AIR QUALITY MONITORING AND EVALUATION TOOLS FOR HUMAN HEALTH RISK REDUCTION IN SOUTH AFRICA

Caradee Wright[1] and Rietha Oosthuizen
CSIR Environmental Health Research Group, Pretoria, South Africa.
[1]cwright@csir.co.za

Abstract

Air pollution is a serious environmental health threat to humans. Adverse effects range from nausea, difficulty in breathing and skin irritations, to birth defects, immuno-suppression and cancer. Moreover, the severity of health outcomes associated with air pollution exposure is not uniform within populations. In South Africa, the problem is exacerbated since vulnerable communities reside on land in close proximity to pollution sources. New air quality legislation aims to protect the health of South Africans through the implementation of air quality management plans and air quality monitoring programmes. To assess the effectiveness of these actions and implemented mitigation measures with respect to health outcomes, specific indicators are required. Air quality monitoring and evaluation tools were reviewed to consider their application in South Africa. For effective protection of human health, information on air pollution source, type and concentration is essential, but so are data on the severity and magnitude of adverse health effects both spatially and temporally. Information on population exposure and exposure-health associations derived from epidemiological evidence is also required. While it is acknowledged that ambient air quality limits were established from the documented effects of air pollution exposure on human health, air quality monitoring and evaluation methods for South Africa should also consider the evaluation of air quality results in relation to specific health outcomes.

Keywords: air pollution, health, population exposure

1. Introduction

Air pollution comprises both indoor and outdoor pollution. Outdoor air pollution is largely a consequence of fossil fuel combustion for transport and electricity generation, industrial non-fossil fuel emissions and other human activities. Indoor air pollution usually results from the burning of wood, coal or paraffin for space heating, cooking and lighting purposes.

Air pollutants may be grouped into four categories:

1. **Gaseous pollutants**, e.g. sulphur dioxide, carbon monoxide, ozone.
2. **Persistent organic pollutants**, e.g. dioxins.
3. **Heavy metals**, e.g. lead, mercury.
4. **Particulate matter**, e.g. PM_{10}.

Inhalation of air pollutants is a major environmental health threat. Adverse effects range from nausea, difficulty in breathing and skin irritations, to birth defects, immuno-suppression and cancer (Kampa and Castanas, 2008). An increase in hospital admissions has been associated with increased air pollution (Brunekreef and Holgate, 2002), however, the difficulty lies in determining which air pollutant is responsible. The air inhaled by an individual is a mixture of gases, including air pollutants such as particulate matter, which may differ in composition. Also, exposure may vary by concentrations, duration and timing, further complicating analysis of actual causation.

Several epidemiological studies have considered the associations between air pollutants and adverse health effects (Dockerty, 1993; Pope et al., 2002). However, confounding factors, such as smoking, and challenges relating to pollution composition and mixture, as well as personal exposure, prevent concrete evidence from being defined. Despite these uncertainties, sufficient evidence exists to suggest that increased air pollution exposure may cause increased mortality and morbidity in some countries.

The monitoring of air quality (AQ) and evaluation of results is fundamental for assessing the nature of population exposure to air pollution. The aim of an AQ monitoring programme is to reduce or eliminate air-related diseases and illnesses through implementation of effective preventative measures to reduce air pollution. Thus, the ultimate goal of AQ monitoring and evaluation (M&E) as part of an AQ management programme is to protect the receiving environment and reduce human health risks.

For effective protection of human health, information on pollution source, type and concentration is essential, but more so are data on the severity and magnitude of adverse health effects, i.e. number of cases attributable to air pollution (Mucke, 2000). Also, information on population exposure, and exposure-health associations derived from epidemiological evidence, is needed. In order to define an AQ M&E framework focusing on health outcomes for South Africa, a review of available programmes and indicators was made.

2. Methods

Studies published in the English language, 1990 to July 2009 inclusive, were identified through systematic searches of several computerized bibliographic databases, including ScienceDirect and Entrez PubMed.

Combinations of search terms and subject headings were used to search for articles on AQ, AQ monitoring and AQ evaluation. Search terms included 'air quality/AQ', 'AQ measurement', 'AQ monitoring/air quality monitoring', 'AQ evaluation/air quality evaluation', 'air pollution monitoring', 'air pollution evaluation' and 'monitoring and evaluation programmes'.

