Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia

ICIMOD

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Rapid Urban Assessment of Air Quality for Kathmandu, Nepal

Summary

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Rapid Urban Assessment of Air Quality for Kathmandu, Nepal

Summary

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About this Booklet

As South Asia becomes more and more industrialized, populations are moving from an agrarian lifestyle to one that is increasingly urbanized. More than 700 million people now live in the main urban centres of India and China and it is estimated that by 2030 more than half of South Asia's population will live in urban centres. Increased industrialization and the growth of urban areas are generally linked to deterioration in air quality, and it is important to address air quality management issues to ensure the wellbeing of the ever-increasing number of people living in urban areas. But before air quality management can begin, it is necessary to have a system for monitoring ambient air quality so that appropriate approaches can be designed. There are many well-developed and intensive systems available for detailed monitoring of air quality at high resolution, with examples of application in cities like London, Paris, and New York, but these are not yet practical or affordable for most of the burgeoning cities in South Asia. Rapid, low-cost approaches are needed that provide sufficient information to pinpoint – and address – the major air quality issues.

This booklet provides an overview of a method for rapid assessment of urban air quality which can be used in cities in South Asia and elsewhere that have less access to highly developed monitoring systems. The rapid urban assessment (RUA) methodology was developed and tested in Hyderabad, India, by the Stockholm Environment Institute under the Regional Air Pollution in Developing Countries (RAPIDC) programme. The methodology is now being implemented for the Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia, with technical support from the IVL Swedish Environmental Research Institute. The Malé Declaration is the first ministerial-level environmental agreement for South Asia. The overall programme is funded by the Swedish International Development Cooperation Agency (Sida); the Secretariat is at the Regional Resource Centre for Asia and the Pacific – A United Nations Environment Programme Collaborating Centre (RRC.AP) in Bangkok. Technical support was provided by the Stockholm Environment Institute.

In principle, the RUA method can be used anywhere, but it must first be adapted for the specific conditions in the city or town of interest. A modified and revised version was developed for Kathmandu, Nepal, under Phase III of the Malé Declaration. The International Centre for Integrated Mountain Development (ICIMOD), in close collaboration with the Ministry of Environment, Science, and Technology and RRC.AP, implemented the study with technical support from IVL.

This booklet provides an introduction to the method with a general overview followed by a brief account of its application in Kathmandu. The Kathmandu application is included as a useful example of how the method is applied in practice; at the same time it was less successful than expected and thus provides and indication of some potential constraints. The overview is provided in the form of questions and answers; the detailed technical report for the Kathmandu study with all references and the maps produced is included on a DVD in the back pocket of the booklet.

Foreword

Today, the world's unprecedented rate of growth and the consequent urbanization, industrialization, and expanding consumerism are creating many environmental problems. The energy required to meet the growing demand, especially in the transport and industry sectors, has come mainly from combustion of fossil fuels, which releases greenhouse gases and air pollutants such as carbon dioxide, methane, and nitrous oxide into the atmosphere. While greenhouse gas emissions are resulting in global climate change and melting of Himalayan glaciers, air pollutants are degrading air quality in urban areas. Air pollution is not only a local problem; it can regional and global implications. Because pollutants respect no boundaries, anyone anywhere in the world can be affected by air pollution, and the lives of thousands of millions of people are at risk because of the associated health impacts. Air pollution also has adverse impacts on crops, biodiversity, infrastructure, cultural heritage, and the natural climate system.

Air pollution is an increasing concern in South Asia, as it has a quarter of the world's population and some of its fastest urbanization and economic growth. The air quality in many of the region's major cities is deteriorating at alarming rates, and the transport of air pollutants is exposing the whole region to this risk. According to the World Health Organization (WHO), in urban areas of Asia alone more than half a million premature deaths are linked with degrading air quality every year. Health and environmental impacts of air pollution result in significant economic costs. Estimates of actual damage range from 1 to 3% of the gross domestic product (GDP). The knowledge base on health and environmental impacts of air pollution in Asia has improved, but reliable methodologies are needed to quantify the economic impacts in Asian cities.

Air quality needs to be considered within the larger sustainable development context. At the United Nations Conference on Sustainable Development (Rio+20) in June 2012, governments noted that transportation and mobility are central to sustainable development and that sustainable transportation can enhance economic growth as well as improve accessibility and respect the environment.

In Kathmandu, Nepal, air pollution has emerged as one of the biggest threats to residents. Various studies clearly indicate that Kathmandu's air quality fails to meet national and international standards owing to the high level of particulate matter in the air.

This publication provides a detailed account of the pollution hotspot areas in Kathmandu. This is the first study done using quantitative data to get an overall picture of the major pollutants. Population density and pollution concentration data are overlaid to provide easily understood maps that will be of particular relevance to policy makers. This study provides an example that can be replicated for other cities.

The publication was prepared by ICIMOD in partnership with the Regional Resource Centre for Asia and the Pacific – A United Nations Environment Programme (UNEP) Collaborating Centre – and the Ministry of Science, Technology and Environment of the Government of Nepal. It was prepared under the Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia (Malé Declaration), which calls for regional cooperation to address shared local air quality problems and the increasing threats of transboundary air pollution and its possible impacts. The Declaration also calls for the formulation and implementation of national and regional action plans and protocols based on a fuller understanding of transboundary air pollution issues. Nepal is a member country to the Malé Declaration.

We are particularly grateful to the Stockholm Environment Institute (SEI) and IVL Swedish Environmental Research Institute for providing technical guidance.

This publication underlines the importance of science, assessment, and policy towards attaining a clean environment in Nepal. With it we hope at both policy and practical level to contribute to healthier and cleaner air.

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Acronyms and Symbols

Cl^-	chlorine
CO	carbon monoxide
Ca_2^+	calcium
GIS	Geographic Information System
LPG	liquefied petroleum gas
K^+	potassium
Mg_2^+	magnesium
Na^+	sodium
NH_3	ammonia
NH_4^+	ammonium
NMVOCs	non-methane volatile organic compounds
NO	nitric oxide
NO_X	nitrogen oxides
NO_3^-	nitrate
PM_{10}	particulate matter with a diameter of 10μm or less
$PM_{2.5}$	particulate matter with a diameter of 2.5μm or less
RUA	rapid urban assessment
RAPIDC	Regional Air Pollution in Developing Countries
RRC.AP	Regional Resource Centre for Asia and the Pacific
SO_2	sulphur dioxide
SO_4^{2-}	sulphate
TAPM	The Air Pollution Model
VOCs	volatile organic compounds

Monitoring Ambient Air Quality – An Introduction

What is ambient air?

Ambient air is the name given to open air or the air outdoors. Technically it is 'any unconfined portion of the atmosphere'. (This is in contrast to indoor air, which poses different challenges.)

Why is it important to monitor ambient air quality?

When the ambient air is polluted – containing elevated levels of harmful gases and particles – it can threaten the health and wellbeing of the population and can harm the environment. In the long run, these effects can result in considerable financial costs. However, before planners can decide on cost-effective measures to reduce exposure and lessen damage, they must first have a reasonable idea of the existing air quality. Air quality monitoring is used to determine what pollutants are present and in what concentration, and is thus an essential first step in air quality management.

What is air quality management?

The main focus of air quality management is to reduce the impacts of pollution by reducing exposure. This means identifying the major sources of the pollutants that are affecting human health and the environment, and reducing the impact through emission controls and other measures. It includes knowing where people are most exposed as well as the major sources of pollutants. Many cities around the world have introduced air quality management and taken specific measures to achieve their targets. Countries that have successfully implemented air quality management approaches find that the benefits usually outweigh the costs.

What are the major airborne pollutants in urban areas?

