). They are also noted in the EU Air Quality Daughter Directives (EC, 1999; 2000; 2002) with specific limit values for the protection of health and the environment and the proposed EU Air Quality Directive (EU, 2005). The first three indicators are also specified in the World Bank limit values for ambient air pollution (World Bank, 1995). The WHO guideline values also include the above indicators (WHO, 2000a; 2000b; 2005).

For specific purposes it may be necessary to select other air pollutants as indicators for potential impacts. These include:

- polycyclic aromatic hydrocarbons (PAHs), often represented by benzo[a]pyrene
- lead (Pb)
- benzene
- BTEX (benzene, toluene, ethylbenzene, xylenes)
- volatile organic compounds (VOCs)
- other heavy metals such a arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni).

This is especially the case when vehicle emissions (PAHs, BTEX, VOCs) or industrial emissions (Pb, Cu, Ni, Cd, As) dominate the air quality in a certain area or region. Some of these indicators have also been related to air pollution standards, limit values and/or air quality guideline values as presented by WHO (WHO, 2000a; 2000b).

PAHs need specific high volume samplers and can only be sampled intermittently. One of the PAH compounds of specific interest is benzo[*a*]pyrene (BaP) which has a high carcinogenic potential. Instead of sampling VOCs for analyses by gas chromatography in the laboratory, BTEX are often measured with automatic monitors. Some of the gaseous compounds can also be measured with diffusive samplers.

1.9 Meteorological Measurements

An air pollution monitoring programme is not complete unless there are also local meteorological and micro-meteorological data available from at least one meteorological station. These data are needed for air quality assessment and interpretation as well as for input to air quality modelling and source impact identification. Meteorological data such as:

- wind speed
- wind direction
- temperature and/or vertical temperature gradient
- net radiation
- turbulence
- relative humidity
- precipitation;
- atmospheric pressure.

are needed from the surface layer of the atmosphere, normally collected along 10 m towers, and to the top of the atmospheric boundary layer. The latter information may be obtained from radiosonde data or from upper air data based on forecast models, supplied by the local meteorological office or by the World Meteorological Organisation (WMO). It will also be possible to obtain some of this information on wind speed and direction by using wind profilers, such as a SODAR (SOnic Detecting And Ranging) (see Module 3).

Section 2 Equipment Selection

Instruments for measurements of air pollutants may vary in complexity and price from the simplest passive sampler to the most advanced and often expensive automatic remote sampling system based upon various kinds of light absorption spectroscopy. Table 4.4 indicates five typical types of instruments, their abilities and cost.

Relatively simple equipment is usually adequate to use in preliminary screening studies to obtain an approximate picture of the spatial distribution in an area. However, for a complete picture of regional air pollution distributions, source apportionment, hot spot identification and operation of warning systems more complex and advanced monitoring systems are needed. To investigate compliance with short-term (less than 24 hours) air quality limit values and standards and identify emergency situations automatic monitors, which enable measurements of one-hour average or shorter interval concentrations are needed. For compliance testing with long-term (more than 24 hours) air quality standards passive samplers may be used. Also when data are needed for dispersion model validation and performance, more expensive monitoring systems are usually needed.

Integrating measurement methods such as passive samplers are fundamentally limited in their time resolution. However, as indicated above, they might be useful for the assessment of long-term exposure, as well as being invaluable for a variety of area-screening, mapping and network design functions. Problems can arise, however, when using manual sampling methods in an intermittent, mobile or random deployment strategy. The data collected may have limited applications in assessing diurnal, seasonal or annual pollutant patterns or when assessing population exposure and possible impacts.

Well-recognised semi-automatic methods such as acidimetric SO_2 samplers are adequate for measurement against daily standards or criteria. For automatic analysers or samplers to reliably measure ambient pollutant concentrations, it is essential that these pollutants be transferred unchanged to the instrument reaction cell. The air intake system is a crucial component of any monitoring system, which strongly influences the overall accuracy and credibility of all the measurements made.

Even if intermittent sampling is still widely used worldwide the solution for a permanent air quality monitoring system will mainly contain automatic monitoring equipment located at permanent

Table 4.4: Different types of air quality monitoring instruments

Instrument type	Type of data collected	Data availability	Typical averaging time	Typical price (US $)
Passive sampler	Manual, in situ	After lab analyses	1-60 days	10 - 70 per sample
Sequential sampler	Manual /semi- automatic, in situ	After lab analyses	24 hours	1,000-3,000 per sampler
DustTrak	Automatic, Continuous, in situ	Directly, on line	1 hour, 24 hours	6,000 per dust Trak
Monitors	Automatic, Continuous, in situ	Directly, on-line	1 hour	>10,000 per monitor
Remote monitoring	Automatic/Continuous, path integrated (space)	Directly, on-line	1 min-1 h	>70,000 per sensor

measurement sites. A comprehensive air quality monitoring programme may combine the use of different types of equipment covering near zone or local measurements as well as regional scale measurements. In general the network may be a combination of:

- permanent monitoring sites;
- mobile or movable stations;
- manual/semi-automatic samplers;
- passive samplers; and
- open path measurement devices (see e.g. ET (2007)).

The main ambient monitoring programme will be using *in situ* measurement instruments located at permanent measurement stations. Instruments are needed for determination of ambient concentrations of the indicators selected for the monitoring programme such as PM; NO_2; O_3; CO; SO_2; VOCs or BTEX; and Pb.

A fixed, permanent network of stations is normally required if the main objective of the air quality monitoring programme is to assess possible health impacts and evaluate trends and compliance with standards. Measurement instrumentation for each of the pollutants is discussed below.

2.1 Samplers

Simple passive samplers have been developed for surveillance of time integrated gas concentrations. These types of samplers are usually inexpensive in use, simple to handle and have an adequate overall precision and accuracy dependent upon the air pollution concentration level in question. Passive samplers involve the collection of air pollutants without the use of pumps. Passive samplers have many advantages but also some disadvantages over other approaches and so should be regarded as complementary to other techniques, such as continuous or semi-continuous fixed instruments, and manual pumped methods. Because they are generally unobtrusive and require minimal operator involvement, passive samplers are usually the most cost-effective solution to a measurement problem. Since all analyses can be performed centrally, highly skilled personnel are not required on-site. The advantages of low cost and simplicity facilitate the deployment of passive samplers in large-scale networks. They can also have advantages in uniformity, quality assurance and quality control. Whereas active samplers have problems with noisy pumps, passive samplers are silent and small and therefore easy to site. Passive samplers do not have to be calibrated in the field, which is also the case for active samplers but not for automatic analysers. There are many types of passive samplers such as bulk collectors, surrogate surfaces, flux samplers and diffusive samplers. Their main disadvantage, compared to methods where the sampling rate can be controlled directly by means of a sampling pump, is that they are only useful for relatively long exposure times, resulting in time-weighted average concentration measurements. The most forward passive samplers are the diffusive samplers. Diffusive samplers are special passive samplers, which collect air pollutants using absorbent material (Schwela, 2003). Figure 4.1 shows a diffusive sampling device.

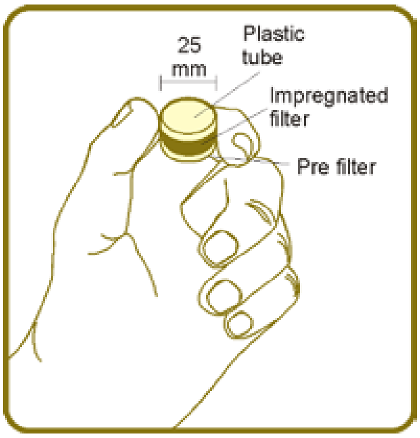


Figure 4.1: A simple diffusive sampling device

A number of manual and semi-automatic samplers have been developed for measurements of gaseous and particulate compounds. The methods of collecting gases and PM by these type of samplers include:

- adsorption
- absorption
- freeze-out
- impingement
- thermal and electrostatic precipitation
- direct measurement
- mechanical filtration.

The most commonly used active device for gaseous sampling has been the bubbler with an absorption solution, often together with a filtration system. A chemical solution is used to stabilize the pollutant for subsequent analysis with minimum interference by other pollutants. Samplers have also been used with impregnated filters based on the iodide absorption method. The flow is set with a restrictor and measured with a mass flow meter. In the sequential version of these samplers the desired start time can be set to start sampling at the same start time every day at 24 hour intervals.

The collection device is based on discrete sampling periods, semi-continuous or continuous sampling coupled to a recorder or a computer network. Automatic sequential samplers have been developed and used for collection of time-integrated samples with averaging times from a few hours and usually up to 24 hours. A few semi-automatic sequential samplers have been used for measurements of daily average concentrations of SO_2 and NO_2. The samplers have also a pre-filter that may be analysed for PM and Black Smoke (BS). Box 4.3 indicates the main characteristics of active and passive samplers.

