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

Malé Declaration 1998-2013: a Synthesis

Progress and Opportunities

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Summary for Decision-Makers

Work under the 1998 "Malé Declaration on Control and Prevention of Air Pollution and its Likely Transboundary Effects for South Asia" (Malé Declaration) provides an operational platform for gathering and disseminating reliable information on regional air pollution as a basis for envisaged policy development. Coordination of the programme is facilitated by the Secretariat at the Regional Resource Centre for Asia Pacific (RRC AP), at the Asian Institute of Technology in Bangkok. Results from the Malé Declaration highlight the following recommendations:

- It should be recognized that there is a significant transboundary dimension of air pollution in the region, calling for international co-operation.

- Key areas for action include the reduction of harmful emissions which have an impact on human health, food security, ecosystems and corrosion, as well as on economic development.
- Human health and agricultural productivity (food security) are impaired by emissions of many air pollutants, such as small particulate matter (PM) and ozone but also sulphur and nitrogen compounds, heavy metals and persistent organic pollutants. The economic and social losses of this type of damage are very significant but measures to alleviate these burdens exist and are readily available. A comprehensive approach to tackle these issues could be of considerable benefit to South Asian economies, environment and population. By controlling emissions, damage can be reduced and major societal benefits will accrue for individual countries, the region at large and beyond.
- Corrosion of man-made and natural materials increases due to certain air pollutants and leads to unnecessary costs for repair and replacement. Corrosion can also impact on the cultural value of national monuments and buildings, which may be lost forever, even with protective action. The perceived value of avoided damage should guide emission control programmes for this purpose.
- Continued monitoring and modelling, as well as effect studies and awareness-raising will facilitate science-based political decision-making for the immediate benefit of the whole region and beyond. National technical centres, as well as the Secretariat for the Malé Declaration, are important for securing sustained progress.
- To improve the performance of mitigation measures, further assessment of dose-response functions and possible scenarios should be carried out and analysed in parallel with implementation of technical and strategic programmes. Measures to control emissions of air pollution may benefit from coordinated action on climate change and vice versa.
- Cost-effectiveness of envisaged measures should be considered as a basis for optimized solutions, national as well as regional, taking into account the transboundary component of air pollution.
- Continued multilateral cooperation should be enhanced to secure long-term stable and sustainable progress in the Malé Declaration countries, ideally leading to intergovernmental policy arrangements.
- The Malé Declaration process is exclusively owned by the eight participating countries. This joint ownership is an obvious strength for optimal performance of its activities. Safeguarding and strengthening such ownership would facilitate funding of further implementation and programme delivery.

Executive Summary

The 'Malé Declaration on Control and Prevention of Air Pollution and its likely Transboundary Effects for South Asia' is an intergovernmental network involving Bangladesh, Bhutan, India, Iran, the Republic of Maldives, Nepal, Pakistan and Sri Lanka. Since its inception in 1998 the Malé Declaration National Focal Points (NFPs) and National Implementing Agencies (NIAs) have worked on a comprehensive set of activities, funded by the Swedish International Development Co-operation Agency (Sida), to build capacity in South Asia for the assessment of air pollution impacts and prevention and control options. The programme was very ambitious from the outset and considerable progress has been made to build the required capacity and institutional linkages in South Asia to assess a serious and growing problem. This synthesis report presents the achievement of the Malé Declaration in areas as diverse as emission inventory preparation, air pollution monitoring and modelling, health, crop, ecosystem and corrosion impact assessment, integrated assessment modelling, the development of policy responses and awareness raising activities. It shows that the Malé Declaration has established a platform that can potentially deliver significant benefits for the people of South Asia and their environment.

The Problem

Air pollution can affect people directly, through breathing unhealthy air, and indirectly by damaging the environment in which they live and reducing the yield of crops they eat. Important air pollution impacts are: human health effects, including premature death and lost work and school days through illness; damage to natural vegetation and crops, compromising ecosystem services and food security; corrosion of man-made materials and cultural heritage; acidification and eutrophication (excess nutrient availability) of soils, lakes and streams; and degradation of visibility (see Figure below). In all of these ways, air pollution contributes significantly to the downward cycle of poverty around the world, with the poorest communities being those most affected. As air pollution, especially particulate matter and the precursors of ground-level ozone formation, can be transported long distances, the problem therefore becomes a tranboundary one that requires co-operation at a regional/international level to solve, as described in the Malé Declaration.

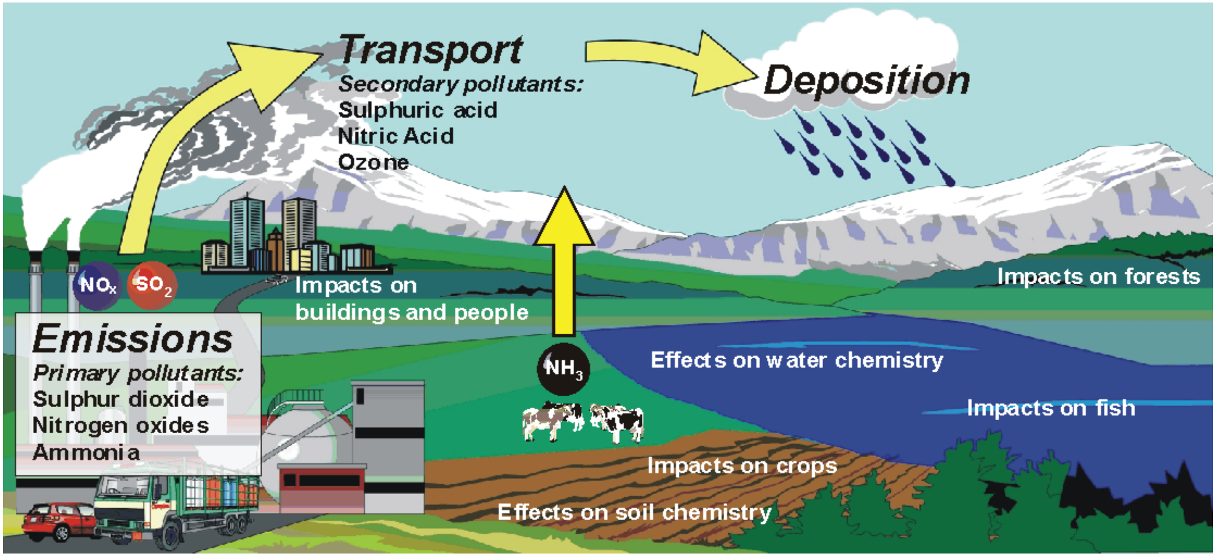


Figure: Illustration of the origin and regional transport of air pollution. The secondary pollutants formed from the primary pollutants in the atmosphere can travel large distances making the problem transboundary and requiring international co-operation to solve.

Impact Studies: Malé Declaration Achievements

Human Health Impacts in South Asia

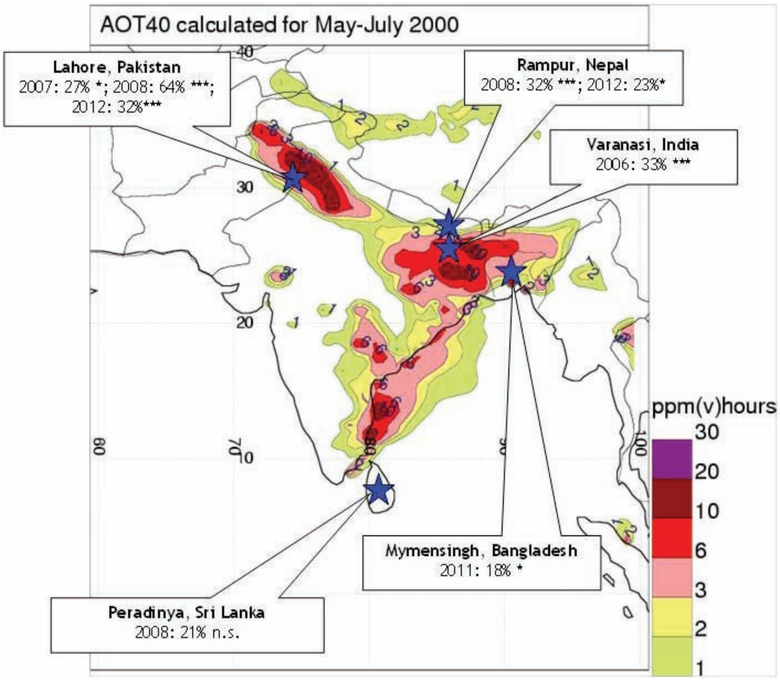
- Successful studies carried out by South Asian practitioners on the relationship between air pollution (particulate matter (PM)) and the health of school children in Dhaka, Bangladesh, Kathmandu, Nepal and Islamabad, Pakistan.
- Regionally specific data shows that lung function of children is impacted by levels of particulate matter pollution found in Asian cities.
- The Malé Declaration studies are some of the first to have been conducted where particulate matter concentrations are at the highest levels found in many large Asian cities.
- The findings of these studies emphasise the high cost of air pollution to the health of the community and the need to implement cost-effective measures to reduce emissions of health-damaging air pollutants.
- A Regional Centre of Health Impact Assessment is currently being established in Bangladesh to oversee coordination, harmonization, quality control and reporting of the Malé Declaration health impact activities.

The Malé Declaration health studies emphasise the high cost of air pollution to the health of the community and the need to implement cost-effective measures to reduce emissions of health-damaging air pollutants

Crop Impacts in South Asia

- New large-scale experimental evidence of effects of air pollutant ozone (O_3) at ground level on yield of important South Asian crops, such as mung bean, spinach, wheat and potato; evidence fits well with modelling-based regional prediction of O_3 concentration fields and the national emission inventory work of the Malé Declaration;
- The Malé Declaration has produced wide-spread evidence of plant-damaging concentration levels of O_3 during main growing seasons of important South Asian crops;
- Standardized risk assessment methodologies have been developed that have been evaluated for their application across the region;

- There is increased awareness of the yield-damaging effect of O_3 in South Asia among policy makers, the scientific community and general public through seminars, training workshops and information material (e.g. policy briefs);
- There has been successful capacity building in the region due to training of numerous junior and senior scientists in application of risk assessment methods;
- Institutionalized cooperation between South Asian, European and North American scientists has been enhanced with active mutual exchange of knowledge and skills (e.g. via the Air Pollution Crop Effect Network (APCEN) and the Global Atmospheric Pollution Forum (GAP Forum));
- A Regional Centre of Crop Impact Assessment is currently being established in Pakistan to oversee coordination, harmonization, quality control and reporting of the Malé Declaration crop impact activities.



The Malé Declaration has produced experimental evidence of effects of air pollutant ozone (O_3) at ground level on yields of important South Asian crops, such as mung bean, spinach, wheat and potato

Corrosion Impacts in South Asia

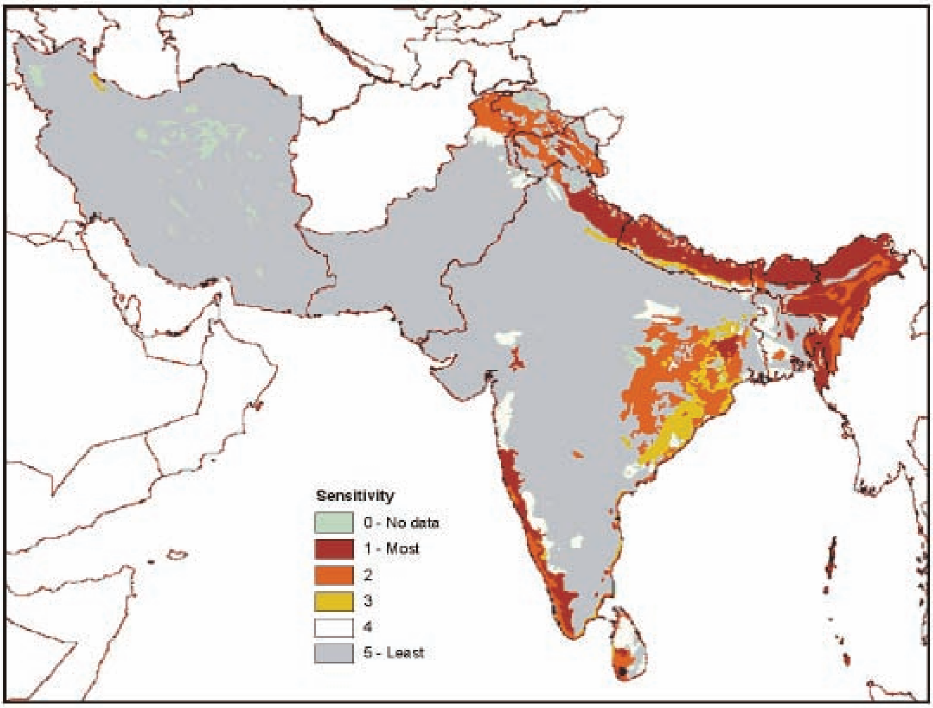
- The capacity to understand the air pollution impacts of corrosion on materials and cultural heritage has been significantly increased in South Asia, as well as the capacity to undertake stock at risk and economic loss assessments.
- The most important pollution parameters have been shown to be the same in subtropical/ tropical climates as in temperate climates, but the relative importance of the effects as well as the influence of climate can still be different.
- New dose-response functions have been developed for carbon steel, zinc, copper and limestone for South Asian conditions.
- In South Asia, dry deposition of sulphur dioxide (SO_2) is the most important parameter for corrosion impacts but acid rain is also important for all materials while nitric acid (HNO_3) is important for the corrosion of zinc and limestone.
- Using results from the Malé Declaration a tolerable SO_2 level for materials including cultural heritage in the Kathmandu Valley of 6 μg m^{-3} has been proposed.

- A Regional Centre of Corrosion Impact Assessment is currently being established in India to oversee coordination, harmonization, quality control and reporting of the Malé Declaration corrosion impact activities.

The Malé Declaration has produced new dose-response functions for carbon steel, zinc, copper and limestone for South Asian conditions

Ecosystem Impacts in South Asia

- Modelling studies and training events under the Malé Declaration have demonstrated that there are limited areas in South Asia which may be at risk from acidification from sulphur and nitrogen pollution such as in the Western Ghats, parts of Sri Lanka and eastern India. In the Himalayan regions of India, Bhutan and Nepal soils that are naturally acidic may also be under pressure from acidifying deposition.
- Modelling results suggest that acidification will not be a major issue compared to other air pollution problems in South Asia but further field research is required to determine the real extent of the problem.
- A potentially greater problem to ecosystems and their biodiversity than acidification in South Asia is eutrophication (excessive input of nitrogen and other nutrients). Nitrogen pollution from the transport, industry and agriculture is linked to health impacts, impacts on ecosystems, crops and climate, as well as the formation of ground-level ozone.
- Despite some progress there is still a need for a comprehensive regional assessment of these issues, especially using studies that have been conducted in South Asia.
- The Regional Centre on Crop and Vegetation impacts in Pakistan and on Soil Monitoring in Bhutan are currently being established to oversee co-ordination, harmonization, quality control and reporting of the Malé Declaration ecosystem related impact activities.

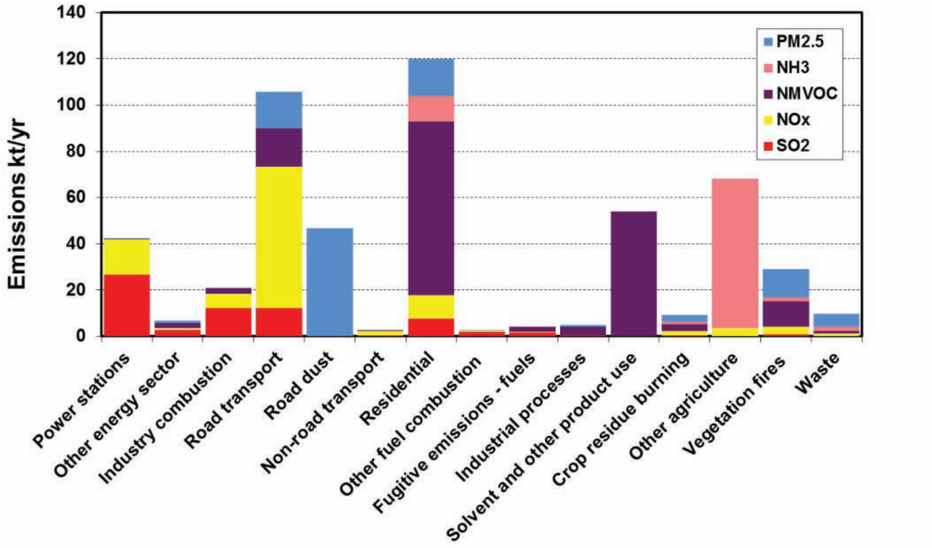


The Malé Declaration has shown that a potentially greater problem to ecosystems and their biodiversity than acidification in South Asia is eutrophication (excessive input of nitrogen and other nutrients)

Assessment of Emissions and Deposition: Malé Declaration Achievements

Emissions inventory activities

- Air pollutant emission inventory (EI) compilation capacity has been considerably enhanced in all eight Malé Declaration countries.
- Using a harmonised methodology (the Malé Declaration Emission Inventory Manual/Workbook), national EIs have been produced for the baseline year 2000 and draft EIs for 2005 are currently being finalised in some countries.
- As a result of this activity, decision makers will now be better able to identify national and regional trends in air pollution emissions and prioritize emission sources for mitigation.
- The EI data will also provide input for modelling the regional impacts of these emissions and assessing the likely benefits of alternative mitigation scenarios.
- A major achievement has been the establishment of the Regional Centre on Emission Inventory (at the Central Environment Authority, Colombo, Sri Lanka) to oversee coordination, harmonization, quality control and reporting of the Malé Declaration EI activities.



As a result of the Malé Declaration emission inventory activities, decision makers in South Asia will now be better able to identify national and regional trends in air pollution emissions and prioritize emission sources for mitigation

Prior to the Malé Declaration emission inventory activity, no comprehensive, national-level inventories of the main regional air pollutants had been produced by the Malé Declaration countries with the exception of India.

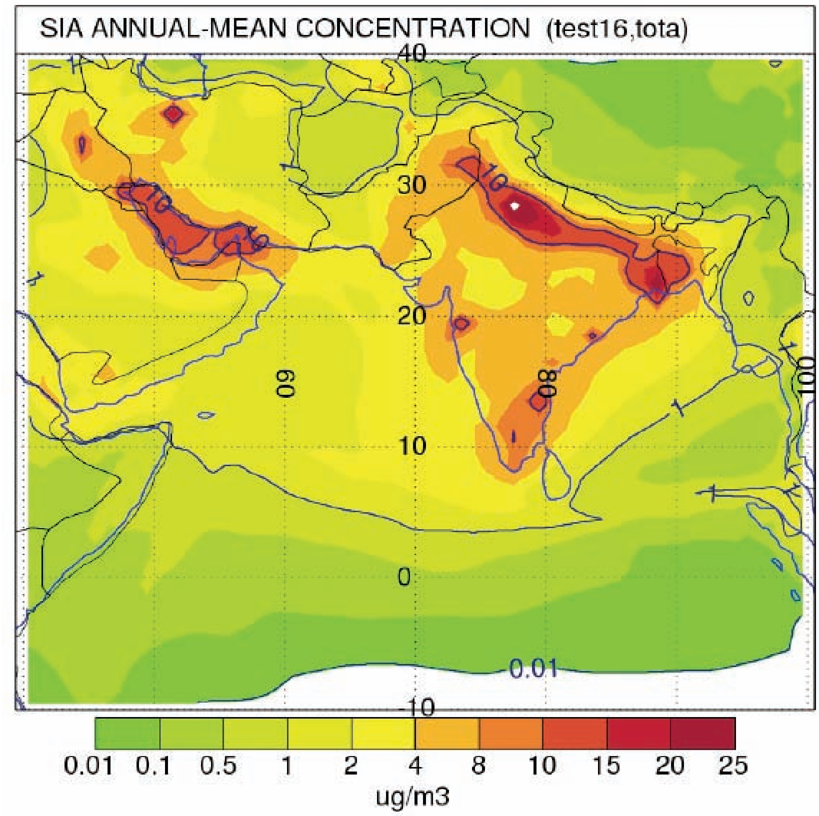
Monitoring Activities

- Monitoring is the backbone of all other activities and must be stable and long-term and organized in a robust network of monitoring sites. The Malé Monitoring Network was established in 2003 with at least one regional monitoring site established in each of the 8 Malé Declaration countries, further sites have subsequently been added in Bhutan, India, Iran, Maldives and Sri Lanka and there are currently 15 sites in the network;
- Monitoring data has been reported to the Malé Declaration Secretariat for almost 10 years, consisting of: monthly passive sampler (IVL, Sweden) measurements of air concentrations of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and Ozone (O_3); rain chemistry including pH and electrical conductivity measurements and ionic composition of rain conducted by the Malé Declaration; measurement of airborne particulate matter; plus some meteorological measurements;
- The passive sampler network has shown strong seasonal trends in the air concentrations of the three gases measured, with significant increases over time in mean annual concentrations of SO_2 (Bangladesh, Bhutan, Nepal and Sri Lanka), NO_2 (Bangladesh, Bhutan, Maldives, Nepal and Sri Lanka) and O_3 (Bangladesh, Bhutan, Maldives and Sri Lanka).
- Regular training and capacity building workshops have taken place, with India taking an active role in the training;
- Quality control and assurance procedures with training have been conducted for the Malé Declaration sites, three reports on Inter – Laboratory Comparison of Precipitation Chemistry Analyses among the National Implementation Agencies (NIAs) of the Malé Declaration have been compiled;
- A regional centre on monitoring activities is being established in India.

The Malé Declaration has built significant capacity for the monitoring of air pollution in South Asia but further progress is required to produce data of sufficient quality for policy making

Modelling Activities

- Modelling activities under the Malé Declaration have demonstrated the transboundary dimension of the air pollution problem in South Asian conditions;
- The potential for monitoring and modelling results to be used together to build up a regional picture of the air pollution situation in South Asia has been clearly demonstrated;
- A regional centre on modelling activities is being established in Iran.



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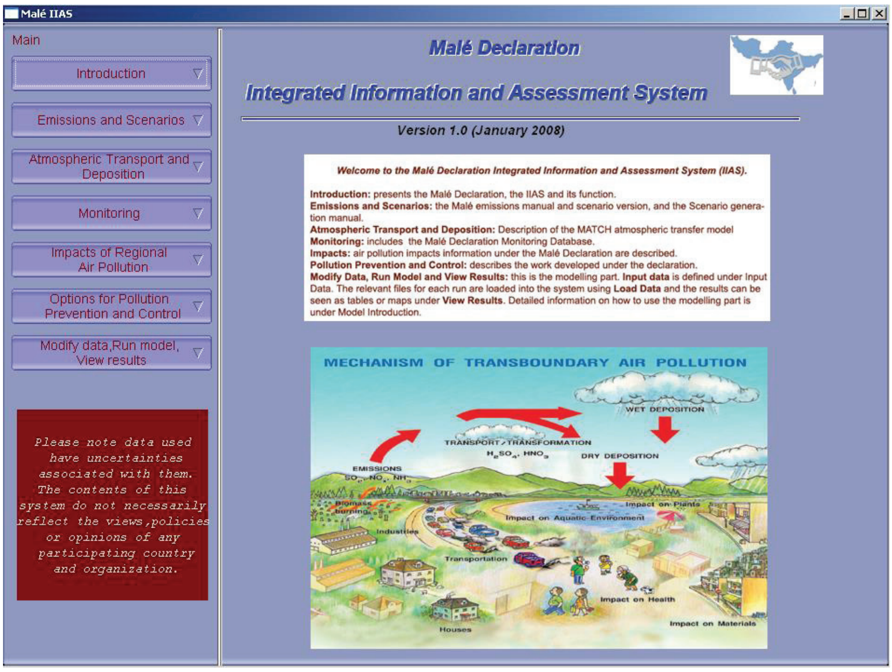
Integrated Assessment

- An Integrated Information and Assessment System (IIAS) has been developed by the Malé Declaration that can take emissions and monitoring data from South Asia and assess health impacts from particulate matter, crop yield impacts due to ozone and ecosystem impacts of nitrogen and sulphur. The Malé Declaration now has the capacity to quantify the benefits, in terms of reduced impacts, of different scenarios of emission abatement.



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Rapid Urban Assessment

- The application of rapid urban assessment methods has developed capacity in Kathmandu, Nepal, and Hyderabad, India, to undertake rapid urban emission inventories which are the basis for policy development and health risk assessment in cities.
- The validity of these inventories has been cross-checked by monitoring data which show reasonable agreement.
- The work conducted under the Malé Declaration has made it clear that the most important pollutant in Kathmandu is particulate matter, largely from the transport sector, which is known to have the greatest impact on human health.
- The Malé Declaration now has the capacity to calculate the distribution of emissions the rapid urban assessment methodology enabling targeted strategies to be developed to reduce air pollution in the hotspots.

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Decision Support Information for Policy Formulation and Mitigation: Malé Declaration Achievements

- Information on best and good practice on air pollution policy, using international examples and examples of policy implementation in South Asia for the housing, transport and power sector, examining Best Available Techniques (BAT), has been synthesised for the Malé Declaration.
- Another project has considered the implementation of policy measures in some countries of South Asia and factors that affect how well policy interventions work in the social and political contexts of the different countries in the Malé Declaration region.
- Workshops were used to train National Implementing Agency (NIA) representatives in the Malé Declaration in the different types of policy approach. The workshops assessed which policy in a particular sector would be most appropriate for South Asian conditions, given resource constraints and institutional aspects.
- The capacity of Malé Declaration officials and experts involved in the policy making process has been enhanced through training on regional cooperation issues focusing on good practices and knowledge on international policies and regulations related to air pollution in other parts of the world.
- Bangladesh is the first country to produce an air pollution reduction strategy in South Asia under the Malé Declaration.
- A regional centre on Pollution Reduction Policies/Strategies is being established in Nepal / Maldives.

	Strategy	Area of application
A	Improve public transport	Large cities
B	Strengthen vehicle inspection and maintenance	All, especially large cities
C	Ban vehicles older than 20 years	Commercial vehicles, large cities
D	Encourage Diesel to CNG switch through incentives	All diesel vehicles, especially, truck & buses in large cities
E	Emissions (age) based annual registration fees	All vehicles
F	Stringent emissions standards	All new vehicles
G	Emissions based import tariff	All new vehicles
H	Comprehensive land use plan for industry locations	All industries, especially new ones
I	Cluster management	Cluster of highly polluting industries
J	Emissions (technology and fuel) based license fee	All kilns
K	Technology standards	All kilns
L	Alternate construction material	All country, especially large cites
M	Ensure adequate power supply	All country
N	Emissions standards	All new plants
O	Emissions standard for diesel generators	All new generators
P	Inspection & maintenance of diesel generators	All existing generators
Q	Technology specification	Existing steel mills, cement and glass factories
R	Inspection and maintenance	Existing steel mills, cement and glass factories
S	Emissions standards	All new and existing plants
T	Import control for quality of coal	Whole country, primarily brick and power industries
U	Better construction practices on site & during transport	All construction sites
V	Air pollution mitigation plan and its enforcement	Large construction projects
W	Timely road maintenance	All roads
X	Landscaping and gardening	All exposed soil in urban areas
Y	Encourage fuel switch	Urban slums and rural areas
Z	Improved cooking stoves	Rural areas

The capacity of Malé Declaration officials and experts involved in the policy making process has been enhanced

Awareness Raising

- The Malé Declaration communication activities have targeted a broad audience in South Asia. This has been accomplished through the development of newsletters and through stakeholder involvement in workshops and national initiatives. In addition, the progress in the Malé Declaration has frequently been presented to international meetings.
- The Malé Declaration has an annual regional stakeholder meeting and a number of national stakeholder meetings. Dissemination is also conducted through youth groups such as South Asia Youth Environment network (SAYEN).
- Awareness activities have included dissemination of brochures, posters, and stickers on air pollution by the NIA as well as filmed songs on air pollution by popular singers and short plays using well-known actors.