The major airborne pollutants in urban areas are sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), particulate matter (PM_{10} with a diameter of 10μm or less and $PM_{2.5}$ with a diameter of 2.5 μm or less), non-methane volatile organic compounds (NMVOCs), ozone, and ammonia (NH_3). Some pollutants are emitted directly (primary pollutants), while others are formed in the atmosphere from emitted precursors (secondary pollutants such as ozone and secondary particles). Ammonia is of increasing interest because it plays an important role in acidification and eutrophication, which can have considerable environmental impacts. Lead, which used to be considered a major pollutant, has been sharply reduced in most cities following the introduction of lead-free petrol.

How is air pollution detrimental to human health and the environment?

Air pollution is mainly associated with human health, particularly with an increase in respiratory and cardiovascular diseases. Airborne particles can be inhaled. Larger particles are trapped in the nose and throat, but the small PM_{10} particles can penetrate into human lungs and the very small $PM_{2.5}$ particles can lodge deep down in the respiratory bronchioles. These particles are particularly harmful to high-risk populations such as children and adults with pulmonary diseases. On a global scale, four to eight per cent of premature deaths are attributed to exposure to particulate matter in ambient air. Carbon monoxide is of particular concern because it is toxic. It binds strongly with haemoglobin in the blood reducing the oxygen carrying capacity, so that even short-term exposure is harmful.

The effects of SO_2 on human health are well documented and include a higher incidence of respiratory diseases, especially when the exposure is frequent and when it is accompanied by dense concentrations of fine particles.

Oxides of nitrogen impede pulmonary functions. Both methane and NMVOCs react with nitrogen oxides in the air and, in the presence of sunlight, form ozone. Ozone is beneficial in the upper atmosphere (stratospheric ozone layer) because it absorbs harmful ultraviolet radiation from the sun; however, in the lower atmosphere (tropospheric ozone or surface ozone), it poses a health threat because it can cause respiratory and skin problems.

Pollutants can affect the environment in various ways. Greenhouse gases contribute to global warming and environmental change. More directly, ozone can cause damage to crops and forests, as it is phytotoxic. Pollutants such as SO_2 and NO_2 also contribute to the formation of acid rain, which can harm aquatic and other organisms as well as affecting building materials.

Where does air pollution come from?

The major source of urban airborne pollutants is combustion from industry and transport. These processes emit NO_x, CO, and SO_2 from burning of fossil fuels such as oil, gas, and petrol. Volatile organic compounds (VOCs) and nitric oxide (NO) are both produced by fossil fuel combustion. VOCs form peroxy radicals which react with NO to produce NO_2. In sunlight, NO_2 dissociates into O and NO. The O reacts with O_2 to produce ozone. Thus NO_2 can produce ozone when VOCs are present.

NMVOCs are released into the atmosphere as a by-product of transportation and as a consequence of industrial processes wherever organic solvents are used. These compounds are significant greenhouse gases because of their role in creating ozone and in prolonging the life of methane in the atmosphere, although the effect varies depending on the local air quality. Ammonia is present even in unpolluted air because it is emitted by microorganisms involved in the decay of animal matter and in sewage treatment.

Particulate matter can originate from various sources, ranging from simple grinding of bulk matter to the transport sector, waste incineration, other types of combustion, and a whole range of complicated chemical and biochemical processes. Especially in developing countries, open burning of fuel for cooking and heating, uncontrolled burning of waste, and poorly regulated brick kilns and other factories using local biomass fuels, can contribute substantial amounts of particulate matter to the atmosphere. Dust stirred up by vehicles and wind from unpaved or poorly maintained streets can also be a major contributing factor.

How do the changing population patterns in South Asia contribute to air pollution?

Migration and urbanization are part of the fast-paced growth of industrialized cities in South Asia. If not managed properly, urbanization and the accompanying increase in population, number of vehicles, and industry, can all play a part in degrading the environment.

Kathmandu, Nepal's capital and major urban centre, is a typical example. In the 1970s, Kathmandu was idealized as an unspoiled haven in the Himalayas and its air quality was comparably pristine. Since then, the population has more than tripled. The population increase has been accompanied by unprecedented growth in industry, and the traffic has increased to such an extent that now more than half a million vehicles ply the streets. One result is that the air quality has deteriorated to a point where it is now a health risk.

What are the main constraints and limitations to air quality monitoring in the developing countries of South Asia?

The main constraints to air quality monitoring in South Asia are the cost, lack of specialized equipment, and lack of skilled personnel. Practical considerations also limit routine monitoring; for example, power supplies are often disrupted, which prevents long-term continuous monitoring, and instruments are often not sufficiently robust or adaptable for the conditions.

Rapid Assessment of Urban Air Quality

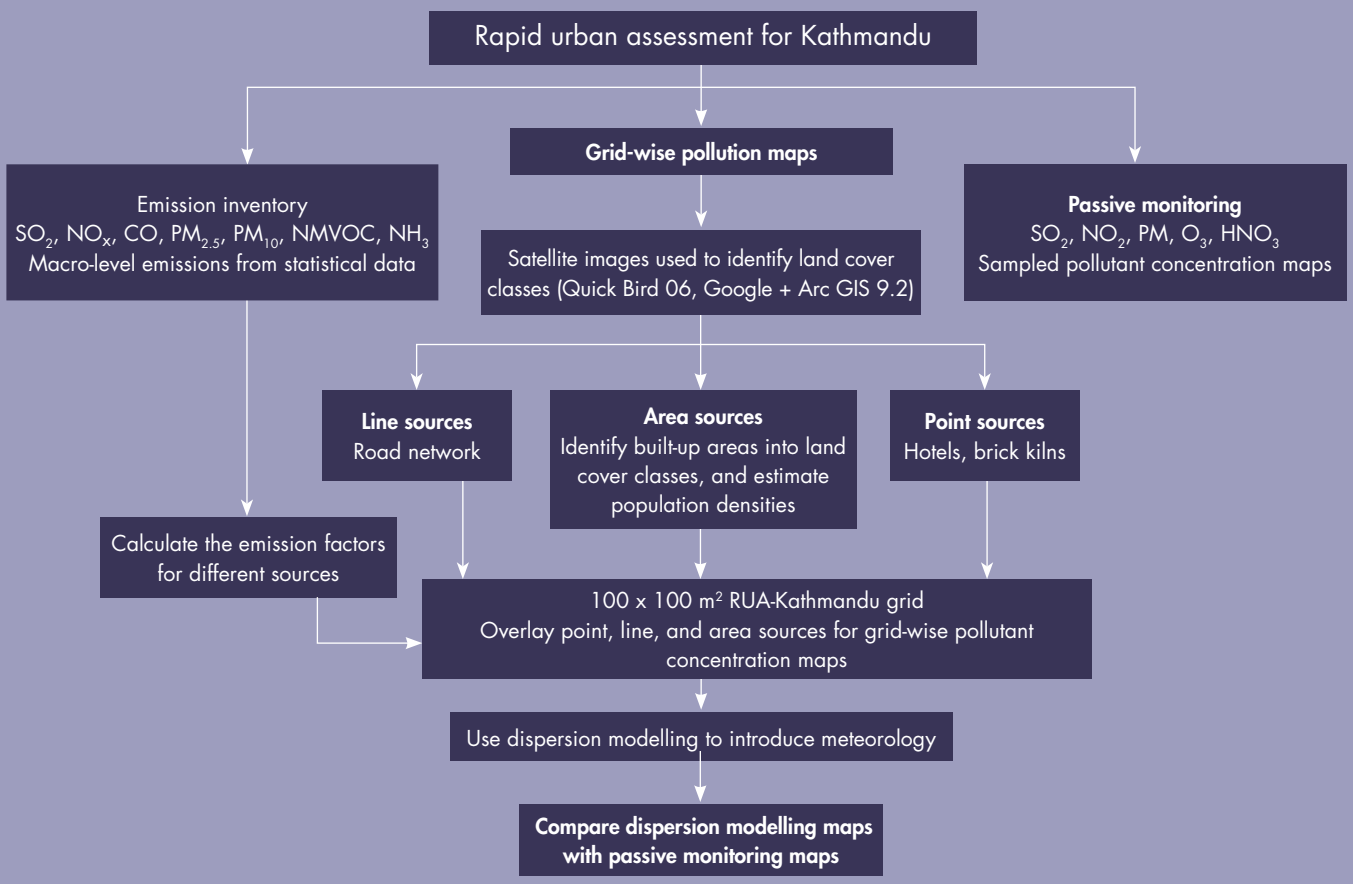
A rapid urban assessment (RUA) method was developed to study air pollution in the urban areas of South Asia, resourced through the Regional Air Pollution in Developing Countries (RAPIDC) Programme developed and implemented by the Stockholm Environment Institute, which supports the Malé Declaration on Control and Prevention of Air Pollution and Its Likely Tranboundary Effects for South Asia.. RUA is an inexpensive method with a fast turnaround time which can be used to locate hot-spot areas and identify the major pollutants and their concentrations. The RUA gives results that are comparable to those obtained with traditional approaches, but has the advantage of being both quicker and less costly. The RUA was initially tested in Hyderabad, India; a modified and revised version was developed for Kathmandu in close collaboration with the IVL Swedish Environmental Research Institute.