For measurements of ambient suspended particles the most accurate way to determine aerosol mass concentration is to pass a known volume of air through a filter. Each filter has to be weighed unexposed, before being installed in the sampler. The weighing should be performed in a conditioned room for 24 hours at a pre-controlled temperature and relative humidity. After weighing, the filter is placed in the plastic bag with zip tightening and marked with station identification and/or number.

For traceable and robust measurements, samplers must be fitted with a tested PM_{10} or $PM_{2.5}$ inlet head and an accurate flow control system. The PM_{10} sampling inlet should be tested to ISO Standard 7708:1995 (ISO, 1995) to ensure accurate size fractionation at the point of sampling.

To determine the pollutant concentration, it is necessary to measure the air volume sampled. The gas flow rate or the total gas volume integrated over the sampling period may be determined

Box 4.3

Active and Passive Samplers

Active and passive samplers are available for a wide range of important gaseous and particulate pollutant (active samplers only) species.They offer a cost-effective and robust way of measuring air quality where more expensive automatic analysers cannot be procured, supported or operated in an effective and sustainable manner. As such, they can be particularly useful in developing or transition countries.

Passive samplers can be used together with active or automatic samplers, in order to achieve spatial representativeness of monitoring air pollution in an urban area. In contrast to active samplers, they cannot indicate the occurrence of episodes, although in the integrated values the elevated concentrations during an episode are included.

The most forward passive samplers are diffusive samplers. Diffusive samplers are special passive samplers, which collect air pollutants using absorbent material. Exposure times of diffusive samplers range from a few hours to a day or a couple of weeks.

using gas flow meters, rotameters, anemometers or liquid burettes. Temperature and pressure corrections are taken to convert the air volume to standard condition.

2.2 Automatic Monitors

The most commonly used methods for automatic monitoring of some of the major air quality indicators are discussed here. Methods and instruments for measuring air pollutants continuously must be carefully selected, evaluated and standardised. Several characteristics must be considered:

- specificity, i.e. the device is responding to the pollutant of interest in the presence of other substances;
- sensitivity in the range of lowest to highest expected concentrations;
- stability, i.e. the device remains unaltered during the sampling interval between sampling and analysis;
- precision, accuracy and representativeness for the true pollutant concentration in the atmosphere where the sample is obtained, adequate for the sampling time required;
- reliability and feasibility relative to human resources, maintenance cost and needs, zero drift and calibration (at least for a few days to ensure reliable data);
- response time short enough to record accurately rapid changes in pollution concentration;
- ambient temperature and humidity shall not influence the concentration measurements;
- maintenance time and cost should allow instruments to operate continuously over long periods with maximum data availability (“minimum down-time”);
- data output should be considered in relation to computer capacity or reading and processing.

Typical air pollutant concentrations may increase by approximately a factor of 1,000 between background concentrations through urban concentrations to downwind concentrations of an industrial complex. Another factor of approximately 1,000 occurs when concentrations in exhaust or stack gases are considered. The selection of instruments, therefore, has to be set to cover the “correct” range of concentration levels.

Analytical principles or measurement methods used in automatic air pollution monitors are:

- UV fluorescence for SO_2;
- chemiluminescence for NO_2;
- non-dispersive infra-red spectrometry for CO;
- gas chromatography for benzene and VOCs;
- UV photometry for O_3;
- atomic absorption spectroscopy for lead and other heavy metals.

2.3 Air Quality Instrumentation

This section provides an overview of measurement instrumentation used for determination of ambient concentrations of PM, NO_2, O_3, CO, SO_2. Measurement instrumentation for each of the pollutants is discussed separately. The organisation of this section is such that the instrumentation is discussed in order of increasing complexity and cost.

Particulate Matter

A large number of sources contribute to ambient airborne PM. These include: motor vehicles; power plants; smelters; quarries and cement industries; resuspended and wind blown dust; photochemical processes producing secondary PM, and tobacco smoke. Airborne particles can be classified and characterised in a number of ways, for example; according to their physical, chemical or biological properties. The most important physical properties of aerosol particles include:

- number and number size distribution;
- mass and mass size distribution;
- surface area;
- shape and electrical charge.

Chemical properties of particles are defined by their chemical composition and, particularly by the trace elements absorbed on their surfaces. Biological agents are usually particles and include bacteria; fungi; endotoxins; pollen, cat and dog allergens; allergens from dust mites and cockroaches; and viruses. Most of these biological agents occur in indoor environments; pollen and endotoxins also occur outdoors.

Particle size is of particular importance, as health and environmental exposures to and effects of particles depend strongly on this parameter. For example, size is a predictor of the region in the lung where a particle will be deposited and also indicates the outdoor and indoor locations to which the particles can penetrate or be transported (see Module 5 *Impacts*). Also, sampling of particles and choice of appropriate instrumentation and methodology is primarily based on particle size.

Particle size is a consequence of the process that resulted in its generation, and thus is also dependent on the source and its characteristics. Particles smaller than one micrometre (sub-micrometre particles) are mainly generated by combustion, gas to particle conversion, nucleation processes or photochemical processes; while larger particles result mainly from mechanical processes such as cutting, grinding, breaking and wear of material and dust resuspension. Particles in the sub-micrometre range typically contain a mixture of components including soot, acid condensates, sulphates and nitrates, as well as trace metals and other toxic compounds. Coarse particles are largely composed of earth crustal elements and compounds.

Various classifications and terminologies have been used to define particle size ranges. The division most commonly used is between fine and coarse particles, with the boundary between these two fractions widely accepted as 2.5 µm. The terminology that has been used in the wording of the ambient air quality standards, and also for characterisation of indoor and outdoor particle mass concentrations, includes $PM_{2.5}$ and PM_{10} fractions and the total suspended particulate matter (TSP). $PM_{2.5}$ (fine particles) and PM_{10} are the mass concentrations of particles with aerodynamic diameters smaller than 2.5 µm and 10 µm, respectively (more precisely the definitions specify the inlet cut-offs for which 50 per cent of particles is below the respective cut-off parameter). $PM_{10-2.5}$ is denoted as the coarse particle fraction. TSP is the mass concentration of all particles suspended in the air. Although coarse particle size ranges may cause significant local nuisance or soiling impacts, it is the finer fractions, such as $PM_{2.5}$ or PM_1 (particles of size smaller than 1 µm) that are capable of deep airway/lung penetration. Concern about the potential health impacts of fine PM has increased rapidly over recent years (see Module 5).

To ensure the proper application of instruments and to avoid misinterpretation of the results it is important to understand the principles of operation of the instruments used for particle characterisation; their advantages and shortcomings for specific applications; as well as the properties that are measured directly and those that are determined indirectly. Instrumental methods for determination of particle mass concentrations as they relate to air quality guidelines and standards ($PM_{2.5}$ and PM_{10}. TSP) are discussed below. Information on instrumental methods for measuring other particle properties (e.g. number, surface area, etc) can be found elsewhere (e.g. McMurry (2000), Baron and Willeke (2001) or Schwela *et al.* (2002)).

Passive samplers

Passive particle samplers can measure particle deposition ($\mu g/(m^2 \cdot s)$) which can be transformed into particle mass concentrations ($\mu g/m^3$) only with the help of a deposition velocity (m/s) according to the formula:

Concentration = deposition/deposition velocity

Deposition velocities are not usually specifically known for particles of a certain size distribution. Passive samplers are, therefore, not normally used for quantitative measurements of ambient particle concentrations.

Active samplers

The most accurate way to determine aerosol mass concentration is to pass a known volume of air through a filter and then to determine the increase in mass of the filter due to the aerosol particles collected. For traceable and robust measurements, samplers must be fitted with a tested PM_{10} or $PM_{2.5}$ inlet head and an accurate flow control system. The PM_{10} sampling inlet should be tested to ISO Standard 7708:1995 (ISO, 1995) to ensure accurate size fractionation at the point of sampling. Figure 4.2 shows a high volume sampler for TSP and PM_{10} (LSA, 2007).

The gravimetric analysis of particles collected on a filter is a simple, accurate and widely used method for determination of particle mass concentration. It requires accurate measurement of the sampling flow rate, and measurement of the net mass collected on a filter. This is done by weighing the filter before and after sampling with a balance located in a dust-free environment which is controlled for temperature and relative humidity. The normal requirement is that the filters are equilibrated for 24 hours at a constant (within ±5 per cent) relative humidity between 20 and 40 per cent and at a constant (within ±3°C) temperature between 15 and 30°C. This is intended to normalize the content of water absorbed by the filter material.