- Awareness activities have also included activities under the Malé Declaration targeted on three levels of education and understanding for the general public, schools and university students and technical/science professionals.

The Malé Declaration communication activities have targeted a broad audience in South Asia.

Regional Cooperation and Financing

- The Malé Declaration has succeeded in establishing regional co-operation on air pollution issues in South Asia, which was missing before its establishment in 1998. Also, recently the Malé Declaration has been successful in establishing a sustainable financing mechanism and some countries have already initiated financial contributions.

The Malé Declaration has succeeded in establishing regional co-operation on air pollution issues in South Asia

Next Steps – Opportunities for the Malé Declaration

Overarching considerations

- Regional centres could play a key role but require funding.
- Malé Declaration activities have benefited from interactions with competent universities and relevant institutions which have regional, technical know-how on crops, health and corrosion studies. Monitoring and modelling could also benefit from being more closely linked with existing scientific expertise in South Asia, for example, the Atmospheric Brown Cloud (ABC) programme.
- Sharing information through the Malé Declaration can help countries achieve national priorities.

Opportunities

- Malé Declaration provides a basis for regional but differentiated science-based programmes on emission control and review of implementation. Reliable long-term monitoring is at the base of everything. The Secretariat plays a very important role for supporting countries' decision-making and for facilitating further progress.
- The Malé Declaration process is exclusively owned by the eight participating countries. This joint ownership is an obvious strength for optimal performance of emission inventory compilation, monitoring of deposition and concentrations, addressing transboundary issues, studies on effects of air pollution on human health and the environment, assessments and reviews, operation of technical centres and training events, stakeholder and inter-ministerial meetings and intergovernmental cooperation. Safeguarding and strengthening such ownership would facilitate funding of further implementation and programme delivery.
- This report demonstrates that all Malé Declaration countries would benefit from committing to efforts to tackle regional problems, as there is now sufficient evidence on the impacts and capacity to address them.
- The Malé Declaration provides a framework to promote integrated approach for air pollution issues at national and regional level in South Asia. Some Malé Declaration countries have initiated an integrated approach by prioritising action on air pollution and short-lived climate pollutants (SLCPs) such as black carbon and methane (a precursor of ground-level ozone). This good practice in region can be shared and the Malé Declaration is prime vehicle for doing this.
- The transboundary nature of air pollution in South Asia offers incentives for action and regional and international co-operation.
- The atmospheric brown cloud phenomenon and the black carbon problems in the Himalayas related to retreating glaciers, provide extra incentive and urgency for action.
- There is a need to address short-term problems (e.g. health and crops) and long-term problems like climate and sustainability.
- The Malé Declaration monitoring programme is important to protect and promote so it can provide the basis for action and the crucial task of the reviewing success of implementation.
- There is now a good basis for working towards a regional treaty on air pollution, or at least some type of international agreement covering the different sectors.

1. Introduction to the problem of air pollution

Air pollution can affect people directly, through breathing unhealthy air, and indirectly by damaging the environment in which they live and reducing the yield of crops they eat. Important air pollution impacts include: human health effects, including premature death and lost work and school days through illness; damage to natural vegetation and crops, compromising ecosystem services and food security; corrosion of man-made materials and cultural heritage; acidification and eutrophication (excess nutrient availability) of soils, lakes and streams; and degradation of visibility (see Figure 1.1 below). In all of these ways, air pollution contributes significantly to the downward cycle of poverty around the world, with the poorest communities being those most affected. As air pollution, especially particulate matter and the precursors of ground-level ozone formation, can be transported long distances, the problem therefore becomes a tranboundary one that requires co-operation at a regional/international level to solve, as described in the text of the Malé Declaration.

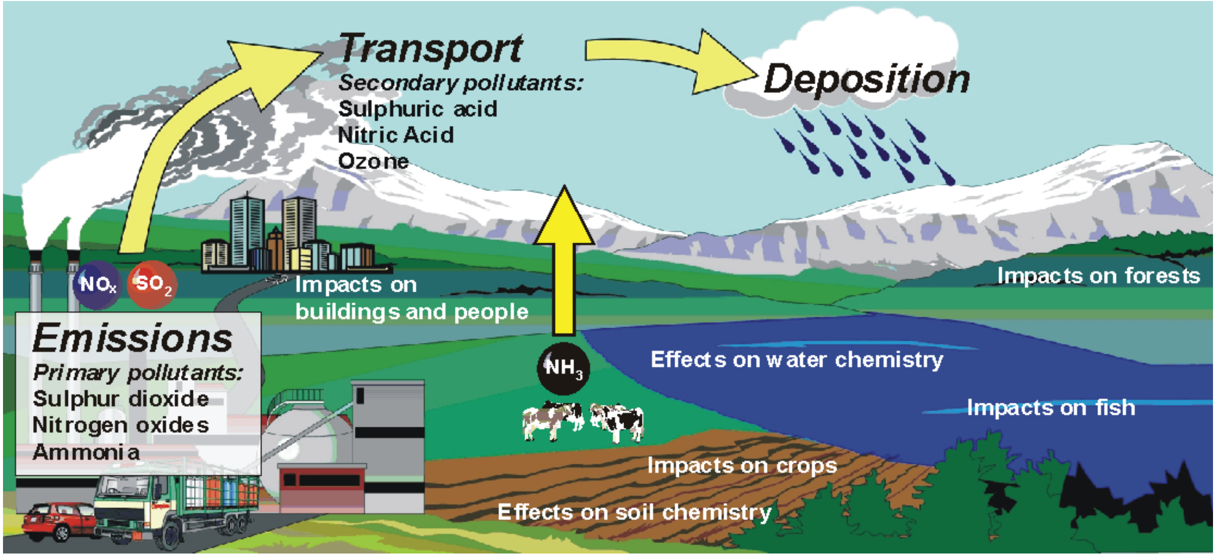


Figure 1.1: Illustration of the origin and regional transport of air pollution. The secondary pollutants formed from the primary pollutants in the atmosphere can travel large distances making the problem transboundary and requiring international co-operation to solve.

1.1 Impacts of air pollution in Malé Declaration countries of South Asia

The 'Malé Declaration on Control and Prevention of Air Pollution and its likely Transboundary Effects for South Asia' is an intergovernmental network involving Bangladesh, Bhutan, India, Iran, the Republic of Maldives, Nepal, Pakistan and Sri Lanka (Hicks et al., 2001). Since its inception in 1998 the Malé Declaration National Focal Points (NFPs) and National Implementing Agencies (NIAs) have worked on a comprehensive set of activities, funded by the Swedish International Development Co-operation Agency (Sida), to build capacity in South Asia for the assessment of air pollution impacts and prevention and control options.

There is an emphasis on the generation of regionally specific information as experience shows that it is not sufficient for policy makers to be told only of the experiences of other regions such as Europe and North America. To achieve the results below the Male Declaration has worked in close cooperation with the Swedish International Development Cooperation Agency (Sida) funded programme Regional Air Pollution in Developing Countries (RAPIDC) and its partners in Asia and Europe. There has also been south-south exchange of information between the Malé Declaration and the Air Pollution Information Network for Africa (APINA) which has been carrying out similar activities in southern Africa under the RAPIDC programme.

2. Major Impacts of Air Pollution in South Asia

2.1 Human health impacts in South Asia

Malé Declaration achievements and results

- Successful studies carried out by South Asian practitioners on the relationship between air pollution (particulate matter (PM)) and the health of school children in Dhaka, Bangladesh, Kathmandu, Nepal and Islamabad, Pakistan.
- Regionally specific data shows that lung function of children is impacted by levels of particulate matter pollution found in Asian cities.
- The Malé Declaration studies are some of the first to have been conducted where particulate matter concentrations are at the highest levels found in many large Asian cities.
- The finding of these studies emphasise the high cost of air pollution to the health of the community and the need to implement cost-effective measures to reduce emissions of health-damaging air pollutants.
- A Regional Centre of Health Impact Assessment is currently being established in Bangladesh to oversee coordination, harmonization, quality control and reporting of the Malé Declaration health impact activities.

Background

Air quality in large cities is a major health and environmental concern in most countries around the world. The priority to address the severe impacts of air pollution on health has grown as the population and emissions in cities have rapidly increased. Numerous studies have shown that particulate matter has the greatest impact on health of all common air pollutants (Lim et al., 2012; WHO, 2006). The World Health Organization (WHO) states that the higher the concentration of particles in air the greater the risk to human health especially respiratory and cardiovascular diseases (WHO, 2006). Recent studies have identified fine particles in air called $PM_{2.5}$ (particles with a mean diameter of 2.5 micrometres or smaller) as being especially harmful because they may reach and persist in the alveolar region of the lungs causing long-term damage. Action to reduce emissions of fine particulates in large cities is now a high priority.

The WHO Global Burden of Disease published in 2010 identifies especially high risk levels in the developing countries of Asia where air pollution levels are the highest in the world. In South Asia in 2010, outdoor air pollution, mostly particulates, ranked 6th in the 20 leading factors for death where it contributed to 712,000 deaths, whilst indoor household air pollution from solid fuels ranked 3rd contributing over a million deaths (see Figure 2.1.1). The analysis found that reducing the burden of disease due to air pollution in Asia will require substantial decreases in the high levels of particulate matter pollution, which is substantially higher than estimated in previous analyses (Lim et al., 2012).

Far more studies have been conducted in developed countries than in developing countries. Consequently information is needed to assess the impacts of the high concentrations of fine particles found in the large cities of developing countries in the Asia-Pacific region.

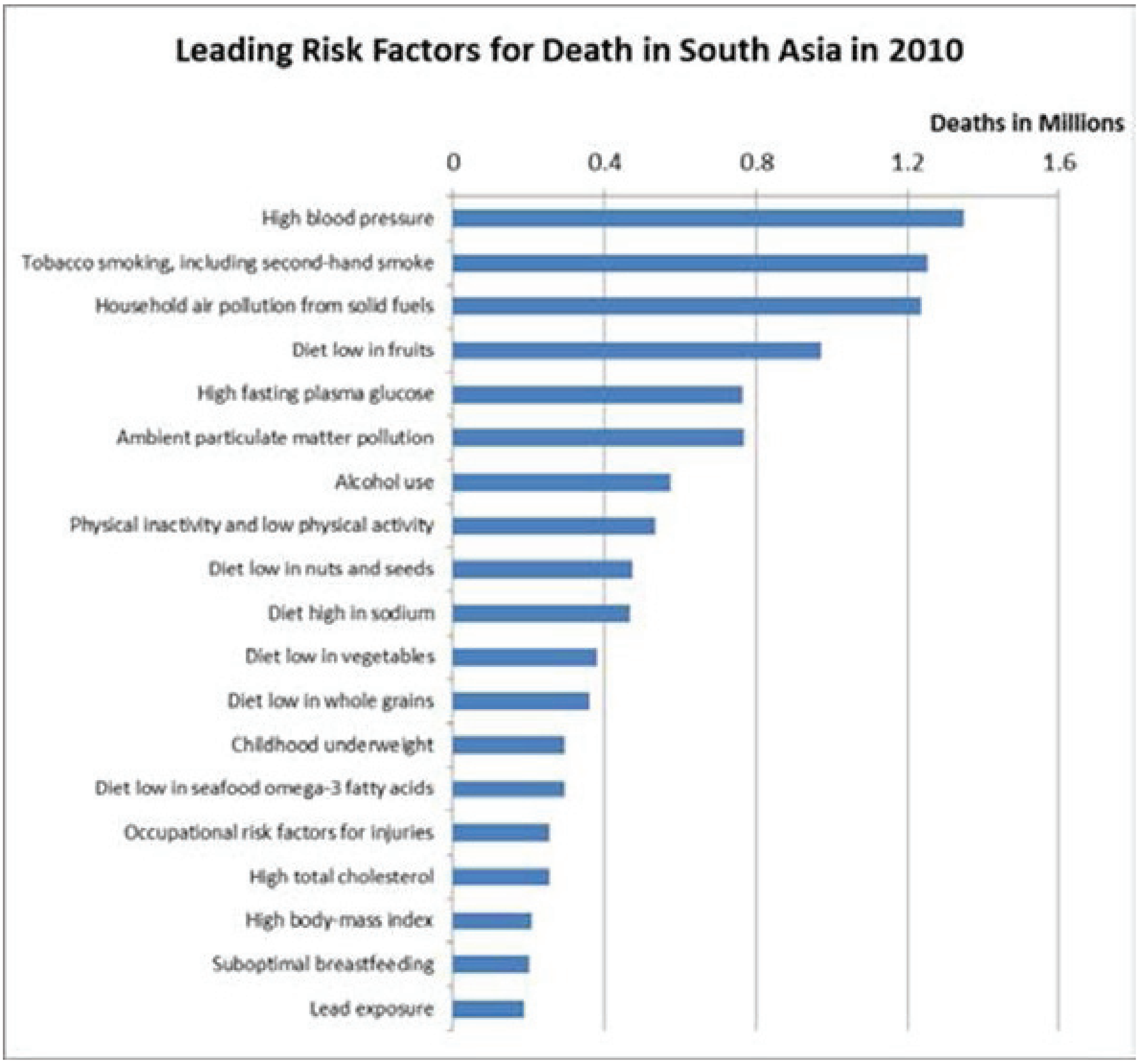


Figure 2.1.1: Number of Deaths Attributable to 20 Leading Risks in South Asia 2010 (Lim et al., 2012)

The health studies conducted by the Malé Declaration have helped to address the need for information on the effects of particles on human health in South Asian cities. They provide locally-gathered evidence to support actions by governments to control particulate emissions. These studies were conducted on the health of children, as the developing lungs of children are more vulnerable to the adverse effects of air pollution than adult lungs. Children are more susceptible to air pollution than adults because of higher ventilation rates and higher levels of physical activity. In addition, adverse impacts in childhood can continue throughout their adult lives with health, social and economic consequences.

Health studies carried out on school children in South Asia

The activities of the Malé Declaration have concentrated on enhancing the capacity of key regional stakeholders, including government agencies and health professionals, in health impact assessment methods and helping them to access relevant information. It also provides scientific evidence from South Asian cities to support informed policy decisions on air pollution. Three health studies were conducted in different locations in major South Asian cities supported by the Malé Declaration. The objectives of the studies were to assess the impacts of particulate air pollution on the respiratory health of school children of selected schools in Dhaka, Bangladesh (NIPSOM and Department of Environment, 2008); the Kathmandu Valley, Nepal (NHRC and ICIMOD, 2013); and Islamabad, Pakistan (PakEPA and PMRC, 2013) and measure the association between the concentration of $PM_{2.5}$ and lung function in selected schoolchildren in these cities.

The studies had two components: Phase 1: a baseline survey and Phase 2: a health impact assessment. The baseline survey used a structured questionnaire, developed for international use by the International Study of Asthma and Allergies in Childhood (ISAAC). A baseline survey of 1618 children was conducted in Dhaka, of 801 children in Kathmandu and 328 children in Islamabad. The response rate was 90% in Dhaka, 68% in Kathmandu and 66% in Islamabad. The results showed a relatively high level of respiratory illnesses not associated with colds or flu in about a third of children in all studies. Children with pre-existing lung diseases, allergy or other related factors were excluded while a representative sample of the remaining students were selected for Phase 2 of the studies in Islamabad and Kathmandu. In the Dhaka study asthmatic children were compared with non-asthmatic children.

A correlational study was conducted in Phase 2 to assess the impact on respiratory health of fine particles in air ($PM_{2.5}$) in 120 children with clinical evidence of asthma and 60 non-asthmatic control children in Dhaka, among 137 students in Kathmandu and 132 children in Islamabad. Children of age between 9-16 years in Dhaka, 10-15 years in Kathmandu and 9-14 years in Islamabad were assessed daily for their lung function by measuring morning peak expiratory flow rate (PEFR) (see Figure 2.1.2). Meanwhile, measurements of $PM_{2.5}$ were recorded daily using particulate measurement instruments. Weather data were also recorded. PEFR and $PM_{2.5}$ measurements were conducted simultaneously on a daily basis for a total of 42 days in Dhaka, 31 days in a period of 42 days in Kathmandu and for a total of six weeks in Islamabad.

Figure 2.1.2: Research Assistant guiding the children to measure the peak expiratory flow rate (PEFR) in Kathmandu, Nepal

Results of health studies on school children

The results of the studies show very high levels of particulate pollution in all three cities, which consistently exceed the WHO Air Quality Guidelines (AQGs) for $PM_{2.5}$ of 25 µg/m^3 expressed as a 24 hour mean (WHO, 2006). The WHO recommended that countries with areas not meeting the 24-hour guideline values undertake immediate action to achieve these levels in the shortest possible time.

Dhaka, Bangladesh

The daily mean concentrations of $PM_{2.5}$ varied from 18 to 233 µg/m^3 with a mean of 67 µg/m^3. It exceeded the Bangladesh daily $PM_{2.5}$ standard of 65 µg/m^3 on 13 of the 42 days of health data collection.

Although 16.5% of the children completing the questionnaire reported having asthma, 25.8% were diagnosed by the study physicians as having clinical symptoms of asthma. This figure is much higher than most international studies where the asthma rate is usually about 10%. For example it is 7.7% in the USA.

The study showed that there was a relationship between PEFR in both asthmatic and non-asthmatic children and $PM_{2.5}$ concentrations (Figure 2.1.3). PEFR decreased by about 30% in both asthmatic and non-asthmatic children when $PM_{2.5}$ increased from its lowest level of 18 µg/m^3 to its highest daily mean of 233 µg/m^3. The difference in PEFR between asthmatic and non-asthmatic children was maintained across the range of $PM_{2.5}$ concentrations.

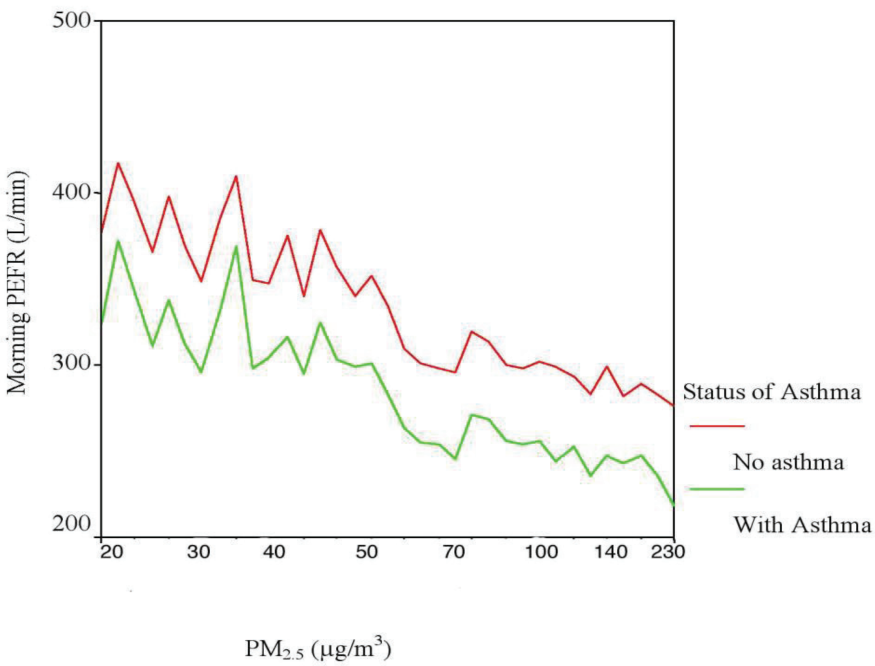


Figure 2.1.3: The relationship between $PM_{2.5}$ concentrations in air and morning peak expiratory flow rate (PEFR) in children with and without asthma in Dhaka (NIPSOM and Department of Environment, 2008).

This study conducted surveys that found that the total annual expenditure for respiratory illnesses of an asthmatic child (6918 Taka, about 100 USD) was twice the expenditure for respiratory illnesses of a non-asthmatic child (3478 Taka). There are about 2.37 million children of school age in Dhaka, and this study suggest about 25.8% have clinical symptoms of asthma, about 0.61 million children. The additional annual expenditure on respiratory illnesses for about 0.61 million children with asthma is about USD 30 million.

Although data from Dhaka are not readily available, based on data from the USA, and assuming the same proportions apply to Dhaka, the 0.61 million children in Dhaka with asthma will have 12 million restricted activity days, 1.5 million school absence days, (2.48 days per child with asthma), and 51 school age children would die of asthma per year. If ambient concentrations of $PM_{2.5}$ could be reduced these impacts on respiratory health of children could be substantially reduced.

Kathmandu, Nepal

The study in Kathmandu contrasted an urban roadside school with a semi-urban school in a residential area. The 24 hour mean concentration of $PM_{2.5}$ was 203 µg/m^3 (±75.01) in the urban school and 137 µg/m^3 (±44.52) in the semi-urban school and the difference is statistically significant (p =0.04). It usually exceeded the Nepal daily $PM_{2.5}$ standard of 40 µg/m^3.

The PEFR level of the students at the urban school was found to vary with the changing levels of $PM_{2.5}$ concentration which ranged between 100 µg/m^3 and nearly 340 µg/m^3 (Figure 2.1.4). The PEFR levels of younger (10-12 years) children seem to be correlated with the changes in $PM_{2.5}$ concentrations in the initial days and later days of the assessment. Also, the PEFR levels of female children also seem to be associated with the variation in daily $PM_{2.5}$ concentrations on a few days.

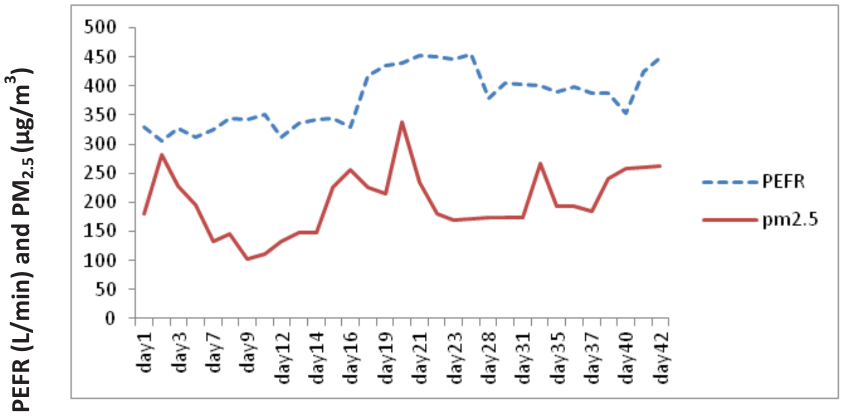


Figure 2.1.4: The relationship between peak expiratory flow rate (PEFR) (L/min) of 10 to 12 year old children and $PM_{2.5}$ (µg/m³) concentration at the urban roadside school in Kathmandu (NHRC and ICIMOD 2013).

Islamabad, Pakistan

In the baseline survey two schools (girls and boys) with similar socioeconomic populations were selected from Ternoul, Islamabad. The mean concentration of $PM_{2.5}$ in Islamabad was 81 µg/m³ with a range of 25- 142 µg/m³ (Figure 2.1.5). Measurements frequently exceeded the 24 hour air quality standard in Pakistan of 40 µg/m³. The peak expiratory flow rate (PEFR) ranged from 120 L/min to 420 L/min, with a mean of 287 L/min. There was no significant difference in PEFR among children of different schools.

The study found that over the six weeks of monitoring, the concentration of $PM_{2.5}$, started to increase in week 2 and kept on increasing until week 3 and then showed a decline. During this period a drop in PEFR was also observed which reverted to normal at week 4. However, this association was not statistically significant.

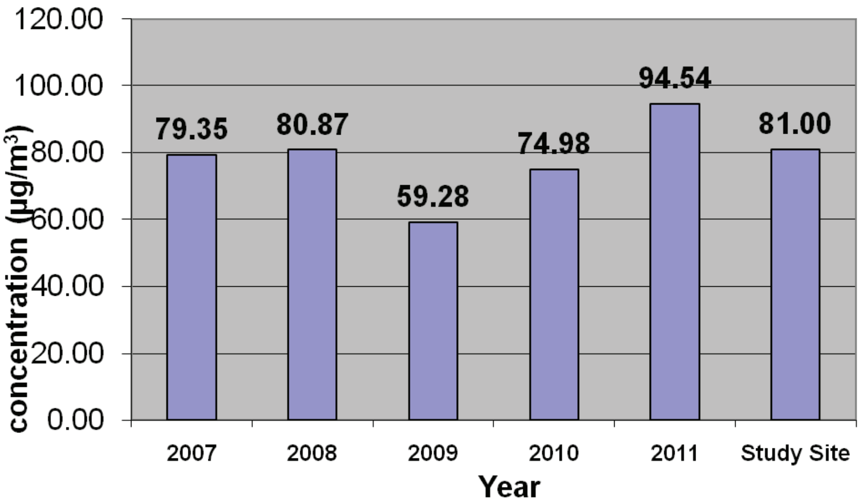


Figure 2.1.5: Annual average concentration of PM2.5 for 2007-2011 at the study site in Islamabad. The 24 hour air quality standard for Pakistan is shown by the red bar (PakEPA and PMRC 2013).

Implications of the studies

The results of air quality monitoring during the period of the studies in Dhaka, Islamabad and Kathmandu show that ambient concentrations of $PM_{2.5}$ exceeded the relevant national air quality standards by substantial margins (Table 2.1.1).

Table 2.1.1: Concentrations of $PM_{2.5}$ during these studies in Dhaka, Islamabad and Kathmandu (NHRC and ICIMOD, 2013; NIPSOM and Department of Environment 2008; PakEPA and PMRC 2013).

Parameter (in μg/m^3)	Dhaka	Islamabad	Kathmandu Urban school	Kathmandu Semi-urban school
Mean concentration	67	81	203	137
Maximum concentration	233	142	337	231
Minimum concentration	18	25	102	76
Air quality national standard	65	40	40	40

The decrease in PEFR by about 30% in both asthmatic and non-asthmatic children in Dhaka when $PM_{2.5}$ increased from its lowest level of 18 μg/m^3 to its highest daily mean of 233 μg/m^3 is a major and important finding. These results are similar to studies conducted with children in Bangkok (Preutthipan et al, 2004) to assess the impact of particles in air on child health. Similar associations between PEFR and PM_{10} have been reported in many studies (Pope and Dockery, 1999, Romieu et al, 1996 ; Braun-Fahrlander et al, 1992; Pope and Dockery, 1992; Schwartz et al, 1994; Timonen and Pekkanen, 1997; Ward and Ayres, 2004). A number of studies indicate an adverse effect of particulate air pollution that is greater for $PM_{2.5}$ than PM_{10} especially for PEFR (Ward and Ayres, 2004).

These studies in Dhaka, Kathmandu and Islamabad show a surprisingly high level of respiratory illnesses not associated with colds or flu in about a third of children. Nearly 30% of children were reported to have respiratory symptoms such as sneezing, running nose or nasal blockage even when they did not have common cold or flu. Of the students with respiratory symptoms, about 70% of them had such symptoms in the last 12 months and about a quarter of them had symptoms that hampered their studies and activities.

The studies in Dhaka, Kathmandu and Islamabad suggest that nearly 30% of all children were found to be suffered with respiratory health issues and had to visit a doctor or other health facility. Due to these respiratory health issues in Kathmandu 43% of the children missed school for one or two days, 42% of their guardians missed their work due to these illnesses in children and the number of days missed were mostly one or two days. The median expenditure in Kathmandu for the health facility or doctor was NRs 1000 and for travelling to medical facilities was NRs 200. The total median expenditure was NRs 1400.

A study in Dhaka showed that seven million people are suffering from asthma including four million children (Hassan et al, 2002). Based on that estimate, around 27.67 billion taka (about US$ 395 million) is needed for the treatment of four million children in Bangladesh. This expenditure could be substantially reduced with greater control of air pollution emissions.