What does the rapid urban assessment method consist of?

The main components of the rapid urban assessment are an emission inventory, dispersion modelling based on the emission inventory database, exposure analysis for health risk assessment, and cross-validation with low-cost monitoring data. The different activities involved are summarized in Figure 1 and described in more detail in the following sections.

The major output of the RUA method is a series of grid-based maps that identify the hot-spot areas in terms of types of major pollutant and their concentrations.

Figure 1: **Flow diagram of the rapid urban assessment**



What is an emission inventory?

An emission inventory is an accounting method used to estimate the yearly average of total emissions of individual pollutants. The RUA emission inventory focuses on the emissions of SO_2, NO_x, CO, NMVOC, NH_3, and PM_{10} and $PM_{2.5}$. The inventory summarizes the different possible sources of emissions, their general location, and the average emissions expected per source.

Emission inventories can be either top down or bottom up. The top-down statistical method uses inventories that are already available for a greater emission area and disaggregates these overall emissions to sub-units using actual data for the source strength of emission-generating activities. For example, data for the entire Kathmandu Valley on the total fuel used, total number of vehicles, total length of roads, and so on were used to calculate the total emissions of CO, SO_2, NO_2, and particulate matter from the transport sector. The bottom-up approach uses data from baseline statistics obtained from field visits and surveys; for example, traffic counts of the number of vehicles on a given stretch of road, the type of fuel used by each, and other factors are used to calculate emissions by the transport sector over that particular stretch of road. Often a combination of the two methods is the most cost-effective approach.

An emission inventory gives the average amount of the emitted pollutants for the whole area over which it is collected: it is a macro-scale method which does not pinpoint the location of the polluting sources or give any indication of seasonal variations. The RUA method uses these macro-scale emission data to produce grid-based emission maps which give a spatial indication of where the pollutants are generated; dispersion modelling adds the seasonal variations from the meteoreological data input.

What are grid-based emission maps?

The RUA method merges the macro-scale emission data with high-resolution satellite images to produce grid-based emission maps that provide a spatial indication of where the pollutants are generated. The high-resolution satellite images (e.g., Quick Bird 06, Google) are used in a GIS programme (e.g., Arc GIS 9.2) to identify land-cover classes, and primary surveys are used to help establish the classifications in order to relate the emissions to the areas where they are produced. All line, area, and point sources are displayed on a 100 x 100 m^2 grid of the study area. The total emission from all sources is calculated for each grid. The grid layers are summed to produce individual concentration maps for each pollutant. The RUA emission maps are annual averages; seasonal variation was estimated by introducing dispersion modelling which included meteorological parameters.

Grid-wise concentration maps help to pinpoint major hot spots for each pollutant. This approach gives a better estimate of the levels and spatial distribution of emissions than the macro-scale method that relies on more averaged and aggregated information. In addition, since the maps also contain information on population densities, they can be used in public health studies to correlate the incidence of specific ailments to the pollutants present in the ambient air, as well as for city planning purposes.

What is dispersion modelling and what are its advantages?

The next step in using the emission inventory is dispersion modelling, which means calculating the extent of the dispersion of pollutants from different sources and displaying these on the area map. A dispersion model estimates the ambient concentrations using the emission data from the inventory and the meteorological (weather) data for the same area. Where emission data with the necessary temporal resolution are unavailable, which is a common situation in developing countries, it may only be possible to use mean annual values for both emission and climate data.

Dispersion modelling makes it possible to determine which emission sources have the greatest effect on ambient pollution concentrations; information that is vital in developing a strategy for air quality management. For example, emissions from tall stacks are dispersed much farther than those from low sources such as vehicles and lead to lower local concentrations of pollutants.

Various dispersion models are available. The Kathmandu Valley study used The Air Pollution Model (TAPM), developed by the Atmospheric Research Division of the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). This model has the advantage of calculating meteorological information and pollutant concentrations for air pollution applications from existing databases. This eliminates the need for site-specific meteorological observations. TAPM predicts the flows important to local-scale air pollution transport, such as breezes and terrain-induced flows, against a background of larger-scale meteorology provided by synoptic analyses. It predicts meteorological and pollution parameters directly at local, city, or inter-regional scales and can be used to analyse seasonal variations resulting from different meteorological conditions.

What considerations apply to the rapid urban assessment's dispersion modelling method?

One limitation is that the necessary parameters – including both data on emission factors and meteorological parameters – are not always available. In addition, major pollutants may be sourced from outside the study area but transported by prevailing winds into the study area. Brick kilns located beyond city boundaries are a good example; they generally contribute to air pollution in the city, but they were not included in the calculation. The modelling would have been improved if this information, based on local knowledge of ground conditions, had been considered in setting the boundaries for the model. Finally, modelling is an iterative procedure. The modelling results are based on the emission inventory; thus whenever the emission inventory is updated or changed in any way, the model must also be updated.

How is it possible to verify an emission inventory or dispersion model?

Emission inventories are difficult to validate. The best way to validate one is by carrying out an intensive, referenced, bottom-up survey with direct measurements of pollutant emissions at different locations and times. However, this is not always possible. An alternative is to compare the simulated concentration maps from the dispersion model prepared using the emission inventory data with maps prepared from direct measurements of SO_2, NO_X, and particulate matter obtained using passive samplers in a monitoring campaign. Correlation between the two maps indicates that the model estimates reflect the situation on the ground. If the correlation is inadequate, it indicates that more work is needed and that either the emission database or the meteorological parameters need to be modified. Once a model has been validated, it can be used in later years with only occasional further validation.

What are passive samplers?

Passive or diffusion samplers are single-use pieces of equipment designed to absorb or attach to the pollutant under study over a given length of time. The quantity of the pollutant absorbed is later analysed in a laboratory. For gases, the basic principle on which they operate is molecular diffusion, with molecules of a gas diffusing from the open end of the sampler to the absorber end of the sampler. In particulate samplers, particles in the air simply adhere to a surface, and the total weight of particles and their chemical composition is analysed.

There are two main types of design: a tube-type configuration with one end open (Palmes tubes); and a shorter badge-type configuration in which the open end is protected from wind by a membrane filter or other screen. In both cases, the closed end contains an absorbent for the gaseous species to be monitored. Several different types of commercial diffusion tubes are available but all are based on these two types.