Nominal values of 30 per cent relative humidity and 15 to 20°C best preserve the particle deposits during sample weighing. A microbalance is the instrument normally used for weighing the filters and, to determine the mass of airborne PM. The instrument's sensitivity for most applications should be better than 10 μg. The collected particle mass is divided by the sample volume to obtain the mass concentration. After determination of particle mass collected on the filter, the material can be used for further analyses of, for example, the chemical or biological composition of the particles.

Figure 4.2: High volume sampler for TSP (left) and PM_{10} (right)

Source: LSA (2007)

There are many types of filters used, each with different properties and different collection efficiencies, the choice of which depends significantly on the size of the collected particles. It is normally recommended to use a filter of greater than 95 per cent efficiency at the most penetrating particle size of 0.3 micrometres. For circular disks, common filter sizes are 13, 23, 37, and 47 mm in diameter. Rectangular sheets of 200 x 250 mm (8 x 10 in) are used in high-volume samplers, which sample ambient air to evaluate air quality; however, due to the high flow rates these cannot be used indoors.

To ensure that the collected particles constitute a larger fraction of the total weight of the filter after collection, it is advisable to use filters with a low tare weight. A low tare weight filter will also experience a smaller change in weight due to moisture or temperature. Teflon and PVC filters experience a smaller gain in weight due to humidity changes than cellulose or glass filters. It is advisable that the measurement of the total accumulated mass on filters is at least 0.5 mg, to ensure that the concentration measurement is not unduly affected by the weight stability of the filter.

The flow rate and thus the volume of air sampled for different applications varies considerably, with low flow rate samplers in the order of tens of litres/hour and high volume samplers of the order of 100 m^3/hour. The weight of PM deposited on the filter is normally used to calculate a 24 hour average mass concentration. Medium or low volume gravimetric samplers are more portable and less noisy than high volume samplers, making them more suitable for use in urban areas or for indoor application. However, the mass of particulate collected is far less than with high volume samplers, giving a greater potential for errors due to filter weighing.

A target accuracy figure of $< 10\ \mu g/m^3$ and precision of $< 5\ \mu g/m^3$ (for daily average concentrations $< 100\ \mu g/m^3$) are given for PM_{10} measurements by CEN EN 12341 (1998). The United States Environmental Protection Agency (USEPA) procedure for PM_{10} using the high volume sampler is given in Federal Register 40 CFR Part 50. A number of commercially available high and medium volume samplers are equivalent to a reference Wide Ranging Aerosol Collector (WRAC) (EN, 1999). Other standard methods of relevance include the norms CEN EN 12341:1998 and CEN EN 14907:2005.

The MiniVol Portable Air Sampler samples ambient air at 5 litres/minute for PM (TSP, PM_{10}, $PM_{2.5}$) and/or non-reactive gases (CO, NO_x) simultaneously. The MiniVol provides results that approximate reference method data. Particle size separation is achieved through impaction. The PM is collected on 47 mm filters, which must be weighed pre- and post-exposure to determine particle concentrations (PO 1996-2007). Figure 4.3 shows a MiniVol sampler.

Figure 4.3: The MiniVol sampler

Source: USEPA (2006a)

Automatic analysers

Instruments are commercially available using the following techniques:

- beta-ray absorption analysers
- Tapered Element Oscillating Microbalance (TEOM)
- light scattering systems.

Automatic analysers of particle mass yield real-time data and do not require capture of the analysed particles for subsequent analysis. However, a shortcoming of some of these methods is that they do not directly measure particle mass, but recalculate its value based on another measured property. For example, optical counters count particles crossing the sensing area of the instrument, which is then related to particle mass; while oscillating microbalances measure changes in the oscillating frequency of a crystal or filter on which particles are sampled, and translate the change of the frequency into the mass collected. Without previous calibration of the instrument for the specific measured aerosol, the quantity measured must be regarded as an approximation. Therefore measurements from different instruments that do not measure particle mass directly are not always equivalent or comparable. Reference methods for active monitors can be found in NILU (2001).

Beta Attenuation

Beta attenuation is one of the oldest automatic methods for measuring airborne particulate mass concentration. It uses the relationship of beta attenuation's approximate proportionality to the mass of the sample. It has been mainly used for outdoor measurements, but it is also suitable for indoor applications. Beta radiation passing through the collected sample is attenuated, and the mass collected is proportional to the degree of the attenuation. The response time depends on the concentration measured and is typically over 30 minutes. The advantage of this technique is that it does not require further laboratory analyses for mass determination. The disadvantages are the use of the radioactive source, the long response time and an inherent inaccuracy arising from the fact that the sensitivity is somewhat dependent on the material sampled. Figure 4.4 shows a beta attenuation monitor.

Figure 4.4: Beta attenuation monitor

Source: PE (2003)

Tapered Element Oscillating Microbalance Mass Detector (TEOM)

The TEOM (Patashnik and Ruprecht, 1980) operates on the principle that the particle sample is collected on a filter mounted on the thin end of a tapered oscillating hollow element, which is fixed at its thick end. This element is electrically excited to oscillate at its natural resonant frequency, which decreases with the mass loading of the filter. This change in resonant frequency is sensed electronically, converted to a mass measurement, and displayed. The main advantages of this method are the fast response time and near real-time results it provides. The instrument is usually operated with a 2.5 or 10 µm cut-off sampling inlet. The inlet air is heated to 30 or 50°C to keep moisture in the vapour phase.

The transducer's temperature is stabilized to 50°C, to minimise the temperature drift of the calibration constant and to stabilize the measurement. This constitutes a problem for volatile components, such as ammonium nitrate, that are present in the particulate phase; as they will be vapourised and therefore lost from the particulate phase. In such situations TEOM underestimates particle mass and up to 30 per cent higher signals at a transducer's temperature of 30°C compared with 50°C have been reported. As a consequence, lower TEOM concentrations are generally measured when compared with reference methods, a situation especially encountered during colder sessions and outdoor measurement. In the US, TEOM has obtained the status of an automated equivalent method (Federal Register: Vol 55, page 43406). Figure 4.5 shows a TEOM analyser (NYU, 2004).

Light Scattering Instruments

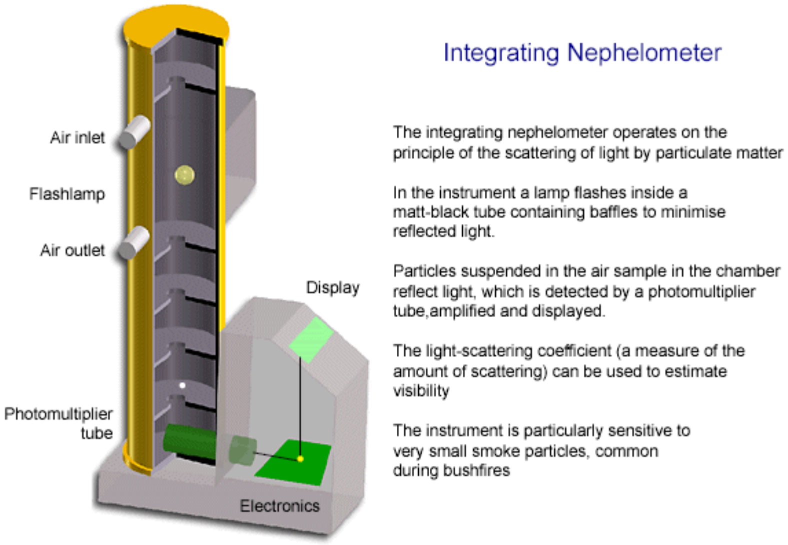
Light scattering by small particles suspended in gases is widely applied to obtain information about the concentration of airborne particles. Instruments based on this principle combine *in situ*, real-time, measurements of air sampled directly by the instrument, with a high degree of automatization. These instruments can be broadly divided into two categories: nephelometers and photometers. The nephelometer is used for outdoor measurements.

Figure 4.5: A TEOM analyser

Source: NYU (2004)

Figure 4.6 shows an integrating nephelometer (QEPA, 2007).

Photometers are perhaps the most commonly used direct-reading aerosol instruments and have been commercially available for over 25 years in a variety of configurations. Photometers have many advantages over the traditional gravimetric sampler: they provide real-time data; they are simpler to use and in the long term they are less expensive to operate. They can be used to identify immediate hazards, to screen for prioritisation of further air sampling, and to enable measurements of spatial and temporal variation in particle concentrations in the environment under investigation. However, their major disadvantage is that they do not directly measure gravimetric mass. Since air quality standards for PM are usually based on utilization of gravimetric methods of sampling, it is therefore necessary to correlate photometer signals with the gravimetric mass concentration of aerosol. Most photometers are factory calibrated against a gravimetric reference using the respirable fraction of standard Arizona Test Dust (ATD) according to ISO12103-1:1997 (ISO, 1997). However, the factory calibration could depart quite significantly from the gravimetric measurements in environments with high concentrations of combustion sub-micrometre particles or other aerosols that differ significantly from ATD.