The reference lists of studies retrieved from the initial searches were then searched for any previously unidentified studies. These studies and their subject headings were located and used to conduct further searches, cross-referencing and searching again until no further studies were identified. This technique was used because the multidisciplinary and multidimensional studies of interest are not easily located with a single search in one database.

We are not aware of any other completed but unpublished studies to date (July 2009), although such studies may be in progress. All of the identified studies were reviewed, data were abstracted using standardized forms, and the abstracted data were summarized in tabular format. Given variation in the topic studied and the diversity of measurement techniques used, no systematic scoring system was developed to rate the quality of the studies. Nevertheless, by summarizing methods, and by identifying the strengths and weaknesses of each study, a pragmatic working procedure was developed.

3. Results and Discussion

The aim of an M&E framework is to assess whether progress is being achieved in line with predetermined expectations. Monitoring is the ongoing collection and analysis of data to determine whether goals are being met. Evaluation is a comprehensive appraisal that considers short- and long-term impacts and exposes what worked, what did not work and how improvements may be made for future monitoring and evaluation schedules. A typical M&E framework may include the following principles:

- contribute towards ensuring objectives of the plan are achieved;
- track progress on implementation of plan;
- identify gaps and weaknesses;
- plan, prioritise, allocate and manage resources; and
- ensure sound financial management.

A logical M&E approach entails five core steps: input, process, output, outcome and impact indicators. Figure 1 represents such a process diagrammatically. The framework follows a fairly linear path, with iterations in the middle phase incorporating monitoring and evaluation.

For an AQ M&E framework, the largest challenge is deciphering impacts and indicators thereof, particularly related to health outcomes. Previous AQ monitoring programmes may be considered lacking in this regard. Their focus was predominantly on monitoring ambient AQ levels and comparing results to criteria pollutants' ambient standards. Furthermore, consultation with stakeholders for both indicator development and results evaluation is an important consideration for inclusion, especially in a South Africa context.

3.1 Air quality monitoring techniques

Monitoring of ambient air pollution and personal air pollution exposure may be carried out using several techniques and instruments, illustrated in Table 1. However, procedures for population exposure at individual level are not routine in most countries, where ambient AQ monitoring tends to be the norm. Population exposure research has been done for specific research studies. For example, bio-monitoring has been used to assess population exposure to benzene (Tchepel, Penedo and Gomes, 2007) and activity-based population modelling for exposure analysis (Beckx et al., 2008).

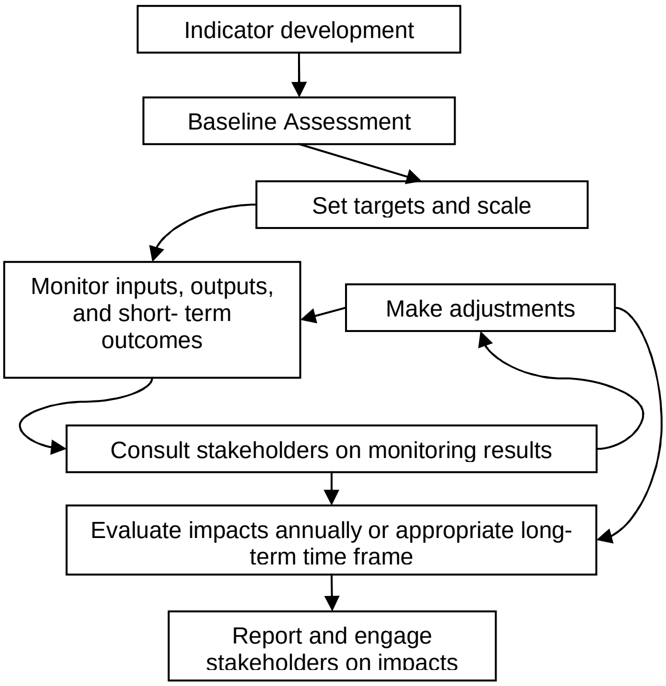

Figure 1. Generic M&E framework

Table 1. Examples of techniques and instruments for monitoring air pollution

Ambient air pollution
Instrumentation
Continuous monitors
Passive Samplers
Open path instruments
Fluorescence analysers
Chemiluminescent Analyser
Ultraviolet Photometric Analyser
Gas chromatography
Particulate samplers

