Simple Interactive Models for Better Air Quality

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# Informed Decision Support for AQM in Developing Cities

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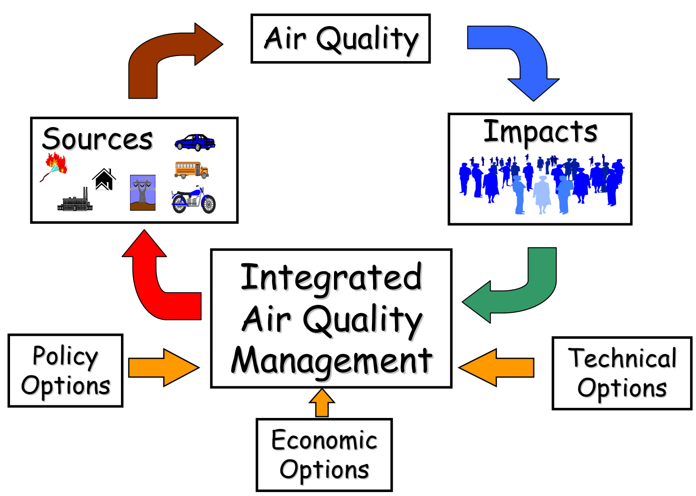
July, 2008




Information to Emissions Management

SIM-air Working Paper Series: 03-2008

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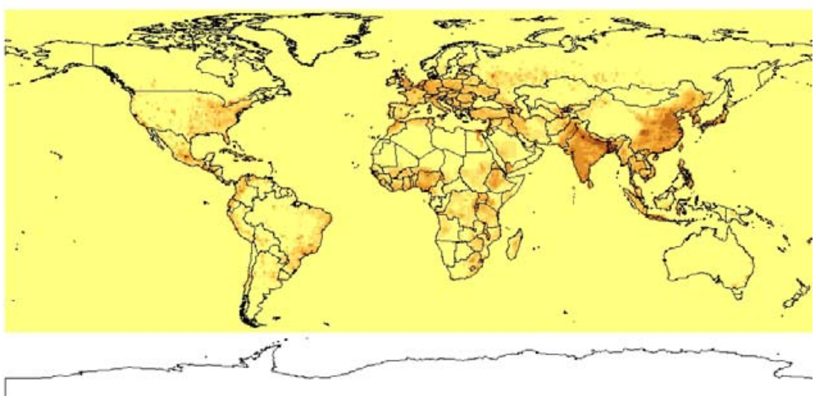
## Urbanization and Pollution

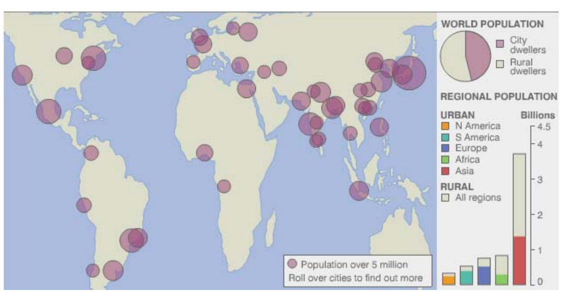
The growing economies of the developing world, particularly in East and South Asia, are leading to increasing urbanization, industrialization, and motorization. Urban areas have grown from being home to a few at the turn of the century to claiming almost half the population of many of these countries. Cities are growing at the rate of 1 million people per week. The 23 current megacities (9 in Asia) on 2% of the land are expected to grow to 36 (13 in Asia) by 2015 and about 300 cities with 2 million+ populations are expected by 2025[1]. China is expected to have 1.3 billion people in urban cities, by the middle of this Century.

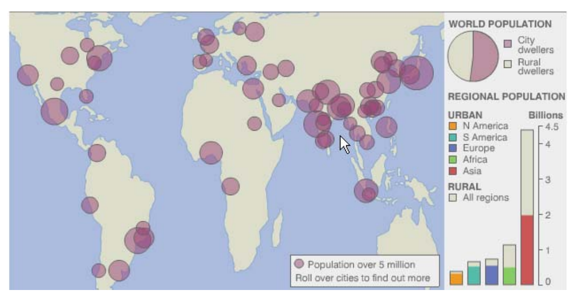


**Grids in 2005 with**
1-2 million = 755
2-5 million = 560
5-10 million = 186
10-20 million = 39
20+ million = 7

**Grids in 2015 with**
1-2 million = 791
2-5 million = 615
5-10 million = 198
10-20 million = 59
20+ million = 10

Figure 1: World population in 2005 at 1 x 1 degree resolution (SEDAC GPW3)[2]