Passive samplers can be used to monitor gaseous pollutants such as SO_2, NO_2, O_3, and HNO_3, as well as particulate matter and ions such as Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Ca_2^+, Mg_2^+, Na^+, and K^+.

What are the advantages and disadvantages of passive samplers?

Passive samplers are light, inexpensive, robust, and easy to install. The measuring range is high and they yield a correct average without interruption. An added advantage is that passive samplers do not need on-site power. The samplers can be left unattended during sampling; stored for several weeks; and transported to off-site laboratories

for analysis. Passive samplers are often the method of choice for monitoring air pollution in developing countries like Nepal where active, continuous air quality monitoring is a challenge.

However, with passive samplers there is no means to measure the air flow and they have low apparent sampling rates. The low sampling rate requires a long exposure of samplers; polluting species need to be present in the ambient air for at least one week before they can be detected and the samplers cannot be used to detect the effects of transient events such as chemical spills or fires. The deployed passive samplers cannot detect CO, nor can they distinguish between the larger and smaller (more harmful) fractions of suspended particulate matter.

What needs to be considered when deploying passive samplers?

Many passive monitoring sites are needed, both within and outside the study area limits, in order to interpolate the spatial coverage over the entire city area. The samplers need to be deployed using information on the local topography, land-use information, meteorological conditions, and ambient concentrations from emission data. It is good practice to ensure that air quality is monitored at a variety of locations. Samplers are placed in urban hot spot areas affected by vehicular and industrial emissions; in residential areas representative of general population exposure; and in rural areas as an indication of background concentrations.

Why is passive monitoring alone not sufficient?

Passive monitoring only records an aggregate average concentration of pollutants for the time the monitors were exposed. It cannot be used to detect minima or maxima in the concentrations. Passive monitoring detects pollutants after they have been dispersed by the local meteorological conditions. Since pollutants can be collected at some distance from where they are produced, passive monitoring cannot be used reliably to pinpoint the sources of pollution.

How can pollutant concentration maps be used for health studies?

When pollutant concentration maps are superimposed on population density maps it is possible to estimate the number of people who may have been or are being exposed to critical levels of pollutants and the potential costs.

How can the rapid urban assessment with dispersion modelling be used by policy makers?

Once the model performance has been proven through validation and testing, the simulation results can be used to support decision making. The RUA pollutant concentration maps can be used in any decision-support system which aims to achieve air quality goals at a low cost, since they provide the link between emissions and ambient concentrations. Better and shared information is one of the elements in an improved decision-making process. Decision makers and policy makers can share these model-generated dispersion maps to improve environmental planning, policy making, and management since they give the geographical distribution of pollutants and can be used to calculate location-specific annual averages. In addition, models can be used to simulate different air pollution scenarios in order to compare the cost-efficiency and benefits of alternative strategies and solutions as well as for environmental impact assessments and health-related studies.

Situation in the Kathmandu Valley

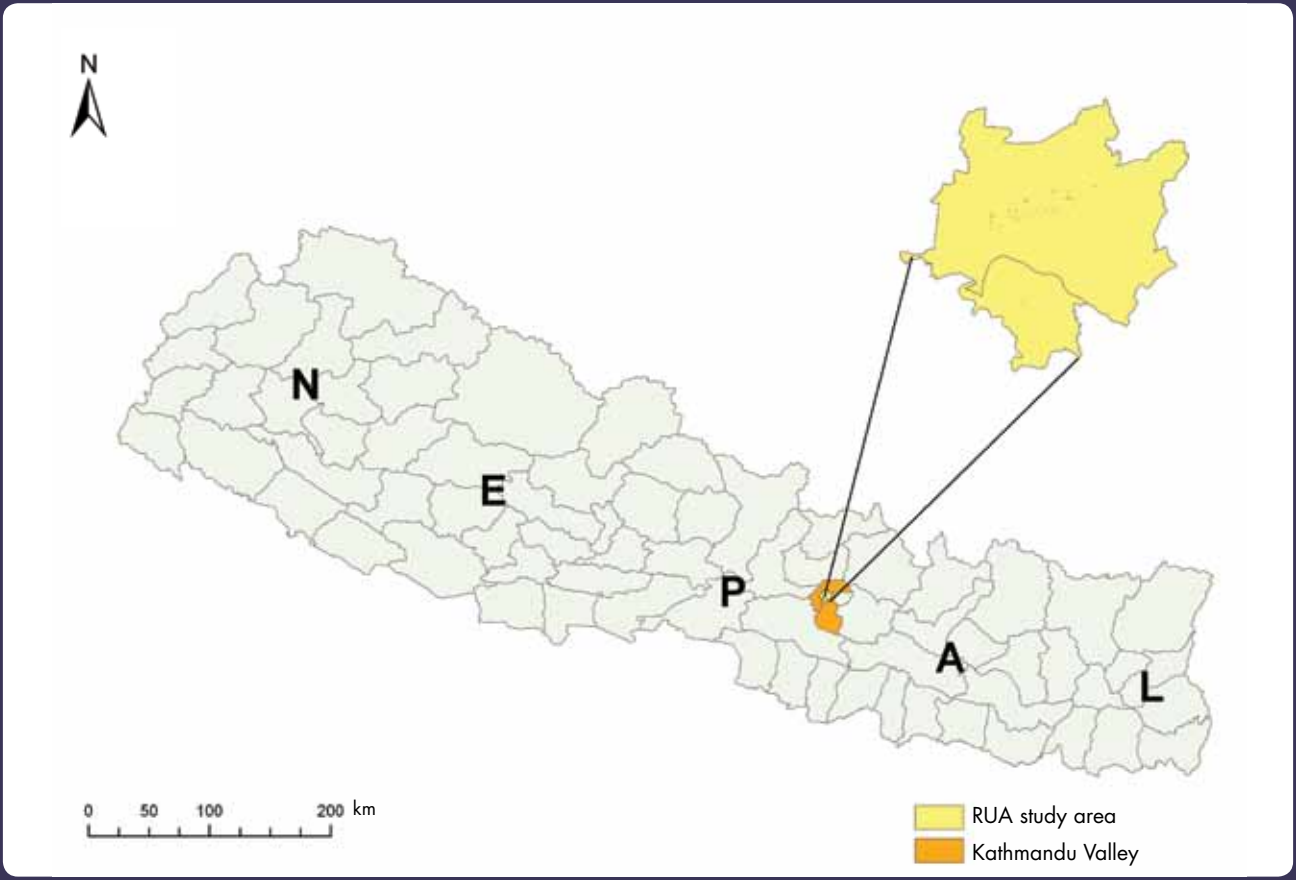
The Kathmandu Valley is a basin in central Nepal formed by the surrounding Mahabharat mountain range (Figure 2). The valley lies at 1,300 metres above sea level and covers an area of approximately 600 km^2. Temperatures range from below 0°C in winter to above 30°C in summer. South and southeasterly winds dominate throughout the year. During the dry winter season, low wind speeds and the valley's bowl-like topography create poor dispersion conditions and make it susceptible to air pollution.

How have urbanization and industrialization affected air quality?

In Nepal over the past few decades, rural-urban migration has led to an increase in the number of people living in urban areas. In 1990, less than nine per cent of Nepalese people lived in cities, by 2050 it is estimated that almost half of the population will be urban. The trend is even more noticeable in the Kathmandu Valley where the urban growth rate is estimated to be more than four per cent per year.