This study has revealed that $PM_{2.5}$ concentrations in ambient air have a significant adverse economic impact on the families of affected children. It has been estimated that the reduction of PM_{10} concentration by 20% - 80% in Dhaka could allow for avoidance of 1,200 to 3,500 deaths, 80 to 235 million cases of sickness and a saving of US$ 169 to 492 million equivalent to 0.34 – 1.0 % of Gross National Income (World Bank, 2006). Clearly measures to reduce particulate matter emissions by prudent air quality control measures could not only contribute in reducing individual suffering but also contribute towards attaining Millennium Development Goals in health as well as poverty alleviation.

The results of these studies in Dhaka, Islamabad and Kathmandu are consistent with other studies and show a high level of respiratory illnesses not associated with colds or flu. Many studies have demonstrated increases in respiratory illness, asthma symptoms, medication use, pulmonary function decrements and hospital admissions associated with increases in particulate matter concentrations in air (McGranahan and Murray, 2002). However, few studies have been conducted where particulate matter concentrations are at the highest levels found in many large Asian cities such as Dhaka, Islamabad and Kathmandu, making these studies especially important. The results of the studies show very high levels of particulate pollution in these cities, which consistently exceed the World Health Organization (WHO) Air Quality Guidelines for $PM_{2.5}$ (WHO, 2006). The WHO recommended that countries with areas not meeting the 24-hour guideline values undertake immediate action to achieve these levels in the shortest possible time.

The findings of these studies emphasise the high cost of air pollution to the health of the community and the need to implement cost-effective measures to reduce emissions of health-damaging air pollutants.

Future steps

The following future steps may be considered:

- Carefully selected technical studies of the health impacts of $PM_{2.5}$ should be established to inform policy, with an emphasis on analysis of social and economic impacts of air pollution on health to enable more thorough national and regional assessments of impacts, policy options, costs and health benefits of key options.

- A regional study should be conducted to quantify and assess the health costs and associated social and economic costs of ambient concentrations of health damaging $PM_{2.5}$ particles in Malé Declaration countries and reporting to the Governments. The aim is to enable more thorough national assessments of impacts, policy options, costs and health benefits of key options to reduce the burden of disease caused by air pollution. This could be conducted by a team nominated by governments of Malé Declaration countries using national data and working to a common methodology.

2.2 Crop Impacts in South Asia

Malé Declaration achievements and results

- New large-scale experimental evidence of effects of air pollutant ozone (O_3) at ground level on yield of important South Asian crops, such as Mung bean, spinach, wheat and potato; evidence fits well with modelling-based regional prediction of O_3 concentration fields and the national emission inventory work of the Malé Declaration;
- The Malé Declaration has produced wide-spread evidence of plant-damaging concentration levels of O_3 during main growing seasons of important South Asian crops;
- Standardized risk assessment methodologies have been developed that have been evaluated for their application across the region;
- There is increased awareness of the yield-damaging effect of O_3 in South Asia among policy makers, the scientific community and general public through seminars, training workshops and information material (e.g. policy briefs);
- There has been successful capacity building in the region due to training of numerous junior and senior scientists in application of risk assessment methods;
- Institutionalized cooperation between South Asian, European and North American scientists has been enhanced with active mutual exchange of knowledge and skills (e.g. via the Air Pollution Crop Effect Network (APCEN) and the Global Atmospheric Pollution Forum (GAP Forum));
- A Regional Centre of Crop Impact Assessment is currently being established in Pakistan to oversee coordination, harmonization, quality control and reporting of the Malé Declaration crop impact activities.

Background

Ground level ozone (O_3) is a secondary air pollutant that is not emitted but is formed in the atmosphere by chemical reactions between the pollutants oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Major sources of NOx and VOC are related to the combustion of fossil fuels, such as in industrial facilities, motor vehicle engines or domestic heating and cooking facilities.

Ozone is arguably the most important atmospheric pollutant causing damage to agricultural productivity across the globe. Foliar damage and reduced yields after exposure to ambient levels of O_3 have been widely reported from Europe, North America as well as – to a lesser extent - South Asia. However, unlike in Europe and North America, prior to the RAPIDC project a standardised methodological approach for the assessment of O_3 impacts on crops had never been applied across South Asia. The RAPIDC crop impact studies aimed at developing and applying such a standardised regional approach to be able to a) identify agricultural regions in South Asia that are at risk of experiencing O_3 impacts on crops and b) quantify the extent of this risk. A pre-condition for this approach was to train local scientists in applying these standardised regional risk assessment methods.

These findings will eventually contribute to the assessment of socio-economic effects of air pollution impacts on crop yields for (small- to large-scale) farmers and hence offer policy makers a methodology to assess the risk of food insecurity and the population's susceptibility to poverty.

Methodological approach

Field experiments to quantify the effect of ambient O_3 on the nutritionally and economically important crops mung bean, spinach, potato and wheat were carried out in Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka between 2006 and 2012. All these field campaigns were carried out according to crop-specific standardised protocols that were specifically developed for the application in South Asia. As such, the results between countries are directly comparable and therefore offer interpretations of the regional extent of the threat O_3 poses to crop yields. O_3 concentrations were monitored at all field sites using passive samplers, as were the prevailing meteorological conditions using local weather stations or provided data loggers.

The effect of O_3 on the yield of locally grown crops was quantified using the chemical protectant ethylenediurea ((N-[2-(2-oxo-1- imidazolidinyl)ethyl]-N-phenylurea), abbreviated EDU). EDU is an anti-ozonant that has been used successfully throughout the globe; it suppresses typical O_3-induced biomass reductions. Half of the plants exposed to ambient O_3 were treated with EDU. The biomass difference between EDU-treated and non-treated plants at the final harvest can then be directly attributed to O_3. In addition, foliar injury was recorded weekly during the experiment; this parameter is especially important for leafy crops such as spinach, because leaves with clear damage symptoms are less likely to be sold on markets with direct economic effects for farmers.

Evidence of wide-spread impacts of ozone on crops in South Asia

Regional ozone pollution and prevailing meteorological conditions

Ambient four-weekly mean O_3 concentrations at various experimental sites across South Asia as monitored with passive samplers are presented in Figure 2.2.1. Since passive samplers capture both night-time (low O_3 concentrations) and day-time (high O_3 concentrations) periods, peak day-time O_3 concentrations during each four-week passive sampler exposure period will have been much higher than the average recorded here. Generally, O_3 concentrations above 40 ppb are considered as being toxic to plants; as such, Figure 2.2.1 indicates that peak O_3 concentrations during the major South Asian crop growing seasons (Nov. – Jan. and March – June) will have almost certainly been at levels that were toxic to plants (i.e. above 40 ppb).

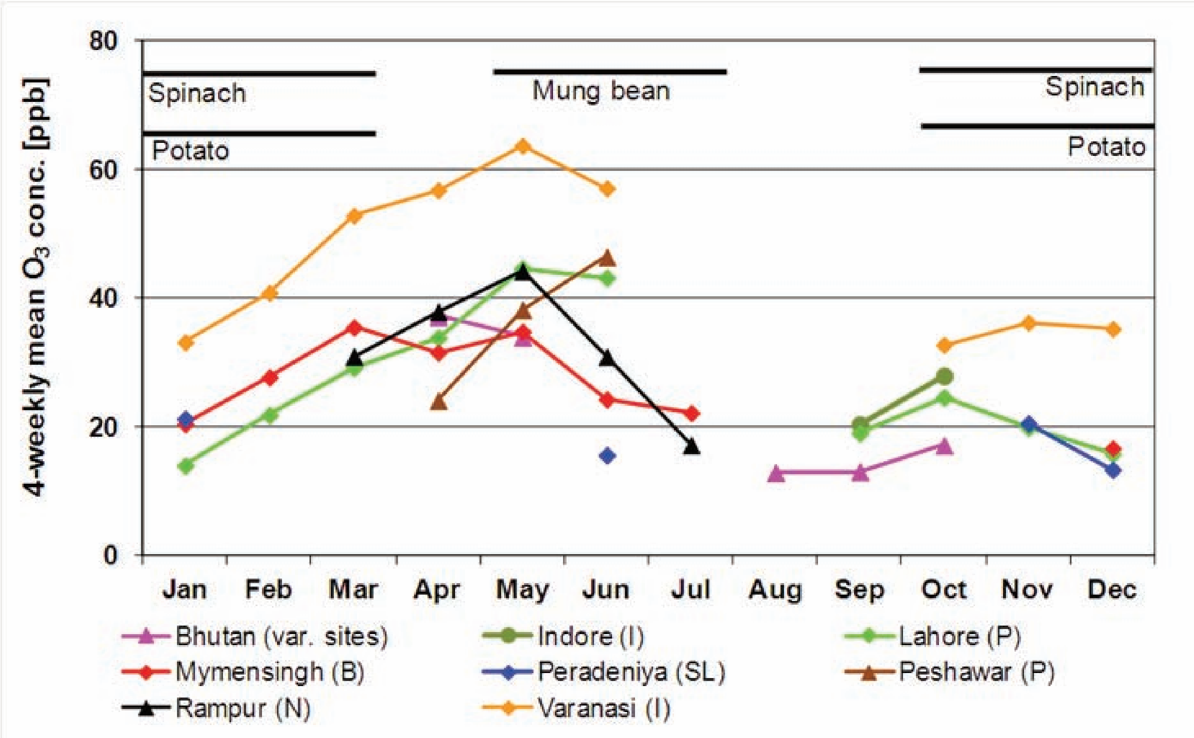


Figure 2.2.1. Four-weekly mean ambient ozone concentration monitored using passive samplers at various sites across the South Asian region.

High air temperatures due to high levels of solar radiation and high levels of air humidity were detected during field campaigns. These meteorological conditions not only favour O_3 formation, but also the plants' uptake of O_3 due to an increased gas exchange at the leaf level in hot and humid conditions. In fact, the experimental sites with the highest temperatures and relative humidity levels experienced the highest levels of O_3 and yield losses.

Yield losses

Substantial yield losses to mung bean, spinach, potato and wheat were found after exposure of these crops to ambient air at various field sites in six Malé Declaration countries. The extent of these yield losses are presented in Figure 2.2.2 and range from 17 to more than 50% with an average yield loss for mung bean and spinach of 24% and 31% respectively. Please note that with some very few exceptions there is a good match of O_3 concentrations with yield loss levels.

These yield losses are in the range of losses that were reported from other field studies in South Asian countries and that were published in the scientific literature during the last two decades. Yield loss figures of 20 to 30% clearly demonstrate that current ambient levels of O_3 pose already now a threat to crop yields in large parts of South Asia. With O_3 concentrations expected to rise in the region during the next decades, these yield losses might even be higher and more wide-spread in the foreseeable future. Concern also arises from the fact that scientists have found that Asian cultivars of wheat, soybean and rice are in general more sensitive to O_3 as compared to their European and North American counterparts (Emberson et al., 2009).

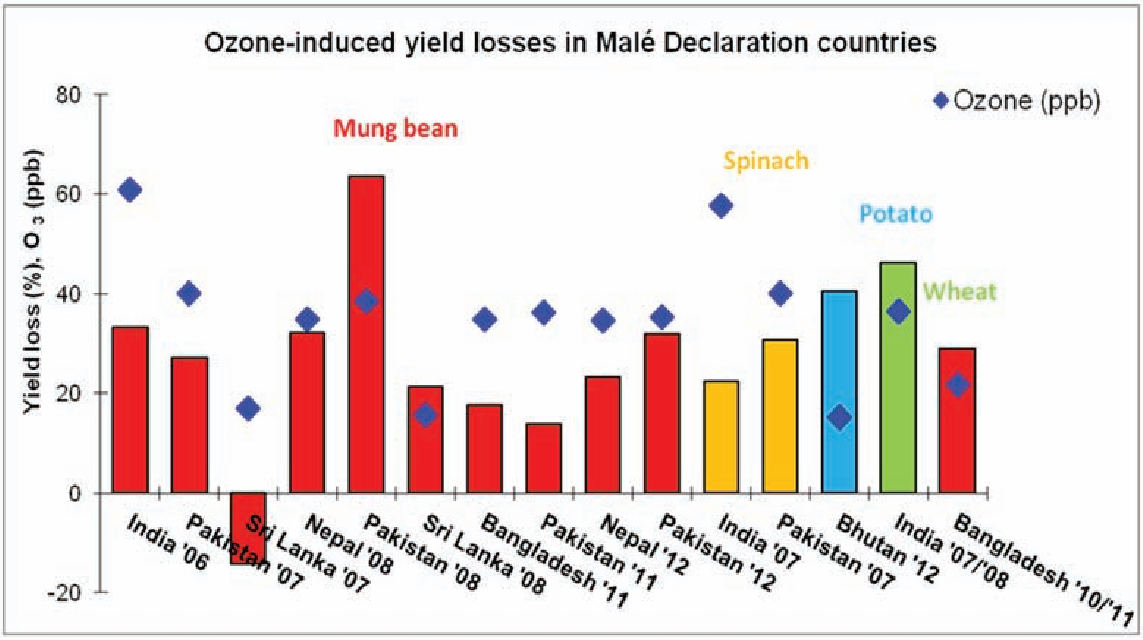


Figure 2.2.2. Ozone-induced yield losses for Mung bean, spinach, potato and wheat in various South Asian countries as recorded during field experiments conducted between 2006 and 2012.

The spatial distribution of yield losses across Malé Declaration countries confirms the results of a modelling-based provisional risk assessment that was performed at an early stage of the RAPIDC programme. Figure 2.2.3 shows the yield losses in relation to O_3 concentrations predicted by the MATCH model and presented as AOT40 (hourly O_3 concentrations Accumulated Over a Threshold of 40 ppb) for the period May, June and July which coincides with the important "pod filling" mung bean growth period. Those areas identified by the modelling study as being at greater risk from prevailing O_3 concentrations correlate well with those sites where statistically significant damage was recorded during the experiments. The sites with the greatest O_3 damage are those in the Indo-Gangetic plain where between 2006 and 2012 robust statistically significant yield losses for mung bean ranged from 23 to 64 %. In contrast, statistically significant yield losses were not recorded in Sri Lanka.

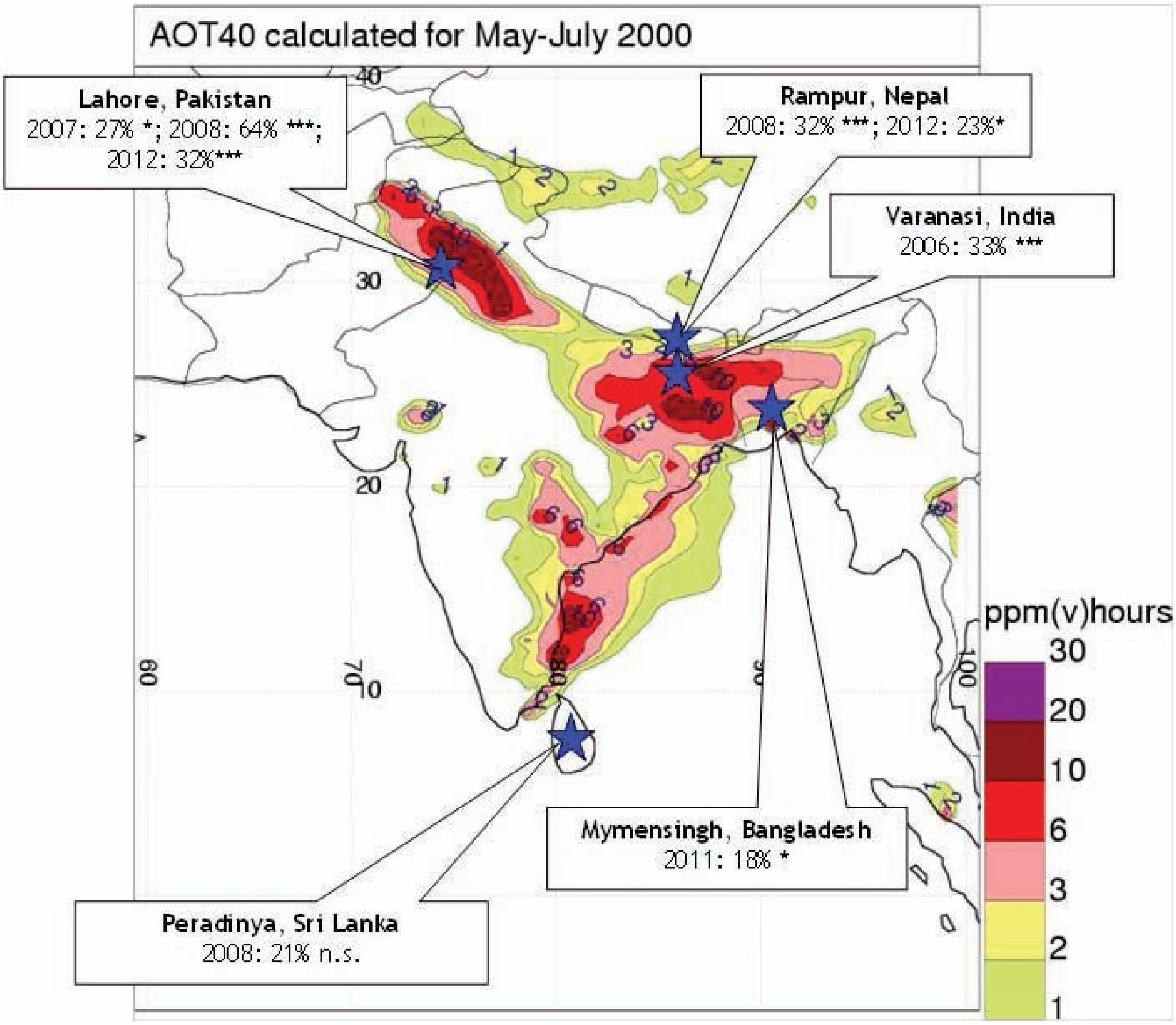


Figure 2.2.3. MATCH modelled O_3 concentrations for the year 2000 presented as 3-month AOT40 values for May to July. Also shown are the results of the EDU chemical protectant study for mung bean conducted at the South Asian experimental sites (indicated by blue stars) during equivalent months. The significance of the experimental results is presented (n.s. = not significant; * moderately significant and *** highly significant).

Significance of results for Malé Declaration countries

The future sustainability of cereal production in South Asia is rather uncertain. South Asia's Indo-Gangetic Plains benefited from the 1960s Green Revolution. Using improved wheat and rice varieties, irrigation and higher doses of fertilizer, South Asian farmers were able to double rice production and boost wheat output by almost five times in just three decades. However, the area under rice and wheat cultivation has stabilized, and further expansion seems unlikely. In addition, evidence suggests that growth in cereal yields have begun to slow down in many high-potential agricultural areas, with large variability in trends occurring between countries of South Asia. Factors such as soil nutrient mining, declining levels of organic matter, increasing salinity, falling water tables and the build-up of weed, pathogen and pest populations will all have contributed to this decline. Given the magnitude and extent of yield losses found for key crops across the South Asian region in this and other studies, it would seem that O_3 pollution is an additional and significant stress on agro-ecosystems. A comprehensive understanding of the relative importance of all stresses facing current and future agricultural production in the South Asian regions is vitally important given the challenge of the region to provide sustainable increases in productivity to balance reduced per capita area harvested.

Global modelling of ground level O_3 concentrations (Dentener et al., 2006, Prather et al., 2008) suggests that O_3 concentrations, which are already at concentrations capable of causing yield and productivity losses across many parts of South Asia, will continue to rise over the next decades. This prediction highlights the importance to consider O_3 in future research to assess the effect of multiple-stresses on sustainable crop production across South Asia.

This crop impact assessment programme also provided the Malé Declaration with the opportunity to more closely co-operate with other regional air pollution networks of policy bodies, such as the Global Atmospheric Pollution (GAP) Forum and the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) of the United Nations Economic Commission for Europe's (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP). In fact, an official exchange of letters between the LRTAP Convention and the Malé Declaration on the development of joint programmes and sharing of expertise was initialised in 2007 and further developed ever since. This co-operation for example included the attendance of ICP Vegetation meetings by junior and senior Asian scientists and vice versa to discuss potential future research collaborations.

A substantial number of scientists in the Malé Declaration countries were trained in the application of crop impact assessment at various workshops across the region. Emerging young scientists in all involved countries used the EDU field studies as subject for their MSc and PhD theses and quite a few of them have since pursued a promising career in science. As such, the RAPIDC crop programme has been extremely successful in building capacity in the South Asian region and is expected to benefit from this new capacity in the foreseeable future.

Last but not least, during the RAPIDC programme, the awareness of the threat O_3 poses on crop yields in the South Asian region was raised significantly among policy makers, the scientific community and the general public through public seminars, training workshops and the production of information material (e.g. policy briefs).

Future challenges – knowledge gaps

Although this work has established methods that enable increased understanding of current day air pollution impacts in the Malé Declaration countries, there still remain a large number of future challenges to fill the remaining knowledge gaps, such as a better estimation of the extent of yield losses of staple crops across the entire South Asian region, the differing O_3 sensitivity of common crop cultivars cultivated in the region, the effect of a changing climate on crop growth and eventually a robust estimation of the extent of the socio-economic effects of O_3 and climate change on crop yields for small- to large-scale farmers in the region.

Future assessments related to crop impacts from O_3 would therefore ideally incorporate the effects of climate change, and seek to involve specialists on adaptation options. Ideally, key decision-makers from governments would come together to discuss likely combined impacts, measures to reduce vulnerability of end users, national risk assessments and policy options to reduce the threat from this environmental problem. The opportunity for co-benefits for air pollution and climate change in emission reduction policy is of particular importance in South Asia as well as in other developing regions around the globe.

Future steps

- Modelling studies to be able to derive dose-response relationships
- Pan-Asian open top chamber (OTC) studies
- Crop impact studies that account for changing climate (temp rise and shift of growing seasons)

2.3 Corrosion Impacts in South Asia

Malé Declaration achievements and results

- The capacity to understand the air pollution impacts of corrosion on materials and cultural heritage has been significantly increased in South Asia, as well as the capacity to undertake stock at risk and economic loss assessments.
- The most important pollution parameters have been shown to be the same in subtropical/ tropical climates as in temperate climates, but the relative importance of the effects as well as the influence of climate can still be different.
- New dose-response functions have been developed for carbon steel, zinc, copper and limestone for South Asian conditions.
- In South Asia, dry deposition of sulphur dioxide (SO_2) is the most important parameter for corrosion impacts but acid rain is also important for all materials while nitric acid (HNO_3) is important for the corrosion of zinc and limestone.
- Using results from the Malé Declaration a tolerable SO_2 level for materials including cultural heritage in the Kathmandu Valley of 6 $\mu g\ m^{-3}$ has been proposed.
- A Regional Centre of Corrosion Impact Assessment is currently being established in India to oversee coordination, harmonization, quality control and reporting of the Malé Declaration corrosion impact activities.

Background

Atmospheric corrosion is an important impact of air pollution damaging cultural heritage and other man-made materials and resulting in large economic losses. The corrosion is due to a combination of the action of a number of pollutants interacting with meteorological parameters. The damage can be caused by wet deposition of acidic rain, dry deposition of gases such as sulphur dioxide and particulate deposition. The impacts of corrosion are felt mainly in urban and marine settings and in urban areas are particularly related to the concentrations of pollutants such as sulphur dioxide. These impacts have occurred widely in Europe and this has been particularly clear on cultural monuments where many have been destroyed over the last one hundred years, even if they survived the previous three hundred. Pollution damage to cultural monuments is of concern in developing countries where impacts are now being felt, especially as there is evidence that corrosion at a given level of pollution proceeds more rapidly under warm humid conditions. In Europe high costs of pollution related corrosion have been calculated for the maintenance of deteriorating buildings and cars in the urban environment.

Against this background the Malé Declaration set out to establish dose-response relationships for the tropical and sub-tropical regions of South Asia, working in collaboration with the RAPIDC Corrosion Network (CORNET) with site across the whole of Asia and in Southern Africa. CORNET put the information together to derive dose-response relationships for various materials under Asian and African conditions, which are a pre-requisite for economic loss assessments.

Methodological approach

Corrosion racks with sample materials were positioned in 5 countries of South Asia (India (Taj Mahal), Iran, Nepal, Sri Lanka and the Maldives), 5 countries in southern Africa (Mozambique, South Africa, Tanzania, Zambia (2 sites), Zimbabwe) as part of the Air Pollution Information Network for Africa (APINA) and sites in four further countries across Asian (Thailand, Vietnam, China (including Hong Kong) and Malaysia) that are also part of CORNET (Figure 2.3.1). The training in the setting up of the racks and in the use of the results was undertaken with relevant qualified institutions in each country. The exposure rack and passive sampler set-up at the Taj Mahal site is shown in Figure 2.3.2. The materials exposed on the racks at each site were carbon steel, painted steel, Portland limestone, zinc and copper.

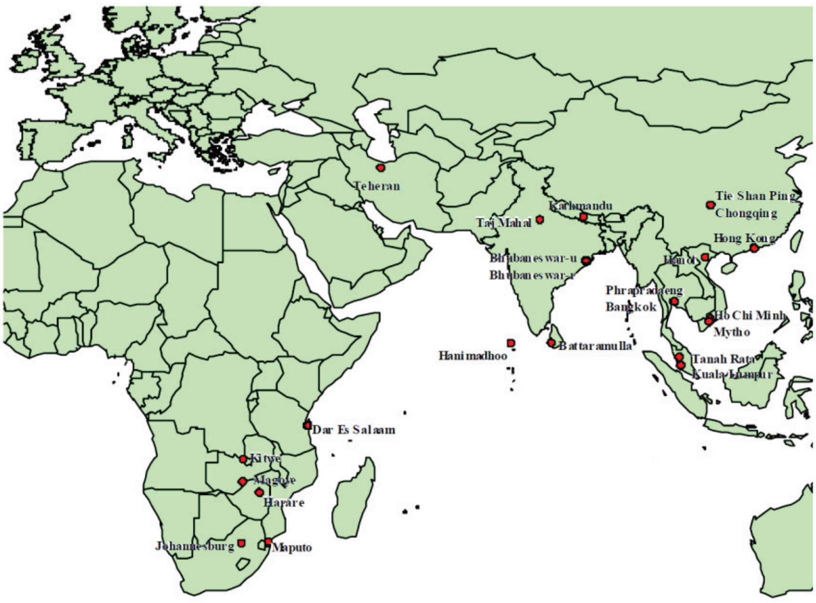


Figure 2.3.1. Map of corrosion 23 test sites in 14 countries test sites across Asia and Africa.

Figure 2.3.2. The corrosion rack and the covered passive sampler exposure mount at the Agra site in India (Taj Mahal is behind the trees).

Results of corrosion network

The Malé Declaration has been conducting air pollution monitoring at the South Asian sites using IVL passive samplers for sulphur dioxide (SO_2), nitrogen dioxide (NO_2), Ozone (O_3) and nitric acid (HNO_3) and the results for 2006/2007 are shown in Figure 2.3.3. The highest SO_2 value at sites in Malé countries was measured in Teheran, Iran. Corrosion data for the corrosion of carbon steel and zinc after 1, 2 and 4 years of exposure is shown in Figure 2.3.4. High values of corrosion are generally observed when SO_2 is high. Assessment of the relative importance of the different pollutants monitored shows that dry deposition of SO_2 is the most important parameter but acid rain is also important for all materials while HNO_3 is important for the corrosion of zinc and limestone.