**2000** **2015**

Figure 2: Megacities and urban centers (BBC Urbanization)[3]

Urbanization exerts pressure not only on the local infrastructure and environment but also links to regional (e.g., acid rain) and global (e.g., climate change) environment. Due to the rapid industrialization and motorization, high levels of air pollution is being experienced (and worse is anticipated) firstly in the urban areas, and gradually sprawling to the growing number of secondary and tertiary centers (highlighted in red numbers in Figure 1). WHO estimates damages at 800,000 deaths and 4.6 million lost

[1] www.demographia.org
[2] SEDAC – Gridded Population of the World - http://sedac.ciesin.columbia.edu/gpw
[3] BBC Urbanization Trends - http://news.bbc.co.uk/2/shared/spl/hi/world/06/urbanisation/html/urbanisation.stm

life-years caused by the urban air pollution every year, and two-thirds of such deaths and lost life-years are assumed to occur in the Asia.

The increasing consumption of fossil fuels such as coal, oil, and natural gas has led to rapid increases in emissions of pollutants. The Figure 3 presents trends in energy consumption for coal, oil, gas, and electricity in the major sectors in the last three decades (IEA Outlook)[4]. Major sources include transport, power plants, industries, domestic and other area sources. The coal consumption in the industries and the oil in the transport are the largest growing fuel sources. In the developing countries, growth rate is higher, the largest observed in China and India, owing to their economic growth and consequently increasing the burden on local and regional environment.

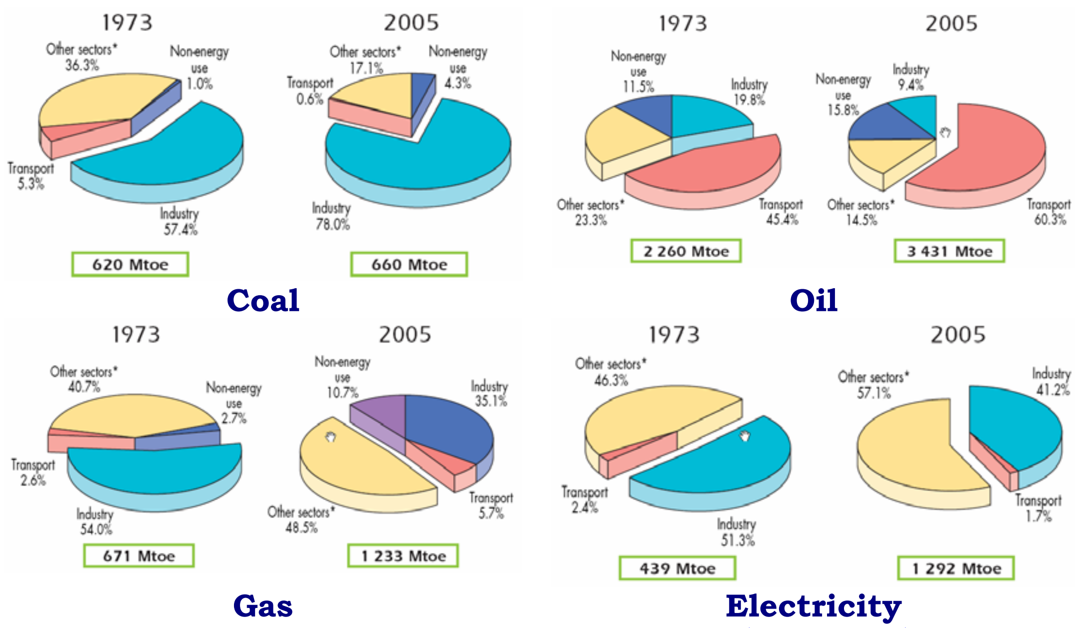



Figure 3: World energy consumption by sector (IEA Outlook)

The most typical pollutants include particulate matter (PM), nitrogen oxides (NO and $NO_2$, collectively termed $NO_x$), sulfur dioxide ($SO_2$), carbon monoxide (CO), volatile organic compounds (VOCs), lead (Pb), and carbon dioxide ($CO_2$). Pollution includes both - the primary emissions from various source categories and secondary sources, where primary emissions transform to form other pollutants via a series of chemical reactions, such as ozone ($O_3$) and secondary organic aerosols.