Urbanization has helped Kathmandu to diversify its economy by facilitating the growth of an industrial base. However, this rapid urban growth, with its accompanying rise in the number of motor vehicles and industry, has also resulted in deteriorating air quality. In 2001, the Kathmandu Valley was home to an estimated 1.6 million people and approximately 38 per cent of all the industries in the country.

Figure 2: **Study area of the Kathmandu rapid urban assessment**



How many cars are registered in the valley and how extensive is the road network?

Between 2000 and 2009, the number of cars in the Kathmandu Valley grew at an unprecedented rate: in 2000 there were less than 200,000 registered vehicles but by 2009 there were half a million vehicles; more than 60 per cent of all the vehicles registered in Nepal. Despite the increasing number of vehicles, the total length of the road network in the valley is still only about 1,200 km (of which only about half is black topped), less than 2.5 m of road per vehicle.

How do vehicles contribute to air pollution?

Vehicle exhaust is a major contributor to the presence of inhalable particulate matter and noxious gasses – the major causes of air pollution in Kathmandu – and the problem is exacerbated by the fact that more than a third of vehicles fail to comply with the Nepal code for emission standards. Urban development and the ever-increasing number of vehicles have far outpaced the city's capacity to maintain the road network on a regular basis. At present, most motorable roads in Kathmandu are too narrow for the dense traffic they carry. The type and condition of the vehicles and the sub-standard road network also contribute to the deteriorating air quality.

What are the health costs of air pollution for people?

High concentrations of atmospheric pollutants pose a particular threat to the health of the residents of the Kathmandu Valley, especially during the dry winter months. Acute respiratory disorders are among the top five diseases reported in Nepal; and in urban areas about 16 per cent of hospital visits and a disproportionate number of premature deaths are attributed to them. Studies have highlighted the increased incidence of respiratory disorders and of eye, throat, and skin conditions, as well as an increase in the incidence of cardiovascular-related problems among people living in Kathmandu in comparison with those living in rural areas. An estimated 30 million Nepalese rupees (USD 400,000) of hospital costs every year could be saved by reducing the level of airborne pollutants to meet World Health Organization guidelines.

What is the situation of air quality monitoring in Nepal?

To date, only a few systematic studies of air pollution inventory, monitoring, and air quality assessment have been carried out in Nepal. There have been very few studies on the impacts of air quality and long-term epidemiological studies are almost non-existent. On the other hand, there is a large amount of anecdotal evidence linking air pollution with rises in the incidence of respiratory disorders and cardiovascular disease and in the reporting of eye, throat, and skin problems.

Nepal established national threshold limits for airborne pollutants in 2003 which have been updated in 2012. However, the monitoring system is still intermittent, as are the design and implementation of measures to address pollution issues. It is important to find ways to monitor urban air quality at low cost and with low technical input in urban Nepal.

Rapid Urban Assessment for Kathmandu

The RUA method was developed and adapted for use in the Kathmandu Valley. The detailed process and results, including the output maps, are given in the text on the DVD accompanying this publication. The following provides a brief overview of the approach and results as an example of the application of the method.

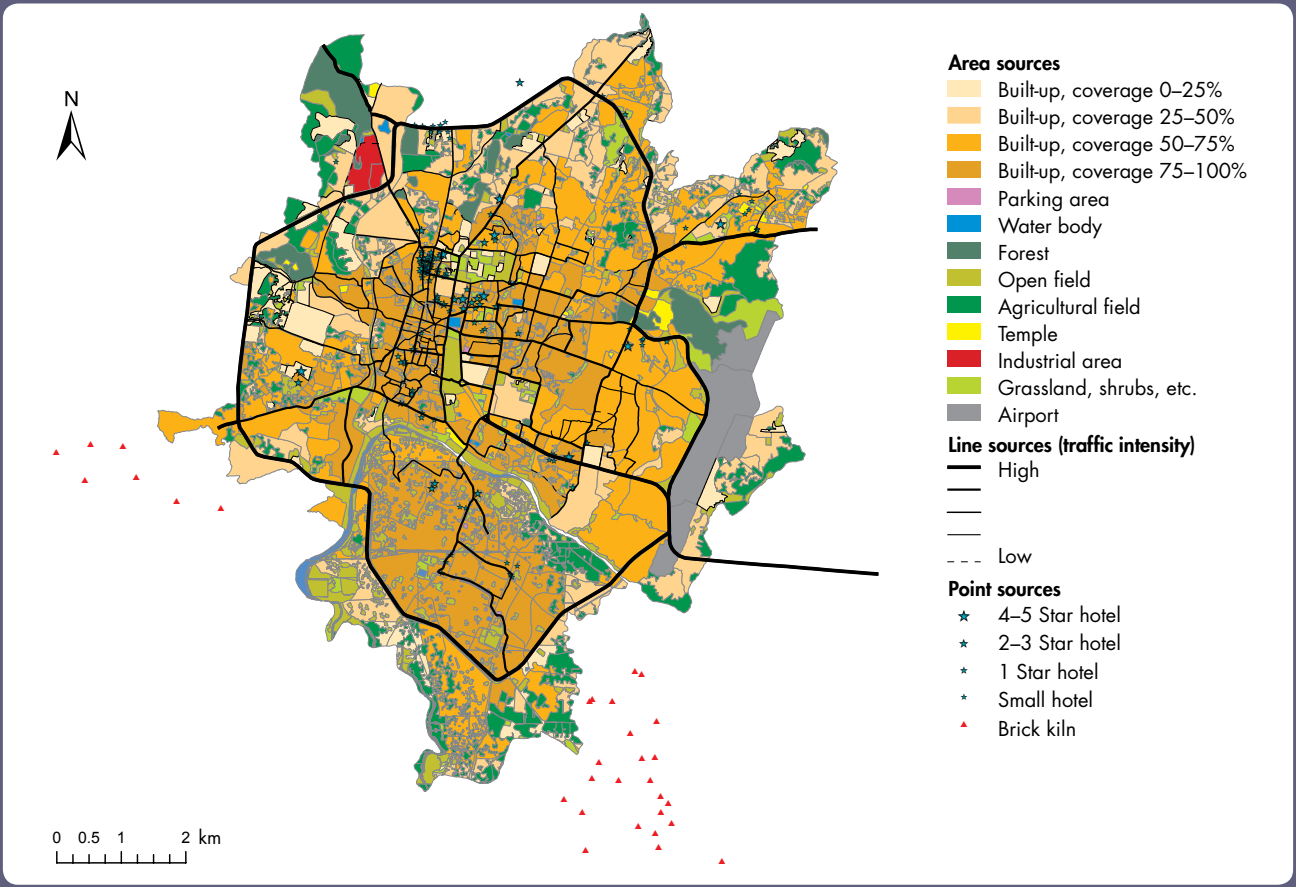
Which urban areas were included in the assessment?

The RUA-Kathmandu study area covered Kathmandu Metropolitan City and Lalitpur Sub-Metropolitan City, two of the largest municipalities in the valley. Kathmandu Metropolitan City is the capital of Nepal. It covers an area of around 50 km^2 and has 35 wards with a total of 152,155 households (as of 2001). Lalitpur Sub-Metropolitan City (known locally as Patan) is the fourth largest city in Nepal, and is situated on an elevated tract of land separated from Kathmandu to the north by the Bagmati river. It covers an area of around 16 km^2 and has 22 wards with a total of 35,000 households.

What major area, line, and point sources were included in the study area?

Area sources of emissions included the following 13 classes: built-up areas (four classes), parking areas, water bodies, forested areas, open fields, agricultural fields, temples, industrial areas, green areas (other than forest, including grassland, shrubs and so forth), and the airport area (Figure 3). The main line source was traffic; the road network was digitized and categorized into different classes in terms of traffic intensity. Brick kilns and hotels were considered point sources; hotels were classified based on energy use, specifically, the number of cooking gas cylinders used per hotel per month.

