An Extension of SIM-air for Kathmandu, Nepal Under Program for Rapid Evaluation of Air Pollution (PREPair)

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Abstract

The aim of this paper is to describe an enhanced SIM-*air* program and an application to help develop rapid and reliable actions for air quality management in Kathmandu, Nepal, under the Stockholm Environment Institute's (SEI) Program for Rapid Evaluation of Air Pollution (PREPair). The new developments in the program include an interface to two dispersion models - The Air Pollution Model (TAPM) and Atmospheric Transport Modeling System (ATMoS); calibrations schemes to integrate monitoring data; analysis to account for CO_2 savings and reduction of health impacts in a co-benefit framework; address the positive externalities within a set of scenarios; and inclusion of a library of policy interventions covering a number of institutional, technical, political, legal and economic areas.

For the city of Kathmandu, Nepal, a link between the emissions inventory workbook for urban areas utilized local emission data collated by the International Centre for Integrated Mountain Development (ICIMOD, Kathmandu). The emissions analysis was followed by dispersion modeling and optimization of various mitigation and control options.

Whilst the modifications were initially customized for Kathmandu, the enhancement will enable users to enter their own information and to determine how the interventions will effect the local global emissions in PREPair program. A user manual will allow the model to replicate in other cities after straightforward adaptation of emissions data, meteorological data, monitoring data and acceptable policy interventions.

Keywords: Kathmandu, Nepal, Asia, emissions inventory, dispersion model, policy interventions.

1. Program for Rapid Evaluation of Air Pollution (PREP*air*)

The air quality (urban and rural) is a pressing issue for a growing number of cities in Asia. Currently, urban/regional/sub-regional level agreements are in place, analyzing the air quality and developing action plans that will decide the emissions and pollution trends for the coming decades. In most of the cases, either this is at an initial stage or does not exist, especially in the developing countries of Asia and Africa. Multiple stakeholders such as government bodies, NGOs, development agencies, and academic groups, have begun to work towards a collaborative effort on air quality and have launched initiatives that have aimed to instigate cooperation and build foundations for policies at the urban and regional level.

An important aspect of this policy planning is knowledge base management (Schwela et al., 2006). In order to make informed choices amongst a wide range of possible control measures (**Table 1**), decision-makers need to be able to analyze these options from an environmental, economic, social, political, and economy viewpoint. This approach is effective in brining together interdisciplinary stakeholders and collecting knowledge from a large pool of decision makers and end users. 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 emissions and characteristics of management options.

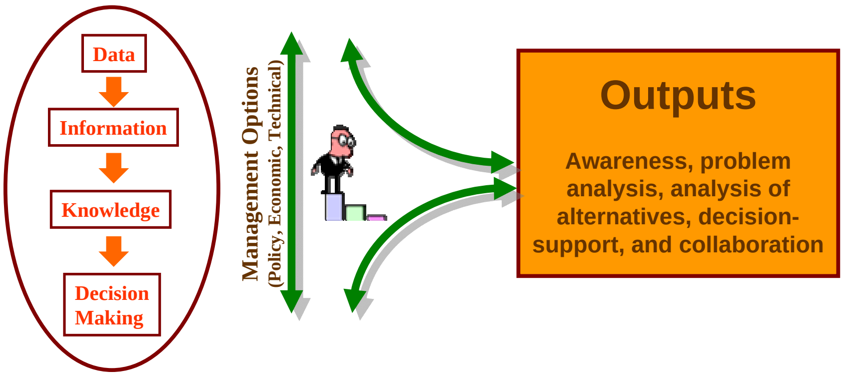


Figure 1: Schematics of data to informed decision making for a manager

However, the city managers (the decision makers – shown in **Figure 1**) have a difficult time addressing air pollution (and GHG emissions for co-benefits) reductions in a systematic manner given a history of limited capacity, institutional fragmentation, poor availability and quality of data, lack of adequate modeling tools, poor public participation and a bewildering array of policy, technical, economic, and institutional management options listed in **Table 1**.