A fair amount of $SO_2$, $NO_x$, and $CO_2$ come from industrial sources, and especially the industries contribute a high percentage of the whole $SO_2$ emissions. Domestic emissions come from use of coal for cooking and heating purposes. Such usage also contributes to the indoor air pollution, but this paper concentrates on the urban air pollution only.

[4] International Energy Agency - http://www.worldenergyoutlook.org/

Motor vehicle emissions, the primary pollution includes the pollutants that are directly emitted to the air, such as PM, $SO_2$, $NO_x$, VOCs, CO, and $CO_2$, and the mix of the emissions, such as $NO_x$ and VOCs dictate the formation of secondary pollutants, for example $O_3$.

In the developing countries, besides the common sources listed in Figure 3, other sources that significantly contribute urban air pollution include, biomass burning, open waste burning, unconventional fuel burning (field residue, fuel wood, and cow dung), and resuspension of the road dust in conjunction with wear and tear of tires. Natural sources also contribute to the ambient concentrations, but seasonal in nature, e.g., the dust storms and forest fires.

Emissions of these pollutants are dispersed into the atmosphere (influenced by parameters such as meteorology and topography), raising ambient levels of these pollutants. This dispersion stage could also change the ambient levels of pollutants (e.g. photochemical reactions to form secondary particulates).

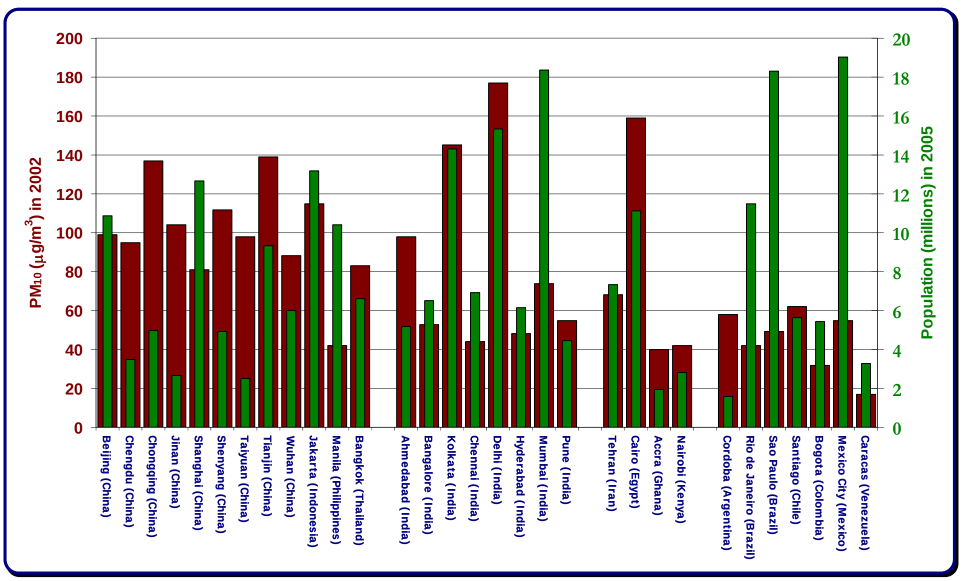



Figure 4: Population vs. $PM_{10}$ in urban centers (WDI, 2007)[5]

The developing country cities are experiencing the highest *PM pollution, the main reference pollutant for evaluating and analyzing the human health impacts*. Fine PM are of special concern and known to cause health problems such as premature mortality and morbidity, implying significant economic damages (studies by Health Effects Institute). In addition, the air quality of a city could impact buildings, monuments, and also deter investors and impact the quality of life of residents. The Figure 4 presents average estimated $PM_{10}$ concentrations against the population.

[5] World Development Indicators - http://devdata.worldbank.org/data-query/

The secondary and tertiary cities, following the urbanization trends of the megacities, not only for the economic success, but also the environmental fate at all levels, need immediate sharing of the lessons learnt.