Figure 3: **Area, line, and point sources of emissions**



How was the emission inventory for the Kathmandu Valley conducted?

To compile an emission inventory, all sources of pollutants must be identified and quantified. The sources of emissions were categorized into six different activity sectors: energy (combustion activities, non-combustion fugitive emissions, and transport-related activities), industrial processes (non-combustion emissions), solvent and other product uses, agriculture, vegetation fires, forestry, and waste. The primary inputs for the study were taken from government statistics of annual consumption such as the number of liquefied petroleum gas (LPG) cylinders sold, number of cars plying the streets, kilogram of nitrogen fertilizer sold, and so forth. Where needed, primary data from local surveys were also used.

The emission inventory was based on a common methodology developed by the Swedish Environment Institute for countries in South Asia; it uses the Malé Emissions Inventory Work Book Version 2.4., which mainly uses emission factors prescribed by the Intergovernmental Panel for Climate Change.

The general equation for emission estimation is $E = A \times EF \times (1-ER/100)$

Where E = emissions; A = activity rate; EF = emission factor; and ER = overall emission reduction efficiency.

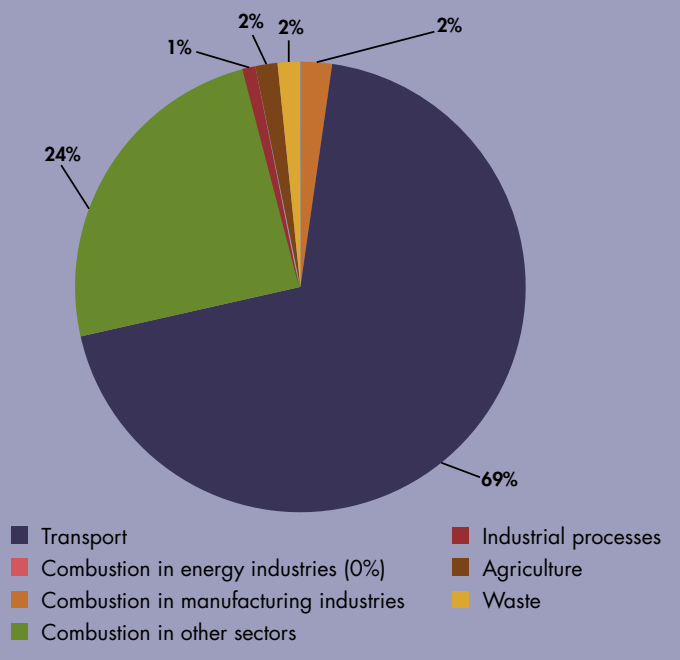
An emission factor is a representative value that attempts to relate the quantity of a pollutant released into the atmosphere with an activity associated with the release of that pollutant. Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data and are generally assumed to be representative of long-term averages for all facilities in the source category. The calculation and/or selection of emission factors are discussed in detail in the text on the DVD which accompanies this booklet.

According to the emission inventory, what airborne pollutants are present in the Kathmandu Valley, in what concentrations, and where from?

The emission inventory calculated the total emissions from human activities from all uses to be close to 196 tonnes per year. More than half the emissions were of particulate matter (PM_{10} and $PM_{2.5}$); CO, the second major pollutant, contributed 32 per cent; and all of the other pollutants combined contributed about 16 per cent. The high value for particulate matter reflects the effects of resuspension of dust from roads by vehicles.

The transportation sector accounted for 69 per cent (136 tonnes per year) of the total pollution load. Combustion from energy was negligible, and combustion from manufacturing industries accounted for only 2 per cent, while combustion in other sectors (residential, commercial, and forestry) was responsible for 24 per cent of the load (49 tonnes per year) (Figure 4).

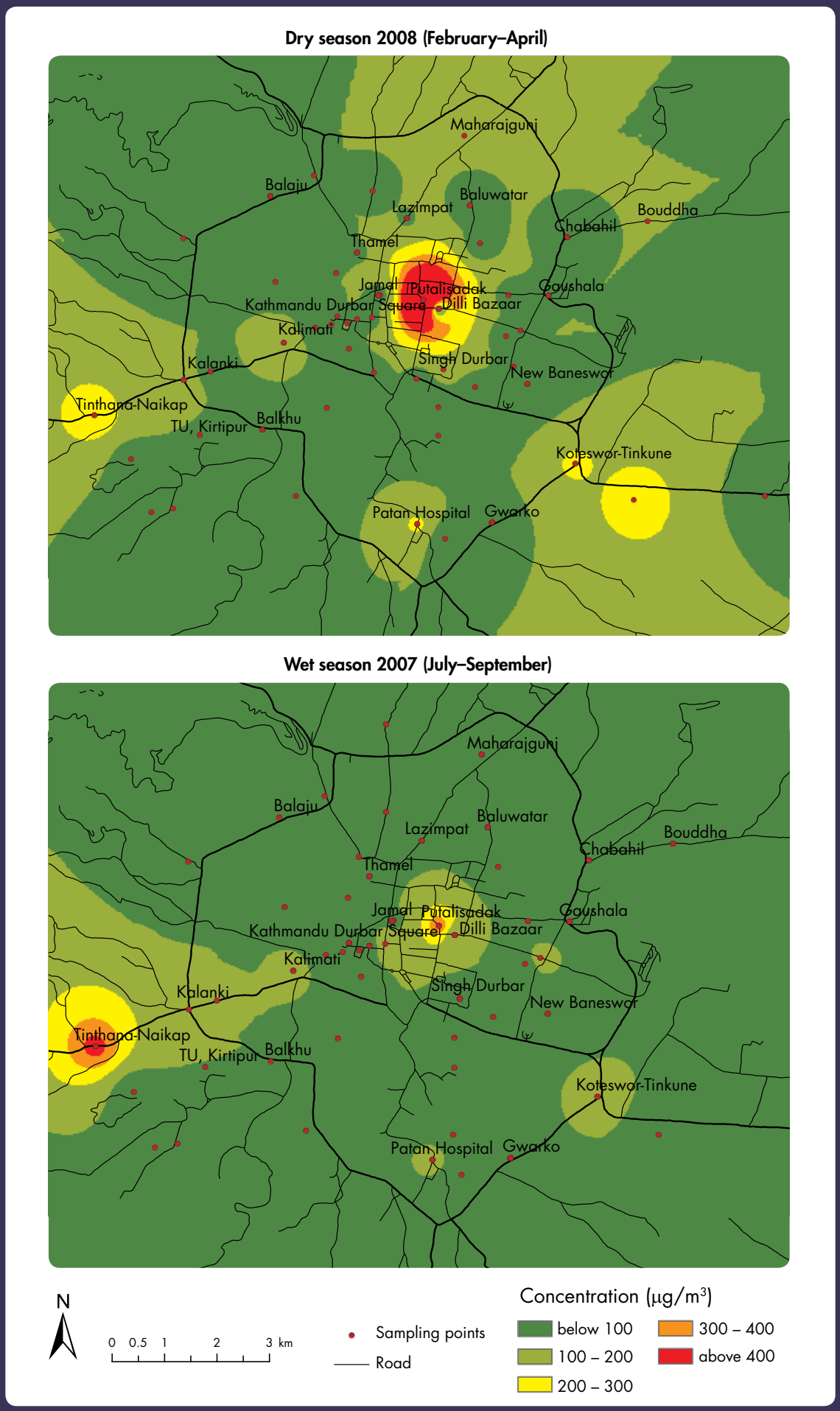
Figure 4: **Total emissions from different sectors in Kathmandu**



How was the passive sampling campaign for Kathmandu carried out?