Table 1: Categorized array of control measures for decision makers

Policy & Legal	Technical	Economic	Institutional
Urban planning	Cleaner technologies	Taxes	Monitoring
Industrial zoning	End of pipe control devices	Pricing	Emission standards
Residential zoning	Fuel switching	Charges (congestion)	Fuel standards
Energy efficiency	Fuel improvements	Fines for violations	Inspections
Traffic management	Cleaner production	Subsidies	Enforcement
Public transport		Tradable permits	Maintenance
Non-motorized transport			Capacity building
Environmental law			Knowledge base
Compliance			Awareness

Of the measures listed, there is no single measure on its own that will realize the full attainment of the air quality compliance objectives and so packages of measures will need to be deployed. Measures can be technological (e.g. fitting pollution abatement technologies to road vehicles and industrial processes) as well as measures designed to change behaviors (e.g., smarter choices, traffic management measures, incentives for cleaner vehicles and road pricing).

PREPair

Program for Rapid Evaluation of air Pollution

The PREPair program, initiated by the Stockholm Environmental Institute (of University of York, UK), aims at developing programs that will prepare the cities to develop a systematic knowledge base for informed decision making. The objective of this program is to shed some light on the following set of issues:

- Introduce rapid air pollution assessment techniques, without undermining local priorities.
- Develop emissions inventory for industrial, transport, domestic and non-conventional sources in a multi-pollutant framework.

- Provide capacity building for dispersion modeling and local air pollution analysis under multiple scenarios with co-benefits.
- Provide a platform for the stakeholder dialogue to support informed decision making.

As a pilot case study, PREPair program is under implementation for the city of Kathmandu, Nepal, and the program will be replicated to support similar activities in the a number of key secondary cities around the world. A series of tools were developed and coupled with some existing tools used for training. This paper presents a brief description of the tools and some preliminary results from the application in Kathmandu.

2. Extension of SIM-air

Every city has unique air quality challenges that require customized approaches depending on its setting (e.g. critical pollutants, sources, meteorology, population distribution, history, institutions, information base, etc.) and a ***one-size-fits-all*** strategy is undesirable and potentially counter-productive.

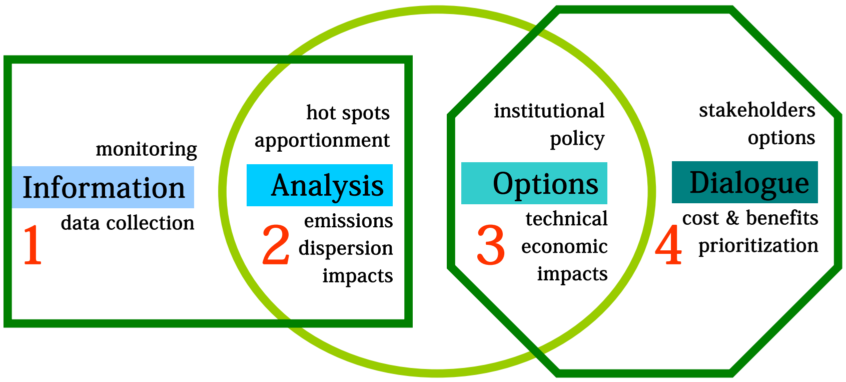


Figure 2: Components of simple interactive (SIM-air) tools for air quality management

The cost of making good air quality models based on international high-quality consultancies is prohibitive when considered for all the megacities and rapidly evolving secondary cities (many megacities of tomorrow) in the developing world. A potential solution is to develop a new generation of air quality management tools that are simple, interactive, and customizable to the needs of each city and that can help provide "zero-order" insights into the key issues and options to improve air quality management. These need to be supplemented by both technical innovations (e.g. use of remote sensing datasets) and institutional innovations (e.g. structured stakeholder participation, capacity-building through learning-by-doing) working together to support some air quality management framework (e.g. developing and implementing air quality management plans for the city on a continuous basis forever). At a basic level, these tools would need to provide a simple framework to organize and update critical data on air quality customized for the needs and data availability in each city. As awareness grows, and senior policy makers and city managers are convinced of the need for well-argued robust options even in an environment of poor information, better tools can slowly get introduced as institutional capacity is built.

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 (see www.sim-air.org for details and application reports). 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. Readers can access the tools and application reports @ www.sim-air.org. *Please note that the version available online 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. **Figure 3** presents a list of cities currently applying the SIM-air tool. The user can also download the SIM-air application summary sheets from cities around the world.