## Informed Decision Making

Informed analysis helps policy makers narrow the range of policy, economic, administrative, and technical options to improve air quality and to achieve desired objectives of sustainable environment (in a broad sense).

To mitigate air pollution in developing country cities, a number of options are under consideration. Some of the examples include fuel quality control, inspection and maintenance (I&M), technology improvement, fines, taxes, and installing better monitoring stations.

In order to make informed choices amongst the bewildering array of options (presented in Figure 5), decision-makers need to be able to analyze these options from an environmental, economic, social, and political economy viewpoint. All this requires flexible analysis frameworks to evaluate options as they emerge, which, in turn, need substantial quantities of relevant information on various aspects of air quality and characteristics of management options.

City-level assessment is essential because each urban region is unique not only in its air pollution quality and its amount of emissions, but also they are culturally, economically, and socially different, affecting the viability of various management options. It is important to note that the conditions and magnitude of exposures to pollution and the health status, including the level of health care, of city populations differ between cities. This is to say that there is a growing need in developing countries for the city-level AQM - a systematic approach to formulate a strategy for improving air quality, taking into consideration the local needs and the availability of local information.

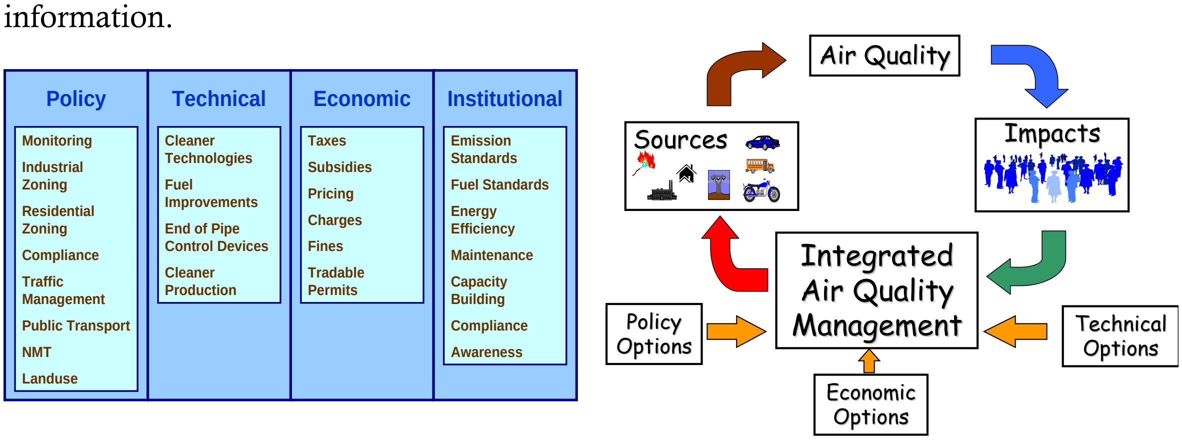



Figure 5: Array of management options & schematics of integrated air quality management

Thus, it is important that reliable information on a city's air pollution sources and air quality are utilized to perform a city-level integrated AQM. Such management with three main components – assessment, analysis and control - follows the steps from monitoring, to emissions and dispersion modeling, to exposure and health impacts assessment, and finally to cost-benefit analysis of different pollution control options.

## Air Pollution Analysis and SIM-air

Although it is essential to have city-level data on air quality, the compilation of various data on urban air pollution is extremely difficult (especially in developing countries). Firstly, the amount of existing data is limited when compared to those in developed countries. Secondly, even if data sets are available, most of datasets are often incomplete, out of date, or unreliable. Thirdly, methodologies and reporting methods vary between countries and often within the country.

Integrated air pollution analysis is based on information on emissions, ambient concentration, its health impacts, and monetary value of such impacts to conduct economic analysis. Only then, can we develop an optimal solution for better air quality taking available options into consideration.