Separate passive sampling campaigns were carried out for the rainy and dry seasons. Samplers were exposed from July to September 2007 in the first (rainy season) campaign and February to April 2008 in the second (dry season) campaign. The samplers were strategically exposed within the study area at representative points. Particulate matter was measured at 60 sites, NO_2 at 40 sites, and SO_2 at 20 sites. At the end of the campaign, samplers were collected and analysed in the laboratory.

Figure 5: **Results of passive monitoring of particulates in the dry and wet season; example of PM_{10}**



How did seasonal variations show up in the passive monitoring studies for Kathmandu?

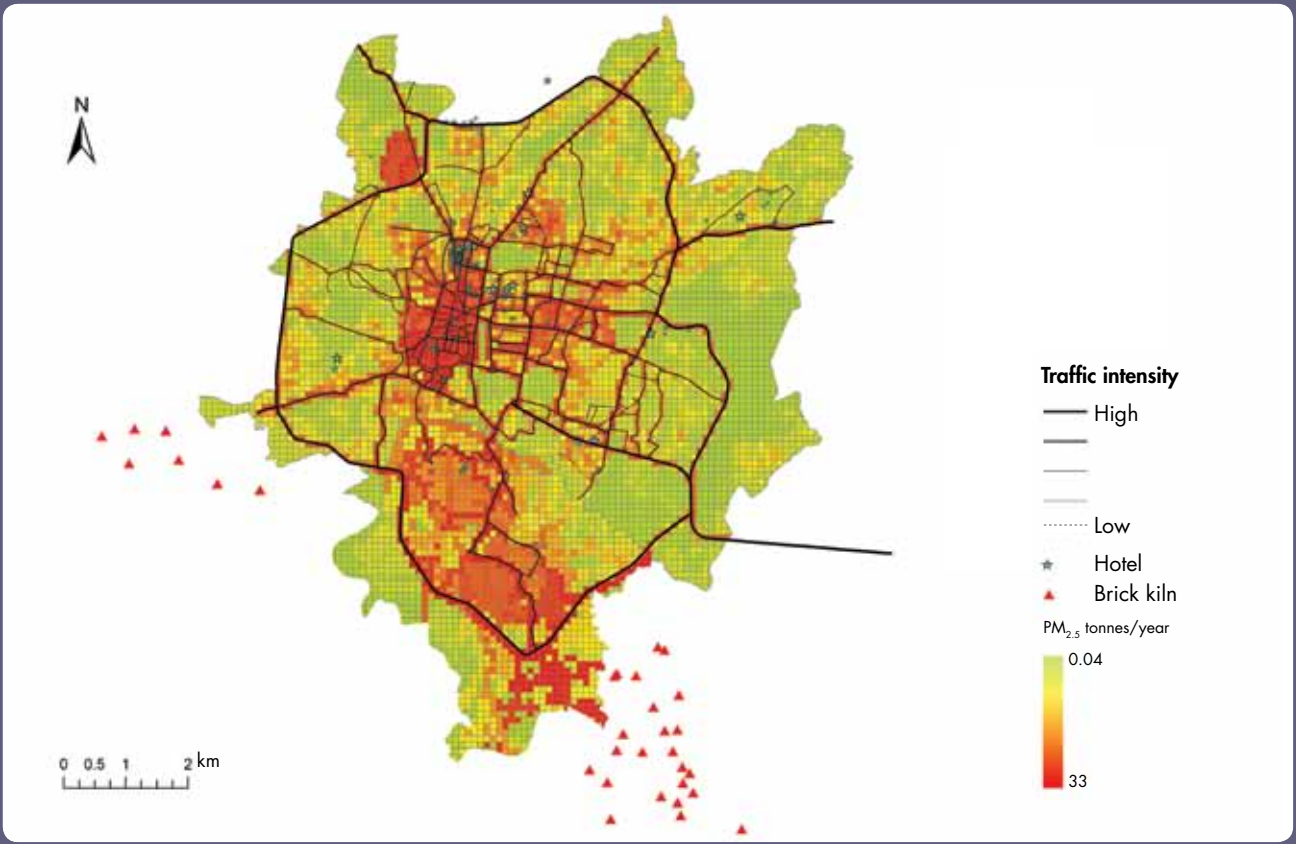
Kathmandu experiences strong seasonal variation: it has a relatively cool, dry winter and a hot, rainy monsoon in summer. Both precipitation and shifts in wind pattern influence how airborne pollutants are distributed over the city. Observations included the following.

- Regardless of the season, pollutant concentrations were high at roadside sampling stations and in the city core areas and low at rural stations.
- During the rainy season, the concentration of all measured pollutants was low. Rain and wind help to clean the pollutants from the lower atmosphere.
- Higher concentrations of all atmospheric pollutants (especially SO_2 and particulates) were observed during the dry season than during the rainy season (Figure 5). Lower wind speeds and substantial emissions from brick kilns, which operate only during the dry season, contributed substantially to pollution in the dry season.

What are the major pollution hot spots?

The pollution hot spots were shown clearly by the passive sampling measurements (Figure 6). They are located along the main roads, near industrial areas, hotels, the airport, and other areas with significant emissions. The road network, with daily traffic of more than 15,000–20,000 vehicles, is a major polluter; the major source of SO_2, NO_X, and particulate emissions is vehicle exhaust. PM_{10} was higher along the roads and high-traffic areas than elsewhere, while other pollutants such as SO_2, CO, and NMVOC were higher at the city centre since these are produced by the fuel used in cooking and industry. NH_3 was found in higher concentrations at the periphery of the urban areas as it is a by-product of agricultural activity.

Figure 6: **Map of the Kathmandu study area showing pollution hot spots; example of $PM_{2.5}$**



How do the results from the dispersion maps compare with the results from passive monitoring?

The dispersion maps were prepared from emission inventory data that covered the whole year. Meteorological parameters were included for the two seasons, wet and dry, to give approximate seasonal maps (Figure 7).
In contrast with the maps obtained from the seasonal passive monitoring campaigns, the maps based on the dispersion modelling results showed slightly higher concentrations during the wet season than during the dry season. Thus the modelled and monitored results did not match well. This is probably because averaged weather data were used, as consistent local weather data were not available; emission data had to be estimated for sources; and the selection of the models was not suitable for the complex terrain of the Kathmandu Valley.

What is the outlook?

In this study the modelled and monitored results did not match well. There are a number of likely reasons. First, there were no consistent local weather data available, and the meteorological values were obtained from the worldwide grid weather map used for TAPM, which is not of high enough resolution to provide good information for the terrain of the Kathmandu Valley. The highly varied topography and basin form of the Kathmandu Valley leads to marked local variation in weather patterns, reducing the usefulness of the coarse-resolution weather data from the worldwide weather map. Furthermore, the situation is complicated because it is very difficult to define clear zones with residential, office, factory, and other characteristics. In Kathmandu, there is no zoning and most areas contain a complex mix of sources rather than separated sources.