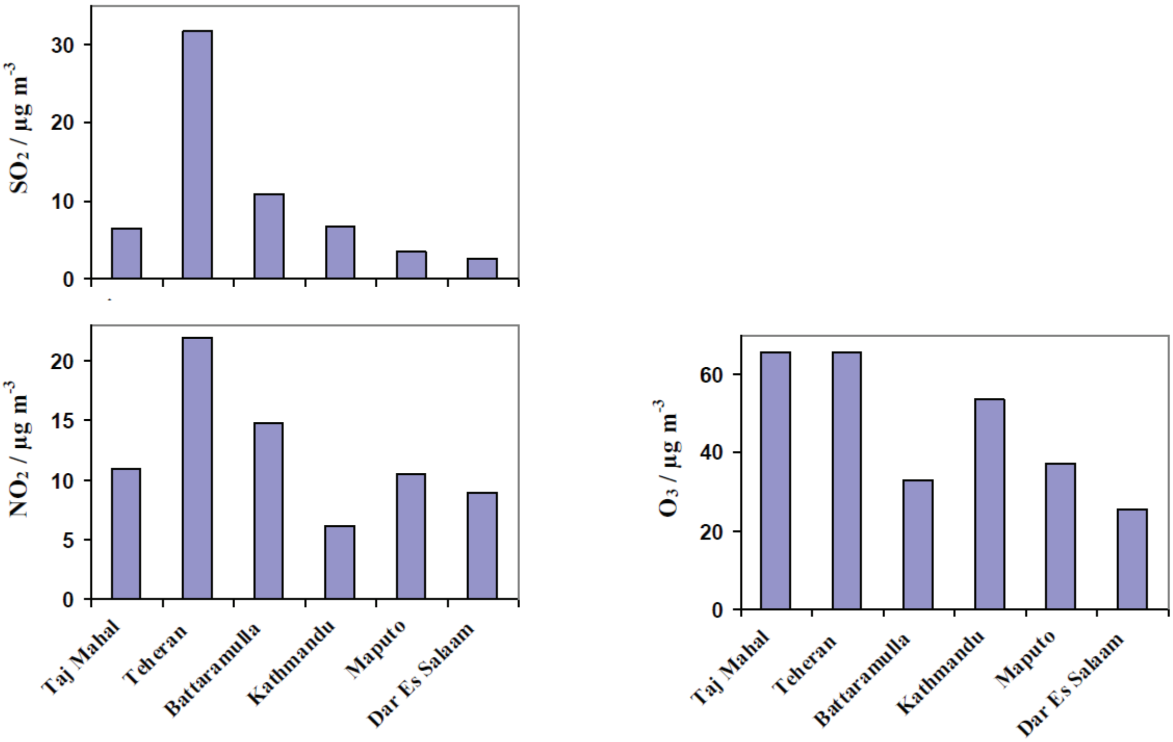


Figure 2.3.3. Average concentrations (2006-2007) of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3) at the Malé Declaration sites for the corrosion racks set up in Phase III.

Comparison of results from CORNET with LRTAP Convention results from the International Co-operative Programme on effects on Materials including historic and cultural monuments (ICP Materials) shows that the most important pollution parameters seem to be the same in subtropical/ tropical climates as in temperate climates. However, the relative importance of the effects as well as the influence of climate can still be different. Absolute corrosion values of the metals zinc, copper and carbon steel are similar in Europe, Asia and Africa. For painted steel extreme values can be seen at individual sites in Asia/Africa, while corrosion of limestone is generally much higher in Asia/Africa compared to Europe.

Attempts to predict corrosion values in Asia/Africa using dose-response functions developed in Europe have failed, especially for limestone where the corrosion is much higher than expected. Therefore, new dose-response functions have been developed for carbon steel, zinc, copper and limestone. Dose-response functions covering Europe, Asia and Africa are given for carbon steel and limestone while for copper and zinc functions only cover Asia and Africa.

The standard racks used in the development of dose-response functions are designed and located with the aim of providing a general corrosion value that is affected only to a limited extent by the presence of surrounding buildings and other objects. It is also important to know the potential levels of corrosion attack including the variability over a region. Kits for rapid assessment of corrosion have also been exposed for one year in the Kathmandu valley and are useful for the determination of local corrosion effects and relative rates of corrosion across an urban or industrial area. The results (Figure

2.3.5) show that the rates of corrosion for iron, zinc and limestone vary considerably across the Kathmandu valley and are correlated mainly with the SO_2 concentration.

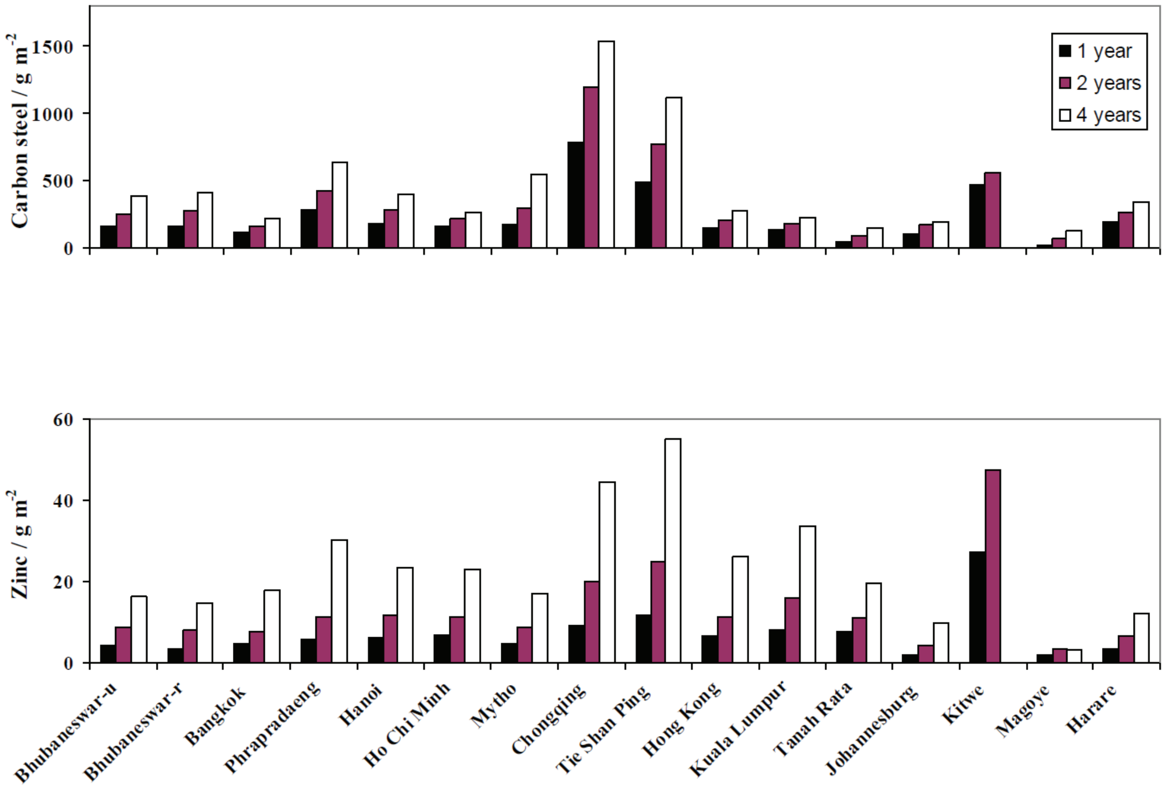
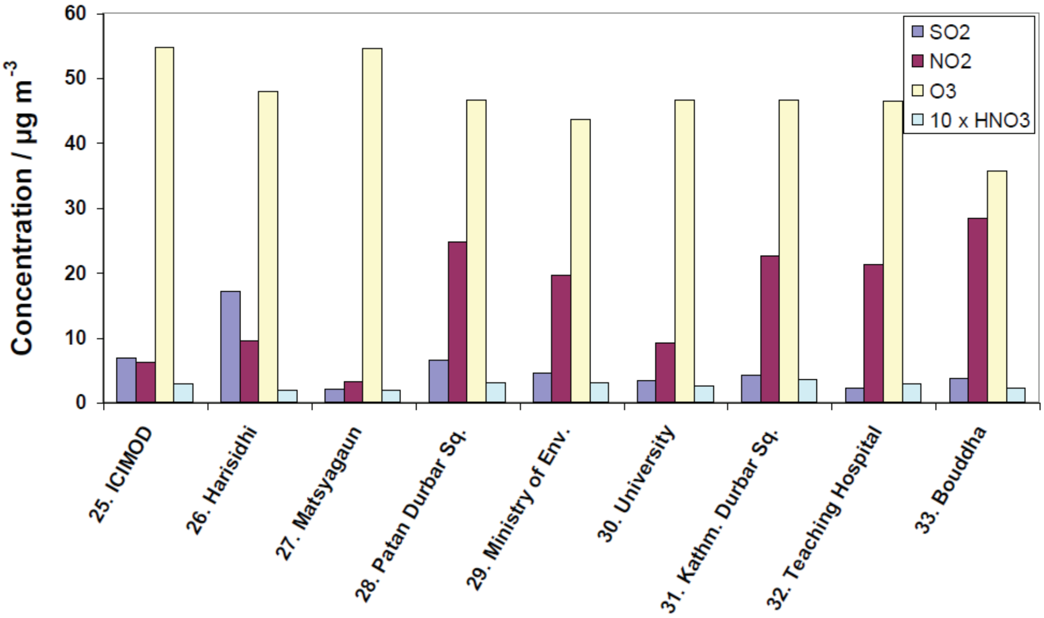


Figure 2.3.4. Corrosion of carbon steel and zinc after 1, 2 and 4 years of exposure (2002-2006) across the corrosion network (CORNET) in Asia and Africa (Phase II).

Based on European projects (LRTAP ICP Materials and MULTI-ASSESS), tolerable levels of corrosion of carbon steel has been established to be 20 µm (first year of exposure). Data obtained from the corrosion kits exhibit a strong correlation between corrosion of carbon steel and SO_2 concentration. It is therefore possible to obtain a tolerable SO_2 concentration of 5-6 µg m^{-3} for the Kathmandu valley based on this these data. A Similar exercise for limestone gives a tolerable SO_2 concentration in the range 6-7 µg m^{-3}. Based on these calculations a tolerable SO_2 level for materials including cultural heritage in the Kathmandu Valley of 6 µg m^{-3} is proposed.

A stock at risk training was also performed in Kathmandu by the coordinators of CORNET, KIMAB, Sweden, in collaboration with the International Centre for Integrated Mountain Development (ICIMOD) based in Kathmandu, Nepal. It included presentations of stock at risk methodologies, in field training of stock at risk assessment based on a case study at Patan Durban square and a sample data sheet, choice of areas for detailed stock at risk studies, and a plan for generalisation of stock at risk data, based on available data in the Kathmandu area. This training, and the derivation of dose-response functions suitable for South Asian conditions, has laid the foundations for economic assessments of corrosion damage in South Asia.



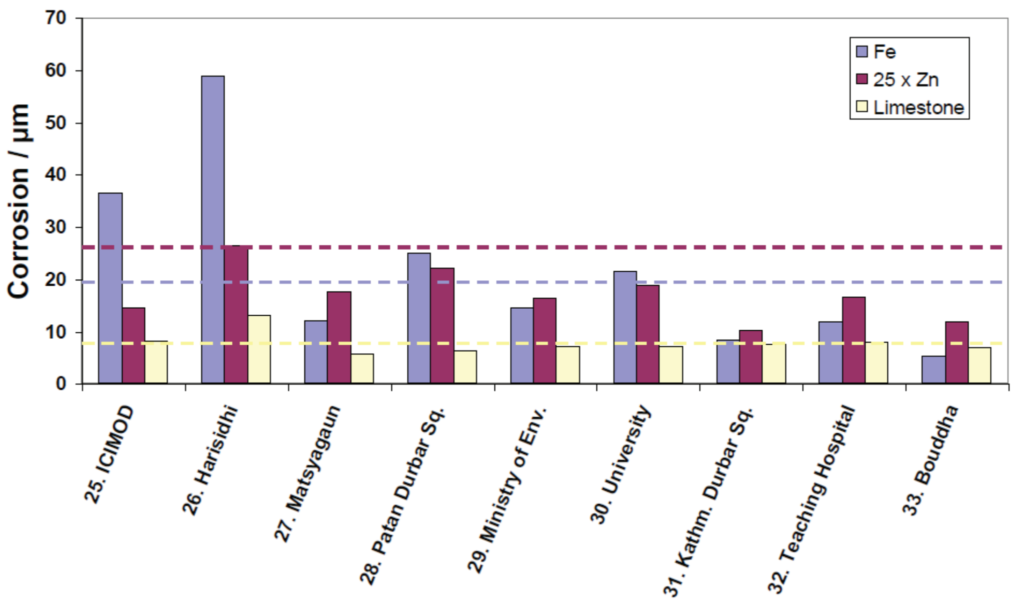


Figure 2.3.5. Corrosion of carbon steel (Fe), zinc and limestone after 1 year of exposure (2006-2007) at 9 test sites in Kathmandu and annual average gaseous pollutant concentrations (SO_2, NO_2, O_3 and HNO_3) after 1 year of exposure (2006-2007). The dotted lines indicate the tolerable level for each material exposed.

Future steps

- Future work of the Regional Centre for Corrosion Impact Assessment – India could include stock at risk and economic loss assessments for South Asia cities.

2.4 Ecosystem Impacts in South Asia

Malé Declaration achievements and results

- Modelling studies and training events under the Malé Declaration have demonstrated that there are limited areas in South Asia which may be at risk from acidification from sulphur and nitrogen pollution such as in the Western Ghats, parts of Sri Lanka and eastern India. In the Himalayan regions of India, Bhutan and Nepal soils that are naturally acidic may also be under pressure from acidifying deposition.
- Modelling results suggest that acidification will not be a major issue compared to other air pollution problems in South Asia but further field research is required to determine the real extent of the problem.
- A potentially greater problem to ecosystems and their biodiversity than acidification in South Asia is eutrophication (excessive input of nitrogen and other nutrients). Nitrogen pollution from the transport, industry and agriculture is linked to health impacts, impacts on ecosystems, crops and climate, as well as the formation of ground-level ozone.
- Despite some progress there is still a need for a comprehensive regional assessment of these issues, especially using studies that have been conducted in South Asia.
- The Regional Centre on Crop and Vegetation impacts in Pakistan and on Soil Monitoring in Bhutan are currently being established to oversee co-ordination, harmonization, quality control and reporting of the Malé Declaration ecosystem related impact activities.

Background

Air pollution such as the wet and dry deposition of nitrogen (N) and sulphur (S) compounds has the potential to cause acidification of ecosystems and impacts on ecosystem biodiversity through both eutrophication and acidification effects. Ozone impacts can also further affect biodiversity of natural vegetation. In South Asia there is still no conclusive evidence of these impacts on natural ecosystems and there is lack of comprehensive studies but there is concern for certain sensitive areas as emissions continue to increase.

Results of international studies

The study of impacts of air pollution on ecosystems in the Malé Declaration region has focused on assessing acidification risks in the region. Acidification is clearly a regional and potential transboundary issue and important in the context of regional policy cooperation on air pollution. In 2001 MISU and SEI published a joint paper that showed the sensitivity of soils to acidic inputs in South Asia (Figure 2.4.1).

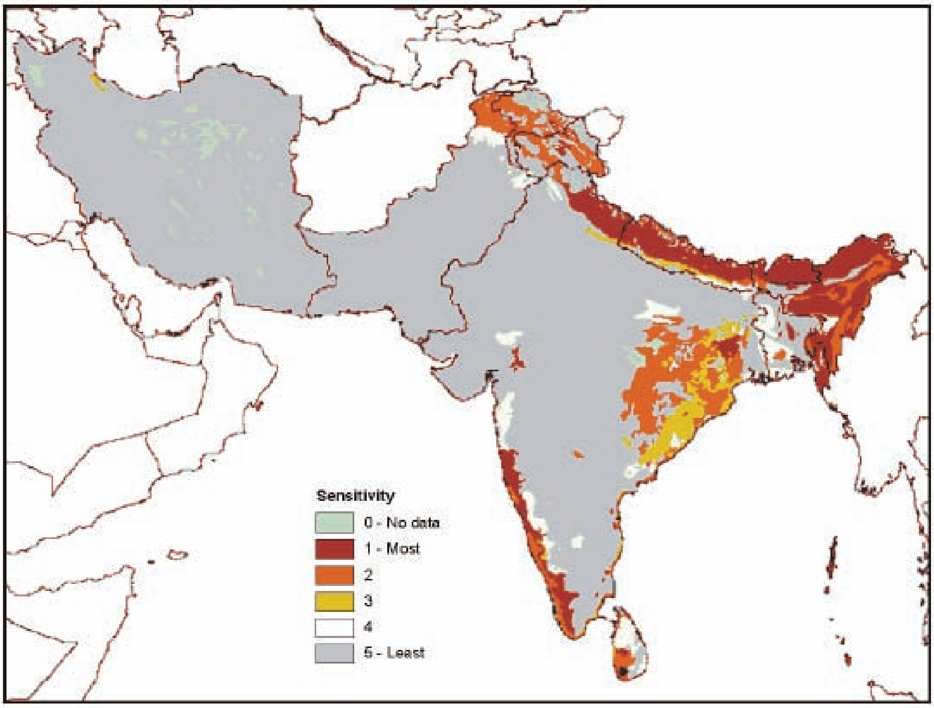


Figure 2.4.1: The sensitivity of South Asian soils to acidic deposition inputs (Kuylenstierna et al., 2001)

Acidification is a process that tends to occur over a number of decades or centuries, and it can be difficult to determine the risk during the early stages of acidification. Therefore a lack of acidification now disguises a longer-term threat in some limited regions of Asia, dependent on the deposition rate of acidifying deposition, the sensitivity of the soil in each location and the land management practices (harvesting plants also leads to soil acidification). For this reason further research was conducted in Phase III on the risk assessment of acidification over time in Asia (Hicks et al., 2008). The study combined available data on acidic deposition inputs (e.g. from the Composition of Asia Deposition (CAD) network and modelling) and ecosystem sensitivity to determine the rate at which acidification may occur in different parts of Asia.

Acidification is a process that gradually reduces the soil buffering capacity over time, leading to lower soil pH. The method devised estimates how long it will take for soils across Asia to acidify from the pre-acidification state down to a level of soil acidity that will confer risks to vegetation and ecosystems growing on the soils. The risk threshold' is defined in this method as a base saturation (BS) of 20%, below which there is a higher risk of aluminium entering the soil water (which is toxic to plants and animals), and where soil acidity will significantly affect nutrient availability. Figure 2.4.2 is an estimate of the time it will take for sensitive soils, at risk from acidifying deposition, to acidify down to the 20% base saturation (BS) threshold level (defined in years) for a scenario of deposition between the year 2000 and 2030. Data to develop this scenario have used modelled input data for the deposition of S and N and base cations, for the year 2000 and a scenario for 2030, modified by monitored data from the CAD network (see Kulshrestha *et al*. 2005). Soil data came from the FAO Soil map of the World and the ISRIC soil properties database. There are ranges of data that could be applied to all of the parameters and whether the mid-point, lowest or highest values were used makes a big difference to the risk picture that emerges. Figure 2.4.2 shows the result of taking values for the input data that lead to the maximum possible acidification at the deposition rates suggested which delivers a more pessimistic' view, where a greater area of soils is at risk, and the time for them to acidify to 20% base saturation (BS) threshold level is shorter.

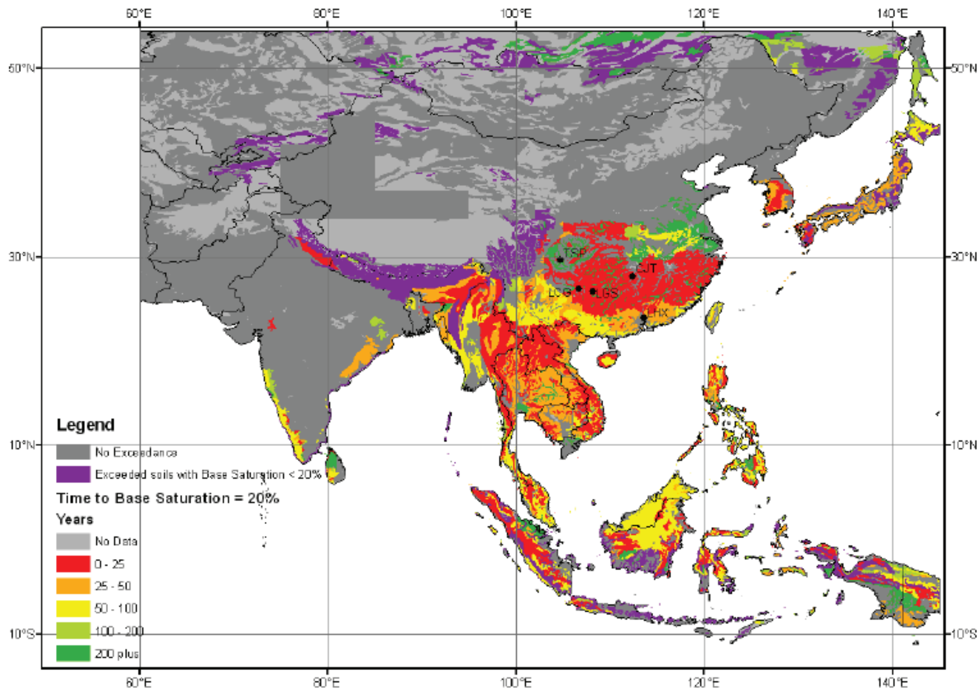


Figure 2.4.2: 'Pessimistic' case map showing number of years to 20% BS in the top 50cm of soil applying in combination: the IPCC SRES A2 (pessimistic) scenario for deposition of SOx, NOy and NHx; 50% reduction in 'adjusted' Ca deposition; 50% N retention; 10% S retention; and 50 meq m-2 yr-1 base cation vegetation uptake (Hicks et al., 2008).

The results show that there are limited areas in South Asia which may be at risk from acidification such as in the Western Ghats, parts of Sri Lanka and eastern India. In the Himalayan regions of India, Bhutan and Nepal soils that are naturally acidic may also be under pressure from acidifying deposition. These results are consistent with a general lack of observed acidification in the region, and they suggest that acidification will not be a major issue compared to other air pollution problems in this region. However, recent international research on acidification of ecosystems (Azevedo et al. 2013) suggests that regions within the (sub)tropical moist broadleaf forest may suffer great changes in species richness following a soil acidification. As the sensitive areas to acidification in South Asia often have this type of vegetation (see Figures 2.4.1 and 2.4.2.), these areas should be the focus for further investigation.

A potentially greater problem to ecosystems and their biodiversity than acidification is eutrophication (excessive input of nitrogen and other nutrients). Human activity linked to energy use and food production has more than doubled the amount of nitrogen circulating in the environment over the past century (UNEP, 2012). This is emitted to the atmosphere as nitrogen oxides (NOx), mainly from the transport and industry sectors, and ammonia (NH_3) and nitrous oxide (N_2O), mainly from agriculture (see Figure 1.1). They have multiple effects on the atmosphere, terrestrial ecosystems, freshwater and marine systems, and on human health, a phenomenon known as the nitrogen cascade (Galloway et al. 2003). Nitrogen compounds are precursors of atmospheric $PM_{2.5}$, which has impacts on human health (see Section 2.1), while nitrogen oxide (NOx) is a precursor of tropospheric ozone, which has impacts on health (see Section 2.1), crop yields (section 2.2), ecosystems and climate. Nitrous oxide and tropospheric ozone are also important greenhouse gases. Nitrogen deposition drives biodiversity loss through eutrophication and acidification in terrestrial and aquatic ecosystems (Bobbink et al. 1998). However, it can also be of benefit to crop yields, and can increase carbon sequestration through the stimulation of forest growth (UNEP, 2012).

Figure 2.4.3 shows that risk to biodiversity due to nitrogen deposition across South Asia may be significant, the figure shows areas receiving more than 10 kg nitrogen $ha^{-1} y^{-1}$, which is a level that has reduced the plant diversity of sensitive vegetation in Europe (Bobbink et al. 1998). South Asia is shown to be one of the regions of the world estimated to have the most Protected Areas (PAs) under the Convention on Biological Diversity (CBD) where N deposition in 2000 was greater than 10 kg nitrogen $ha^{-1} y^{-1}$ and is projected to increase by 2030. This nitrogen deposition is in excess of natural background amounts and as well as impacting biodiversity, it will also have a series of other effects on the environment as described above. These effects have been studied in detail in Europe and North America (see ENA, 2011), but have yet to be demonstrated in other regions such as South Asia.

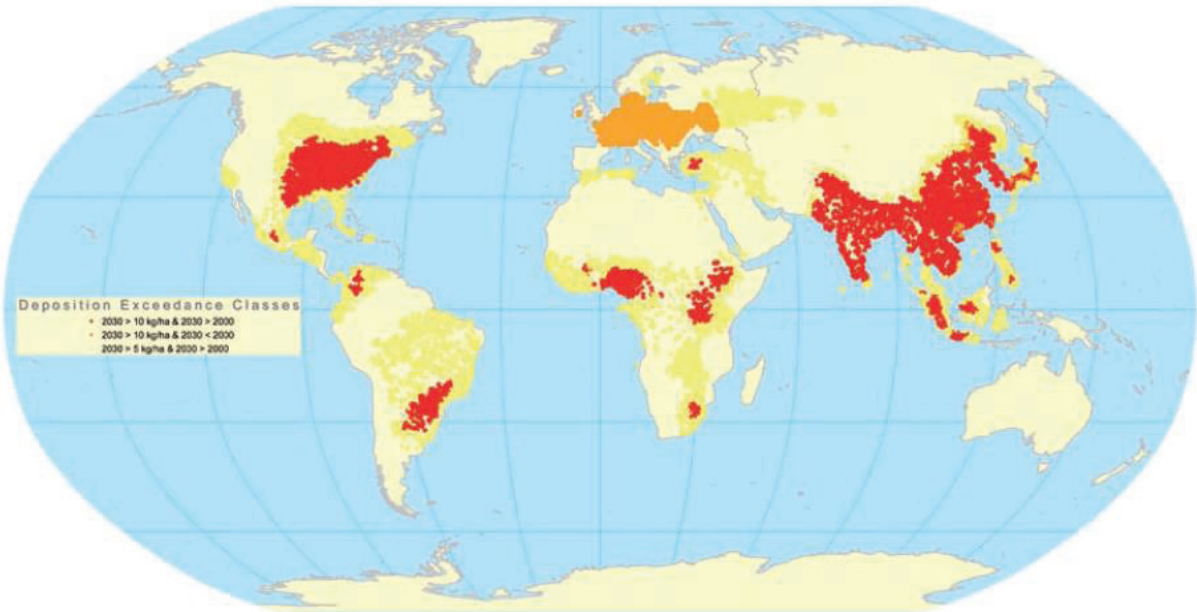


Figure 2.4.3: Distribution of Nr deposition classes and exceedance of deposition levels in the period 2000-2030 on Protected Areas (PAs) under the Convention on Biological Diversity (Bleeker et al., 2011; UNEP, 2012).

Future Steps

These results show that there is potential for ecosystem impacts in South Asia due to:

- soil acidification effects of sulphur and nitrogen pollution in certain sensitive areas; and
- eutrophication effects of nitrogen pollution alone.

There is also the threat to natural vegetation of biodiversity loss due to ground-level ozone which is yet to be studied comprehensively in most regions of the world.

These issues have been discussed by the Malé Declaration at various meetings and country representatives have also received training in some of the assessment methods, but there is still a need for a comprehensive regional assessment of these issues that documents studies that have been conducted in South Asia.

3. Assessment of air pollution emissions and deposition

3.1 Emissions inventory activities

Malé Declaration achievements and results

- Air pollutant emission inventory (EI) compilation capacity has been considerably enhanced in all eight Malé Declaration countries.
- Using a harmonised methodology (the Malé Declaration Emission Inventory Manual/Workbook), national EIs have been produced for the baseline year 2000 and draft EIs for 2005 are currently being finalised in some countries.
- As a result of this activity, decision makers will now be better able to identify national and regional trends in air pollution emissions and prioritize emission sources for mitigation.
- The EI data will also provide input for modelling the regional impacts of these emissions and assessing the likely benefits of alternative mitigation scenarios.
- A major achievement has been the establishment of the Regional Centre on Emission Inventory (at the Central Environment Authority, Colombo, Sri Lanka) to oversee coordination, harmonization, quality control and reporting of the Malé Declaration EI activities.

Building emission inventory capacity

Regional cooperation to curb emissions requires the individual countries to develop mutually agreeable models of air pollutant emissions and atmospheric transport so that the links between emissions and adverse impacts can be evaluated and the results fed into the policy process. Indeed, it is difficult to develop comprehensive policies at any scale without a reliable emission inventory (EI). Clearly in some cases, the problems are so obvious that decisions can be taken without waiting for further study e.g. black smoke large trucks and buses. However, once these 'low hanging fruit' have been addressed, there is a need for more information about the significance of different emission sources and their contribution to local or regional pollutant deposition or concentration levels and their subsequent adverse impacts.