Figure 3: SIM-air application cities, as off 2008

The main components of the SIM-air tool include emission calculators, projection estimates, emission source contributions, emission distribution schemes, dispersion modeling & contributions, health impact analysis, options analysis, optimization of options and summary sheets for the decision makers. For the **PREPair** an extended version of the SIM-air tool is used. The extensions include the following:

- A link to the emissions inventory workbook developed by the Stockholm Environment Institute (SEI) and Global Atmospheric Pollution Forum (GAPF).
- An interface with The Air Pollution Model (TAPM) and Atmospheric Transport Modeling System (ATMoS) to enable realistic dispersion modeling using local or synoptic meteorological data.
- Calibration and validation of the modeling simulations with monitored data.
- Provisions to highlight co-benefits such as CO_2 savings and reduction of health impacts; introduction of positive externalities for scenario analysis.
- The introduction of $PM_{2.5}$ as the key pollutant.
- Insertion of a library of policy interventions covering a number of institutional, technical, political, legal and economic areas.
- Improvements to the user interface including the provision of technical information related to SIM-*air* for outreach purposes.

Details of the modeling tools are presented in the following sections.

2.1 SEI-GAPF Emissions Inventory Workbook

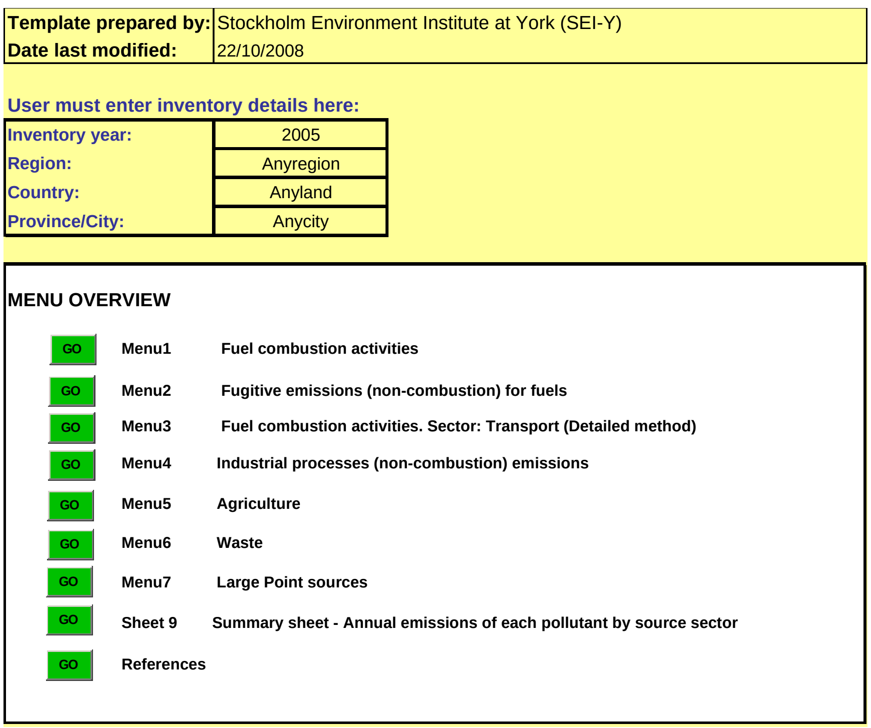
Air pollutant emission inventories are the basic building blocks of air quality modeling and of wider air quality management processes. Without detailed and reliable emission inventories, there is little opportunity to develop strategic plans for dealing with air pollution problems and to monitor the effect of such plans. Good quality emission inventories are the foundation upon which optimised emission prevention and control strategies can be developed.

The **PREPair** emission inventory module is based on the SEI and GAPF workbook (GAPF, 2007). The purpose of this module is to provide a simplified and user-friendly tool for emissions inventory preparation that is suitable for use in different developing and rapidly industrializing countries and which is compatible with other major international emissions inventory initiatives such as IPCC (1996) and EMEP/CORINAIR (2007). SEI has also helped develop the Malé Declaration and APINA emission manuals and workbooks which are compatible with the GAPF manual and which are being used to develop emission inventories by the governments of South Asia and southern Africa.