Integrating Nephelometer

The integrating nephelometer operates on the principle of the scattering of light by particulate matter

In the instrument a lamp flashes inside a matt-black tube containing baffles to minimise reflected light.

Particles suspended in the air sample in the chamber reflect light, which is detected by a photomultiplier tube,amplified and displayed.

The light-scattering coefficient (a measure of the amount of scattering) can be used to estimate visibility

The instrument is particularly sensitive to very small smoke particles, common during bushfires

Figure 4.6: An integrating nephelometer

Source: QEPA (2007)

A sun photometer is an instrument which measures the intensity of sunlight, when pointed directly at the sun. Any aerosols and gases (haze) between the sun and the photometer tend to decrease the sun's intensity. A hazy sky would read a lower intensity of sunlight and give a lower voltage reading on the photometer. A clear blue sky would result in a greater intensity and a higher voltage reading. Thus the reading may be used as a measure of haze. Figure 4.7 shows a typical sun photometer (NASA, 2005).

The DustTRAK™ Aerosol Monitor is a portable, battery-operated laser photometer with real-time mass concentration readout and data logging capability. The monitor provides reliable exposure assessment by measuring particle concentrations corresponding to respirable size ($PM_{4.0}$), PM_{10}, $PM_{2.5}$ or $PM_{1.0}$ size fractions (see Figure 4.8) (TSI, 2007).

Nitrogen dioxide

NO_2 is most commonly formed in the atmosphere from nitrogen oxide (NO) emitted from combustion processes including outdoor (motor vehicles, aircraft, industry, etc) and indoor combustion

Figure 4.7: The NASA sun photometer for measuring haze

Source: NASA (2005)

sources (non-vented combustion appliances such as gas stoves, kerosene heaters and gas fired water heaters). The process of converting NO to NO_2 is very fast. NO and NO_2 are the main components of the collective term NO_x.

Passive, active and automatic analysers are available for NO_2 measurements; however for compliance against standards active samplers must be used. Passive and active samplers are useful for investigations of spatial variation in NO_2 concentrations. In addition, passive samplers are well suited for personal exposure assessment.

Figure 4.8: The DustTrak photometric analyser

Source: TSI (2007)

Passive samplers

Passive diffusion tubes have been widely used for monitoring of ambient NO_2 concentrations providing an integrated, average concentration for the pollutant over exposure periods of several hours to several weeks. This method is particularly well suited to baseline and screening studies for the assessment of spatial distribution of NO_2 concentrations in the urban environment. However, there are no national (or international) standards governing the application of diffusion tubes for ambient air quality monitoring nor standard operating procedures for laboratory preparation and analysis of diffusion tubes. Nevertheless there have been protocols published for sampler preparation and analysis by photospectrometry (Palmes *et al*., 1976; Atkins *et al*., 1986); these have been informally accepted as standard procedures for NO_2 diffusion tube preparation and analysis.

The most widely used techniques are variants on the Palmes-type sampler, which employ a tube sampler, using triethanolamine (TEA) as an absorbent. Sample analysis, after thermal desorption, is conducted by spectrophotometry or ion chromatography. Comparisons of NO_2 diffusion tube measurements with co-located chemiluminescent NO_x analysers generally show good agreement. Over the range of concentrations typically found in urban areas (20-80 $\mu g/m^3$), it was found that, on average, NO_2 diffusion tubes exposed for one month tended to overestimate ambient NO_2 by approximately 10 per cent compared with a chemiluminescent NO_x analyser. Estimates of the precision of this measurement technique have been quoted as 5-8 per cent in similar studies.

Diffusive NO_2 samplers have been validated against corresponding averages from active and/or automatic samplers (see Figures 4.9 and 4.10).

Active samplers

Figure 4.11 presents a general set up for active sampling using sorbent tubes. This set up is used not only for NO_2 but for other atmospheric gases as well (CO and SO_2).

A review of a range of methods that are available for active sampling has been published by (UNEP/WHO, 1994; Schwela, 2003). The best known of these is the Griess Saltzman Method, covered by ISO 6768:1985 (ISO, 1985). This method is sensitive and more selective than other well established methods of chemiluminescence, and requires relatively simple, inexpensive sampling apparatus. In spite of this; there are a number of disadvantages. It is a relatively skilled and labour-intensive technique which uses corrosive chemicals and has to be performed immediately after sampling due to instability of the sample. It is thus not applicable to sampling and sample transport periods above 1-2 hours, particularly if temperature and light exposure cannot be controlled. There also remain doubts about calibration methods, collection efficiency and possible side-reactions. Field intercomparison studies have shown that the Saltzman method is not suitable at concentration levels below 1 µg/m^3. There are other absorbing solutions that have been used, with some of them more applicable for monitoring of elevated concentrations of gas, as they are usually not sensitive enough in cleaner environments. In general, there has also been considerable uncertainty about the absorption efficiency of the absorbing solutions, and to what extent this varies with concentration.

Automatic analysers

The automatic chemiluminescence method is described in ISO standard 7996:1985 (ISO, 1985) for NO_x concentration measurements. This method is used world-wide and is defined as the reference method for compliance with EC Directive 85/203/EEC (EC, 1985). The determination of NO_x is based on the chemiluminescent energy emitted when NO_x in the sample air stream reacts with O_3 in an evacuated chamber to form an excited energy state of NO_2. The chemiluminescent reaction is:

$$NO_x + O_3 = NO_2^* + O_2$$

Light from the return of excited NO_2* to ground level NO_2 affects a photomultiplier tube and amplifier, which converts the signal into an output voltage.

An automatic NO_2 analyser based on the liquid-phase chemiluminescence, produced by reacting NO_2 with a chemical solution, is also available. This monitor has been shown to give almost

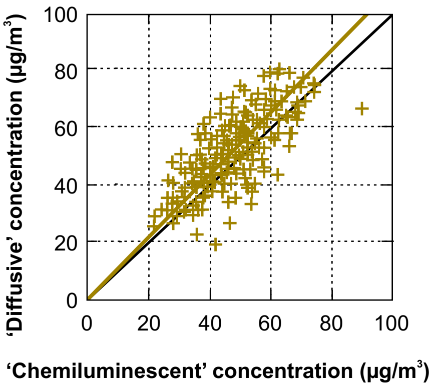


Figure 4.9: UK diffusion tube versus chemiluminiscent NO_2 concentration data, averaged over two weeks

Source: Bush *et al.* (2001)

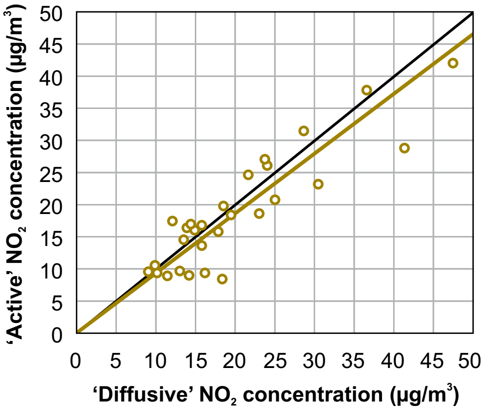


Figure 4.10: IVL diffusive badge sampler versus active NO_2 concentration data, averaged over 24 hours

Source: NILU (1995)

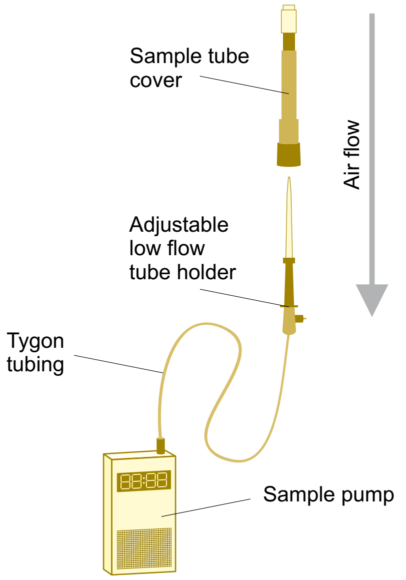


Figure 4.11: A schematic diagram of a set up for active sampling using sorbent tubes.

interference-free values for NO_2. Since this monitor works with a liquid phase reaction, it needs more regular service than the ordinary chemiluminescence instruments. Thus these highly sensitive but relatively fragile instruments are mostly employed for research applications and are not generally regarded as being suitable for routine baseline monitoring purposes.

