IMPACT ASSESSMENT OF GROWING ASIAN MEGACITY EMISSIONS

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1. INTRODUCTION

The urban environment is where an increasing share of the world's people live, where most of the energy is consumed, and where the impacts of the pollution are felt the most. While the effects of high pollution levels in Asia are centered in the urban areas, the impacts are not confined to the city boundaries. Polluted air has damaged human health, ecology and environment in a number of urban centers of the developing countries of Asia. Most of the air pollution is emitted by stationary sources like power plants and industrial estates. Pollution from the mobile sources (NO_x, volatile organic carbons (VOC) and particulates) has become a major contributor to increasing human health effects in the urban environments of Asia (OECD, 2000).

Rapid economic growth in Asia over several decades has attracted millions of rural residents to urban areas. Figure 1 presents gridded Asian population for 2000 along with Asian megacities (with population over 10 million) and major urban centers. Asia presently has ~1 billion (~35% of total population) urban dwellers, projected to grow at an average of 4% per year to ~3 billion by 2025 (~55% of the projected total population). Changing standards of living in these centers have fueled increased industrial and transportation sector activities, often associated with unchecked emissions from automobiles, domestic heating, and small-scale industries. Coal (besides bio-fuel (wood, cow dung, and field residue)) being the cheapest and most widely available source of energy, still remains the primary source of energy, and contributes significantly to sulfur

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Air Pollution Modeling and Its Application XV, Edited by
Borrego and Schayes, Kluwer Academic/Plenum Publishers, New York, 2002

and particulate concentrations often exceeding the WHO air quality guidelines. Increased use of biofuels, especially in the rural regions of the developing countries, pose severe human health concerns due to increased particulate pollution both indoors and outdoors. Every year, Asian urban centers prone to air pollution incur hundreds of millions of dollars in health and economic damages (OECD, 2000). Presently, the urban air pollution problems in Asia are continuing to increase and air pollutants originating from urban regions are now recognized as increasing sources of regional- and global-scale pollution (Streets et al., 1999).

This study is an effort to understand the nature of growing emissions from the urban centers of Asia, to characterize the impact of these emissions on trace gas species at urban and regional scale. And finally, to evaluate costs and benefits of implementing emission reduction techniques for sulfur, particulates and NO_x for Asian megacities.

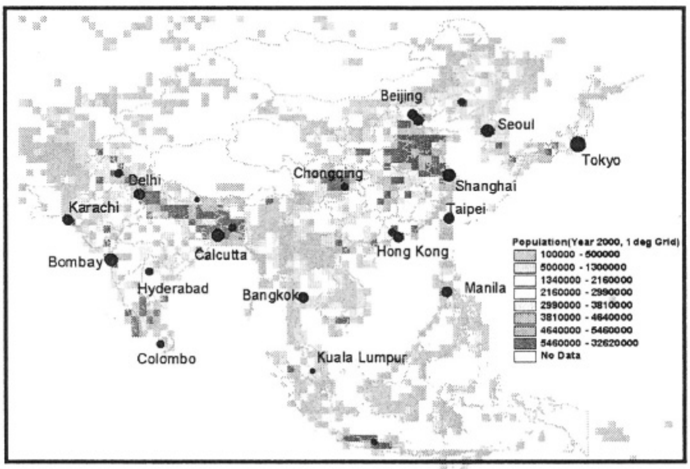

Figure 1. Asian Population in 2000 overlaid with Asian Megacities and urban centers (LandScan 2000[1])

2. MEGACITY EMISSIONS

Emissions of SO_2 and NO_x were estimated through the establishment of emission factors (emissions per unit of energy consumption) by energy source and by sector of energy use, as part of the RAINS-Asia project (Arndt et al., 1997 and van Aardenne et al., 1999). In the case of "business as usual" energy consumption, the projections show an increase of SO_2 and NO_x emissions in the Asian region in 2020 to 2-3 times the levels of 1990 (Foell et al., 1995 and van Aardenne et al., 1999). The fact that the megacities and urban centers in Asia cover less than 1% of the landcover and still produce 10-20% of trace gas emissions signifies their importance.