It was recognised early on that the compilation of national inventories of air pollutant emissions in a consistent format by each of the eight countries of the Malé Declaration would be a first step toward such coordinated modelling in the region. To that end, an EI preparation manual (and associated Excel spread sheet-based workbook) was developed in by the Stockholm Environment Institute (SEI) in collaboration with the National Implementing Agencies (NIAs) of the Malé Declaration countries and regional experts to ensure regional applicability. Beginning in 2006, a series of emission inventory training workshops were held during which participants from all member countries started to compile national EIs using this Malé Declaration Emission Inventory Manual. The manual and workbook have been continuously improved during Phases III and IV in light of new information and learning-by-doing, responding to issues as they have cropped up during the implementation of the EI activities. The EI methodology developed for the Malé Declaration has also fed into the development of the Global Atmospheric Pollution Forum Manual (http://www.sei-international.org/rapidc/gapforum/html/projects.php) which is forming the basis for approaches to be used within the EANET and ABC networks.

Through the process of developing the IE manual, and the training received in inventory preparation and in scenario development, the EI capacity of all Malé Declaration countries has been enhanced. This includes representatives of the NFPs (National Focal Points) (e.g. Ministry of Environment Officials), the NIAs (National Implementing Agencies) nominated by the NFPs, as well as other local institutions brought in to help produce the first government-led national EIs in South Asian. Prior to the Malé Declaration EI activity, no comprehensive, national-level EIs of the main regional air pollutants had been produced by the Malé Declaration countries with the exception of India. For most South Asian countries, emissions estimates were only available from regional or global initiatives carried out by academics or institutions such as the international EDGAR (Emission Database for Global Atmospheric Research) database.

Development of national emission inventories during Phase III

The methodology for developing EIs was first applied during Phase III with all Malé Declaration countries taking part in three training courses during which they learnt how to compile their national inventories for the year 2000. By the end of Phase III, four countries had produced EIs for 2000 and submitted them to the Malé Declaration secretariat. These were checked for quality and three (Bangladesh, Nepal and Sri Lanka) were considered to be fairly comprehensive whilst the fourth (for Bhutan) was incomplete (mainly due to lack of data for fuel combustion in the domestic sector). The emission inventories for Sri Lanka, Nepal and Bangladesh for the baseline year 2000 are presented in Figures 3.1.1 to 3.1.4. As can be seen from Figure 3.1.1, carbon monoxide (CO) tends to have the largest emission, with the next most important pollutant being coarse particulate matter (PM_{10}). CO is important as a precursor of ozone formation and, in urban settings, may be injurious to health. However, the health impacts are likely to be minimal for the concentrations of CO encountered rural areas (where most is emitted) and CO is therefore omitted from Figures 3.1.2-3.1.4 for the purposes of clarity with regard to the other pollutants of interest. Coarse particulate matter (PM_{10}) is also omitted from Figures 3.1.2-3.1.4 as it is the finer fraction ($PM_{2.5}$) that is of most relevance for human health impacts. The Sri Lankan inventory for 2000 (Figure 3.1.2) shows that at the national scale, emissions from residential biomass fuel use and road transport (including road dust) were the dominant overall emissions source sectors. However, fuel combustion in the power generation and industrial sectors were important sources of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) whilst agriculture was the main source of ammonia (NH_3) emissions.

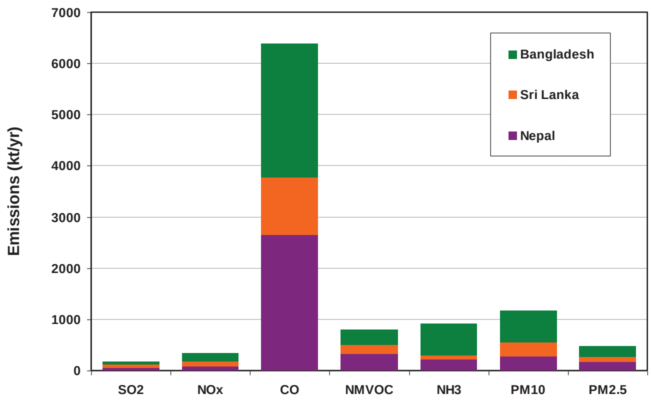


Figure 3.1.1. Baseline (year 2000) emissions inventories combined for Bangladesh, Sri Lanka and Nepal according to pollutant

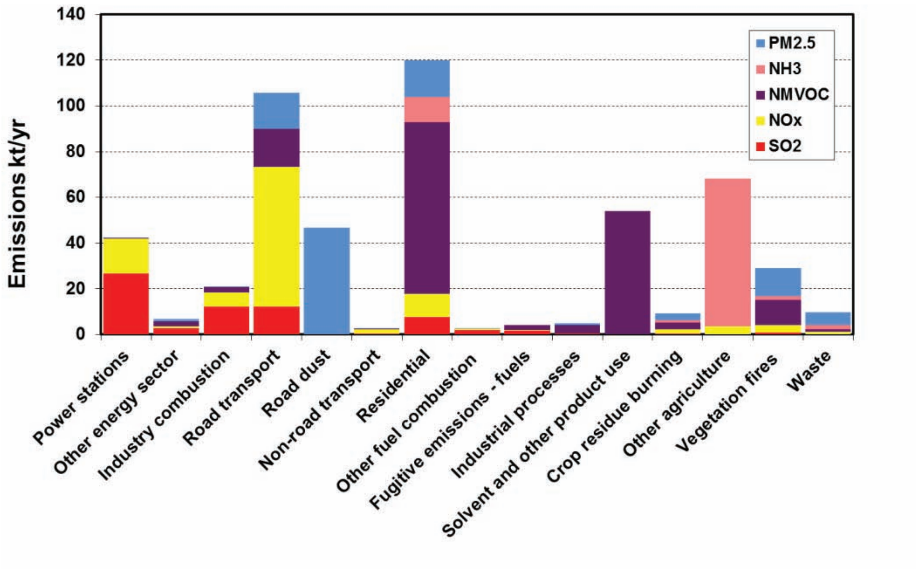


Figure 3.1.2 Emissions inventory for Sri Lanka for baseline year 2000

For Nepal, residential biomass fuel use and vegetation fires dominate overall emissions of the pollutants shown (Figure 3.1.3). However, agriculture releases large quantities of ammonia (NH_3) and dust from unpaved roads is responsible for a large proportion of fine particulate matter ($PM_{2.5}$) emissions. Power stations represent a minimal source of emissions as most electrical grid power comes from hydroelectric generation in Nepal.

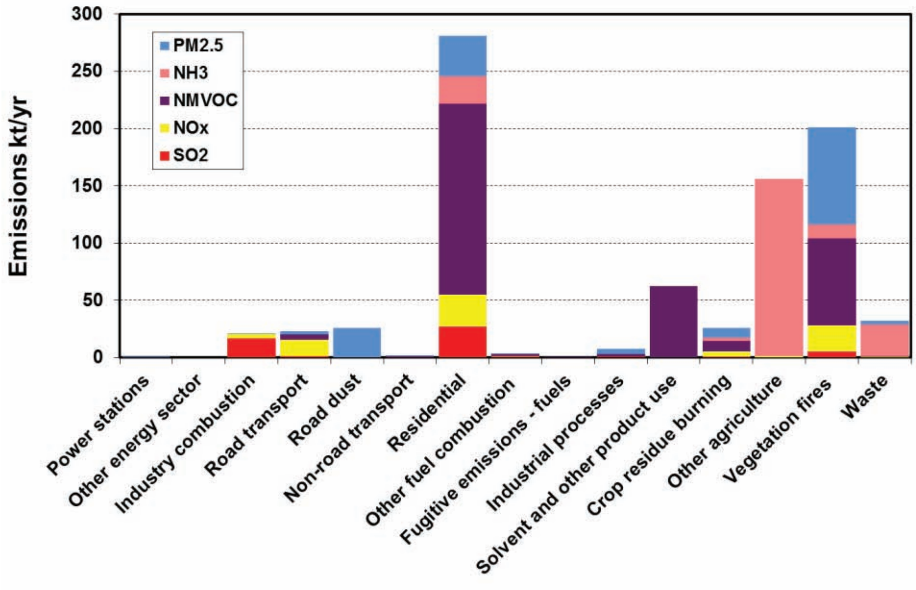


Figure 3.1.3 Emissions inventory for Nepal for baseline year 2000

In Bangladesh, the largest emitting source is the agricultural sector, mostly ammonia (NH_3) from livestock production and the application of nitrogen-containing fertilizers (Figure 3.1.4). However, as for Sri Lanka and Nepal, residential biomass fuel use in Bangladesh is also leading emission source.

Unfortunately, the inventory has a major gap in that no vegetation fire emissions were estimated due to a lack of data for this source.

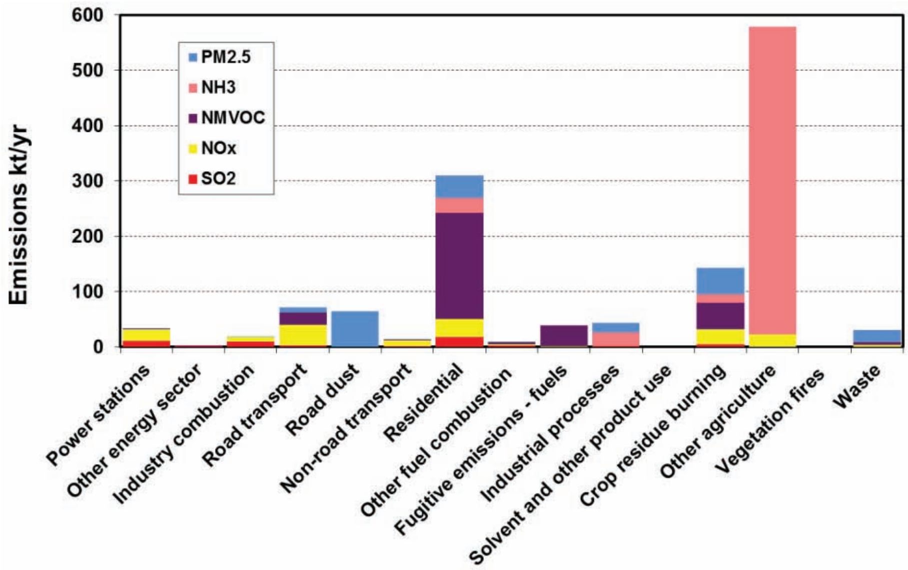


Figure 3.1.4 Emissions inventory for Bangladesh for baseline year 2000

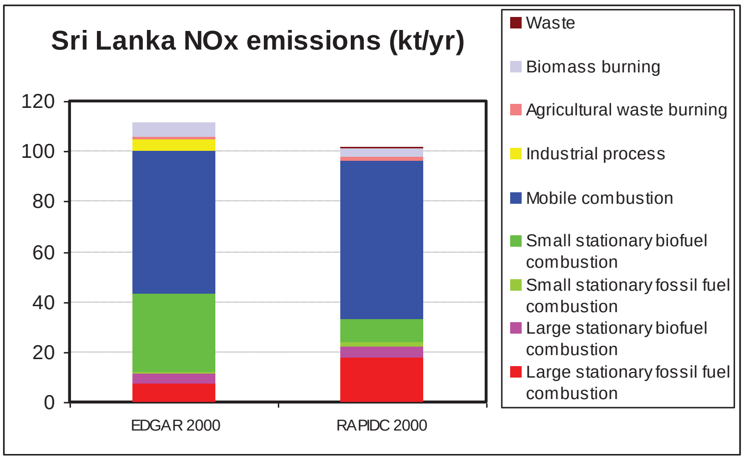
Road dust is a significant source of fine particulate matter ($PM_{2.5}$) emissions in all three countries. This represents re-suspended dust from paved road surfaces and especially, dust from unpaved (dirt) roads. Whilst it is clearly a very important source, it is also one of the most difficult to estimate and more work is required to ground-truth these estimates. Other important sources of $PM_{2.5}$ are residential biomass fuel use, crop residue burning and vegetation fires and these sources are also very difficult to quantify making estimates very uncertain. The profile of emissions obviously varies between countries and will be very different for the more industrial countries of the region (e.g. India) which burn large amounts of coal and make the energy sector a more important emission source.

Comparisons of results with international inventory initiatives

Global and regional emission estimates compiled by different research groups are not always similar and differences can be especially large for developing country regions. Local knowledge of sources, technologies and activity levels can provide valuable insight into the reasons for discrepancies in these emission estimates. Thus, it is to be expected that the global and regional EI initiatives will benefit from incorporating knowledge from the local-level EIs being produced under the auspices of the Malé Declaration.

In Phase III of the Malé emissions inventory activity, collaboration with international inventory efforts started with a representative of the global EDGAR (Emissions Database for Global Atmospheric Research) initiative attending the third training workshop. At this workshop, comparisons between EDGAR and Malé inventories were started as part of an on-going process of identifying reasons for major differences in order that the two approaches might benefit from each other. The comparisons has subsequently been reported in the UNECE LRTAP Convention’s Task Force on Hemispheric Transport of Air Pollution report (HTAP, 2010 see http://www.htap.org/). For example, in Figure 3.1.8 it can be seen that the total emission of SO_2 and NO_X is very similar between the Malé Declaration and EDGAR, which is promising, but there are discrepancies between EDGAR and RAPIDC inventories for NO_X and SO_2 emissions from small stationary biofuel combustion in Sri Lanka and the reasons for these and other differences are being investigated. Such iterative improvement is a normal part of developing emission inventories, and is becoming part of the routine for Malé Declaration countries.

a)



b)

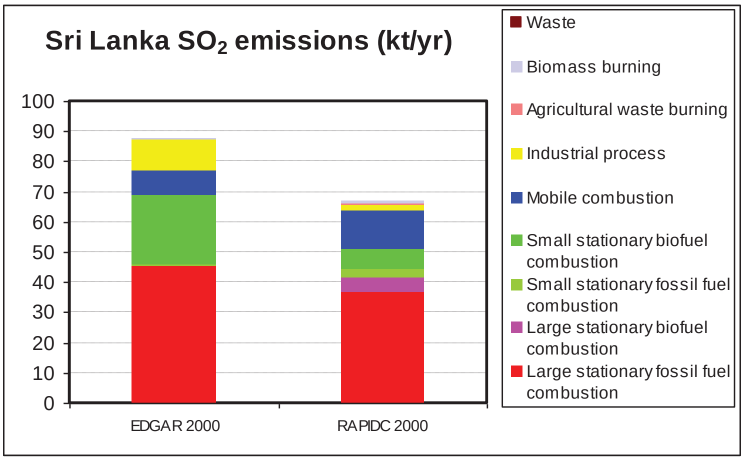


Figure 3.1.8 Comparison between EDGAR and RAPIDC emissions inventories for Sri Lanka for a) NO_X and b) SO_2.

In Phase IV, training continued with two further workshops (held in Delhi, India in November 2010 and in Colombo, Sri Lanka in May 2012) during which several new personnel were trained up in the Malé Declaration EI approach and all participants started compiling updated inventories for the year 2005. As of December 2012, Bangladesh had already submitted their 2005 inventory for quality assurance review (Figure 3.1.9), Sri Lanka had almost completed and the Maldives have reported both capacity issues and data acquisition problems and are commissioning expert assistance to help compile their inventory early in 2013. An initial comparison of the Bangladesh draft inventory for 2005 with the baseline inventory for 2000 (Figure 3.1.4) shows increased emissions from most sectors but especially from power generation and crop residue burning. Quality assurance checks are on-going and the reasons for unexpected differences checked. For example, the apparent increase in ammonia (NH_3) emissions from the waste sector is due to a data gap in the 2000 inventory for NH_3 emissions from human excreta which needs to be addressed.

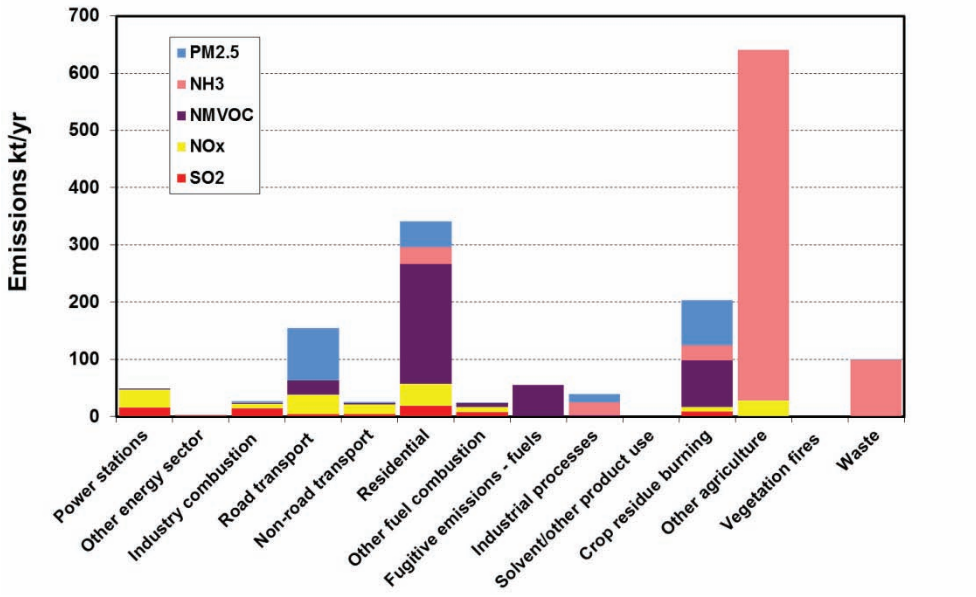


Figure 3.1.9 Draft emission inventory for Bangladesh for 2005

Future steps

While the approach used to develop the national EI's is operational, progress has been slower than originally envisaged. Only four of the eight participating countries finalized their 2000 baseline inventories by the end of Phase III. The role of RAPIDC was to provide training on methodologies and to support practical inventory activities to facilitate governments to develop their own national inventories in line with their resources and availability of suitable staff. It has to be recognized that in a lengthy process such as this one the maintenance of staff over time is crucial to progress. Therefore, relocation of trained personnel introduces delays in programme delivery. It is also indispensable that all participating countries take part in the training events offered and ideally each country should appoint one expert (if possible, with a deputy) responsible for EI's so as to secure stable and competent involvement. It is necessary that each country compile and submit comprehensive EI's according to the agreed format. To safeguard required inventories in a timely fashion it is thus indispensable that staff continuity and institutional competence can be maintained in the long run. The Malé Declaration states that major air pollution problems in South Asia shall be addressed in a cooperative spirit. Close links have to be maintained between technical data providers and governmental data managers regarding all agreed air pollutants, including PM and O_3.

It is hoped that these deficiencies and future needs will be partly addressed by a very positive development in Phase IV - the establishment of the Regional Centre on Emission Inventory (RCEI) of the Malé Declaration located within the Central Environment Authority (CEA), Colombo, Sri Lanka. The RCEI's role is to oversee coordination, harmonization, quality control and reporting of the Malé Declaration EI activities. The RCEI has already helped to show the way forward by holding National Training on Emission Inventory in May 2012 in Colombo, Sri Lanka attended by representatives from the Government of Sri Lanka and a variety of stakeholders/organizations within Sri Lanka involved in environmental issues and air pollution activities. The hope was that many of the participants would also be able to help provide the data required for compiling the national EI for Sri Lanka. The participants had hands-on training in the use of the Malé Declaration EI manual/workbook and thereby gained a thorough understanding of the pivotal role of EIs in the air pollution policy cycle.

The potential data providers present also understood their crucial role in providing the input data required for the Sri Lankan EI as subsequently evidenced by the provision of much need, high quality data to the compilation team. Thus, national-level training of this kind has been demonstrated to both increase awareness of relevant stakeholders/ organizations and to forge important links with those who can locate and provide the required input data. This very successful initiative should therefore be repeated in all the other countries of the Malé Declaration in any follow-up phase.

The Malé Declaration Emission Inventory Manual preparation tool has now been extended to include emissions of methane (in important precursor of tropospheric ozone) and two constituents of particulate matter (black carbon and organic carbon) that can have impacts on regional and global climate in the short-term. Thus, in the future, this will enable Malé Declaration countries to assess the co-benefits of any planned air pollutant mitigation actions for also reducing concentrations of the short-lived climate pollutants (SLCP) such as black carbon and tropospheric ozone.

3.2 Monitoring Activities

Malé Declaration achievements and results

- Monitoring is the backbone of all other activities and must be stable and long-term and organized in a robust network of monitoring sites. The Malé Monitoring Network was established in 2003 with at least one regional monitoring site established in each of the 8 Malé Declaration countries, further sites have subsequently been added in Bhutan, India, Iran, Maldives and Sri Lanka and there are currently 15 sites in the network;
- Monitoring data has been regularly reported to the Malé Declaration Secretariat for almost 10 years, consisting of: monthly passive sampler (IVL, Sweden) measurements of air concentrations of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and Ozone (O_3); rain chemistry including pH and electrical conductivity measurements and ionic composition of rain conducted by the Malé Declaration; measurement of airborne particulate matter; plus some meteorological measurements;
- The passive sampler network has shown strong seasonal trends in the air concentrations of the three gases measured, with significant increases over time in mean annual concentrations of SO_2 (Bangladesh, Bhutan, Nepal and Sri Lanka), NO_2 (Bangladesh, Bhutan, Maldives, Nepal and Sri Lanka) and O_3 (Bangladesh, Bhutan, Maldives and Sri Lanka).
- Regular training and capacity building workshops have taken place, with India taking an active role in the training;
- Quality control and assurance procedures with training have been conducted for the Malé Declaration sites, three reports on Inter – Laboratory Comparison of Precipitation Chemistry Analyses among the National Implementation Agencies (NIAs) of the Malé Declaration have been compiled;
- A regional centre on monitoring activities is being established in India.

Building capacity to monitor air pollution

A large part of the effort during the implementation of the Malé Declaration has been the development, at the request of the governments, of regionally representative monitoring that can contribute to the understanding of trends in pollution and the degree of transboundary transport of air pollution in the region. The main aim has been to strengthen the monitoring capacities of the countries based on common methodologies and protocols and develop a network. There is now at least one monitoring station in each country (Figure 3.2.1; Table 3.2.1) in more remote, regionally representative, sites which is being used to provide data on levels and trends of air pollution and validate the results of the atmospheric transport models (see next section). In all countries there were no regionally representative monitoring sites prior to the implementation of the Malé Declaration network nor was there capacity to run them and analyse results. The sustainability of the network is enhanced by the fact that the sites are run by the governments. In Phase III existing Malé monitoring sites were maintained and audited by the Malé Declaration Monitoring Committee (MoC) and in some cases upgraded. Training has been provided to the practitioners looking after the sites to promote high quality monitoring and they have participated in Quality Assessment and Quality Control (QA/QC) exercises; the third Inter – Laboratory Comparison of Precipitation Chemistry Analyses among the NIAs of the Malé Declaration was completed in 2011.

Figure 3.2.1: The location of the main Malé Declaration regional monitoring sites.

The equipment located at the monitoring sites is as follows:

- IVL passive samplers for sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3);
- Total Suspended Particles (TSP) and PM_{10} are being measured using high volume samplers (HVS) (regionally sourced);
- Two bulk samplers (funnel and bottle) at each site;
- Department of Meteorology, University of Stockholm (MISU) wet-only collector at each site with solar panel;
- Meteorological measurements.

Table 3.2.1. Details of Malé Declaration Monitoring sites

Country	Site Type	Location	Longitude Latitude	Remarks
Bangladesh	Rural	Kulna	22° 18.975' N; 89° 02.607'E	About 30 km North to the Sundarbans forest.
Bhutan	Remote	Gelephu	27°0'N; 90°30'E	350m above sea level close to Jigme Singye Wangchuk National Park and Manas National park
India	Rural	Port Canning	22°15'N 88°40'E,	Average annual rainfall: 1750 – 1800 mm. Dominant wind direction: N/NE during winter and S/ SW in summer close to Sundarbans
Iran	Rural	Chamsari	32° 24'N, 47°31'E	40 km south to the town of Dehlaran and about 200 km south to Ilam, the headquarters of the province
Maldives	Remote	Hanimaadhoo	6.78N, 73.18E	Altitude: ~2 m. Located in the northernmost atoll of Maldives located about 400 km to the north of the country's capital, Malé.
Nepal	Rural	Rampur	27° 38'N; 84° 20'E	At the premises of the Institute of Agriculture and Animal Sciences (IAAS) located about 15 km to the south of the Royal Chitawan national park. Altitude: 164.95 m
Pakistan	Rural	Bahawalnagar	29⁰ 57'N; 73⁰ 15'E	Located within the compound of the meteorological observatory at Bahawalnagar, province of Punjab.
Sri Lanka	Remote	Doramadalawa (formerly Dutuwewa but moved in 2009 as there was no regular power supply).	08° 24.952' N; 80° 29 E	Remote site, in a forest in the north-central part of Sri Lanka

The countries have placed a lot of effort into developing the monitoring sites, and not without problems, for example, in Sri Lanka the monitoring site was changed from Dutuwewa to Doramadalawa in 2009 as there was no regular power supply for carrying out PM_{10} sampling. There had also been problems with monkeys removing passive samplers in Sri Lanka (hence the protective cage that is visible in Figure 3.2.1), and the troubles in Nepal affecting communications with the monitoring site, but most sites have now delivered regular data. The wet sampling equipment is installed and the countries have started to measure the concentration of anions and cations in the rainwater samples. The installation of an Atomic Absorption Spectrophotometer (AAS) in Sri Lanka, Bangladesh, Bhutan and Nepal, has been carried out to help them analyse the rainwater samples. The high-volume samplers are used to monitor PM_{10} concentrations. $PM_{2.5}$ is not currently measured, although it would be important to measure it in the future because of its role in health effects and the fact that it forms a significant proportion of transboundary particulate matter pollution at the regional level.

All of the countries have sent their data to UNEP for the centralised database. The Secretariat has updated the database with monitoring data from NIAs and analysis of passive sampler data from IVL in Sweden. The regional database is available online for the NIAs at: http://www.rrcap.ait.asia/male/. In order to bring all monitoring sites and the analysis up to expected levels of competence, site and laboratory audits have been performed by the MoC during Phase III. As a result, the Bangladesh NIA has been supplied with a power supply to the monitoring site. Other improvements included two new monitoring stations under the Malé Declaration installed and financed by the Indian NIA, and the Maldives NIA is now cooperating with the Ministry of Health and using their laboratory facilities to analyse the data.

To ensure the sustainability of the efforts, spare parts for all equipment have been delivered to the sites and specific training in equipment for countries has been implemented. A number of secondary sites have been established with only passive samplers and rainwater collection in Iran, Bhutan and Sri Lanka to broaden the network. The countries continue to contribute the manpower to undertake the monitoring which enhances the ownership of the process. In addition, the monitoring experts from the different countries have also been trained in the methods of trajectory analysis and models that can estimate the movement of pollutants to the monitoring sites which puts their monitoring efforts into context.

Results of the Malé Monitoring Network

Passive samplers have proved the most useful monitoring method for the Malé Declaration to date, giving consistent and reliable results. Throughout Phase II, III and IV IVL Passive samplers have been used at the Malé Declaration monitoring sites and also for monitoring campaigns associated with the Rapid Urban Assessments and corrosion network exposure sites. Figures 3.2.2, 3.2.3 and 3.2.4 show the results for SO_2, NO_2 samples exposed at the Malé Declaration sites since 2003 and O_3 samplers exposed during Phase III and IV since 2006. The data show two things, one is the clear seasonal trend in these pollutants and the other is the variation of levels according to the level of pollution across the region. For a large part of the region SO_2 and NO_2 levels are highest in winter months and lowest during the summer period. This may follow emission patterns, but also the concentrations of these gases can be lower during the summer monsoon periods because of washout by rain and stable atmospheric conditions in winter months can 'trap' pollution and prevent dispersion. The main difference is found in Iran, which has a different climate from the other sites to the east and south.