The PREPair emission inventory module comprises of a spreadsheet-based workbook (**Figure 4**) for estimating anthropogenic (man-made) emissions from the sources:

- **Energy sources:**
  Combustion in the Energy Industries (*e.g. power stations, petroleum refining, coke*)
  Combustion in Manufacturing Industries and Construction
  Transport *(including road dust)*
  Combustion in Other Sectors *(domestic, commercial/institutional, agriculture/forestry /fishery)*
  Fugitive emissions from fuels *(manufacture of coke, oil refining)*

- **Other source sectors:**
  Industrial Processes (non-combustion)
  Agriculture *(open burning of crop residues, NOx emissions from fertilizer application)*
  Waste combustion *(e.g. incineration or open-burning of municipal solid waste)*



Template prepared by:	Stockholm Environment Institute at York (SEI-Y)
Date last modified:	22/10/2008

User must enter inventory details here:

Inventory year:	2005
Region:	Anyregion
Country:	Anyland
Province/City:	Anycity

MENU OVERVIEW

GO	**Menu1**	**Fuel combustion activities**
GO	**Menu2**	**Fugitive emissions (non-combustion) for fuels**
GO	**Menu3**	**Fuel combustion activities. Sector: Transport (Detailed method)**
GO	**Menu4**	**Industrial processes (non-combustion) emissions**
GO	**Menu5**	**Agriculture**
GO	**Menu6**	**Waste**
GO	**Menu7**	**Large Point sources**
GO	**Sheet 9**	**Summary sheet - Annual emissions of each pollutant by source sector**
GO	**References**	

Figure 4: PREPair Emissions Inventory workbook template (based on GAPF): Main Menu

The air pollutants covered are those of most importance for human health impacts, i.e. PM_{10} and especially $PM_{2.5}$ (particulate matter with an aerodynamic diameters $\leq$ 10 microns (µm) and 2.5 microns (µm) respectively) and the major secondary aerosol precursor gases, sulphur dioxide (SO_2) and oxides of nitrogen (NO_x). In addition, emissions of the greenhouse gas (GHG) CO_2 are also included to allow for estimation of likely co-benefits (or possible 'dis-benefits') for climate change of strategies that may be explored for reducing city-scale impacts of the (non-GHG) air pollutants.

Most emissions can be estimated using the simple relation:

Emissions = Emission factor x Activity rate

An ‘emission factor’ provides emissions per unit activity, for example kg NOx emitted per TJ fuel burnt. Abatement of emissions can be taken into account by applying a different, technology-specific emission factor. In other situations, abatement is taken into account by subtraction:

Emissions = Emission factor x Activity rate – Abatement/Recovery

Default emission factors are offered in the workbook but users are encouraged to develop and use more locally-relevant factors if available. Users may be required to input other parameters the workbook needs for calculating the relevant emission factor such as calorific value of solid fuel, S content of fuel for SO_2 emissions and ash content for PM_{10} emissions from coal combustion. Once the relevant activity data (e.g. ktons of a particular fuel burnt in a particular sub-sector during the inventory year), emission factors and other required parameters are entered by the user, the workbook automatically calculates the pollutant emissions. The **PREPair** emissions workbook is designed to be: flexible, transparent, appropriate, and compatible, in line with local priorities.