The accuracy of data from automatic NO_2 analysers depends on a range of factors and has been estimated to be of the order of ± 8 per cent for NO_2 measurements in well-run automatic networks, taking account of all contributory factors. The precision of NO_2 measurements, as determined from long-term variations in baseline response of in-service analysers, is estimated to be ±6.5 $\mu g/m^3$.

Ozone

O_3 is a secondary pollutant formed in the atmosphere from its precursors in photochemical reactions. The precursors are NO_x and VOCs, which are generated mainly from combustion sources. For the photochemical reaction to occur, sunlight is required. These reactions are not immediate, but may take from hours to days to complete. Sources of indoor O_3 include O_3 infiltration from outdoors and copy machines. In outdoor urban air, spatial distribution of O_3 concentration is usually more homogenous than concentrations of other pollutants, due to being formed in the air during the transport and atmospheric mixing process. For this reason, significant concentrations of O_3 may occur in areas up to hundreds of kilometres downwind of the original precursor emissions, which has important implications for monitoring system design.

Passive samplers

A variety of techniques are available (UNEP/WHO, 1994; Schwela, 2003), none of them, however, has been accepted as a standard technique up to now. The most common include:

- 1,2,di-(4-pyridyl) ethylene absorbent spectrophotometry (Monn and Hangartner, 1990; Cox, 2003; Plainsance *et al*., 2006);
- potassium-iodide (KI) spectrophotometry (Machado *et al*., 1999);
- sodium nitrite/Potassium carbonate/ glycerol ion chromatography (Koutrakis *et al*., 1993; Galán Madruga *et al*., 2001);
- indigo carmine-reflectance (WHO, 2000a).

Active samplers

The most widely used active sampling technique was once the Neutral Buffered Potassium Iodide (NKBI) method. This is based on the principle that O_3 reacts with potassium iodide to release iodine, which is determined spectro-photometrically. Although relatively simple and inexpensive, practical problems with iodine complex solution deterioration and interferences, most notably from NO_2 and SO_2, have reduced its use to the extent that the technique may now be regarded as obsolete (see, however, Machado *et al*., 1999).

Automatic analysers

In general, automatic methods for monitoring O_3 employ UV absorption, a robust, well-developed and commonly used technique, of reference grade technology (ASTM D 5156-02 (ASTM, 2002); EC, 1992). UV absorption monitors are bench top instruments, and therefore are more expensive than the techniques discussed below. Ambient O_3 concentrations are calculated from the absorption of UV light at 254 nm wavelength. The sample passes through a detection cell of known length (L). An ozone-removing scrubber is used to provide a zero reference light intensity, (I_o). The analyser alternately measures the absorption of air in the cell with no O_3 present and with the sample, I_s. The ambient O_3 concentration, c, may be simply calculated using the Beer-Lambert equation:

$$I_s = I_o\, e^{-aLc}$$

where, a, is the relevant absorption coefficient at 254 nm adjusted for temperature and atmospheric pressure. The result is:

$$c = (1/aL)\cdot\ln(I_o/I_s)$$

Given appropriate attention to sample system design, calibration and equipment support, a typical overall measurement accuracy of ±11 per cent and precision of ±4 $\mu g/m^3$ should be readily achievable in well-run automatic networks.

Other methods such as chemiluminescence are less commonly used. Electrochemical and dry calorimetric methods which are more affordable and portable, may, however, not have the desired level of sensitivity.

In general, the equipment cost for the calibration of O_3 monitors is high and requires an O_3 source and a reference instrument.

Carbon Monoxide

CO resulting from incomplete combustion of substances containing carbon is often present in motor vehicle emissions and tobacco smoke. Indoor sources of CO include faulty furnaces and hot water heaters, clogged chimneys and automobile exhaust in houses with attached garages. It is a primary pollutant, and therefore its ambient concentrations closely follow emissions. In urban areas, concentrations are highest at the kerbside and decrease rapidly with increasing distance from the road.

Passive samplers

A passive sampler has been developed for CO, utilising a zeolite absorber and a narrow filamental diffusion passage to optimise uptake, involving GasChromatography/Flame Ionisation Detector (GC/FID) analysis after thermal desorption (Lee *et al.*, 1992). This technique may be useful for screening, mapping and 'hot-spot' identification. Its use does not, however, appear to be widespread at the present time.

Active samplers

Grab samples may be collected for subsequent laboratory analysis using colorimetric tubes and provide a general indication of concentration levels (see: ASTM D 4599-03 (ASTM, 2003)).

Automatic analysers

The measurement of CO in ambient air is covered by international standards ISO 4224: 2000 (ISO, 2000) and ISO 8186: 1989 (ISO, 1989). Methods for automatic monitoring of CO include non-dispersive infrared (NDIR) spectrometry, infrared (IR) spectrometry, and electrochemical detection.

NDIR and IR spectrometry are the preferred baseline technology for CO monitoring, and have been routinely used for the last few decades. The monitors are either bench-top, which are more expensive and of higher performance, or hand held devices, which are cheaper and are of comparable performance with the bench-top devices. The bench-top instruments use pumps, while the hand-held miniaturized version rely on diffusion to deliver samples of the air to the transducer. Calibration of the instrument requires gas mixtures of known concentrations. Pressurized containers of calibration gases can be purchased from a variety of suppliers. Detailed methods are available in ASTM D 3162-05 (ASTM, 2005). CO analysis is based on the absorption of IR radiation at wavelengths of 4.5 - 4.9 μm. Since other gases and particulates can also absorb IR, the analyser must distinguish between absorption by CO and absorption by interferences. The accuracy of data from automatic CO analysers depends on a range of factors encompassing the entire measurement chain. These include accuracy of calibration standards, analyser stability, and sample losses in the measurement system. An accuracy of ± 8 per cent and precision of ±0.5 mg/m^3 may be achieved using this technique in well-managed and quality assured programmes.

Electrochemical detectors may operate on principles of conductivity, potentiometry, coulometry, or ionization. These detectors are generally of lower sensitivity and are less suitable for routine ambient monitoring, however they may have application in areas of high concentrations. A version of this sensor is incorporated in a commercially available roadside pollution monitoring system. For indoor air quality applications electrochemical detectors based on aqueous solutions have been more commonly used. Calibration of the instruments is conducted using gas mixtures. Specificity for most electrochemical sensors is achieved by using selective scrubbers on the inlet air stream to remove interfering compounds.

Sulphur Dioxide

The main source of SO_2 is the combustion of fossil fuels containing sulphur, either in power stations, domestic/commercial space heating or by motor vehicles. They are also emitted indoors from kerosene heaters and by certain consumer products. Automatic analysers need to be used if comparing against short-term guidelines; a variety of active samplers are suitable for comparison with daily or annual guidelines. Passive samplers may also be used to provide data for comparison with long-term annual guideline values.

Passive samplers

As with other gaseous criteria pollutants, there are currently no national or international standards governing the application of SO_2 diffusion tubes to ambient air monitoring, nor for their laboratory preparation and analysis. However, protocols for sampler preparation and analysis by photospectrometry and ion chromatography have been published in scientific literature. Among the most widely used passive sampling techniques (UNEP/WHO, 1994b; Schwela, 2003) are the:

- triethanolamine (TEA)/glycol/ spectrophotometry method (Hangartner *et al*., 1989);
- potassium hydroxyde (KOH)//glycerol/ spectrophotometry method (Hargreaves and Atkins, 1988);
- sodium carbonate (Na_2CO_3)/glycerine/ion chromatography method (Ferm, 1991).

Some of these techniques are also used in combination.

Active samplers

International Standard ISO 4219: 1979 (ISO, 1979) provides a description of the sampling equipment required for the determination of gaseous sulphur compounds in ambient air, including details of the equipment necessary to sample gaseous pollutants by absorption in a liquid bubbler. The standard also includes guidance for site selection and installation of the apparatus. This method is well established and proven, and has been used in many monitoring networks world-wide for a number of years. Consequently, there is a long history of active sampler SO_2 measurements available for trend assessment. There are several methods of SO_2 monitoring based on this principle, which differ in respect to the solutions used in the bubblers for absorption of SO_2, and the method of analysis. The four most widely used methods are described below.

Acidimetric (total acidity) method. This method, given in ISO 4220: 1983 (ISO, 1983), is used to determine a gaseous acid air pollution index. Although this method measures total acidity, and is not specific to SO_2, it is adequate for general use. The simplicity of the method, and the fact that the reagents are relatively safe, make it a popular choice for routine monitoring (AEA, 1997). Taking into account all contributory factors, an accuracy of ±10 per cent has been estimated using the total acidity method, and precision of ±4 $\mu g/m^3$.