[1] LandScan 2000, Global Population at 30 Arc Second Grid, developed by Oak Ridge National Laboratory, United States Department of Defense, March 2001.

For 1990, at a 1° x 1° resolution, grid cells containing Karachi, Bombay, Calcutta, Bangkok, Singapore, Jakarta, Manila, Hong Kong, Beijing, Shanghai, Chongqing, Taipei, Seoul and Tokyo each had emissions in excess of 0.1 Tg SO_2 per year (Guttikunda et al., 2001a). Figure 2 presents growth in sulfur emissions for six of the megacities in Asia – Bangkok, Delhi, Jakarta, Seoul, Beijing and Shanghai. Not all the urban centers have had an increase in sulfur emissions in the recent years. Increased pollution awareness campaigns, stringent industrial and power sector pollution control regulations, use of low sulfur coal, implementation of desulfurization techniques and periodic monitoring resulted have in significant reductions of sulfur emissions in some countries. The megacities of East Asia have had a slower increase in emissions from year-to-year for 1990-1997 than any other region, with some cities even showing an average decrease of emissions. The megacities in Japan and Korea have shown an average decrease while the megacities in China had an average annual growth rate of 1.7% in sulfur emissions since 1990.

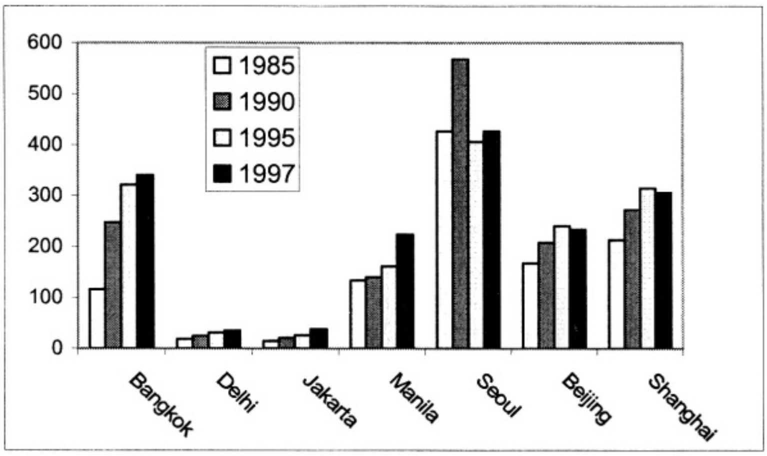

Figure 2. SO_2 Emissions from the Megacities of Asia, ktons/yr

NO_x Emissions has its sources in large industry such as chemical manufacturers, and combustion sources such as power plants burning fossil fuels; automobiles, trucks and buses; and off-road engines such as aircraft, locomotives, construction equipment and gasoline-powered lawn and garden equipment (van Aardenne et al., 1999). In the last decade, NO_x emissions have increased significantly in Asia due to increased mobile sources. Figure 3 presents NO_x emissions for 1990 and projected levels in 2020 for the same six megacities in Asia. In general, emissions are expected to increase 2-3 fold throughout Asia. Besides, NO_x, VOC emissions from industries and automobiles have portrayed an increasing trend, which plays an important role along with NO_x species in enhanced photochemical activity in urban environments. The transportation sector has emerged as a critical source of NO_x, VOC and particulate pollution in the urban centers of Asia. Figure 4 presents percentage contribution from the transportation sector to NO_x emissions in six cities. The contributions varied from as low as 10% for Beijing and Shanghai to as high as 80% for Bangkok and Jakarta in 1990. In 2020, percent contribution increased atleast 2% for each of the cities and more than tripled for Beijing and Shanghai. In Seoul, it is projected that there will be more stringent controls for NOx and VOC emissions from automobiles by 2020, reducing its contribution.