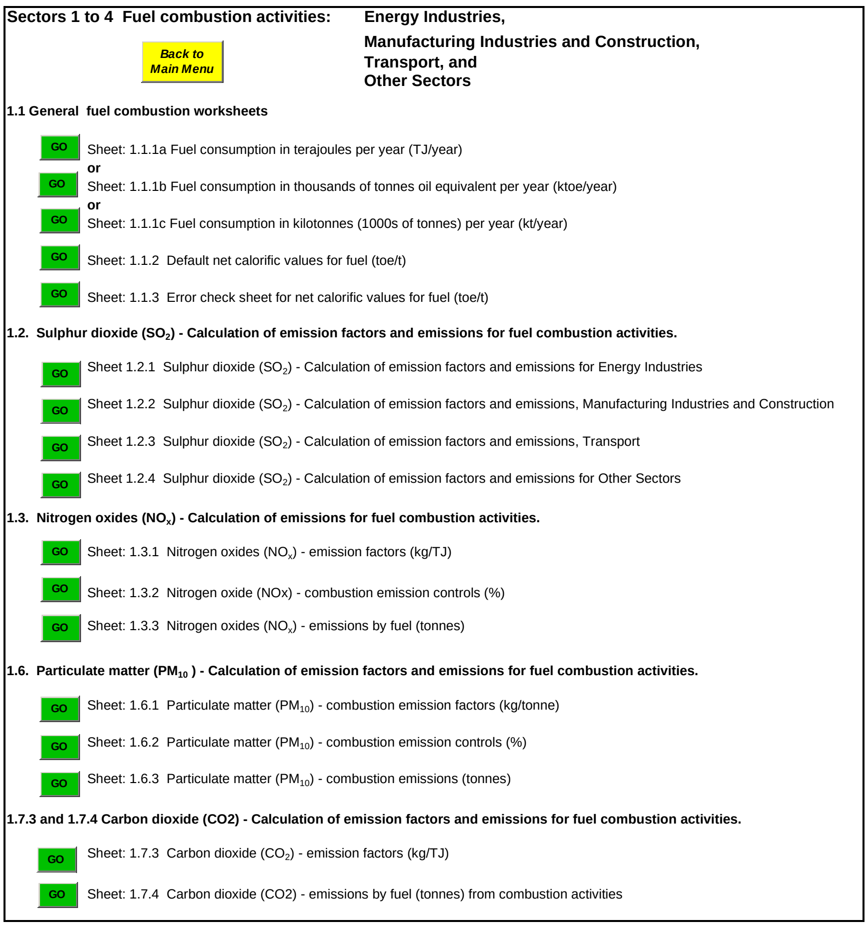


Figure 5: Workbook menu 1: Fuel combustion activities

Details on each of the components is available in the form of Workbook Manual, available with GAPF @ http://www.sei.se/gapforum/tools.php .

Emissions of NO_x, PM_{10}, and $PM_{2.5}$ from the transport sector are treated in more detail. For aviation, where data on landing and takeoff cycles are available, emissions can be determined down to the level of individual aircraft types. For road transport, data are required on numbers of each vehicle class in use, their average annual distance traveled, and estimates of percentage distance traveled on unpaved roads. The vehicles classes listed in the workbook are passenger cars, motorcycles (2-stroke), motorcycles (4-stroke), 3-wheelers, light duty vehicles and heavy duty vehicles. These are further sub-divided by fuel type (gasoline, diesel, LPG and CNG) and three levels of emission control; uncontrolled, moderate control [as for 2-way (oxidation) catalysts] and good control [Euro I].

The workbook also provides to calculate non-combustion emissions from industrial processes. Which includes, Mineral Products (e.g. cement, lime, asphalt, brick kilns), the Chemical Industry (e.g. ammonia, carbon black, urea), Metals Production (production of pig iron and aluminum; smelting of copper, lead and zinc), Pulp and Paper Industries, and Fugitive emissions of PM from major construction activities

Process	Activity rate (kt product/ year)	SO_2 emission factor (kg SO_2/t)		SO_2 emissions (Tonnes)	NO_x emission factor (kg NO_x/t)		NO_x emissions (Tonnes)	PM_{10} emission factor (kg PM/t)		PM_{10} emissions (Tonnes)	CO2 emission factor (kg CO2/t)		CO2 emissions (Tonnes)
			Default	(A x B)		Default	(A x D)		Default	(A x J)		Default [d]	(A x O)
Pig iron production			3[a]	0		0.076[d]	0		1.0[i]	0		1600	0
Aluminium production			15.1[e]	0		2.15[e]	0		37.28 [b]	0		1500	0
Copper smelting (primary) as blister and other unrefined			2120[f]	0					230 [f]	0			0
Lead smelting (primary)			320[g]	0					0.43[k]	0			0
(secondary)			40[h]	0					162[h]	0			0
Zinc smelting (primary)			1000[g]	0					293 [j]	0			0
Other (please specify)				0			0			0			0
Total emissions				0			0			0			0

Figure 6: Workbook for process (non-combustion) emissions from metal production

The worksheet to calculate emissions from metals production is presented in **Figure 6**. The emission factors here are uncontrolled and must be adjusted accordingly.

Other worksheets cover emissions from - agriculture NOx emissions from the application of N-containing fertilizers; emissions of SO_2, NOx and PM_{10} from the field burning of agricultural residues; emissions from waste incineration and open-burning, the latter often being an important source of air pollution for cities in developing countries; and large point sources (LPS), if plant-specific data are available.

The final worksheets bring the emission data together into summary tables, which acts as the data input portal to **PREPair** 'air quality modeling' module.