Ion chromatography. This is a variation on the above technique. Exposed peroxide solutions are analysed for sulphate ions by means of ion chromatography, rather than titration. This has the advantage of being sulphate-specific, but requires the use of an expensive ion chromatograph. Often alkaline impregnated filter methods are used in combination with ion chromatography, because it combines a small extraction volume and low measurement uncertainty with a large air volume, and therefore gives a good measurement accuracy even at low SO_2 concentrations.

Tetrachloromercurate (TCM) method. This is also known as the Pararosaniline method ISO 6767: 1990 (ISO, 1990). This is the reference method specified in the EC Directive on SO_2 and TSP (EC, 1980). However, the reagents used are very toxic, and for this reason the method is not widely used.

Thorin method. This method is given in ISO 4221: 1980 (ISO, 1980). The reagents used include perchloric acid, barium perchlorate, dioxane and thorin. These are hazardous and must be handled and disposed of with care. Accordingly, this method is not commonly used world-wide.

Automatic analysers

The measurement of SO_2 in ambient air using automatic analysers is covered by ISO 10498: 2004 (ISO, 2004). The most widely used method for automatic SO_2 measurement is ultra-violet fluorescence (UVF), which employs a convenient sampling procedure and permits high time resolution. SO_2 molecules in the sample air stream are excited to higher energy states by UV radiation at 212 nm. These energy states decay, causing an emission of secondary fluorescent radiation with an intensity proportional to the concentration of SO_2 in the sample.

However, one disadvantage of this technique is the need for frequent calibration, regular maintenance and skilled workers. The sensitivity of the monitor is generally not as good as the manual method, giving uncertain results at concentrations below 1 μg S/m^3. An accuracy of ±10 per cent has been estimated for SO_2 measurements in UK national automatic networks, taking account of all contributory factors. The precision of SO_2 measurements as determined from long-term variations in baseline response of in-service analysers is estimated to be ±3 $\mu g/m^3$ (AEA, 1996). Box 4.4 summarizes the commonly used automatic methods for the gaseous compounds considered above and additional organic pollutants.

Lead

In ambient air, lead (Pb) arises mainly as particles from combustion of petrol containing lead-based additives and industrial emissions. Indoor sources could include lead glazed ceramic flooring, lead-based paint and cigarettes.

There are no passive sampling methods applicable for lead determination or standard automatic methods. The recently introduced Time of Flight Aerosol Mass Spectrometer technique (DeCarlo *et al.*, 2006) is very expensive and used for research applications. Active sampling is based on sampling ambient air through a filter and capturing fine ambient PM for subsequent Pb analysis. Analysis of filters for lead is covered by ISO 9855:1993 (E), which specifies atomic absorption spectroscopy as the standard analytical method (ISO, 1993). There is no standard sampling method for lead; however, standard methods used for particle mass measurements apply (PM_{10} or $PM_{2.5}$).

2.4 Data Transfer Systems

All data from the instruments mentioned above may be collected by a data logger and transferred directly to a database for processing, control and evaluation. There are many different options on the market for efficient data communication from monitors to a database. The various conditions at the locations decide the best solutions. Several factors may have to be considered such as: availability and reliability of telephone networks, quality and speed of the network, the amount of data to be transferred, the frequency of transfer, available mobile telephone options and satellite communication systems.

For every site there is a need for a data acquisition system (DAS) to receive the measurement values collected by one or several gas or dust analysers, meteorological sensors or other parameters. These parameters must be stored, every minute, every five minutes or every hour locally and then transmitted to a central computer via modem and telephone lines. The local storage time must be several days or up to some months in case of problems with modems, transmission lines or the central computer. Automatic DASs are available from a number of companies and instrument providers.

Data Retrieval via Telephone Lines

Air quality data collected by automatic monitors are normally transferred directly from a data logger unit to a central data unit at a monitoring centre. This transfer may take place on an hourly or on a daily basis. Data are often transferred via public telephone lines during night time hours.

The data retrieval from monitoring stations, which are equipped with modems and telephone lines, may be performed by the monitoring or computer centre using the following procedures:

- The central data base system asks for data automatically once a day (normally during night time hours, e.g. at 02:00 hours).

Box 4.4

Commonly Used Methods for Automatic Monitoring

Sulphur Dioxide (SO_2)
SO_2 are measured from the fluorescent signal generated by exciting SO_2 with UV light.

Nitrogen Oxides (NO and NO_2)
The principle of chemiluminescent reactions between NO and O_3 is being used for measuring NO and NO_x. NO_2 is being calculated from the difference between NO_x and NO.

Ozone (O_3)
An ultraviolet absorption analyser is being used for measuring the ambient concentrations of ozone. The concentration of ozone is determined by the attenuation of 254 nm UV light along a single fixed path cell.

Suspended particles; TSP, PM_{10} and $PM_{2.5}$
Gravimetric methods including a true micro-weighing technology are being used to measure ambient concentrations of suspended particulate matter (TSP). For automatic monitoring the method of "Tapered Element Oscillating Microbalance (TEOM)" has been most frequently used. Using a choice of sampling inlets, the hardware can be configured to measure TSP, PM_{10} or $PM_{2.5}$.

Measurement on filter tape using the principles of beta attenuation for estimating 30 minute or one hour average concentrations of PM_{10} or $PM_{2.5}$ have been operated with an air flow of about 18 l/min.

The DustTrak monitor is based on a laser-photometric method and is a cost-effective device to monitor PM_{10}, $PM_{2.5}$ and PM_1.

Carbon monoxide (CO)
The CO analyser often used in urban air pollution studies is a non-dispersive infrared photometer that uses gas filter correlation technology to measure low concentrations of CO accurately and reliably by use of state-of-the-art optical and electronic technology.

Hydrocarbons (HCs) and VOCs
Hydrocarbons (Non-Methane HCs, Methane and Total HCs) are being measured continuously by using a flame ionisation detector (FID). In developing countries short power breaks may interrupt these continuous measurements, and the devices will thus have to be restarted manually. To avoid these problems volatile organic compounds (VOC) can be sampled manually and analysed by gas chromatography in the laboratory.

BTEX monitor
A multipurpose gas chromatograph has been designed to continuously monitor single or multiple gas components in a wide range of applications. The BTEX analyser provides direct measurement of benzene, toluene, ethyl benzene and xylene's in ambient air. It employs a photo ionisation detector (PID) as the sensing element specific to volatile organic compounds. The individual compounds in the gas sample are separated using gas chromatography.

- The computer centre operator initiates download (manually) which requires that the modem is functioning.

The automatic data acquisition system (ADACS) is often a sophisticated modern solution using standardized and object-oriented technology to handle data flow, retrieval, quality assurance and storage. All these processes can be scheduled to run automatically. The system will thus save time in terms of replacing manual performance and avoiding human errors.

The ADACS typically consists of the following features:

- configuration for defining necessary information for accessing the monitoring stations and collecting data through the data logger;
- calibration and quality assurance with automatic flagging of monitored data;
- logging all the steps during acquiring monitored data.

The ADACS will also serve as a link to a meta-information system, which includes information on external environmental data, information on regulations, requirements, and air quality guideline values and standards for various applications. These functions might also include:

- navigation facilities to access the needed information;
- support for standardization activities;
- worldwide web/internet functions and links.

The database model is designed to support the user at local and regional levels and meet most of their requirements. Modifications and additions should be easy to make in the database. Routines for safe copying and reconstruction of lost or corrupted data should be available. As different data interfaces might be operating in different systems this requires the establishment of open communication solutions.

Monitoring Stations without Telephone Lines

A number of communication options for data retrieval can be used in cases that telephone lines are not available. Data have been transferred via blue-tooth to radio frequency transmission as well as via satellite and mobile phones. On-site options also include storage modules and laptop computers, which enable storage of air quality and meteorological data for several months.

In the absence of any telecommunication system data have to be collected manually via diskettes, CDs or memory sticks. Calibration values should always follow the data collection units for transmission into the database. This will then enable the necessary data quality controls and calibrations to be taken into account before data are approved. This manual collection of data should follow the instrument calibration routines. Normally the stations are visited every week for checks and calibrations. The same frequency should be applied for collecting data.

Manually collected data should be imported immediately to the central data base system and checked as soon as possible. Reports should be printed at least once a week, controlled manually and statistical procedures should be applied before approval.

3.1 Data Validity and Traceability

Before air quality data can be used to assess the situation in the area it is important to assure that the data collected are true estimates of concentrations. For each pollutant the following main questions should be answered:

- Have suitable quality assurance/quality control (QA/QC) procedures been set up for all stages and activities?
- Was a QA/QC plan followed rigorously?
- Has monitoring been carried out at suitable locations?
- Have suitable arrangements for data handling and storage been made and implemented?