In further development, attempts will be made to improve the model with data on local meteorological conditions. Once it is validated, it could be a good resource to predict scenarios. The information could also be used

Figure 7: **Dispersion modelling maps for the dry and wet seasons; example of particulate matter**

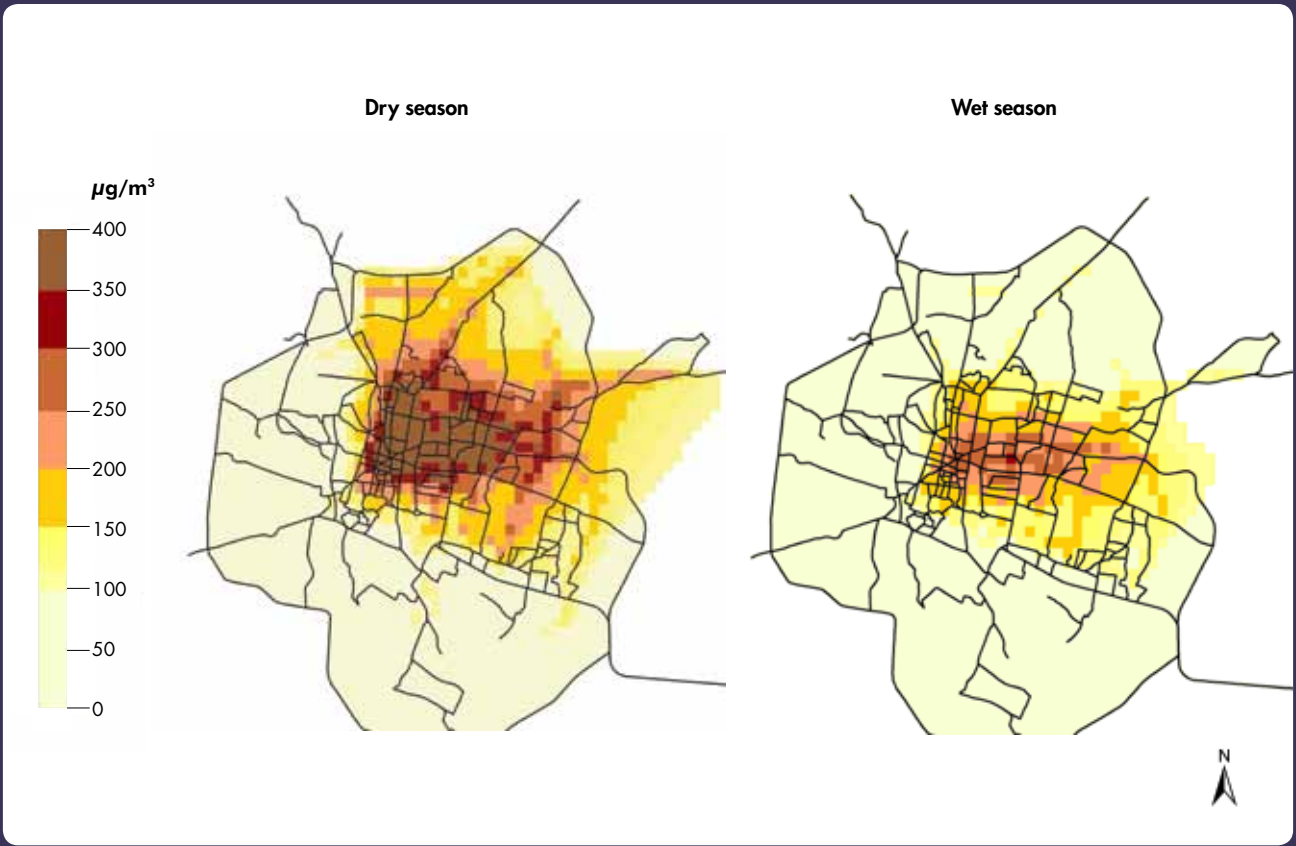
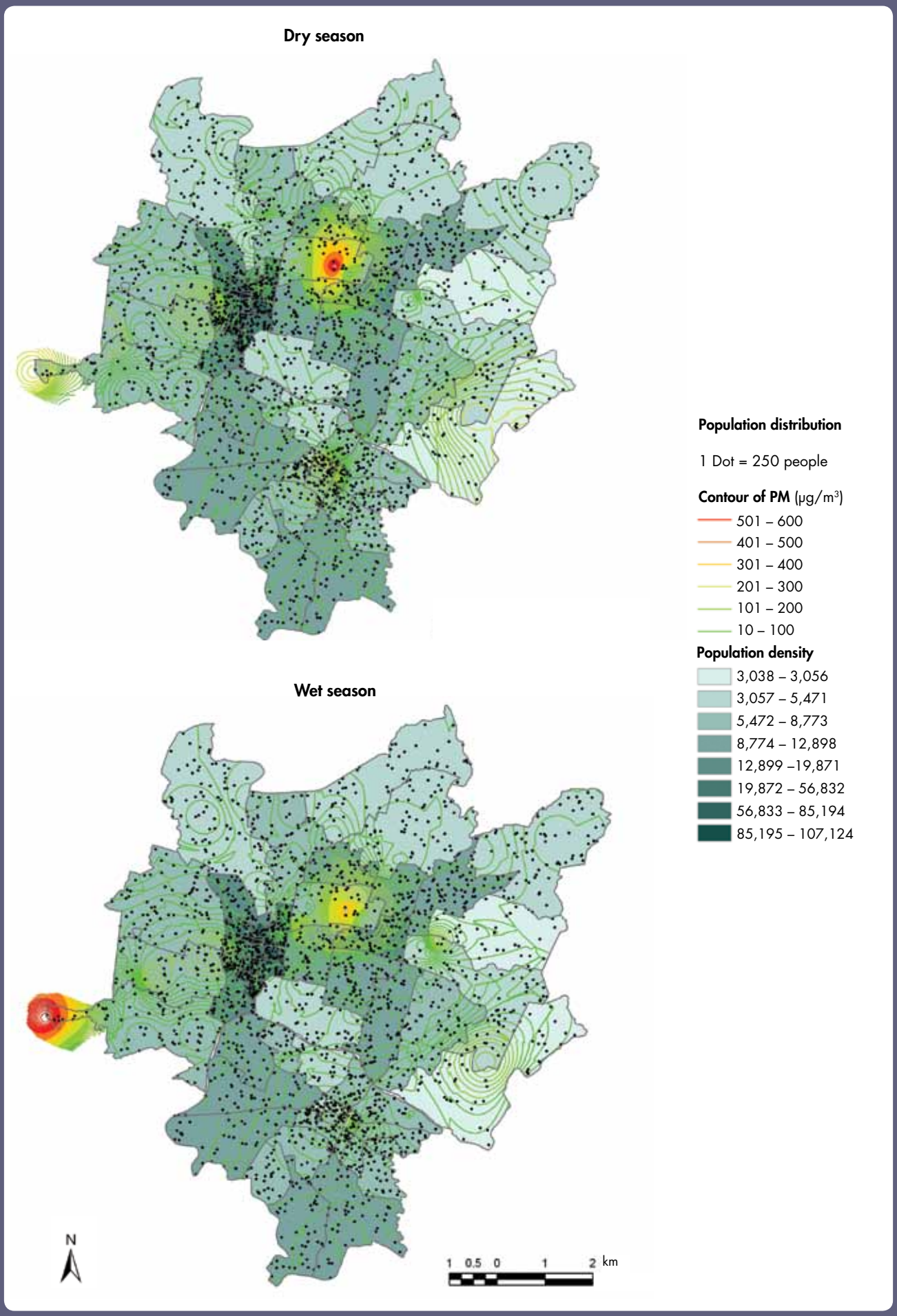


Figure 8: **Pollution hot spots mapped against population density; example of particulate matter**



to estimate in monetary terms the impact of poor air quality on the health of inhabitants in different areas of Kathmandu. As a start, pollution hot spots have been mapped against population density (Figure 8).

Overall, the original (unpublished) results from Hyderabad, and the results described here, indicate that this is a potentially useful method and low in cost compared to the bottom-up emission inventory method. The model can be applied in urban areas in the countries of South Asia to obtain a rapid overview of urban pollution that can be used to support air quality management; however, for mountain cities with complex terrain and no zoning regulations separating residential, industrial, and commercial areas, the model will require further modification.

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About ICIMOD

The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalization and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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Rapid Urban Assessment of Air Quality for Kathmandu, Nepal

DVD with Full Report

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