2.2 Dispersion Modeling

The summary output table delivered by this module provides the 'soft-wired' input to the PREPair 'air quality modeling' module (which models atmospheric transport/air concentration/health impacts and scenario analysis of different emissions mitigation and control options).

The pollutants emitted disperse in the spatial extent of the city (and beyond) – the extent and direction of dispersion is dependent primarily on the winds and topography of the city. The dispersion can be computed from first principles (e.g. Gaussian plume models or Eulerian models) (Jacobson, 2000) or from transfer matrices (computed from running more detailed dispersion models to determine, for example, incremental changes in concentration due to an incremental change in emissions in a given grid cell).

Separate model simulations are conducted for area sources (small industries, incinerators, boilers and mobile sources), which release emissions into the well-mixed layer during the day and into the surface layer at night, and for elevated sources (large point sources), which emit into the well-mixed layer during the day and above the surface layer at night. In many cases, emission sources from outside the city domain constitute an important fraction of ambient concentrations observed in the city. Such background concentrations can be derived from the monitoring data in the city and from the trends in ambient levels.

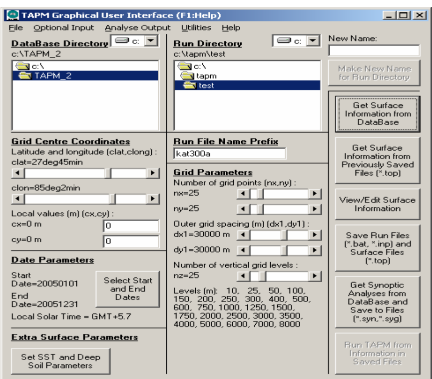
The dispersion modeling is a time consuming and data intensive step of this process, but a necessary step to convert the emission calculations to concentrations for impact assessment. A number of models exist in the public and commercial domain. Two dispersion models are currently linked in this analytical setup (**Figure 7**) and the user is free to utilize these or any other model in use for that city.

The two dispersion models are interlinked with the SIM-air modules to allow the user to either conduct the modeling activities externally and transfer the results for further analysis of the interventions or use simplified transfer matrices within the SIM-air framework, which are generated using the dispersion modeling in a multi-grid incremental contribution framework.

TAPM – The Air Pollution Model

(Reference: CISRO)

- TAPM (The Air Pollution Model) is a three-dimensional Eulerian dispersion model.
- PC based software connected to databases of terrain, vegetation and soil type, and sea-surface temperature
- Uses synoptic-scale meteorological analyses for various regions around the world.
- Commercial



ATMoS – Atmospheric Transport Modeling System

(Reference: Calori, et. al., 1999)

- ATMoS (Atmospheric Transport Modelling System) is a 3-layer lagrangian puff transport dispersion model
- Linux based utilities linked with pre-calculated mixing layers based on local terrain, vegetation, soil type, and surface temperature.
- Uses synoptic-scale meteorological analyses
- Free

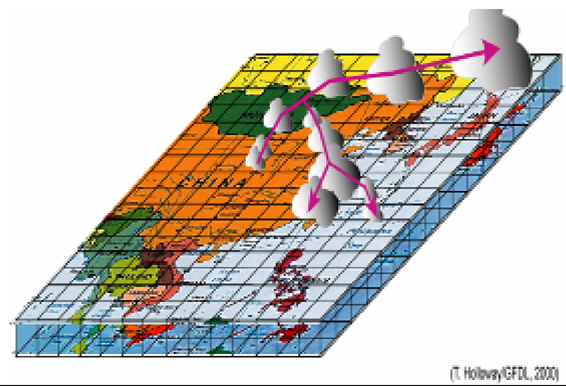


Figure 7: Schematics and brief description of the dispersion modeling – TAPM and ATMoS

2.3 Impact Assessment – Health Evaluation

Any increase in ambient pollutant concentrations lead to impacts (e.g. on human health). These impacts are often computed by dose-response relationships which provide information, say, about the increase in premature mortality and different types of morbidity based on hospital records and ambient pollution data. (see HEI, 2004). Details of health impacts of various pollutants and the extent of these impacts are well documented by the Health Effects Institute (HEI), which also suggests that the dose response functions developed during the epidemiological studies in the developed countries are transferable. Common impacts include premature mortality, respiratory infections, asthma attacks, work loss days, and increasing hospital admissions. Actual health impacts of air pollution are determined by two factors, i.e., by sufficiently high concentrations of pollutants in the atmosphere and exposure.