The sites in Sri Lanka, Maldives, Nepal and Bhutan all have very low SO_2 concentrations throughout the year (note the smaller scales on the y axes). Bangladesh, India, Pakistan and Iran all have much higher values as might be expected in more industrialised regions. The Indian and Bangladesh sites show very similar seasonal patterns (lower during the summer monsoon) and similar values, as might be expected in these sites that are relatively close together. This underlines the fact that these sites are regionally representative. These SO_2 concentration values are not dissimilar from remote sites in Europe (see EMEP website: http://www.emep.int/). Iran follows a different seasonal pattern and it has been suggested that the high values could be due to emissions from oil field operations in the vicinity.

For NO_2, as for SO_2, the Maldives and Bhutan have the lowest values of the eight sites. Sri Lanka NO_2 values are also low but are a bit higher than these other two countries. India and Pakistan show a story of consistently higher concentrations and all these countries follow the same seasonal patterns. Interestingly, India has much higher NO_2 concentrations than the Bangladesh site, not too distant from it, and must have an influential source upwind – maybe Kolkata. In the sites with higher NO_2

and SO_2 concentrations, the high-volume samplers were able to monitor seasonal trends. The results for sites in India and Bangladesh are shown in Figure 3.2.5.

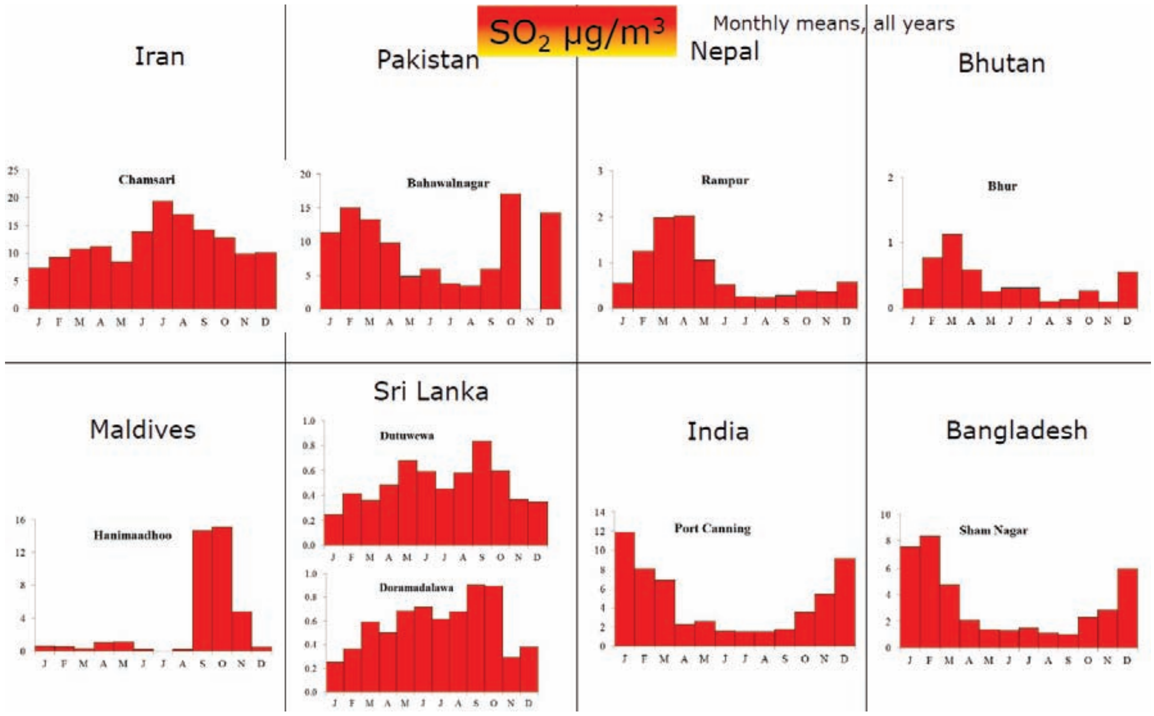


Figure 3.2.2: Monitoring of sulphur dioxide concentrations with IVL Passive Samplers at Male Declaration regional sites, monthly means 2003-2012 (note scales on y axis are not all the same)

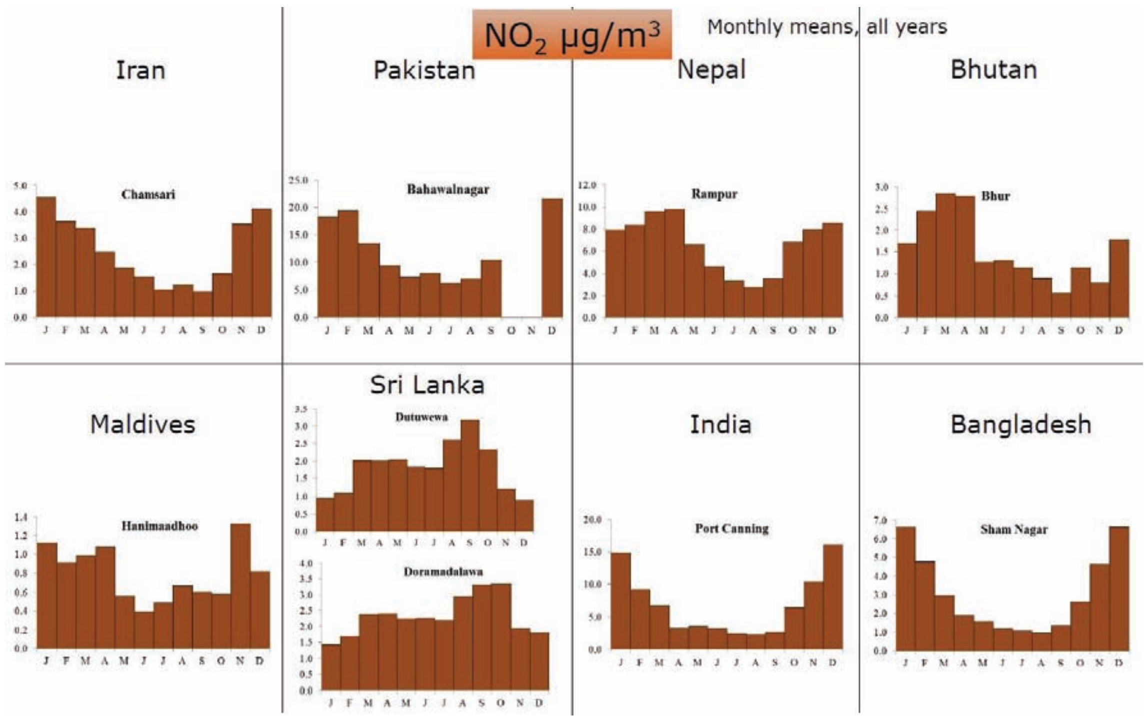


Figure 3.2.3: Monitoring of nitrogen dioxide concentrations with IVL Passive Samplers at Malé Declaration regional sites, monthly means 2003-2012 (note scales on y axis are not all the same).

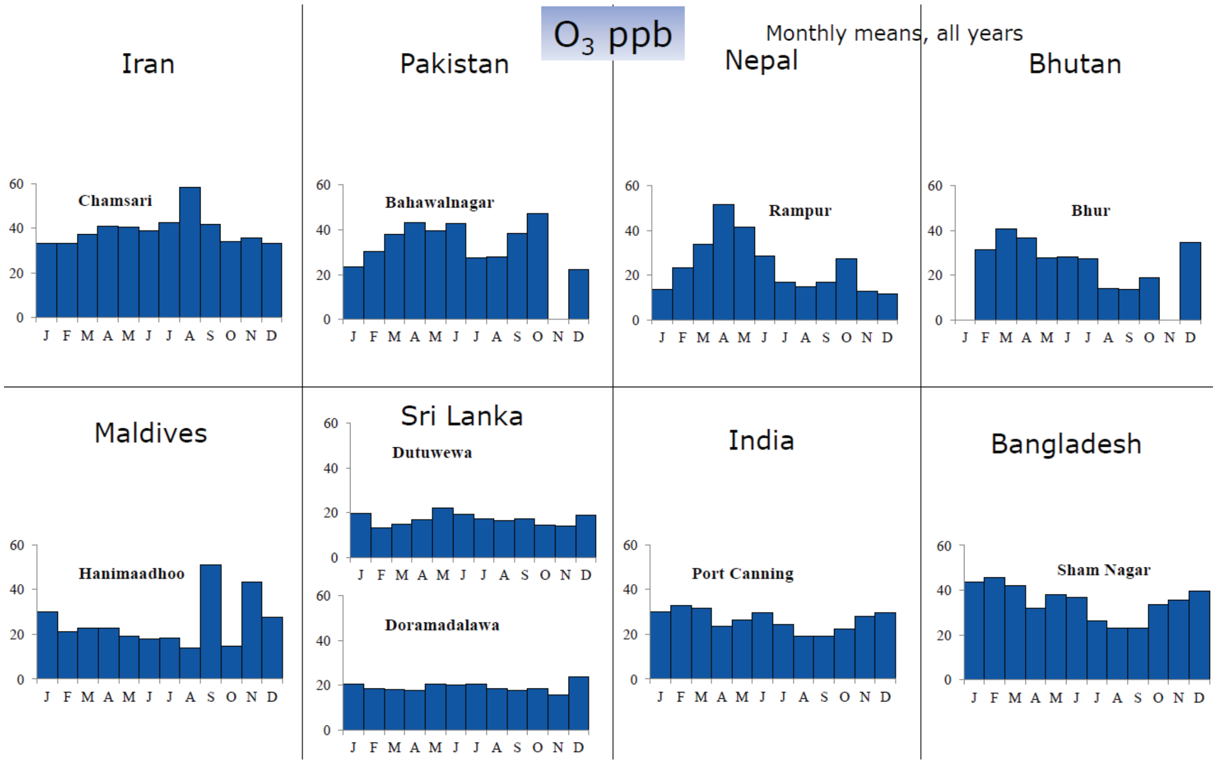


Figure 3.2.4: Monitoring of ground level ozone concentrations with IVL Passive Samplers at Malé Declaration regional sites, monthly means 2006-2012.

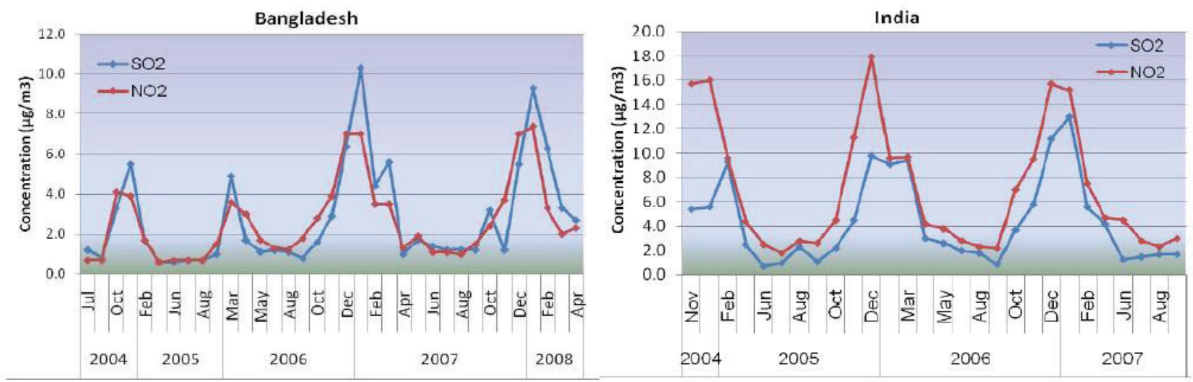


Figure 3.2.5: Seasonal variation of SO_2 and NO_2 concentrations at the Indian and Bangladesh sites (measured with the High Volume Sampler (HVS) bubbler system).

The annual means for NO_2 and SO_2 can be used to examine trends in concentrations and compare the values at the different sites with WHO guidelines for human health or thresholds for vegetation damage. For example, the WHO guidelines (WHO 2005) are currently 40 µg/m^3 annual mean for NO_2 and 20 µg/m^3 24-hour mean SO_2. Comparison with the mean monthly values for these pollutants shown in Figures 3.2.2 and 3.2.3 indicates that in most Malé Declaration countries these pollutants are not a health risk at these sites, although the situation is likely to be very different in urban areas or near point sources of pollution. The WHO air quality guidelines (WHO, 2005) revised the ozone standard based on time-series studies showing an increase in daily mortality in the range of 0.3–0.5% for every 10 µg/m^3 increment in 8-hour ozone concentrations above an estimated baseline level of 70 µg/m^3. The WHO air quality guideline for ozone is currently set at 100 µg/m^3; this 8-hour mean relates to daylight hours so the monthly means values shown in Fig. 3.2.3, around 100 µg/m^3 (i.e. 50 ppb), will certainly have exceeded the 8-hour guideline value during parts of the month.

The ozone story is very interesting with lower values generally found in Sri Lanka and the Maldives, although there can be some interesting seasonal variations e.g. September in the Maldives. Since passive samplers capture both night-time (low O_3 concentrations) and day-time (high O_3 concentrations) periods, peak day-time O_3 concentrations during each monthly passive sampler exposure period will have been much higher than the average recorded here. Generally, O_3 concentrations above 40 ppb are considered as being toxic to plants so at most of the Malé sites these conditions are likely to be met at some point in the year (see crops section). Ozone concentrations are clearly higher in the north, where NOx concentrations and emissions are higher, presumably leading to higher rates of ozone formation. Similar trends in ozone concentrations are found in Bangladesh and India, following the same seasonal pattern, as expected from these sites located relatively close together under the influence of this regional air pollutant.

There are strong seasonal trends in the concentrations of the three gases measured. There are also many data gaps. Seasonal Kendall was therefore chosen to analyse if there are any statistical significant time trends in the Malé Declaration passive sampler data analysed by IVL, Sweden, 2003 to 2013. The trends are classified in three different significance levels (*=p<0.05, **=p<0.01 and ***=p<0.001). As can be seen from Tables 2.2.2 to 2.2.4, increasing significant trends have been observed at 4 to 5 stations of the Malé Declaration monitoring sites depending on the pollutant. It should be noted that the SO_2 concentrations are close to the lower detection limit for IVLs diffusive samplers for one month exposure time (about 0.1-0.2 µg SO_2 m^{-3}).

Table 3.2.2. SO_2 concentration time trends for available data 2003-2013 at the stations with a statistical significant trend, µg SO_2 m^{-3} at STP (20 °C, 101 kPa).

Station	Dutuwewa, Sri Lanka	Rampur, Nepal	Bhur, Bhutan	Sham Nagar, Bangladesh
Annual conc. change	0.02	0.03	0.04	0.13
Median concentration	0.42	0.43	0.27	2.2
%/year	5.4%	6.1%	16%	5.7%
p	0.001	0.005	0.001	0.002
Significance	***	**	**	**
N	103	90	48	92

Table 3.2.3. NO_2 concentration time trends for available data 2003-2013 at the stations with a statistical significant trend, µg NO_2 m^{-3} at STP (20 °C, 101 kPa).

Station	Dutuwewa, Sri Lanka	Doramadalawa, Maldives	Rampur, Nepal	Bhur, Bhutan	Sham Nagar, Bangladesh
Annual conc. change	0.11	0.16	0.26	0.11	0.09
Median concentration	1.8	2.2	7.1	1.5	2.2
%/year	5.9%	7.1%	3.6%	7.5%	3.9%
P	0.000	0.006	0.000	0.011	0.005
Significance	***	**	***	*	**
N	99	44	84	47	90

Table 3.2.4. O_3 concentration time trends for available data 2003-2013 at the stations with a statistical significant trend, µg O_3 m^{-3} at STP (20 °C, 101 kPa).

Station	Dutuwewa, Sti Lanka	Doramadalawa, Maldives	Bhur, Bhutan	Sham Nagar, Bangladesh
Annual conc. change	1.2	1.7	7.8	1.3
Median concentration	36	39	57	73
%/year	3.4%	4.2%	13.6%	1.8%
p	0.001	0.002	0.018	0.016
Significance	***	**	*	*
N	65	44	27	72

The main use of the high volume samplers at the regional monitoring sites has been to measure particulate matter (PM). Of the countries that monitored PM_{10}, the highest annual average 2009-2011 was observed in the case of Iran (Figure 3.2.6), followed by Bangladesh, India, Nepal, Bhutan and Sri Lanka (the Pakistan average is of only three months and thus not representative; no data available for the Maldives)). The annual average concentration of PM_{10} in the case of Bangladesh and India has been decreasing over the years but this trend has not been tested statistically. However, this could be as a result of measures taken to control the sources of air pollution in both countries. For example, in Bangladesh measures have been introduced by the Bangladesh Government for the introduction of cleaner brick manufacturing technology, reducing traffic congestion, introduction of cleaner fuels and imposing an emission tax and by carrying out extensive awareness campaigns for the people.

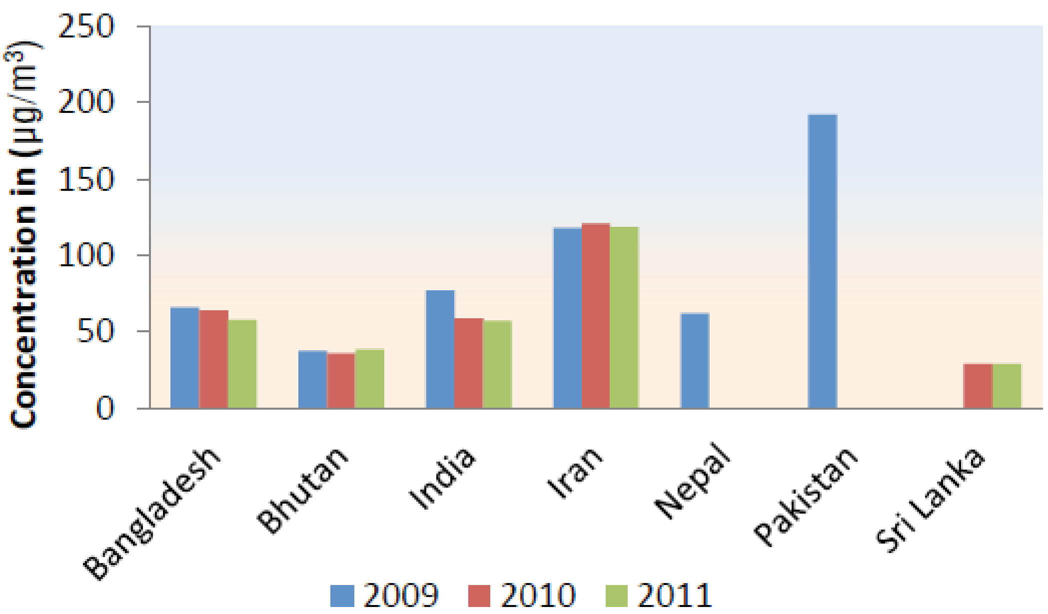


Figure 3.2.6: Annual average particulate matter concentrations (PM_{10}) at Malé Declaration Sites 2009-2011 using High Volume Samplers. Note: All countries exceed the WHO (2005) guideline for annual mean PM_{10} concentration of 20 µg/m^3.

Monthly mean results for six countries are shown in Figure 3.2.7 and generally show a clear seasonal variation in the PM_{10} concentration with relatively high concentrations during the winter months of

December to January and very low concentrations during the wet summer months. The Iran site however has different conditions with the highest concentrations occurring in the months May-July, on days that are dusty and cloudy (in Iran the concentration of particulate matter in ambient air is also influenced by the occurrence of dust storms). It can be seen that the concentrations of PM_{10} are very high (e.g. the WHO (2005) guidelines for PM_{10} of 20 µg/m^3 annual mean and 50 µg/m^3 24-hour mean). The concentrations recorded therefore indicate that rural remote sites across South Asia could have levels of particulate matter giving rise to significant health impacts, meaning that this is not only an urban issue in this region.

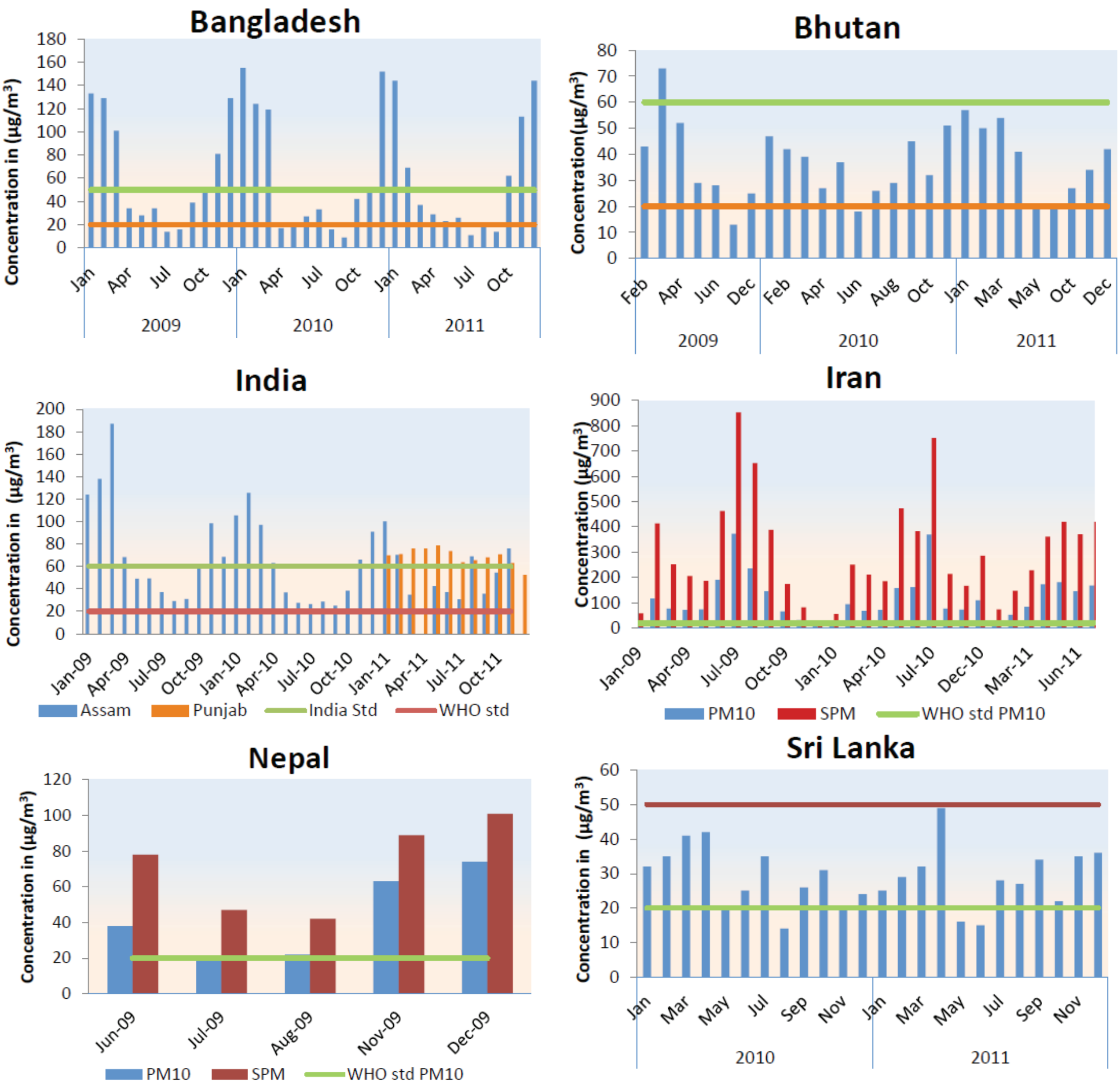


Figure 3.2.7: Seasonal trends in particulate matter monthly concentrations (PM_{10}) at Malé Declaration Sites 2009-2011 using High Volume Samplers. Orange or green line represents WHO annual guideline value (20 µg/m^3) unless otherwise stated. Note: the Indian data are from different rural sites than the official Malé Declaration site at Port Canning.

The results of wet deposition monitoring have not been reported by all the countries and no particular trends or conclusions can be drawn. The variation in pH during 2009-2011 is given in Figure 3.2.8 and although some variations in pH have been observed, no particular trends could be established. In Bhutan the pH of the samples varies between 3.5 to 6.3 with pH 4 or less at least in a few months, but there is no particular trend, although the reasons for these episodes of more acidic deposition warrant further study. It should be noted that there is not a clear correlation between the pH and the acidifying potential of the deposition as the rainfall is buffered by ammonia and ammonium deposition can acidify in the ecosystem through its interaction with soil chemistry (see Section 2.4 on soil acidification).

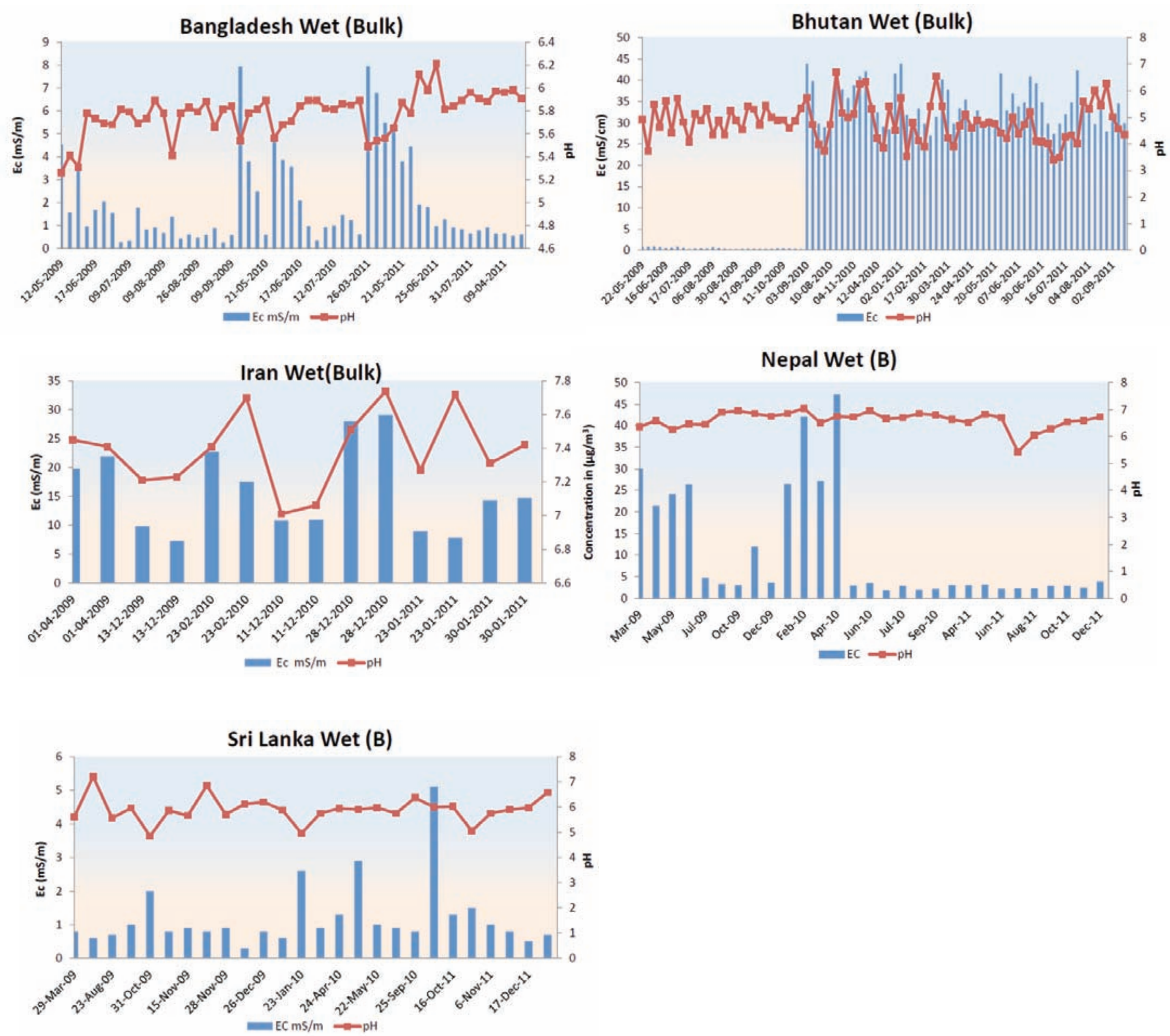


Figure 3.2.8: Variation in electrical conductance and pH as measured by the bulk collectors at the Male declaration sites 2009-2011.