The documentation to support the credibility of data collection and initial data quality assurance are the responsibility of the data provider. This includes the process of data collection, application of calibration factors, initial QA/QC procedures, data analysis, data "flagging", averaging and reporting. A combination of data record notes, data quality flags and process documentation are all part of this first phase of processing. During the data collection phase, one role of the data provider is to assist in maintaining process credibility and validity of the data.

The assessment makes sense only if three characteristics have been tested:

- validity
- traceability
- reproducibility.

Validity is supported by documentation that provides:

- Proof that all applicable standard scientific procedures were adhered to.
- Precise descriptions of all collected and processed numeric data including collection method; instrument type; instrument accuracy; instrument precision; data format; unit conventions; variable naming conventions; and QA/QC flags.
- Technical justification of all calculations and processes including parameter interpolations; quality assurance criteria; and scientific conclusions based upon new data processing and analysis routines built into the data management system. The last item enables inter-comparisons of new state-of-science monitoring technologies with existing technologies.
- Reference to external information upon which calculations, processes and conclusions are based.

Traceability is a documented history of all processes performed on each raw data set transmitted to the database.

Traceability is assured by maintaining tabulated, chronological listings, which summarize each step that is performed along with the method by which it is performed. It indicates the chain of steps along with the verification and quality assurance procedures implemented and the corresponding results.

Reproducibility allows the duplication of results at any data validity level. Reproducibility requires traceability, since all processing steps performed in producing specific results must be duplicated. Reproducibility requires that all data management tools used be stored together with a chronological set of data validation records for all data sets (e.g., source codes for processing programmes must be stored and available if needed).

It is of primary importance that data providers and the data manager make the necessary efforts to ensure that all aspects of data collection, handling, analysis, and evaluation are well documented. This is essential with respect to considerations of data validity, traceability, and reproducibility. Documentation accompanying data are a requisite for providing a data history, which gives value to the data. To accomplish this requires that good reporting procedures be maintained and implemented at each step of data handling and processing.

A rigorously implemented QA/QC plan assures the above elements and the achievement of good quality data or at least data of known quality. The implementation of the QA/QC plan is verified through a quality assessment, which assures that all procedures have been successfully followed. The implementation of QA/QC will also satisfy the data quality objectives (DQOs) defined by the responsible authorities. As a complete QA/QC plan is rather complex, the procedures to be followed should be carefully documented. A very important element in the quality control procedures is the calibration and traceability of the calibration standards used back to absolute standards of known quality. Institutions responsible for the QA/QC plan and its implementation may be national, regional or local.

3.2 Data Analysis

Once the data have been collected, transferred into the database and subjected to quality assurance procedures, they are ready for analysis and interpretation. Data analysis and data interpretation should be conducted to provide quantitative responses with respect to the objectives of the monitoring programme. The process should be designed to provide useful information in an appropriate format for the end-user.

Examples of the general type of questions to be addressed in relation to air quality assessment include:

- What pollutants are present and at what concentrations?
- Do the concentration or emission levels exceed standards or targets?
- Which are the sources and their individual contributions?
- Which population is exposed and what may be the impacts?
- To what extent would different mitigation measures help in reducing air pollution?

It is critical that in the planning of the monitoring programme the exact questions to be addressed in the data analysis and interpretation are very clearly identified.

A key tool in the process of data analysis and interpretation is statistics. The role of statistical methods in research is to enable the researcher to accurately utilize the gathered information and to be more specific in describing their findings. Before investigators can use statistical methods for data analysis, they should develop a general understanding of the various methods, their applicability, and data requirements. It is outside the scope of this document to provide an in-depth discussion on this topic (see Daniel, 1995; Johnson and Bhattacharyya, 1996). Statistical methods in the broadest sense are classified into two main groups: *descriptive* and *inferential* statistics.

Descriptive statistics

In a general sense, descriptive statistics can be considered as the formulation of rules and procedures according to which data can be placed in useful and significant order. More specifically, it deals with issues such as central tendency (arithmetic or geometric mean, median), variability (variation) and relationships (correlations). The most important and general methods used include ratios, percentages and frequency distributions, and correlation coefficients.

A minimum level of descriptive data evaluation could be the production of peak/average statistics of daily, monthly and annual summaries, involving simple statistics and graphical analyses that show both time and frequency distributions of monitoring data. The use of a GIS should also be considered, particularly when the intention is to combine pollution data with those from epidemiological and other geo-coordinated social, economic or demographic sources.

In general, simple steps of descriptive data analysis and interpretation include:

- Identify critical variables required to respond to your research question.
- Sort, scale, and graph data in a spreadsheet.
- Evaluate location parameters such as arithmetic or geometric means, median, percentiles.
- Visually display data to emphasise relevant tendencies, trends and patterns.
- Differentiate between recognisable data patterns and outlying data.
- Suggest explanations for recognisable data patterns and outlying data.

The assessment of recognisable data patterns and the test for outliers lead to the application of methods of inferential statistics.

Inferential statistics

Inferential statistics or statistical induction comprises the use of statistics to make inferences concerning some unknown aspect of a population. Statistical inference is inference about a random sample drawn from a population. It includes:

- point estimation
- interval estimation
- hypothesis testing (or statistical significance testing)
- prediction.

There are several distinct schools of thought about the justification of statistical inference – frequency probability and Bayesian approach. All are based on the idea that real world phenomena can be reasonably modelled as probability.

3.3 Air Quality Assessment and Reporting

Standardized statistical analysis should be performed to assess air quality tendencies and trends, changes in emissions or concentrations from specific types or groups of sources. The severity of the air pollution problem or the air quality should be specified relative to air quality guideline (AQG) values, standards or predefined levels of classification (e.g. good, moderate, unhealthy or hazardous).

The number of hours and days, or percentage of times when the air pollution concentrations have exceeded AQG values or standards should be presented. This will also need minimum requirements of data availability. Long-term averages (annual or seasonal) should be presented relative to corresponding AQG values or standards.

On-line air quality monitoring systems enable access to data and quick treatment of data so that presentation in a number of different media is possible. For the evaluation and assessment of air quality data collected by a monitoring system some of the basic statistics are often integrated.

Different use of the data collected and different presentations are needed for different users. The information may be presented in multimedia and contain texts, tables, graphs, images, sound or video messages. The presentations have to be designed to meet the user's needs. Best means for this are graphics which are easy to understand. The most frequently used graphics are:

- time series of measurements or their short-term means from one monitoring location (for one or more pollutants) or comparing various locations;
- bar charts or line graphs presenting long-term (annual) mean values presented over a longer period;

- the cumulative frequency distribution of short-term mean values (hourly) presented over a longer period (year);
- spatial distribution of concentrations of selected indicators;
- percentage of data exceeding limit values (in tables or on maps as spatial distributions);
- wind frequency distributions (wind roses) and stability frequencies;
- average concentration as a function of wind directions (Breuer diagram);
- more complicated spatial comparisons of pollution patterns are greatly facilitated by the use of maps. The (mean) pollution concentrations in various locations can be simplified by presenting bars or dots with varying colour or size on a map of the area.

Data presentations are to be produced to meet the requirements from:

- professionals in air pollution;
- policy makers; and
- the public.

Professionals often need easy access to the data with the ability to work with these data in different ways. A professional may also want to apply the data in hypothesis testing and present results in his own way.

Policy makers need presentations that illustrate in a concise way the conclusions that the professional has drawn from the information available. The presentations should be prepared in a way that the politician can decide on necessary actions to mitigate the problem. Information to the policy makers should be presented in summaries and in annual reports. Reports may include simplified tables and graphs for a considered period. Tables will give the reader the necessary numerical values, while graphs will present a picture of the situation, which are easy and quick to understand.

The ***public*** needs information on the general state of the environment and advice on how to behave under certain exposures. The type of information needs to cover environmental issues that are of special concern to the public. This could be the air quality that is extant or expected to occur in the urban area. This information could be given as actual on-line data or as a short term forecast. The public needs information that is easily understandable. This could be achieved through leaflets, radio broadcasts, television messages or through screens located at public places in the city. These may give a simplified air quality index for the city on the given day, or it can give continuous up-to-date or on-line information on air quality measured in the area. In many countries air quality information are now also available via the internet and can be accessed through peoples' personal mobile telephones.

3.4 Concentration Data for Compliance Testing

Prior to the use of air quality data for compliance testing a comprehensive site review should be undertaken to evaluate the performance of ambient air monitoring stations in the area of interest. For each station it should be verified that established site criteria are met and that data are representative for the area around the monitoring station. In the US the requirements and the site criteria are set out in USEPA, 40 CFR 58 (USEPA, 2006b). UNEP/WHO has also provided publications on site criteria (UNEP/WHO 1994a; Schwela, 2003).