Table 1: Average dose response functions for reference

Health Endpoint	Dose response function (β*Ai) (effects/1µg/m³ change/per capita)
Mortality	0.000014
Adult Chronic Bronchitis	0.000040
Child Acute Bronchitis	0.000544
Respiratory Hospital .Admission	0.000012
Cardiac Hospital Admission	0.000005
Emergency Room Visit	0.000235
Asthma Attacks	0.002900
Restricted Activity Days	0.038280
Respiratory Symptom Days	0.183000

(Reference: SIM-air, 2008)

For analysis, health impacts of changing emissions and concentrations are estimated in the following way: $\delta(POP_{ij}) = \beta * A_i * POP_{ij} * \delta C_{ij}$ where δPOP = population exposed to concentrations in excess of target levels or business as usual; β = dose-response functions for the various health endpoint; average numbers presented in **Table 2**; A_i = incidence rate of health endpoint; POP = population exposed and susceptible to air pollution at the receptor cell; and δC = change in concentration or deposition levels.

2.4 SIM-air Interface for Co-Benefit Analysis

The interface allows for the following analysis:

Pollution Simulations: These are designed to answer "what-if" type questions, when a user selects a combination of values for a set of parameters that are variable (e.g. control options, assumptions) to see its impacts on the desired outputs (e.g. cost, tons of pollutant, ambient concentration change, health impacts)

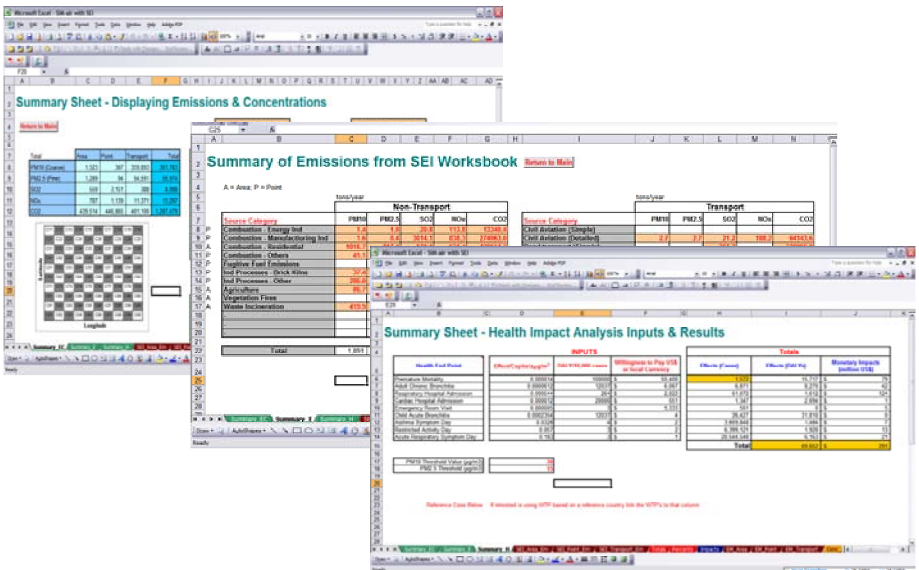


Figure 8: Interface between tools to displaying results from emissions, dispersion, and impact analysis

Optimization: These are designed to answer "what ought to be" type questions. For example, a user could determine what would be the optimal level and combination of control options to achieve a desired outcome (e.g. to meet constraints or targets on activity levels, emissions, ambient levels, health impacts, or budgets) while trying to optimize an overall goal (e.g. at minimum cost, for maximum health benefit). These are generally harder to develop at full-scale, but can yield a wealth of information, including shadow prices corresponding to binding constraints that could help determine a number of factors (e.g. the amount of money it would cost to tighten emission constraints).

3. PREPair Application in Kathmandu, Nepal

Air pollution is becoming significant problem in urban centers of Nepal such as Kathmandu Valley, Birgunj, and Biratnagar, where vehicular activity is dominating and there is an increasing number of industries. Kathmandu Valley covers ~667 sq. km, with mean elevation of ~1350m, above sea level. Population growth in Kathmandu has been critical because of centralization and rural migration economic opportunities. While the national population growth is 2.3 percent, the Kathmandu population growth is recorded at 4.8 percent. The total area of Kathmandu Metropolitan City (KMC) is ~50.6 sq.km, comprises 35 wards and total population of ~702,000 (2001 Census).