Personal air pollution exposure
Approaches
Personal monitoring, e.g. monitored with device
Exposure modelling, e.g. time-activity patterns
Biomarkers, e.g. mercury in urine
Ambient air pollution as proxy for personal exposure

3.2 Air pollution mitigation measures

Air pollution mitigation encompasses a broad range of technological innovations and intervention policies. The aim of air pollution mitigation or abatement measures is to protect public health. Table 2 presents a list of commonly referred to air pollution mitigation strategies.

Table 2. Air pollution mitigation strategies

Sector	**Measure**
General policies	Application of the 'polluter pays principle' Energy and fuel pricing Eco-taxes Prioritise public transport systems Urban planning Renewable energies to replace fossil fuel
Stationary sources	Emission control in industry Regulation of solvent use Fuel production and distribution Coal, coke, oil reformulation for power plants, industrial boilers etc Modification in combustion processes Closed circuit in dry cleaning
Mobile sources	Catalyst and particle filters for heavy duty traffic, cars, trains, motorcycles, off-road vehicles Taxing kerosene for aircraft Low- or no-emission engines Alternate traffic regimes Fuel consumption-dependent taxes
Products	Solvent replacements in paints etc

A comprehensive and holistic approach is needed when implementing interventions to ensure effective and sustainable impact. For example, improving car exhaust technology will only improve air quality if the number of cars on the road remains the same. An increase in traffic, even with improved exhaust systems emitting 'cleaner air', is unlikely to lead to an overall reduction in vehicular air pollution. Traffic policies, such as car pooling, should occur in tandem to technological improvements.

3.3 AQ monitoring programmes

Ambient AQ M&E is carried out in several countries worldwide, including in South Africa. Few countries formally define the process as an AQ M&E procedure; however, in essence, this is what is being done. Figure 2 proposes a generic AQ M&E framework. Such frameworks have been applied in the implementation of AQ monitoring programmes in, for example, Canada (Huyn Shin et al., 2009), Europe (Mucke, 2000), Spain (Ferreira et al., 2000) and New Zealand (Kjellstrom, 2000).

National (and sometimes local) standards for criteria air pollutants (indicators of air quality for which most countries have standards for) are set based on WHO guidelines determined from critical review of epidemiological studies (WHO, 2005). Most AQ M&E processes have used criteria pollutants as AQ indicators (see Table 3 for criteria pollutants). Evaluation is performed using total emissions inventories, absolute measured or modelled ambient AQ levels to determine the reduction in emissions. More complicated evaluations may be done whereby various pollutants are weighted by their toxicity and reductions appear more significant.

AQ monitoring is typically carried out at municipal level of government and often by external parties such as consultants and industry. No evidence suggests that indoor air quality monitoring is a routine part of any AQ monitoring programme, in South Africa or abroad. Furthermore, urban areas tend to be better monitored than rural areas, probably since air pollution is more of a concern in urban areas where resources are also more readily available for monitoring purposes. Health surveillance is not commonly part of an AQ monitoring programme.