A number of tools have been developed to analyze air pollution and benefits of management options. A number of institutions have developed many useful models to simulate various components of the AQM cycle (see table below). Ideally, it would be excellent for all cities to develop a detailed knowledge base and have a working version of all the key appropriate models. However, there are a number of problems in doing so. These include problems with:

- **A**ll Existing models are usually very data hungry, "super-specialized", expensive, and inflexible to the context of developing countries
- **E**nvironmental agencies in the developing cities are often young, with inadequate skills, interaction, and capacity
- **I**nstitutional problems are very common in the developing world (very initial public, bureaucratic, and political interest in environment and with competing demands for scarce financial resources; Decision-making is often ad-hoc and crisis-driven and there is often little time to develop a suite of high-end models for a bewildering array of options)
- **O**ften detailed studies undertaken on a few parameters without a feel for how important these parameters are in the larger picture
- **U**pdated relevant database that is accessible and of the required quality and consistency

**Sample Models Used for Air Pollution Analysis & Management**

RAINS & GAINS: The Regional Air Pollution Information and Simulation (RAINS) model for Asia and Europe, developed by IIASA, Austria, is an analytical tool to help decision-makers analyze future trends in emissions, estimate regional impacts of resulting acid deposition levels, and to evaluate costs and effectiveness of alternative mitigation options. http://www.iiasa.ac.at/rains/index.html

MOBILE 6: Developed by US EPA to analyze emission factors for predicting gram per mile emissions of Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Carbon Dioxide (CO2), Particulate Matter (PM), and toxics from cars, trucks, and motorcycles under various conditions. http://www.epa.gov/otaq/m6.htm

US EPA: A repository of over 50 air pollution models and training kits
http://www.epa.gov/air/aqmportal/management/links/modeling_resources_tool.htm

BenMAP: The Environmental Benefits Mapping and Analysis Program (BenMAP), developed by US EPA, currently estimates benefits from changes in PM and ozone concentrations, but can be used for other pollutants as well. http://www.epa.gov/air/benmap/

HEAT: Harmonized Air Emissions Analysis Tool (HEAT) is developed by the Internatioal Council for Local Environmental Initiatives (ICLEI). HEAT aims at be an multi-national, Internet-based database for storing, tracking, and reporting GHG emissions and co-benefit information on NOx, SOx, CO, VOCs, and PM emissions, to provide optional tools to compute emissions from residential, commercial, industrial, transportation, waste buildings, streetlights, etc. and to be an unprecedented data repository on local government energy use, with hundreds of inventories and action plans to be available. http://heat.iclei.org/ICLEIHEAT/portal/main.jsp

APHEBA: Developed by Dr. Luis A. Cifuentes, from the Catholic University of Chile. This is an object-oriented model that quantifies the change in health effects and social benefits associated to a change in ambient pollutant concentrations. http://www.luiscifuentes.cl/docs/index.html

IDEAS: Informed Decision-support for Evaluating Alternative Strategies (IDEAS), developed under the DIESEL program in Bangkok, can be used to analyze and visualize the impacts of various options for pollution management. The primary tasks being pursued on IDEAS involve the development of an appropriate knowledge base and modeling tools relating to the analysis of pollution management options. http://www.pcd.go.th/info_serv/en_air_diesel.html

IVE: The International Vehicle Emissions (IVE) Model is designed to estimate emissions from motor vehicles in developing countries to focus on control strategies and transportation planning that are the most effective. The model includes local air pollutants, greenhouse gas emissions, and toxic pollutants. http://www.issrc.org/ive/register.html

COPERT 4: This methodology is part of the EMEP/CORINAIR Emission Inventory Guidebook. The Guidebook, developed by the UNECE Task Force on Emissions Inventories and Projections, is intended to support reporting under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU directive on national emission ceilings. http://lat.eng.auth.gr/copert/

DSS/IPC: The Decision Support System for Integrated Pollution Control, developed by World Bank, helps the users to assess pollution sources in an area and organize in a systematic way to gather relevant information for to make an informed decision on control options.
http://go.worldbank.org/P5JGYPAWJ0
http://www.unescap.org/stat/envstat/stwes-mo2-air4.pdf

ADMS: The Atmospheric Dispersion Modeling System (ADMS) is an advanced model for calculating concentrations of pollutants emitted both continuously from point, line, volume and area sources, and discretely from point sources. The model includes algorithms which take account of the following: effects of main site building; complex terrain; wet deposition, gravitational settling and dry deposition; short term fluctuations in concentration; chemical reactions; and meteorological conditions
http://www.cerc-uk.demon.co.uk/nophrame/models/adms/admstech.htm