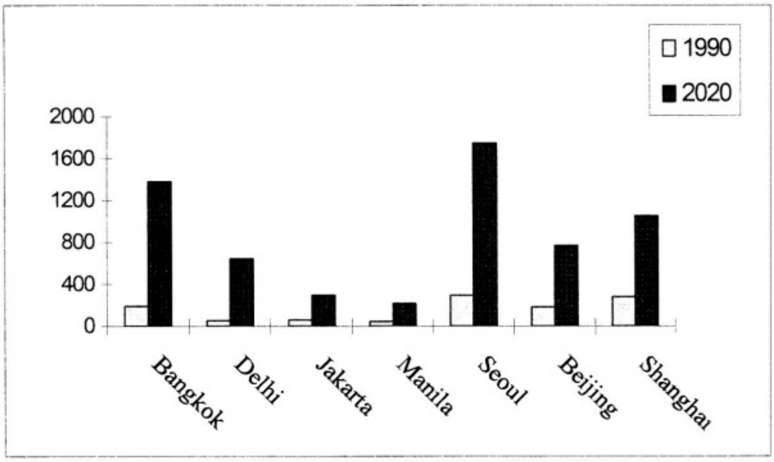

Figure 3. NO_2 Emissions from the Megacities of Asia, ktons/yr

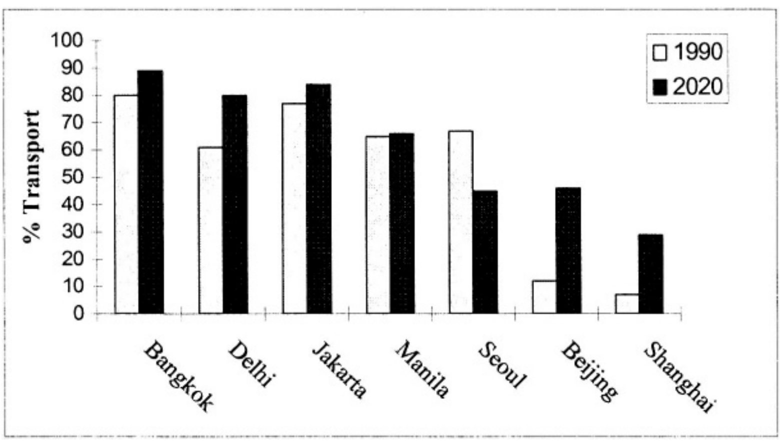

Figure 4. Percentage of NO_2 Emissions coming from the transportation sector in the Megacities of Asia

Though environmental controls are beginning to be implemented in Asian cities, they are insufficient to counteract the growth of emissions (Streets et al., 1999). For a decrease in emission to be realized, the rate of decrease in emissions per unit fuel must exceed the rate of increase in fuel use. However, costs of emission controls are high and the demand for energy is growing, and a balance between economic growth and pollution control is difficult to achieve in developing regions.

3. GCTM SIMULATIONS

The Global Chemistry Transport Model (GCTM) at Geophysical Fluid Dynamics Laboratory (GFDL), Princeton University, was applied to gain an improved understanding of the contribution of growing anthropogenic emissions from the Asian megacities and urban centers on global tropospheric chemistry. In the past, the GCTM was applied to study the nature and frequency of pollution transport from Asia across the Pacific Ocean and impact of Asian fossil fuel combustion on tropospheric chemistry (Yienger et al., 2000). For this study, 27 urban centers, represented in Figure 1 were included, which accounted for 17% of the total NO_x emissions in Asia in contrast to their <1% coverage of landcover. At a global scale, these 27 Asian cities accounted for ~7% of the global anthropogenic NO_x inventory totaling to ~1.54 Tg N/year in 1990. We have conducted simulations for the present and year 2020 emission levels compared to a reference run excluding the Asian megacity and urban center air pollution. Figure 5 presents the percentage contribution due to fossil fuel combustion in Asian urban centers to NO_x and CO levels at 550 mbar and 990mbar respectively. Under present case scenario, average contribution to NO_x levels varied from 4-10% across the Pacific Ocean in the springtime. Contribution to ground level CO concentrations was as high as 10% in the Southeast Asian region.