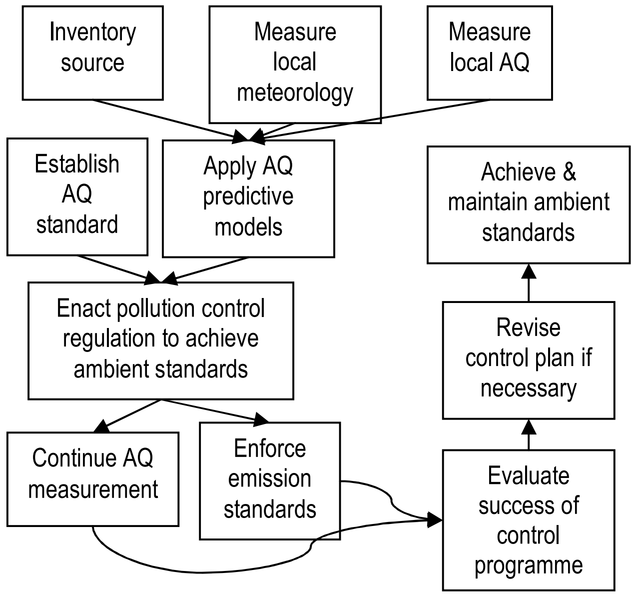

Figure 2. A proposed generic AQ M&E framework

Although AQ standards are determined based on known limit values for adverse air-related health effects, it cannot be assumed that improved AQ will lead to improved air-related human health. Very little is known about air pollution mixtures and subsequent health effects (Sexton and Hattis, 2007). Even less is known for certain about the potential impact of climate change on air pollution-related human health effects (Tagaris et al., 2009) – will standards remain applicable in a changing micro-climate?

3.4 A new approach to AQ monitoring: Putting health on the agenda

The objectives of an AQ M&E framework should be:

1. To reduce air pollution to meet health-based AQ standards;
2. To provide improved data and information for decision-making; and
3. To improve quality of life.

To meet these objectives, a new approach is required whereby health and vulnerability indicators are incorporated into the AQ M&E framework. There is keen interest to expand the thinking behind indicator application to include environmental health indicators with specific focus on air-related health effects.

Table 3. Typical criteria air pollutants and averaging periods

Air pollutant	Averaging periods
Benzene	One year
Carbon monoxide	Eight hour
Nitrogen dioxide	One hour; one year
Ozone	One hour, one year
Sulphur dioxide	One hour, 24 hours, one year
Lead	One year
Particles as PM_{10}	24 hours, one year
Particles as $PM_{2.5}$	24 hours, one year

Health surveillance should not be used as an alternative to the maintenance of AQ monitoring and control measures. The prevention of ill health and disease through sound air pollution controls and mitigation measures is vital. The purpose of health surveillance should be seen as a method to ensure control measures are effective and to provide an opportunity to reinforce specific preventive measures.

Figure 3 presents a preliminary framework for using AQ standards and health status to assess impact. The fundamental concept underpinning this approach is that the focus cannot be on exposure alone, thereby assuming that risk will decrease as exposure is reduced. Rather, both exposure and risk require monitoring and evaluation to ensure positive impact on the receiving environment.

Health indicators should extend beyond mortality and morbidity measures, and respiratory illnesses and diseases. Instead, those factors influencing a person's ability to cope, in other words their vulnerability should also be taken into account. These include socio-economic, service delivery, disease prevalence, nutritional status and demographic indicators as discussed in Wright and Diab (in press) and summarised in Table 4.

4. Conclusions

In South Africa, the implementation of the National Environmental Management: Air Quality Act No. 39 of 2004 saw a shift from individual source-based controls to an ambient AQ objectives approach and more focus on the receiving environment including human communities.

Table 4. Potential health and vulnerability indicators for AQ monitoring and evaluation

INDICATORS
Demographic
Average age of community members
Number of female-headed households
Ratio of previously disadvantaged groups to advantaged groups
Annual average household income less than R430/month
Number of people per km^2
Health
Prevalence of respiratory diseases
Prevalence of HIV/AIDS
Incidence and prevalence of other communicable diseases (i.e. TB, malaria, viral hepatitis, typhoid, measles etc)
Estimated life expectancy at birth
Number of doctors at local health clinic and/or government hospital per 1000 people
Proximity to nearest clinic or government hospital
Proportion of children immunised against diphtheria, pertussis, tetanus, polio, hepatitis, TB and measles at age 1 year
Percentage of nutritional problems recorded at nearest local health clinic
Proportion of schools providing schoolchildren with food at school
Exposure and risk
Specialist study (exposure and activity patterns) completed and presence of risk found
Recent disasters (i.e. floods, fires from tank explosions, toxic waste spills)
Number of crimes reported per annum per 100 000 people (in a South African community)
Socio-economic
Frequency of waste removal
Proportion of community using paraffin and gas
Proportion of community using untreated water
Proportion of community having a shared water supply greater than 200m away
Proportion of community having none or any type of toilet other than a flush toilet
Proportion of informal and tribal settlements
Proportion of community achieving Grade 12 (of potential age) and higher
Proportion of community unemployed, student, home-maker or housewife, pensioner, unable to work due to illness or disability, seasonal worker
Area per capita of community designated public parks, gardens and other open space for potential mental health benefits

AQ management plans and AQ monitoring are essential components of this approach to ensure standards are met and health is improved. In South Africa, air-related health studies have been limited to known problem areas (now defined as priority areas) such as the Vaal Triangle (Terblanche, 1998). Routine health surveillance is not commonly part of an AQ monitoring programme.