Kathmandu valley is vulnerable to air pollution due to its bowl-like topography, which restricts air movement. The situation is worse during the winter when temperature inversion during the night and early morning traps a layer of cool air under a layer of warmer air, trapping pollutants close to ground level for extended periods. Besides the topography, the relatively high elevation of the valley also results in increased vehicular emissions.

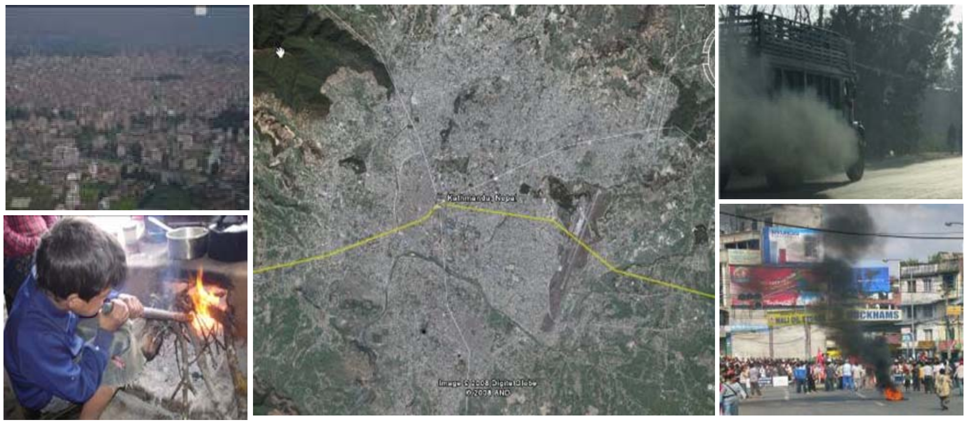


Figure 9: Major sources of air pollution and geographical map for Kathmandu valley

For this project, the PREPair emissions inventory module was utilized to produce a city-scale inventory for Kathmandu, Nepal for the year 2005. The output from this exercise provides the input data for the PREP-air ‘air quality modeling’ module via an interface summary data sheet.

Activity data and other required parameters for Kathmandu, Nepal for the year 2005 were entered into the PREPair emissions inventory workbook. All the emissions calculated in the individual spreadsheets were automatically brought together within the interface summary sheet as shown in **Figure 8**.

The total emissions for the Kathmandu city domain were estimated at 4.10 kilotonnes (kt) for SO_2, 13.30 kt for NO_x, 87.09 kt for PM_{10}, 14.85 kt for $PM_{2.5}$ and 1,287 kt for CO_2. Of the air pollutants, the largest source contributor was fugitive dust from unpaved road dust and it is an increasing source of ground based emissions and ambient concentrations. In the winter months, the ambient concentrations are higher than the other seasons, owing to the increased use of coal and biomass for heating and cooking.

Figure 10: Analytical steps to decision making

Following the emissions inventory, the study followed the steps presented in **Figure 10**, to establish the linkages from emissions to concentrations to decision support. A series of the interventions are detailed for the city of Kathmandu and they include:

- Industry -- Reducing energy demand and improving efficiency (especially in the Brick industry)
- Energy production -- Efficient fuel conversion and introducing renewables for small scale industries
- Transport -- Fuel switch to CNG/LPG/Electric; increased use of mass transit; vehicle maintenance and scrappage of old vehicles
- Households -- energy efficiency in cooking stoves; renewable or cleaner energy for cooking, heating, and lighting

Following the analysis for the city of Kathmandu under PREPair, the program will be extended to the other secondary cities in Asia and Africa.

4. In Conclusion

These models can be developed at different scales and complexity and it is generally a good idea to start modestly and slowly make them more and more complex. It is important in the development of these models that these are not "parachuted" to help save a particular city. They need to be adapted to the local context (e.g. status of the knowledge base, local capacity constraints, options to be considered, etc.). Most importantly, they need to be well-grounded with an interested counterpart that can solicit information and views from multiple stakeholders and can help facilitate the implementation of decisions. Often, the process of development of these models is as important as the product, as stakeholders meet and resolve conflicts in data, share information and develop a shared vision of the goals, constraints, and opportunities for better air quality management.

Acknowledgments

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