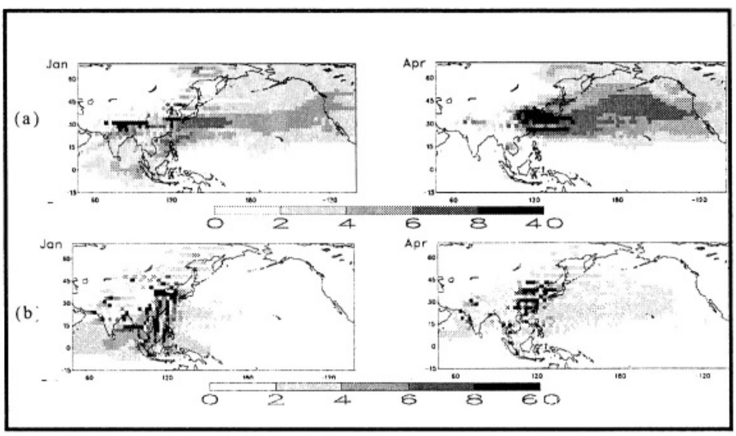

Figure 5. Percentage of contribution to (a) NOx levels at 550mbar (b) CO levels at 990mbar from the Megacities of Asia, present case.

Under a futuristic scenario, the model was run with tripled Asian megacity NO_x emissions and keeping the rest of the fossil fuel emissions constant. An average contribution of ~10% in CO levels is observed from the urban centers signifying the Asian megacity plumes reaching areas away from the source regions. Also, increased photochemical activity due to urban emissions is observed where ozone concentrations of upto 4 ppb were predicted over Indian and Pacific Ocean and Southeast Asia originating from the urban centers. A more detailed animation of GCTM results is available here http://www.cgrer.uiowa.edu/vis5d/index.html

4. INTEGRATED ASSESSMENT OF URBAN AIR QUALITY

Global and Regional scale long-transport models play a critical role in understanding the transport and chemical transformation of trace gas species and particulates. Long range transport models also play a key role in environmental management, in that they link emissions to concentrations, and thus are used to evaluate the impact of emerging energy policies and to analyze the environmental and health effects and the economic benefits of emission abatement options for reducing SO_2, NO_x, VOC and particulate matter emissions. The management of emissions in Asia megacities requires a better understanding on emission sources, distribution and their controls. For this study we developed a conceptual **I**ntegrated **A**ssessment **M**odeling **S**ystem (IAMS), for Asian megacities, which provides a methodology for identifying interactions between environmental drivers (pollutant concentrations and depositions) and endpoints like human health, environmental and structural damage (Guttikunda et al, 2001b).

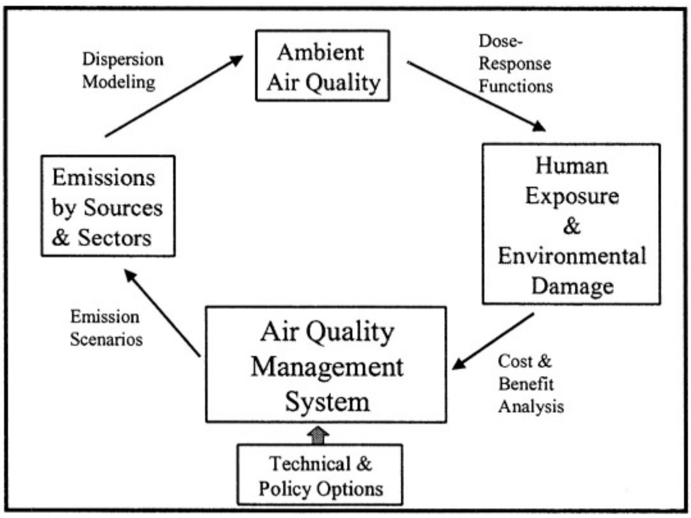

Figure 6. Integrated Assessment of Urban Air Quality

In continuing support of the integrated assessment modeling of air pollution in Asia, which started as part of the RAINS-Asia (**R**egional **A**ir pollution **IN**tegration and **S**imulation – **Asia**) project, the analysis of air quality management studies are extended to include particulates and megacities of Asian developing countries. Figure 6 presents an outline of the modeling system. IAMS has a similar structural framework as RAINS but focuses more on the urban air quality management. Model framework includes a grid-to-grid transfer matrix (generated using lagrangian puff transport model, ATMOS (Arndt, 1997)) for sulfur and particulate concentration and deposition, combined with health and environmental damage assessment and cost-benefit analysis. The framework can be adapted to any urban area of interest enabling a) dispersion modeling of sulfur and particulates b) quantifying costs and benefits of available control strategies c) assessing effects of possible change in energy end-use patterns, technology changes d) assessment of control options by economic sector e) analysis of pollutant levels in an annual or seasonal time frame. IAMS model was successfully applied to the City of Shanghai China.