A preliminary M&E framework for AQ and health impact has been proposed that incorporates health and vulnerability indicators. Foreseen challenges to solve for its implementation entail agreement on responsibilities for action between key government departments; implemented procedures must be adequate to assess health risks and better control air pollution; and health surveillance data issues (i.e. data capturing, processing, availability etc) will have to be resolved. Tackling these concerns and challenges will bring South Africa one step closer to achieving improved quality of life and a healthy and productive population.

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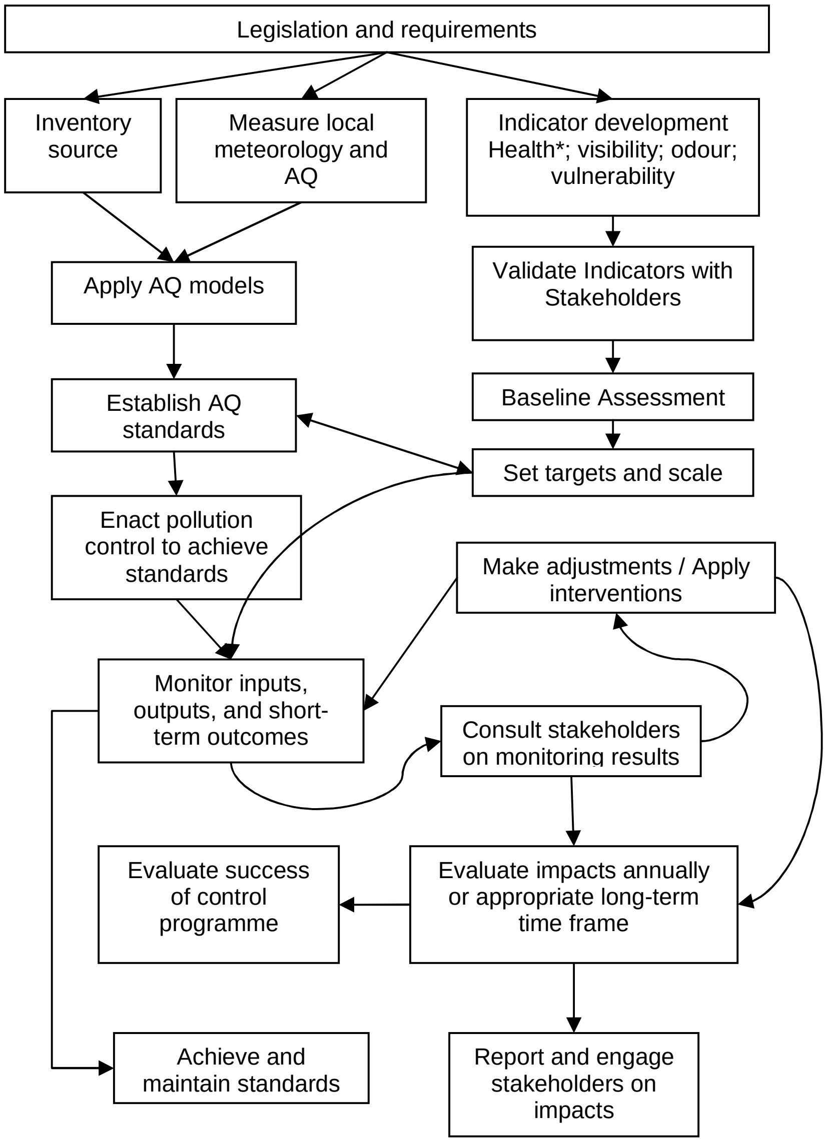

Figure 3. AQ M&E framework using AQ and health status to assess impact

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