MARKAL: MARKet Allocation model (MARKAL) was developed in a cooperative multinational project over a period of almost two decades by the International Energy Agency. MARKAL is a comprehensive energy/economic model that simulates a nation, region, or state's energy system by representing the technologies and demands for energy services addressing environmental challenges, including acid rain and climate change. Briefly, the model finds the least-cost way to meet a given set of demands for energy services (such as building heating and cooling, or transportation).
http://www.etsap.org/markal/main.html

There is a need to develop simple, interactive tools for IAQM. This should aim to use the best available information and educated guesses to arrive at approximate "**first-cut estimates"** of key parameters (e.g. emissions from various sources based on logical criteria) and simulate the essence of interactions among emissions, dispersion, impacts and management options in an economic context – the "**SIM-air tool**".

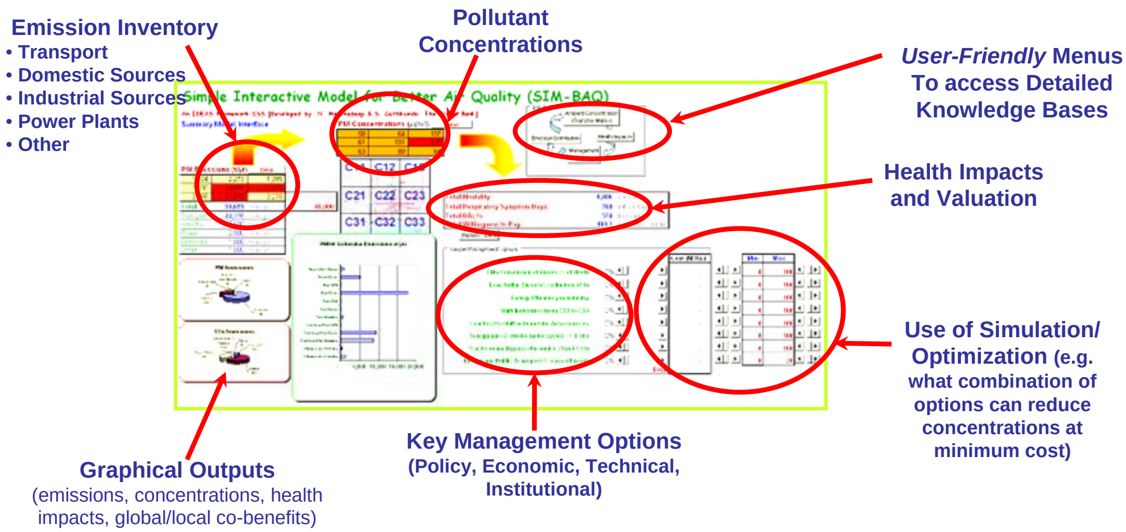



Figure 6: Components of the SIM-air analytical tool

This could be facilitated by the significant computing power and organizational capacity of modern appropriate tools such as spreadsheets, Geographic Information Systems (GIS), and the Internet. The benefits of adopting this approach for any city would help in developing a more comprehensive and systematic knowledge base, a shared-vision planning for institutions, promotion of stakeholder interaction, and developing low-cost ways to get a first-cut in analyzing a set of options and in figuring out what additional data are most important for the decisions ahead. Figure 6 presents the schematics from SIM-air v1.0 (available @ www.sim-air.org).

*Key is to establish a baseline with available data instead of waiting for data availability.*

# What is SIM-air?

The maze of options facing a city management can draw help from both stakeholder views as well as analytical tools. Figure 7 illustrates the typical steps that are required to get a city on track to seriously address its AQM issues. This starts from developing a **good knowledge base** and feel for what the critical pollutants are, **simple tools** to analyze options in an integrated manner, conducting more detailed studies and developing more detailed models as required and eventually (and hopefully quickly!) developing a **portfolio of options** that can be implemented. The timing is important because many cities in the developing world often do not worry about air quality problems until it is a crisis, and early action based on simple analysis could help in averting such crises by being better informed and planning in advance.