Table 1. Summary of Pollution Control Scenarios and Cost-Benefit Analysis for the City of Shanghai, China.

2020 Scenario ==>	C1	C2
% Emission Reduction	Industrial	Power Sector
Sulfur	14	41
NOx	6	13
TSP	9	3
PM10	12	4
PM2.5	13	4

2020 Scenario ==>	C1	C2
Total # of Deaths Avoided	1771	2789
Total # of Chronic Bronchitis Cases Avoided	1106	1740
Total # of Hospital Visits Avoided	60752	95619
Total # of Emergency Hospital Visits Avoided	30603	48166
Total # of Hospital Admissions Avoided	27433	43177
Total Control Costs (US $ in millions)	94	395
Total Benefits Due to Human Impacts Avoided (in millions US $)	106 - 887	168 - 1, 396
Median	265	419
Health Benefit to Scenario Cost Ratio	1.1 - 9.4	0.4 - 3. 5

Two scenarios were evaluated for 2020 for the city of Shanghai, China. Industrial scenario (C1), assumes industrial use of coal is banned in Shanghai City by 2020, of which 75 percent is shut down. And of the remaining 25% coal use is relocated and replaced to the four neighboring counties, the replacement occurs in the future in the form of new industrial boilers erected in existing facilities to increase production capacity in the city and no new plant built, but only boilers. Power Scenario (C2), assumes all new power plants coming online in the period of 2010-2020 are state-of-the-art IGCC, in combination of low-sulfur coal and some limited FGD. For health benefit analysis, dose response functions for mortality and morbidity and willingness to pay statistics were collected from various studies conducted in China and else where. Table 1 presents summary of the control scenarios and cost benefit analysis of the scenarios (Guttikunda et al 2001b and Streets et al, 2001). Cost benefit analysis is conducted for $\mathbf{PM_{10}}$ concentrations only with sulfate concentrations from sulfur dispersion modeling added as a surrogate to secondary particulate concentrations.

5. CONCLUSIONS

Urban air pollution in Asia has worsened in the developing countries, a situation driven by population growth, industrialization, and increased vehicle use. With an estimated 3 billion (~55%) urban residents in Asia in 2025 in <5% of the Asia's land cover and human health effects as a primary measure urban environments are the first to react to any of the pollution control regulations. Modeling activities were conducted to understand and characterize the urban air pollution in Asia at local, regional and global scales. GFDL/GCTM simulations under two scenarios were conducted to establish the impact of growing NO_x emissions on regional photochemical activity where contributions of >10% for CO and NO_x at ground level were predicted. Given the growing importance of urban air quality management, we have applied a conceptual integrated assessment modeling system to conduct cost-health benefit analysis for various pollution control options in the city of Shanghai, China. IAMS was applied for PM_{10} ground level concentrations with sulfate concentrations as a surrogate for secondary particulates. In future, we would like to conduct integrated assessment including other secondary components like nitrates, and secondary organic aerosols. Further advancements in modeling activities like nested grid analysis, will help better understand and manage the urban air quality whose influence on regional and global air quality is growing more than ever.

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DISCUSSION

A. HANSEN — Although your integrated analysis shows promise, I would take issue with the health benefits associated with reductions in particulate sulfate, since epidemiological studies of associations between components of PM10 or PM2.5 and mobility and mortality show no increased risk associated with sulfate.

S. GUTTIKUNDA — I agree that mortality and morbidity show less increased association with sulfate concentrations alone, but chemical composition of PM2.5 and PM10 in Asian cities, especially in cities like Shanghai, Seoul have shown that the secondary particulate concentration in the form of sulfate and nitrate is significantly high which in turn prompts us to look into combinedimplications of controlling particulate, Sulfur and NOx emissions.