Meteorological measurements have also been collected at or near Malé Declaration monitoring sites, for example, wind direction has been studied at each site as shown in Figure 3.2.9. Wind direction is an important indicator of the origin of air pollution events and the potential for transboundary air pollution.

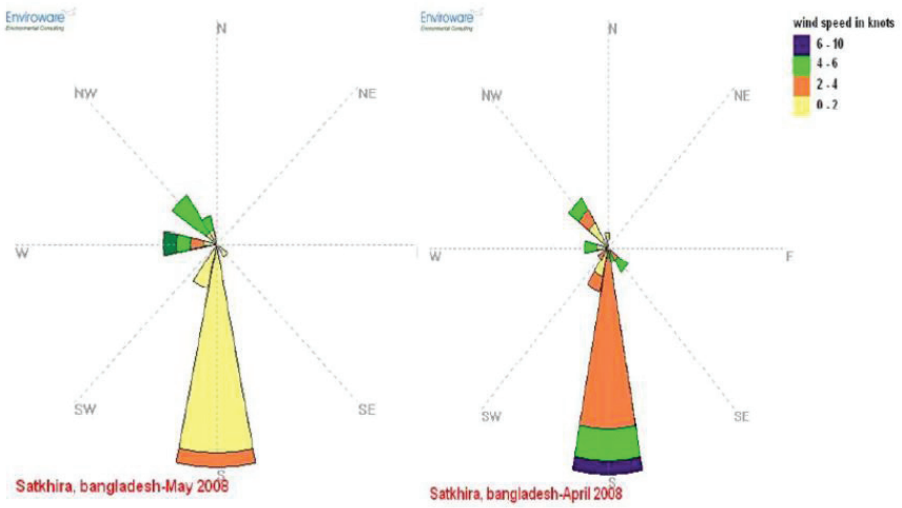


Figure 3.2.9: Wind rose for the monitoring site in Bangladesh.

Future steps

- MD has established a foundation for harmonized monitoring of regional air pollution. The time series data generated by the network need to be continued. It requires sustainable financing from the member countries.

- Regional Center for monitoring has been established. Capacity of national centers need to be further strengthened in a harmonized manner using the regional center.

- Considering the recent developments in atmospheric science, capacity of member countries could be enhanced to monitor climatic impacts of air pollutants.

3.3. Modelling Activities

Malé Declaration achievements and results

- Modelling activities under the Malé Declaration have demonstrated the transboundary dimension of the air pollution problem in South Asian conditions;
- The potential for monitoring and modelling results to be used together to build up a regional picture of the air pollution situation in South Asia has been clearly demonstrated.
- A regional centre on modelling activities is being established in Iran.

Capacity building for modelling activities

Once emitted the transport of air pollutants can be assessed through trajectory analysis and be simulated by dispersion modelling. Atmospheric dispersion modelling is a convenient way to investigate the long-distance transport of air pollution and potential transboundary transport of air pollution, which is an essential component of the knowledge required for regional policy development.

In South Asia, atmospheric scientists, NFP and NIA representatives of the Malé Declaration have been trained in trajectory analysis methods and introduced to the concepts behind the Multi-scale Atmospheric Transport and Chemistry Model (MATCH) of the Swedish Meteorological and Hydrological Institute (SMHI). Each country was encouraged to undertake trajectory analysis using free website software (NOAA HYSPLIT: www.arl.noaa.gov/ready/hysplit4.html) for their monitoring station to more fully understand the methods and assess where the pollutants that are being monitored at their stations originate from. An example of the trajectory work carried out by the Pakistan NIA is shown in Figure 3.3.1. It shows where the air parcels have travelled over the previous five days before reaching the monitoring station. It is interesting to note that on one day the air had travelled from as far away as the African coast and on another, starting from Bangladesh, whereas on other days the air parcel moved much more locally. Clearly this is only a short term snap-shot of air pollution and analysis should match the monitoring periods.

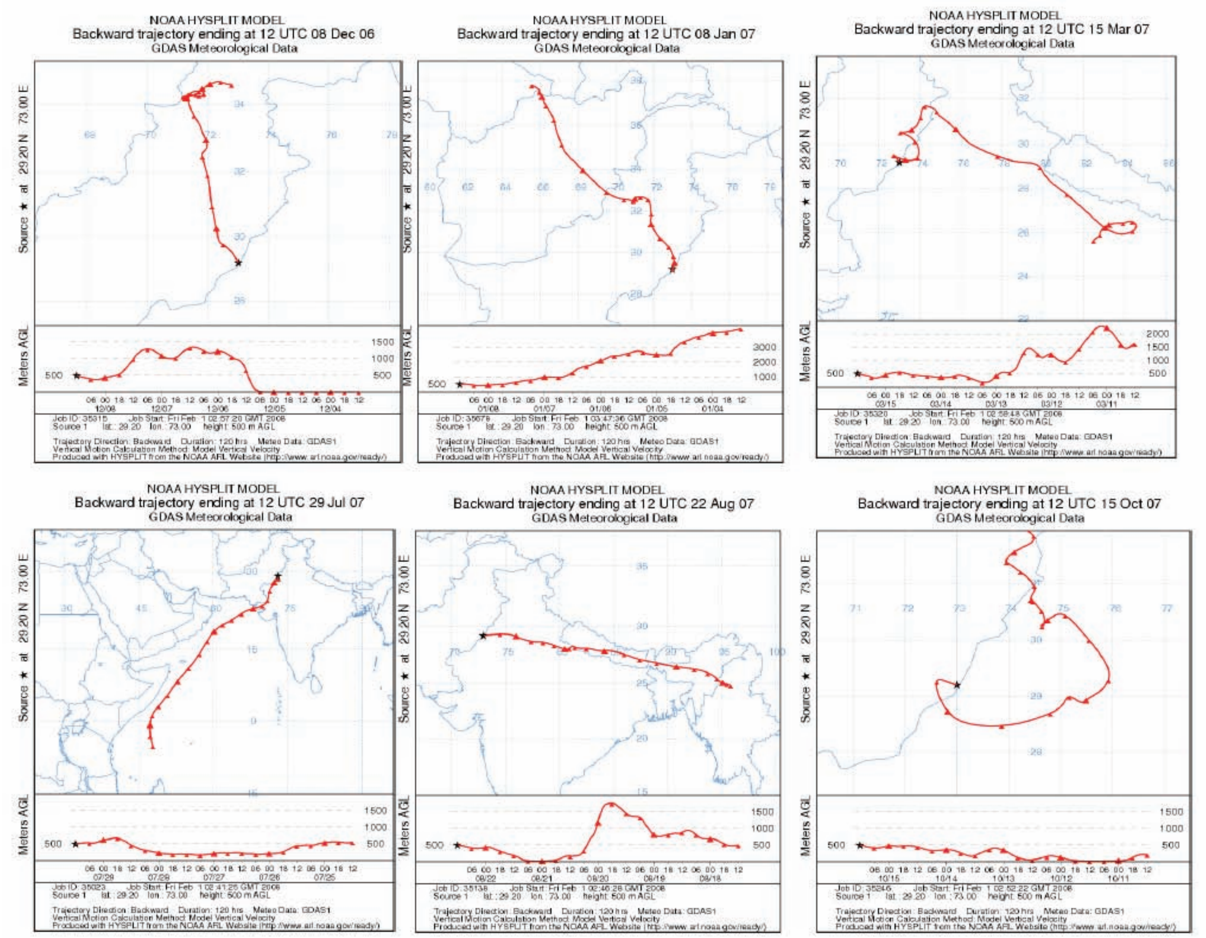


Figure 3.3.1 The figures show calculated three-dimensional, 5-day backward trajectories arriving at one of Pakistan's Malé monitoring stations (black pentagram) during selected days of 2006 and 2007. Results produced by Sajjad Saeed, Zia ul Islam, and Ahsan Rafi Kiani, Pakistan Meteorological Department Islamabad, and Pakistan EPA, Islamabad, Pakistan.

The Multi-scale Atmospheric Transport and Chemistry Model (MATCH) model has been run at SMHI and has been used to provide modelled data on the concentrations and deposition across the South Asian region. Thus far it has used with existing international emission inventories (the EDGAR emissions), to provide estimates of deposition and concentrations of sulphur, nitrogen, $PM_{2.5}$ and ozone for the Malé region. There is potential now for models to be run using the national estimates using recent emission estimates and some simple scenarios with emission estimates that result from the emission inventory activity of the Malé Declaration (see Section 3.1). The atmospheric modelling has enabled the investigation of regional transport and has allowed deposition and concentration data for the South Asia region to be used to inform policy makers through their use in the Integrated Information and Assessment System (IIAS) of the Malé Declaration (see Section 3.4).

Near surface concentrations of sulphur dioxide (Figure 3.3.2a) and nitrogen dioxide (Figure 3.3.2b) have been calculated by the MATCH model for South Asia. The results for sulphur and nitrogen dioxides demonstrate that the largest concentrations are found close to the source regions, as could be expected from these relatively short-lived pollutants. The estimates shown in the figures are based on available international data and require improvement in the light of recent improvements to emissions inventories in the region, both within the Malé Declaration activities and international scientific activities in the region e.g. the Atmospheric Brown Cloud (ABC) initiative. Despite the need for improvement, the results shown do highlight the importance of the air pollution problem in the region.

The MATCH model also calculated the sulphate, nitrate and ammonium concentrations in rainfall, and total deposition which are used in the IIAS for comparison to acidification critical loads and critical levels for vegetation. SO_2 concentrations around major cities, according to the modelled results exceed the critical levels which have been set for sensitive plant communities and lichens (areas experiencing more than 20 μg m^{-3} SO_2 based upon European experience). The deposition of sulphate, nitrate and ammonium are high in some cases, but current levels seem unlikely to exceed critical loads for acidification in most part of South Asia, mainly due to the high load of neutralising base cation deposition, mostly derived from alkaline soil dust which is uplifted by wind and transported around the region. In section 2.4 the potential for acidification in South Asia is explored further with reference to scenarios until 2030. The modelling does show that there may be an impact of nitrogen deposition on biodiversity as substantial areas receive greater than 10 kg N ha^{-1} yr^{-1}, which is a critical load set for sensitive ecosystems based upon experience in Europe. The lack of experimental information from South Asia on such ecosystem impacts makes it difficult to assess this potential effect with any degree of confidence (see Section 2.4).

Simulations using MATCH have shown the degree of transboundary transport of pollution around the region. The transport of emitted gases such as SO_2, NO_2 and NH_3 is limited due to the rapid deposition to surfaces or conversion to sulphate nitrate and ammonium. For secondary pollutants such as sulphate, nitrate and ammonium that are transported much further (see Figure 1.1), the degree of long-distance transboundary transport does not seem to be as extensive as that generally experienced in Europe, but does occur and is substantial nevertheless. However, until the inputs to the model, such as the emission inventory, are improved and fully endorsed by the countries, it is too early to make accurate assessments on the extent of this transboundary transport. Concentrations of tropospheric ozone have also been modelled using the MATCH model by SMHI in Phase III and the results are shown in Figure 2.2.3.

The MATCH model was also used during Phase III to calculate $PM_{2.5}$ concentrations. The total $PM_{2.5}$ load is mainly made up of the inorganic fraction (nitrate, sulphate and ammonium) together with black and organic carbon. Figure 3.3.3 shows that data from South Asia for the composition of the ABC shows that the inorganic fraction is about half of the total. The results of the MATCH model in South Asia (Figure 3.3.4) are for the inorganic fraction only as it was not possible to obtain black and organic carbon emissions for use in the MATCH model. If it is assumed that the ABC composition is typical for South Asia, it would be expected that the inorganic fraction would be about 50% of the $PM_{2.5}$. Once the main missing PM fractions, organic and black carbon emissions, are included in the future this will give a more complete picture of the $PM_{2.5}$ concentrations. However, the concentrations of the secondary inorganic aerosols calculated are a useful initial attempt to characterise the risk of PM to health, even if this is a systematic underestimate.

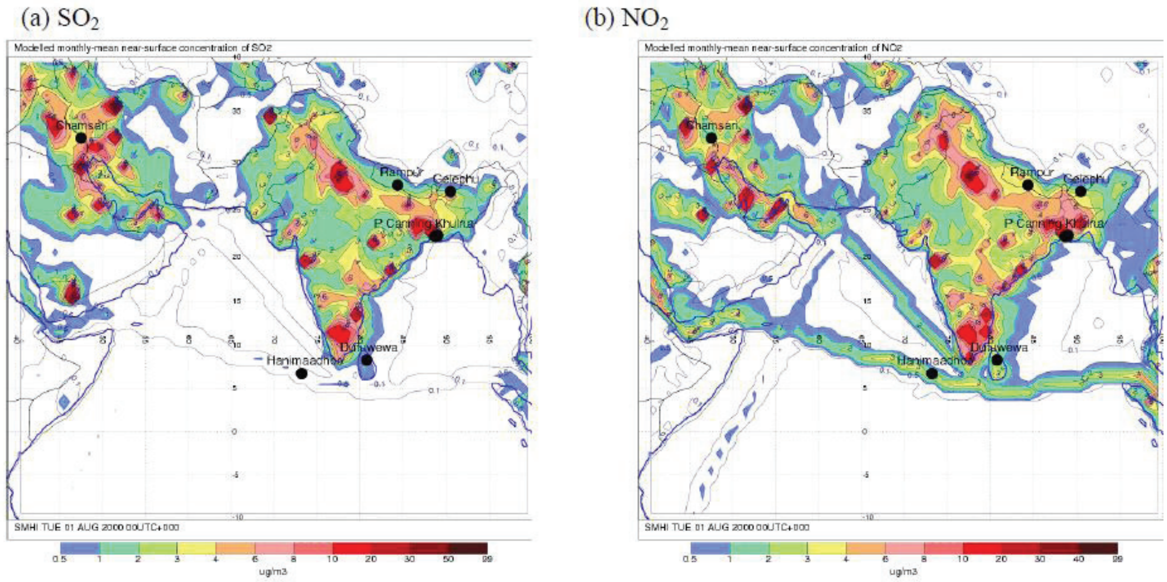


Figure 3.3.2a and b Near-surface monthly-mean concentrations of SO_2 and NO_2 in July 2000 across South Asia from the MATCH model using EDGAR emission estimates for 1995.

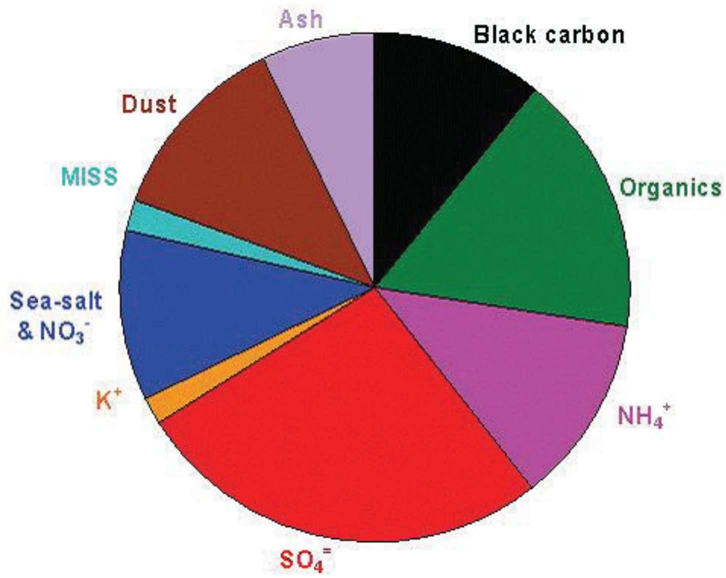


Figure 3.3.3 Measured composition of the Atmospheric Brown Cloud over South Asia from the ABC. website: (http://www-abc-asia.ucsd.edu)

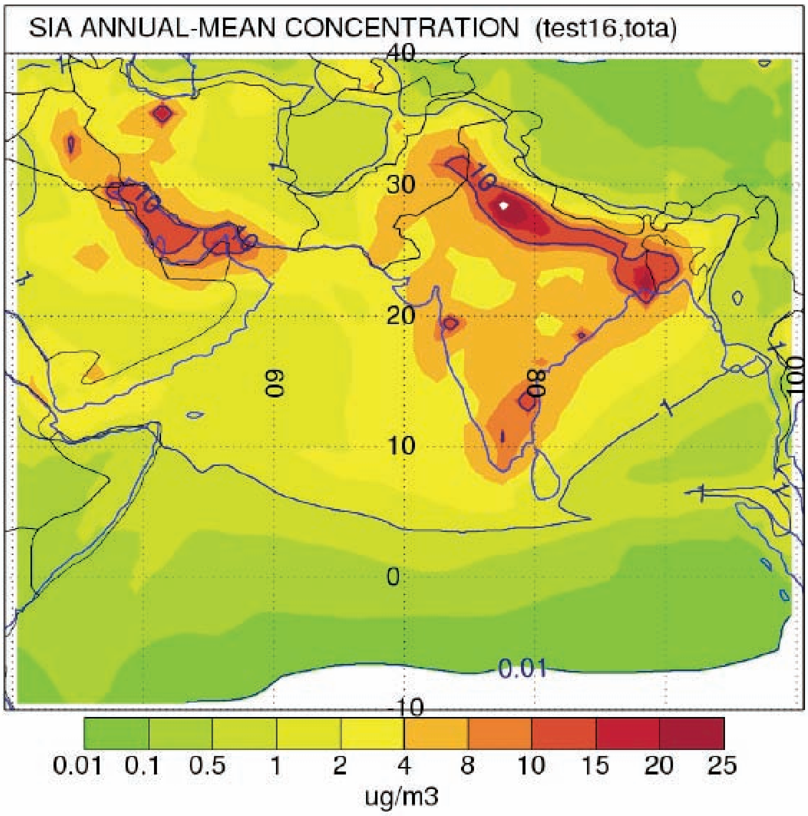


Figure 3.3.4 Calculated annual-mean concentration of secondary inorganic aerosols (SIA) – sulphate, nitrate and ammonium (all within the $PM_{2.5}$ size category)

The MATCH model calculated secondary inorganic aerosols (SIA) shown in Figure 3.3.4 describe fairly high levels of $PM_{2.5}$ of between 2-25 µg m^{-3}. The implications for health impacts are considerable from this regional $PM_{2.5}$ signal. Using WHO dose-response relationships a concentration of 10 µg m^{-3} $PM_{2.5}$ would result in a 10% increase in the risk of cardiopulmonary mortality and a concentration of 20 µg m^{-3} in a 20% increase, in adults more than 30 years old.

Of course, the usefulness of the MATCH model, or any other atmospheric transfer model, relies on the model being able to project concentrations and deposition with a reasonable level of accuracy. Figure 3.3.5 shows the results of comparing the model results against observations for rainfall, sulphate, nitrate and ammonium concentrations in India which were undertaken under the Composition of Asian Deposition (CAD) project. Any value within a factor of 2 is considered to be a reasonable estimate. The modelled rainfall fits the observed data well, as does the sulphate. Many nitrate values are outside acceptable limits, with a general underestimate by the MATCH model. This could be as related to uncertain emission estimates as model structure or parameters. Ammonium does better but with a greater degree of scatter, most likely reflecting the uncertainty in emission estimates.

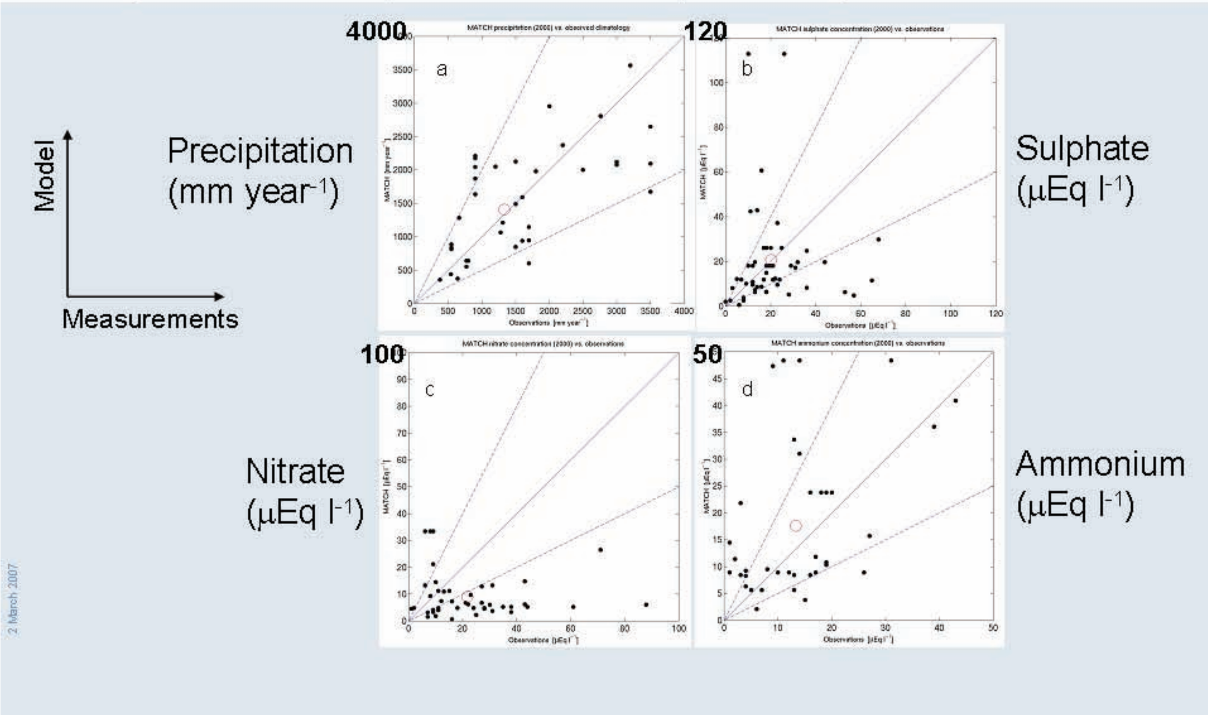


Figure 3.3.5 An evaluation of MATCH's ability to reproduce precipitation amount, sulphate-, nitrate-, and ammonium concentration in precipitation in India. Data taken from Kulshrestha et al. (2005) which resulted from the RAPIDC Composition of Asian Deposition (CAD) project.

Future steps

- The regional centre for modelling can build on existing work and link with modellers in the region to assess the current extent of transboundary air pollution in the South Asia.
- The work of the Male Declaration should also link with other international initiatives, such as the LRATP Task Force on Hemispheric Transport of Air Pollution (HTAP), that estimate the movement of air pollution between regions.
- For regional $PM_{2.5}$ concentration estimates the organic and black carbon component needs to be added plus other $PM_{2.5}$ crustal material.

3.4 Integrated Assessment Modelling

Malé Declaration achievements and results

- An Integrated Information and Assessment System (IIAS) has been developed by the Malé Declaration that can take emissions and monitoring data from South Asia and assess health impacts from PM, crop yield impacts due to ozone and ecosystem impacts of nitrogen and sulphur. The Malé Declaration now has the capacity to quantify the benefits, in terms of reduced impacts, of different scenarios of emission abatement.

Capacity building for integrated assessment modelling activities

The different pieces of the knowledge jigsaw required by policy makers in the Malé Declaration region are put together in the Malé Integrated Information and Assessment System (IIAS) which has been developed through collaboration between UNEP, SEI and SMHI. In Phase II consultation on the form of the system was undertaken with the NIAs of the Malé Declaration to ensure that the system would be useful to the end users. In Phase III the system was put together linking the different inputs to develop results that can inform decision making. The IIAS has also been designed to have the flexibility to allow countries to alter inputs and assess the changes to different impacts. Much of the work has gone into developing the input data for the IIAS, especially MATCH atmospheric transport model results, and linking these to impact-relevant data, such as dose-response relationships. Pollutant emissions are processed by the atmospheric transfer model to give depositions and concentrations. Figure 3.4.1 shows the elements of the calculations that can be made within the Malé Declaration IIAS. At the moment the emission data are from the EDGAR global emission database, but these are being replaced by the emission estimates from the countries as they are derived. The system allows simple scenarios to be developed (increase or decrease in emissions by a certain percentage). These can be used to create new deposition estimates using the region to grid transfer coefficients developed by running the MATCH model for estimates of sulphur, nitrogen and particulate matter emission. Transfer coefficients cannot be used for ozone and so the IIAS contains ready-made scenarios to illustrate the impact of increasing or reducing the emissions of ozone precursors (NOx and VOCs). The MATCH model can be re-run if the distribution of emission sources changes or if other ozone scenarios are to be run. The user friendly front page of the IIAS is shown in Figure 3.4.2.

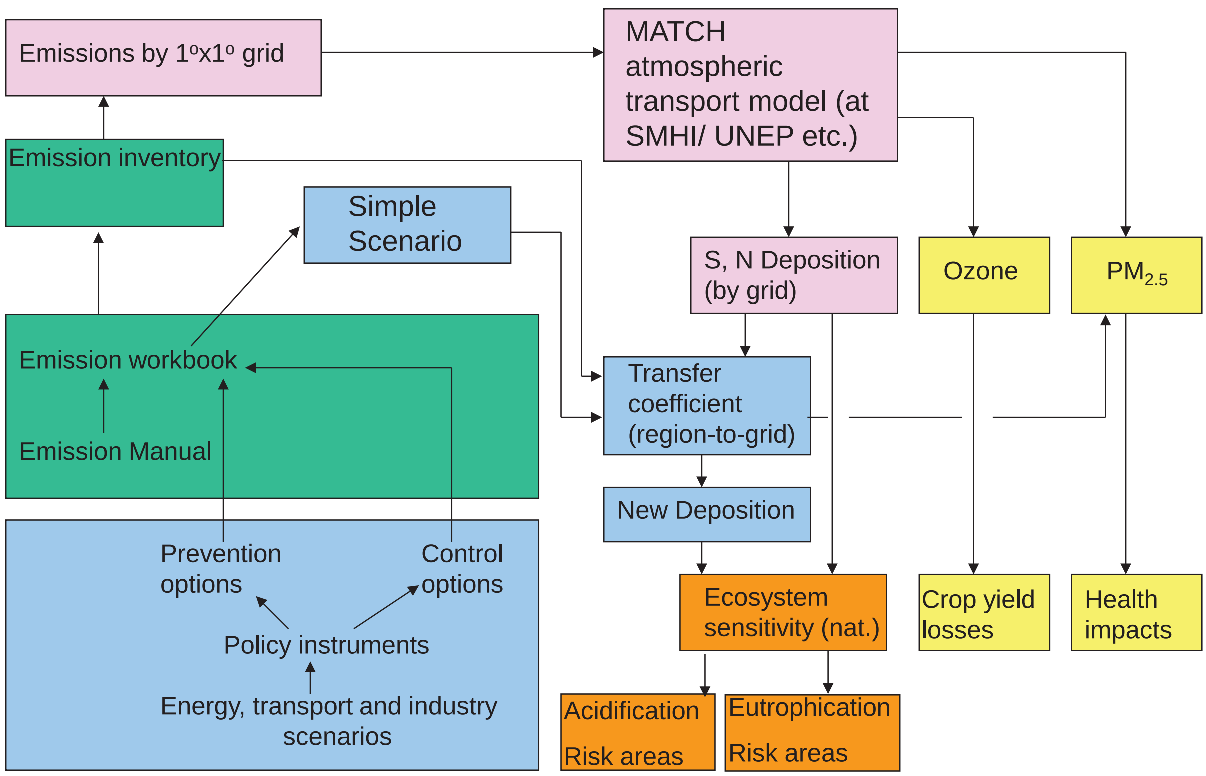


Figure 3.4.1 Schematic outline of the calculations within the Malé Declaration Integrated Information and Assessment System (IIAS).