Each year, a thorough evaluation is necessary at each station for criteria such as sampler selection, purpose, objective, residence time, scale, station temperature, obstacles, traffic, local sources, and dominant influence. While most ambient air monitoring stations carefully adhere to regulations during the initial site set-up, as reflected by their site reports, changes occur over time that are often overlooked by station operators. Some changes that occur include scaling problems, source problems, obstacles, and temperature requirements.

Local, national and supranational authorities often regulate reporting procedures for compliance through setting standards, or providing directives or conventions. They specify the subject, format and frequency of reporting. The frequency by which a certain standard or threshold concentration established by the regulation may be exceeded is often set by legislators.

The statistical analysis of measured air quality data will give, in addition to average and maximum concentrations, the frequency of occurrence of given concentration levels. It may be used to identify the number of exceedances of limit values and compare it with a permitted number.

In Europe a questionnaire has been prepared for annual reporting on ambient air quality assessment under Council Directive 2004/461/EC (EC, 2004). The questionnaire includes a number of forms, which distinguish between items that are legally required to report and items that are voluntary to report for the Member States. All cases of violation of limit values for NO_2, PM_{10}, SO_2 and other indicators given in the list of limit values are to be reported. If the margin of tolerance at a station has been exceeded this also will have to be reported. The total number of hours and days when limit values were exceeded is part of the reporting procedures.

Reports from such compliance monitoring networks are of limited use for assessing population exposure and health effects. Certain health effects may be expected at concentrations below the standard level, and these are not reported. In addition, the location of monitors in compliance monitoring may not be optimal for assessing population exposure, and the reporting may give an incorrect picture of population exposure.

3.5 Use of an Air Quality Index in Different Countries of Asia

The Air Quality Index (AQI) is an index for reporting daily air quality. It tells you how clean or polluted the air is, and what associated health concerns people should be aware of. The AQI focuses on health effects that can happen within a few hours or days after breathing polluted air. The idea of a AQI was first introduced and applied in the US in the form of the pollutant standard index (PSI). The PSI was defined as the sum of the ratios of the concentrations of criteria pollutants and their corresponding standards. Today most of the air quality monitoring systems in Asia is present daily values of AQI.

USEPA's PSI is based on five major air pollutants regulated by the Clean Air Act: ground-level O_3, PM, CO, SO_2 and NO_2. For each of these pollutants, USEPA has established national air quality standards to protect against harmful health effects. The PSI can be considered a yardstick that runs from 0 to 500. The higher the PSI value, the greater the level of air pollution is and the greater the health danger. For example, an PSI value of 50 represents good air quality and little potential to affect public health, while an PSI value over 300 represents hazardous air quality.

Many countries and urban areas in Asia have adapted AQI values with the intent to inform the public. An AQI value of 100 generally corresponds to the national air quality standard for the pollutant. AQI values below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered not to be healthy.

The purpose of the AQI is to help the user to understand what local air quality means to health. In order to make the AQI as easy to understand as possible, the AQI values have been divided into six categories, often presented to the public as a colour code. Each category corresponds to a different level of health concern. For example, when the AQI for a pollutant is between 51 and 100, the health concern is “Moderate” (see Figure 4.13).

From examples of AQI values generated in Asia we have seen that the procedures may vary slightly from one country to another. In Bangladesh the air quality monitoring programme generates a daily AQI value linked to the national ambient air quality objectives. The air quality is classified in five classes. In other countries the selected values used for generating the AQI values have been compared with the WHO guideline values of 1987 or 2000 for air quality. A practical example of the calculation of an AQI is provided in Box 4.5.

Air Quality Index (AQI) Values	Levels of Health Concern	Colours
When the AQI is in this range:	Air quality conditions are:	As symbolized by this colour:
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for sensitive groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very unhealthy	Purple
301 to 500	Hazardous	Maroon

Figure 4.13: Air quality index

Box 4.5

Air Quality Assessment in Ho Chi Minh City

In Ho Chi Minh City (HCMC), Vietnam AQI values are generated automatically every day. The measured results for the potential harmful species PM_{10}, NO_2, CO, SO_2, and O_3 are included for determination of the AQI. All parameters may not be measured at a given station. In this case only the measured parameters are included. Further, both hourly and daily averages are included to take into account that the health deterioration may be initiated both by short time exposure to high concentrations and long time exposure to lower levels. This fact is also reflected in the air quality standards. The AQI has been established in the air quality database and management system (AirQUIS) based on the present and proposed air quality standards for Vietnam (TCVN 5937:1995 and TCVN 5937:2005).

The simplest way to estimate the AQI for HCMC is dividing the procedures into hourly AQI(h) based on hourly concentrations and 1-hour average standards given for Vietnam, and daily AQI(d) based on daily average concentrations and 24-hour average standards. The final AQI for each day will be the highest value of the hourly maximum AQI value and the daily AQI.

In the analysis below the following nomenclatures for HCMC have been used:

h = hour
j = site
i = compound
d = daily (24 hour)
C = concentration
S = standard (hourly, daily, annual)

Sites:
1 = DOSTE
2 = Hong Bang
3 = Tan Son Hoa
4 = Thu Duc
7 = Zoo, District 1
9 = Quang Trung
8 = District 2 PC
5 = Thong Nhat Hospital
6 = Binh Chanh Educ Centre

The highest ratio of concentration to standard for any site and compound during this hour is being estimated from:

$$\mathbf{AQI(h,j) = Max_h\ (C(h,i,j)/S(h,i))\bullet 100}$$

A daily index is also established for the compounds (SO_2, NO_2, CO, O_3 and PM_{10}) available at each station. The procedure is similar to the hourly giving:

$$\mathbf{AQI(d,j) = Max\ (C(d,i,j)/S(d,i,))\bullet 100}$$

The daily AQI will be selected as the higher of the two indexes:

$$\mathbf{Max((\ AQI(h,j), AQI(d,j))}$$

Based on a total of 9 stations in operation in HCMC the index has also been divided in two categories, one for traffic stations one for urban background stations:

Traffic:

$$\mathbf{AQI(traffic) = (AQI(1)+AQI(2)+AQI(5)+AQI(6))/4}$$

Urban/residential:

$$\mathbf{AQI(urban/residential) = (AQI(4)+AQI(7)+AQI(9))/3}$$

To assure that adequate data quality has been taken into account in the generation of an AQI, the following quality assurance has been considered:

- Data with *warning and exclude flags* will not be part of the AQI estimate.
- Negative concentrations are not included.
- At least 6 one-hour average concentrations are needed to produce a daily AQI.

Exclude flags include missing data and too many equal values after each other (presently set at 3 values). Warning flags relates to expected minimum and maximum values. The air quality is categorized in five classes, similar to the USEPA guidelines (USEPA, 2006b). Figure 4.12 presents air quality classes.

The generated AQI values are being transferred every day to the information board near Binh Thanh marked in the city centre of HCMC. The AQI estimated for the preceding day is also presented on the website of HCMC's Environmental Protection Agency (HEPA). The final evaluation of the automatic AQI generator has been tested and evaluated and is now on the HEPA website (HEPA, 2007).

Classification of index	
0 to 50	Good
51 to 100	Moderate
101 to 200	Poor
201 to 300	Unhealthy
301 and above	Hazardous

Figure 4.12: Air quality index in Ho Chi Minh City

Summary

In this module you have learnt about the role of monitoring in AQM and have gained an understanding of the:

- design of monitoring programmes
- monitoring objectives
- site selection
- number of sites needed for monitoring
- sampling frequency
- sampling time
- meteorological measurements needed in modelling.

The module reviewed the different types of monitoring instruments for key air pollutants including:

- Passive samplers
- Active samplers
- Automatic monitors
- Remote sensors.

You have learnt about the different issues one should consider in selecting monitoring equipment and the importance of quality assurance and quality control in air quality monitoring, which should be rigorously implemented. Finally, you have learnt about how air quality data can be used to inform decision-makers and the public, allowing them to take action to protect human health.

The key messages you should take away from this module on air quality monitoring are:

- ▶ Careful planning of monitoring is indispensable.
- ▶ Only a clear definition of monitoring and data quality objectives can lead to reasonable results.
- ▶ Development of a QA/QC plan and strict adherence to it is indispensable to obtaining meaningful results from monitoring.
- ▶ In LDCs, the use of simple monitoring devices such as passive samplers, DustTraks and minivols is preferable to sophisticated devices.
- ▶ Use of a few automatic analysers for PM and gaseous compounds in an otherwise hybrid monitoring network is cost-effective and sufficient to achieve monitoring and data quality objectives in LDCs.

In Module 5 *Impacts* you will learn about how certain pollutants affect human health and environment. In particular, you will learn about the methods used to study and assess the impact of air pollution on a given population and the associated economic costs.

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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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