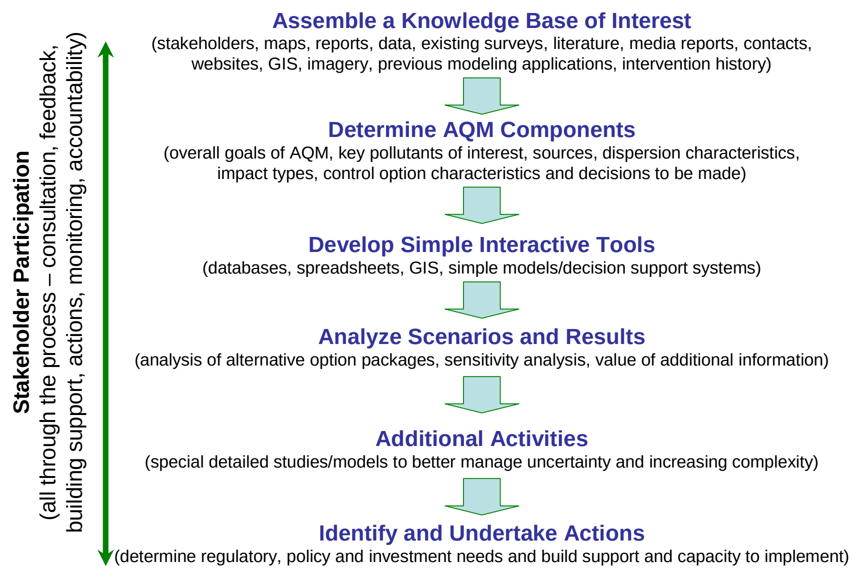



Figure 7: Key steps to air quality management

There is a possibility now, with the tools and methodologies available, to develop simple tools that a wide variety of users can interact with to get a feel for the impact of various options and narrow down the list of parameters and "serious contender" option packages that need to be further studied.

The **SIM-air** tool uses a Microsoft Excel Spreadsheet with visual basic macros to facilitate the development of an integrated interactive decision support system framework for AQM. The spreadsheet simulates the computation of an emission inventory for key pollutants, estimates the impact of the sources on air quality, and assesses and evaluates health impacts. Various policy, economic, and technical options can then be evaluated for their environmental and health impacts and cost-effectiveness. A simple simulation model is also built-into the spreadsheet to determine the optimal combination of options that can achieve desired objectives (e.g. minimize cost) subject to constraints (e.g. for a desired target level of emissions, ambient quality or health impacts).

Most of the navigation through the spreadsheets is self explanatory. *Please note that this spreadsheet is only a prototype to start developing such decision support tools and should not be used to make decisions in the form presented.* Depending on the user requirements and data availability, these should be adapted for the local decision making objectives, parameters, data and context.

A minimum knowledge base would focus on - **Primary & Secondary Data**

- Geography of the city
  - A map showing corners with latitude and longitude or at least two points on the map
  - Location of major residential and industrial areas
  - GIS maps (digital)
- City characteristics
  - Major sources of air pollution
  - Dominant source of pollution
  - Monitoring status
  - General idea of the topography of the city
- Transport Sector
  - Base year
  - Number of vehicles by major categories
  - Splits in the vehicular categories by fuel (Diesel, Gasoline, LPG, CNG)
  - Expected growth rates among the categories for the next ten years
  - (An estimate of) average vehicular kilometers traveled per day
- Domestic Sector
  - Base year
  - Number of households in the city
  - Type of fuels used
  - Average fuel use per day
- Waste / Garbage
  - Average waste generated per household
  - Waste collection in the city (tons per day), if any
  - (An estimate of) average waste burnt in the residential areas
- Industries
  - Types of fuels used (and fuel characteristics – ash and sulfur content)
  - Types of dominant industries
  - Average fuel consumption per year (by industrial type)
- Power plants (if any)
  - Types of fuels used (and fuel characteristics – ash and sulfur content)
  - Types of dominant industries
  - Average fuel consumption per year (by power plant)
- Monitoring
  - Types of pollutants monitored, number of monitors and monitoring data, preferably for PM10 and PM2.5, multiple years
  - Meteorological data (wind speeds, wind directions, and mixing heights)
- General information past studies – emission inventories, dispersion modeling, and impact assessment

The objective of the **SIM-air tool** is not to provide a final answer to the AQM, but to provide beginning of collation of data, better understanding on the local pollution sources, information needs and availability, and help the analysis with relative ease. Readers can access toolkits to play and examples @ www.sim-air.org