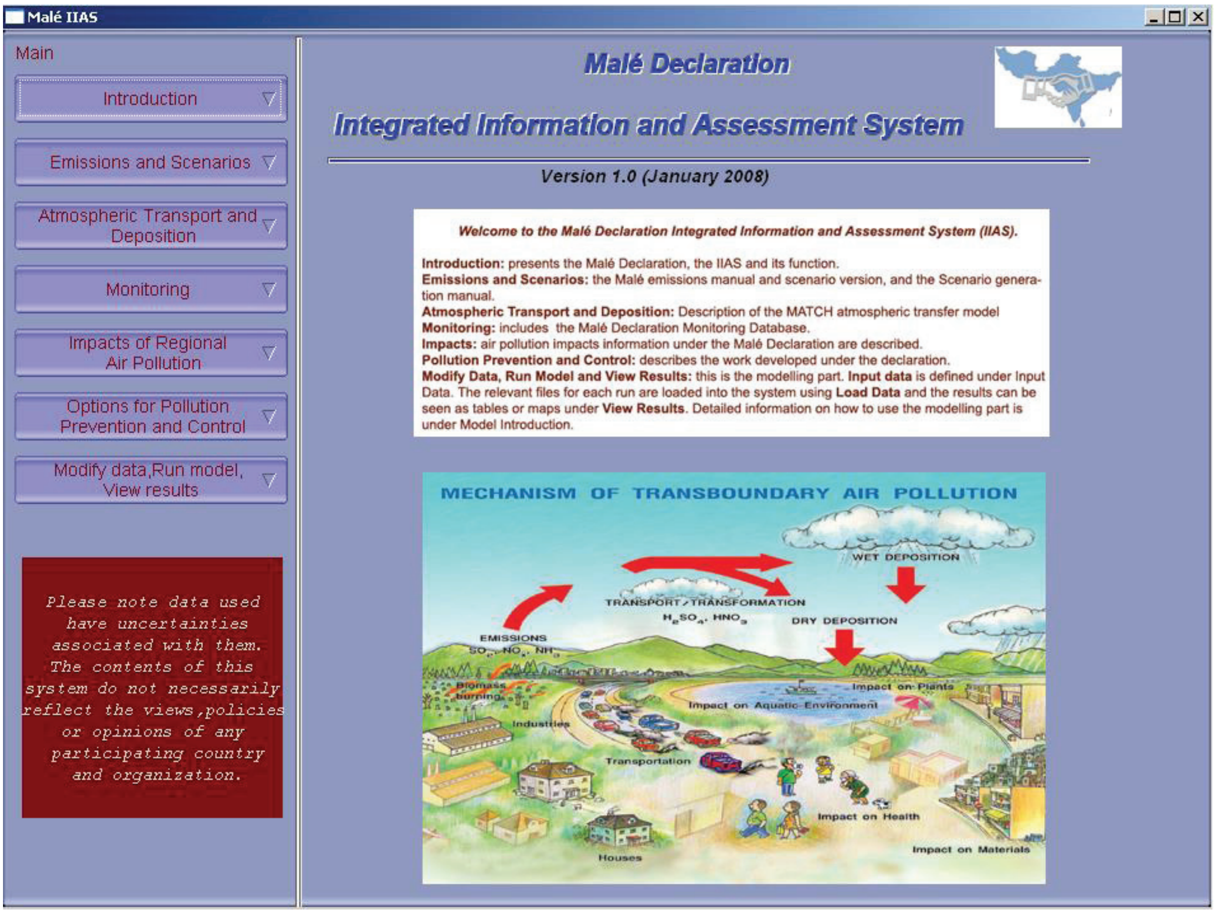


Figure 3.4.2 Front page of the Malé Declaration Integrated Information and Assessment System (IIAS).

Future steps

- The IIAS needs to be run with the most up-to-date emissions data from the Malé Declaration for a series of scenarios projected emissions of air pollution in the future.
- The transfer coefficients used in the IIAs should be updated using atmospheric transfer models currently in use in the region.
- Considering the recent developments in atmospheric science, capacity of member countries could be enhanced to include climatic impacts of air pollutants in an IIAS type approach.

3.5 Rapid Urban Assessment

Malé Declaration achievements and results

- The application of Rapid Urban Assessment (RUA) methods has developed capacity in Kathmandu, Nepal, and Hyderabad, India, to undertake rapid urban emission inventories which are the basis for policy development and health risk assessment in the city.

- The validity of these inventories has been cross-checked by monitoring data which show reasonable agreement.
- The work conducted during Phase III has made it clear that the most important pollutant in Kathmandu is particulate matter, largely from the transport sector, which is known to have the greatest impact on human health.
- The distribution of emissions has been calculated using the rapid urban assessment methodology which will enable targeted strategies to be developed to reduce air pollution in the hotspots.

Background

Urban air pollution is very serious in most South Asian cities. With the shift in the rural populations to urban cities, cities of all sizes are set to expand rapidly in the coming decades. In addition, most cities have no comprehensive system for linking emissions from the various polluting sectors to health impacts and for assessing the effectiveness of policy measures to protect urban populations. This urban focus is a priority for the Malé Declaration as urban emissions make a core contribution to transboundary air pollution and their prevention and control is vital to achieving the aims of the Malé Declaration. The Malé Declaration has developed 'Rapid Urban Assessment' urban-scale projects in Hyderabad, India, in phase II and Kathmandu, Nepal, in phase III.

Capacity building for rapid urban assessment

Due to the rapidly changing nature of the cities and their limited budgets for environmental issues, the very detailed and costly methods of urban integrated assessment commonly used in Europe are not viable. Therefore, the Malé Declaration has been developing and building capacity to undertake relatively rapid, yet reasonably accurate assessment methods. This methodology first undertakes a rapid emission inventory, using top-down estimations linked with bottom-up data. The emissions are distributed across the city using land-use assessments based upon satellite data that allows for regular updating as the city expands. The emissions are used in an atmospheric transport model (the TAPM model from Australia has been used thus far) to give modelled estimates of PM, SO_2 and NO_2 concentration. The validity of the emission inventory and the modelled concentrations is checked using monitoring campaigns across the city. Once a validated emission inventory is established, the influence of policy on emissions can be developed.

The application of the Rapid Urban Assessment (RUA) method in Kathmandu, Nepal, in Phase III, follows on from the successful pilot study in Hyderabad in Phase II. The aim of applying the RUA methodology has been to enhance the capacity of Malé Declaration NIAs in the RUA methods as well as to help the two cities develop their assessment procedures and obtain relevant data for decision making.

The RUA training activities coordinated by IVL have included a number of essential parts for the emissions inventory: identification of emission sectors and linkage to emission data (point, line and area sources), top-down and bottom-up approaches as well as linkage between emission sectors and geographical features in remote sensing data. As well as training the participants in the cities concerned, other countries have also participated in the training. For example, RUA workshops were attended by representatives from most Malé Declaration countries in Kathmandu.

Another part of the urban assessment of Phase III was the continued development of the Air Pollution in Mega-Cities of Asia project, or APMA, which was also funded by Sida. In Phase III APMA has facilitated AQM needs assessments in the Malé Declaration Countries of Pakistan (Karachi) and Nepal (Kathmandu) to coincide with the RUA activity. This involved meetings with key stakeholders to identify the gaps and needs in AQM, completion of a questionnaire survey and collection of available data on air quality management capability in each city. The assessment demonstrated the need for monitoring of PM in the cities. The procedures developed by the APMA activity in Phase II have been used to aid the development of initial 'Strategic Frameworks for Air Quality Management' (AQM) in Kathmandu during this phase using the results of the rapid urban assessment and linked with consultation with the relevant stakeholders.

Under the guidance of APMA the cities of Kathmandu and Karachi have begun monitoring of particulate matter using DustTrak analyzers. The DustTrak™ 8520 Aerosol Monitor is a portable, battery-operated laser photometer with real-time mass concentration readout and data logging capability. The monitor provides reliable exposure assessment by measuring particle concentrations corresponding to respirable, PM_{10}, $PM_{2.5}$ or $PM_{1.0}$ size fractions. The monitors used were calibrated against 'Arizona Dust', a standard method. In Kathmandu and Maputo DustTrak monitoring was used to validate the passive monitoring results of PM by IVL, and to employ an enhanced capacity for $PM_{2.5}$ monitoring for better characterisation of PM.

The APMA project has also produced a compendium of the Air Quality Management (AQM) for 20 Asian cities together with CAI-Asia and analysed their capabilities and required enhancements (Schwela et al.,, 2006). This shows great variation in capacity across Asia and illustrates the very high pollution levels from monitoring data compiled for the cities.

Kathmandu Summary

In Kathmandu, the application of RUA methods has developed capacity in Nepal to undertake rapid urban emission inventories which are the basis for policy development and health risk assessment in the city related to concentrations of nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter (PM_{10} and $PM_{2.5}$) pollution in the ambient air. The work was put into the context of a Strategic Framework for Air Quality Monitoring which was developed through the APMA project which discusses the use of an emission inventory together with monitoring networks and impact assessments as a structure for developing policy (Table 3.5.1). The work conducted during Phase III has made it clear that the most important pollutant in Kathmandu is particulate matter, which is known to have the greatest impact on human health, and is emitted largely from the transport sector (see Figure 3.5.1a). The calculation of the distribution of emissions will enable targeted strategies to be developed to reduce air pollution in the hotspots. It is important to note that due to the position of brick kilns outside the Kathmandu Metropolitan City (KMC) area (see Figure 3.5.1a) the emissions from these prominent point sources could not be incorporated in the assessment carried out. The results of the emission inventory compilation (Figure 3.5.1a) were used in the TAPM atmospheric transfer model and the resulting ambient air particulate matter concentrations are shown in Figure 3.5.1b. The validity of these results has been cross-checked by monitoring data which show reasonable agreement.

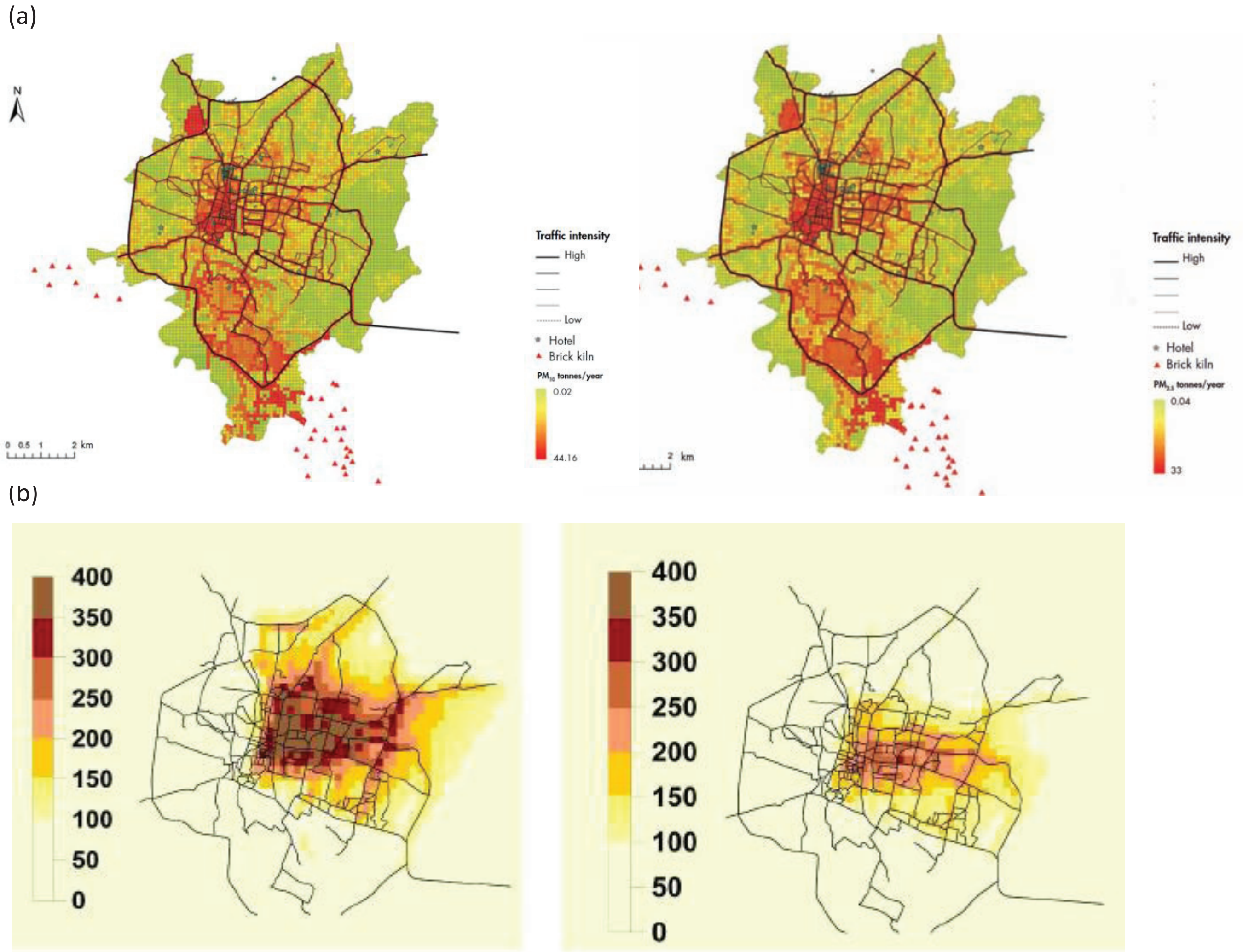


Figure 3.5.1 (a) particulate matter emissions (tonnes per year) estimated using the Rapid Urban Assessment (RUA) technique (left-hand side: PM_{10}; right-hand side – $PM_{2.5}$); (b) calculated air concentrations using the TAPM model (in µg/m^3) of particulate matter (only contribution from emissions) during the two mapping campaigns in Kathmandu (left-hand side: Dry season - February-April 2008; right-hand side: Wet Season - July-September 2007).

Table 3.5.1 Components of a strategic framework for air quality management

Air Quality Policies	To include and/or strengthen the concept of air quality, human health and environment in policies, legislation and its harmonisation and implementation in the development of Kathmandu.
Air Quality Governance	To facilitate law enforcement and inform, educate, train and strengthen stakeholder participation in all aspects related to air quality and the prevention and reduction of air pollution and the corresponding health and environmental impacts.
Emissions	To include and/or strengthen enforceable, affordable, sustainable and highly effective measures to assess and reduce emissions
Air Quality Modelling	To support and strengthen national and local air quality estimates and allow source apportionment and estimations of transboundary pollution
Air Quality Monitoring	To establish and/or strengthen national and local air quality monitoring programmes to assess compliance with national air quality standards and assess health and environmental impacts
Health, Environmental and Economic Risk Assessments	To establish and/or strengthen national and local programmes which monitor the health, environmental and economic impact of air pollution in a harmonised way
Financing of AQM	To establish mechanisms for financial sustainability in regional, national and local air quality, environmental and health programmes including financing from private sector and other sectors

Future steps

- For Kathmandu the concentration data can also be linked to dose-response curves for human health impacts as well as allowing economic assessments.
- Apply methodology in further Malé Declaration cities and countries.

4. Decision Support Information for Policy Formulation and Mitigation

Malé Declaration achievements and results

- Information on best and good practice on air pollution policy, using international examples and examples of policy implementation in South Asia for the housing, transport and power sector, examining Best Available Techniques (BAT), has been synthesised for the Malé Declaration.
- Another project has considered the implementation of policy measures in some countries of South Asia and factors that affect how well policy interventions work in the social and political contexts of the different countries in the Malé Declaration region.
- Workshops were used to train National Implementing Agency (NIA) representatives in the Malé Declaration in the different types of policy approach. The workshops assessed which

policy in a particular sector would be most appropriate for South Asian conditions, given resource constraints and institutional aspects.

- The capacity of Malé Declaration officials and experts involved in the policy making process has been enhanced through training on regional cooperation issues focusing on good practices and knowledge on international policies and regulations related to air pollution in other parts of the world.
- Bangladesh is the first country to produce an air pollution reduction strategy in South Asia under the Malé Declaration.
- A regional centre on Pollution Reduction Policies/Strategies is being established in Nepal / Maldives.

Capacity building for decision making

The knowledge of the emissions, transfer, pollutant levels and impacts should all feed into the policy making process to emphasise the need for action, and also to identify sectoral, spatial and pollution specific priorities. To inform the implementation of policy measures there is a need for information about the solutions to the air pollution problems, their ease of implementation and efficacy. In Phase III a number of activities were undertaken to synthesise information on best and good practice on air pollution policy, using international examples and examples of policy implementation in South Asia. Another project has considered the implementation of policy measures in some countries of South Asia. In addition, there was discussion of policy measure implementation at workshops and inter-governmental meetings.

Syntheses of policy approaches and international 'best practice' from the international arena were developed by the International Institute for Industrial and Environmental Economics (IIIEE), based in Sweden, and training was provided in the results of the syntheses for the Malé Declaration representatives at training courses. In addition to that, further information on the experience of promoting 'good practice' in comparison to international best practice in South Asia has been synthesised by AIT in Bangkok, Thailand. These reports include an analysis of the emitting sectors in the Malé Declaration countries and an analysis of the different types of prevention and control policy that exist to address the emissions, using examples in a policy case book to illustrate innovative approaches and cases where the different instruments have been used. The study highlighting international best practice concludes that in most countries, despite the dominance of command and control, future strategies will rely on combinations of different types of policy such as the use of economic instruments working alongside command and control approaches. Deeper analysis was made into specific sectors: housing, transport and power sector, examining Best Available Techniques (BAT) and good practice in three separate reports. This included looking at prevention opportunities in the different sectors through increased efficiency in end use (e.g. in housing) where the impact of demand management on electricity generation, for example, was highlighted, including a consideration of the whole life-cycle impact of building on air pollutants.

Workshops were used to train NIA representatives in the Malé Declaration in the different types of policy approach. The policy option training for the Malé Declaration was given alongside the emission, atmospheric transport and integrated assessment training at workshops held at AIT. The form of these workshops included asking participants to assess which policy in a particular sector would be more appropriate to their conditions, given resource constraints and institutional aspects. It was clear that systematic thought needs to be encouraged in this area. Development of 'eco-housing' projects was also highlighted to Malé Declaration representatives to emphasise what can be done to minimise the impact of the massive urban growth that will occur over the next decades; further increasing demand for electricity and other resources.

A further activity undertaken by SEI investigated the factors that affect how well policy interventions work in the social and political contexts of the different countries in the Malé Declaration region. This study was written as a report and supplied to the NIAs at the intergovernmental meeting in Colombo, 2008. For the study key decision makers and representatives from NGOs in Nepal, India and Bangladesh were interviewed, using a semi-structured interview technique, concerning the implementation of policy in their respective countries and the prospect for being able to transfer successful policies from other regions and countries. The report concluded that all respondents clearly identified particulate matter as being their most important air pollutant requiring management in their countries. They also said that a number of successful measures have been introduced in South Asia, particularly in major cities. India has established a broader, national approach with multi-level governance for air pollution, leading to improvements across the country, in contrast to Bangladesh and Nepal where most of the measures are restricted to the capital cities.

There are many examples of what the participants considered ‘good practice‘ in the region including introduction of low sulphur diesel, implementation of CNG for buses and taxis, and introduction of cleaner brick-kiln technology, where they are confident that the measures have been effective. The participants in the project considered motorised transport to be the most difficult problem for air quality in the region. It was clear that some aspects of ‘international‘ good practice could not be easily transferred to the region, particularly where enforcement was complicated or expensive. A need for institutional capacity building for air pollution prevention and control was identified by the respondents as being important for the region and some barriers need to be addressed if introduction of new policy measures was to be successful. The findings of the activity were highlighted at the tenth inter-governmental meeting of the Malé Declaration. It is intended that such syntheses on policy implementation will increase the capacity of the NIAs and NFPs regarding the different approaches that are possible to reduce and limit the air pollutant emissions from different sectors. From discussion with NIA and NFP representatives, it is clear that for many countries the focus provided by the Malé Declaration has enabled discussion of the measures that can be taken in their countries.

Air Pollution Reduction Strategy for Bangladesh

Air pollution, especially in the large cities, is a major environmental concern in Bangladesh and in phase IV it undertook the development of an Air Pollution Reduction Strategy. The strategy produced describes the current state of air quality, major sources of air pollution, past policies implemented and suggests future strategies to reduce air pollution in Bangladesh. Around 50 strategies were initially selected, of which 26 are finally recommended after evaluation of the strategies. The criteria for evaluation were likely impact, time to introduce, time to benefits, technical and implementation effectiveness, cost effectiveness and co-benefits. The recommended strategies are presented below (detail inside the report). The strategy choices were based on a *qualitative* multi-criteria evaluation because of lack of information for quantitative benefit-cost modeling. It is strongly recommended each of the strategies is quantitatively evaluated before final implementation.

Table ES 1. Recommended strategies for air pollution reduction in Bangladesh

	Strategy	Area of application
A	Improve public transport	Large cities
B	Strengthen vehicle inspection and maintenance	All, especially large cities
C	Ban vehicles older than 20 years	Commercial vehicles, large cities
D	Encourage Diesel to CNG switch through incentives	All diesel vehicles, especially, truck & buses in large cities
E	Emissions (age) based annual registration fees	All vehicles
F	Stringent emissions standards	All new vehicles
G	Emissions based import tariff	All new vehicles
H	Comprehensive land use plan for industry locations	All industries, especially new ones
I	Cluster management	Cluster of highly polluting industries
J	Emissions (technology and fuel) based license fee	All kilns
K	Technology standards	All kilns
L	Alternate construction material	All country, especially large cites
M	Ensure adequate power supply	All country
N	Emissions standards	All new plants
O	Emissions standard for diesel generators	All new generators
P	Inspection & maintenance of diesel generators	All existing generators
Q	Technology specification	Existing steel mills, cement and glass factories
R	Inspection and maintenance	Existing steel mills, cement and glass factories
S	Emissions standards	All new and existing plants
T	Import control for quality of coal	Whole country, primarily brick and power industries
U	Better construction practices on site & during transport	All construction sites
V	Air pollution mitigation plan and its enforcement	Large construction projects
W	Timely road maintenance	All roads
X	Landscaping and gardening	All exposed soil in urban areas
Y	Encourage fuel switch	Urban slums and rural areas
Z	Improved cooking stoves	Rural areas

In addition, it is important to consider the following for effective implementation of air pollution reduction strategies:

1. Regulatory and fiscal reform to enable the strategies effectively
2. Awareness and motivation about air pollution across sectors
3. Research and development to address the knowledge and information gaps so that future strategies can be based on quantitative modeling
4. Co-operation and coordination among various stakeholders, from regulators to businesses to the general public
5. Capacity building and knowledge retention
6. Institutional reform to ensure coordination and governance

5. Regional Cooperation and Financing

Malé Declaration achievements and results

- The Malé Declaration has succeeded in establishing regional co-operation on air pollution issues in South Asia, which was missing before its establishment in 1998. Also, recently the Malé Declaration has been successful in establishing a sustainable financing mechanism and some countries have already initiated financial contributions.

6. Awareness Raising

Malé Declaration achievements and results

- The Malé Declaration communication activities target a broad audience in South Asia. This is partly accomplished through the development of newsletters and through stakeholder involvement in workshops and national initiatives. In addition, the progress in the Malé Declaration is frequently presented to international meetings.
- The Malé Declaration has an annual regional stakeholder meeting and a number of national stakeholder meetings. Dissemination is also conducted through youth groups such as South Asia Youth Environment network (SAYEN).
- Awareness activities have included dissemination of brochures, posters, and stickers on air pollution by the NIA as well as filmed songs on air pollution by popular singers and short plays using well-known actors.
- Awareness activities have also included activities under the Malé Declaration targeted on three levels of education and understanding for the general public, schools and university students and technical/science professionals.

Capacity building for integrated assessment modelling activities

The Malé Declaration communication activities target a broad audience in South Asia. This is partly accomplished through the development of newsletters and through stakeholder involvement in workshops and national initiatives. In addition, the progress in the Malé Declaration is frequently presented to international meetings. In addition, the Malé Declaration and is promoted through involvement of key people in international scientific meetings.

The Malé Declaration has produced newsletters which have been widely disseminated to all stakeholders and participants of all training programme held for information sharing both within and beyond the Malé Declaration network.

The Malé Declaration has an annual regional stakeholder meeting and a number of national stakeholder meetings. Dissemination is also conducted through youth groups such as South Asia Youth Environment network (SAYEN). SAYEN includes media networks, such as 'Environment TV', as part of its network and has developed a 'Youth for Clean Air' interactive CD. This is hosted at the SAYEN website and as part of the Malé Declaration website. These activities and CD were prepared through a series of consultations with the youths in South Asia at a consultation workshop which was held during January 2008 in India. SAYEN are disseminating this information through conducting national awareness and action programme for other youth, schools and the general community. At the regional level an awareness workshop was held in Bangalore, India on —Air pollution and Asthma during January 2008.

There have also been a number of national activities related to the Malé Declaration implementation. For example, national brochures were developed and distributed to stakeholders during the National Stakeholder Meeting in Bhutan in 2008. Awareness activities in Bangladesh include dissemination of brochures, posters, and stickers on air pollution by the NIA as well as filmed songs on air pollution by popular singers and short plays using well-known actors. These are used on television in Bangladesh. These were show-cased at the inter-governmental meeting in Colombo in 2008 and created a lot of interest in the other countries. There is also a plan to disseminate the information on air pollution through National Stakeholder Meetings. Awareness activities in Sri Lanka include activities under Malé Declaration targeted on three levels of education and understanding for the general public, schools and university students and technical/science professionals.

7. Next Steps - Opportunities for the Malé Declaration

Overarching considerations

- Regional centres could play a key role but require funding.
- Malé Declaration activities have benefited from interactions with competent universities and relevant institutions which have regional, technical know-how on crops, health and corrosion studies. Monitoring and modelling could also benefit from being more closely linked with existing scientific expertise in South Asia, for example, the Atmospheric Brown Cloud (ABC) programme.
- Sharing information through the Malé Declaration can help countries achieve national priorities.

Opportunities

- Malé Declaration provides a basis for regional but differentiated science-based programmes on emission control and review of implementation. Reliable long-term monitoring is at the base of everything. The Secretariat plays a very important role for supporting countries' decision-making and for facilitating further progress.
- The Malé Declaration process is exclusively owned by the eight participating countries. This joint ownership is an obvious strength for optimal performance of emission inventory compilation, monitoring of deposition and concentrations, addressing transboundary issues, studies on effects of air pollution on human health and the environment, assessments and reviews, operation of technical centres and training events, stakeholder and inter-ministerial meetings and intergovernmental cooperation. Safeguarding and strengthening such ownership would facilitate funding of further implementation and programme delivery.
- This report demonstrates that all Malé Declaration countries would benefit from committing to efforts to tackle regional problems, as there is now sufficient evidence on the impacts and capacity to address them.
- The Malé Declaration provides a framework to promote integrated approach for air pollution issues at national and regional level in South Asia. Some Malé Declaration countries have initiated an integrated approach by prioritising action on air pollution and short-lived climate pollutants (SLCPs) such as black carbon and methane (a precursor of ground-level ozone). This good practice in region can be shared and the Malé Declaration is prime vehicle for doing this.
- The transboundary nature of air pollution in South Asia offers incentives for action and regional and international co-operation.

- The atmospheric brown cloud phenomenon and the black carbon problems in the Himalayas related to retreating glaciers, provide extra incentive and urgency for action.
- There is a need to address short-term problems (e.g. health and crops) and long-term problems like climate and sustainability.
- The Malé Declaration monitoring programme is important to protect and promote so it can provide the basis for action and the crucial task of the reviewing success of implementation.
- There is now a good basis for working towards a regional treaty on air pollution, or at least some type of international agreement covering the different sectors.

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