Country Report

Impact of growing urbanization and air pollution on the regional climate over India

India has witnessed an explosive growth of population (0.3 billion in the year 1950 to 1.04 billion in the year 2002) accompanied by uncontrolled urbanization over the last five decades (www.censusindia.net/, Fig. 1). The population growth has been mainly centered around cities due primarily to the large scale migration of rural population, accelerated by high population growth rates especially in Indo-Gangetic (IG) basin. The result is the IG basin is one of the largest and most densely populated regions of the world (Fig. 2).

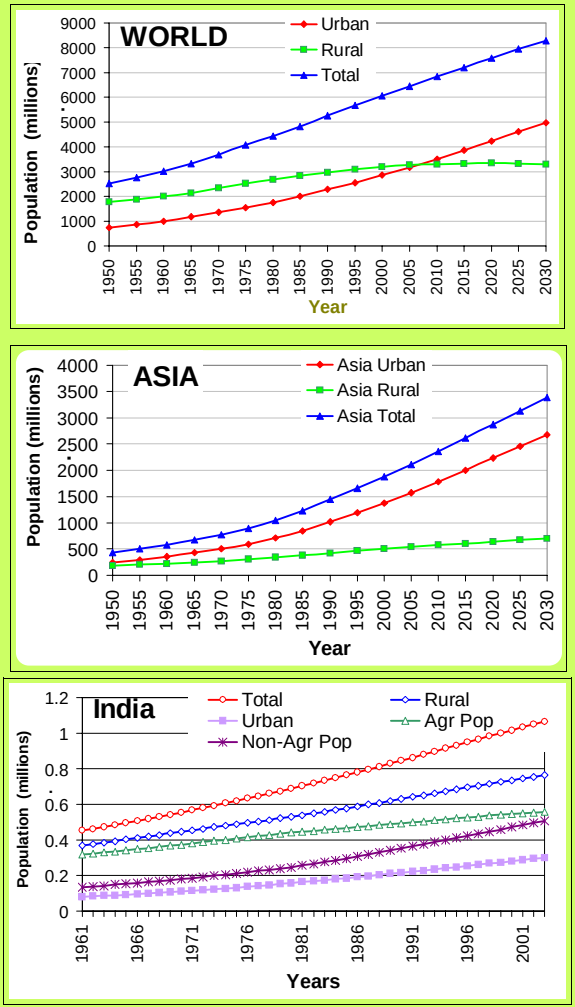


Figure 1. Urban and rural population growth (in millions) for the World (top), for Asia since 1950 (middle) and for India (bottom), including the Total, Rural, Urban, Agricultural population growth since 1961 (Agr Pop) and non-agricultural population (Non-agr Pop)).

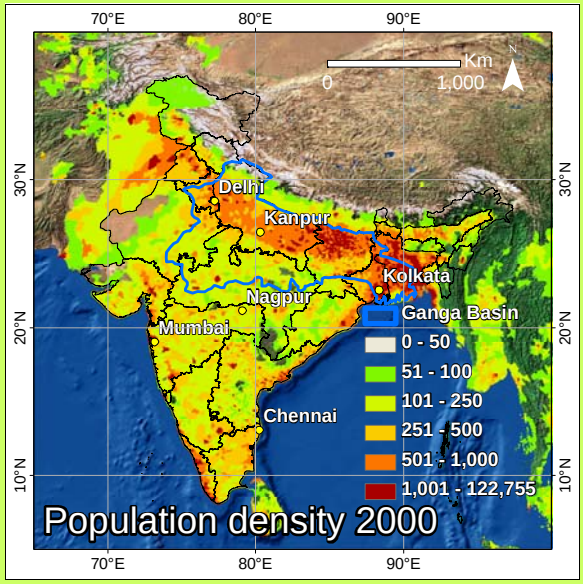


Figure 2. Population density (persons/km^2) over India (year 2000). In the northern Indian plains, the Ganga (IG) basin, have a very high population density.

Rapid industrialization and population growth especially in the last decade have adversely affected urban climate, air quality and caused imbalances in the regional climate at large. Impacts are increasingly visible on the hydrological cycle, agriculture, the energy budget of earth in the form of irregular rainfall distribution, and the monsoon resulting in an increase in the frequency of droughts and floods (Gadgil, 1995; Zhu and Houghton, 1996; Lal et al., 1996a,b; Ramanathan et al., 2001; Menon et al., 2002). Air quality has degraded to moderate to critical levels in major Indian cities with increases in the consumption of fossil fuel (coal and petroleum) especially in transportation sector, thermal power plants, smelters, industries etc. Satellite and ground based indicators of air pollution show disturbing trends that can explain visible changes in the environment. A brief discussion is presented here of the degradation in air quality in major cities, the source of the pollutants and their impact on the environment.

Country Report

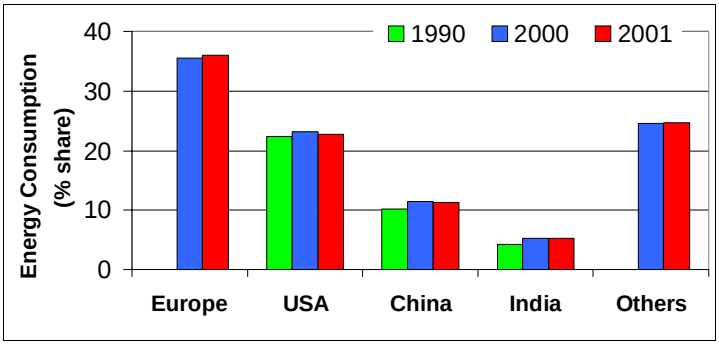
Industrialization, growing population and energy demand

Population growth has been much higher in the Asian region than globally (Fig. 1). The population density (people/km^2) in the year 2000 was 306.9. Rates of urban population growth are higher than those for the rural population primarily due to migration to the cities (Fig. 1). The average annual population growth rate (1980-2000) has been 1.9% (1.6% in the rural areas and 3% in the urban areas). In India, the urban:rural population was 0.181:0.818 (year 1961), 0.742:0.257 (year 1991) and 0.716:0.283 (year 2001). With the increasing population and industrialization, energy demand is increasing and India now stands next to USA, Europe and China in terms of total energy consumption (Fig. 3). Increase in energy needs, along with decreasing dependency on traditional sources of energy (like biomass) especially in the rural sector, has put additional pressure on non-renewable sources of energy like coal and petroleum. In the last decade (1990-2000, Fig. 3), biomass as a fraction of the energy source has declined by 9.9%, with a rise in coal (4.2%) and petroleum (4.2%) (pubs.wri.org).

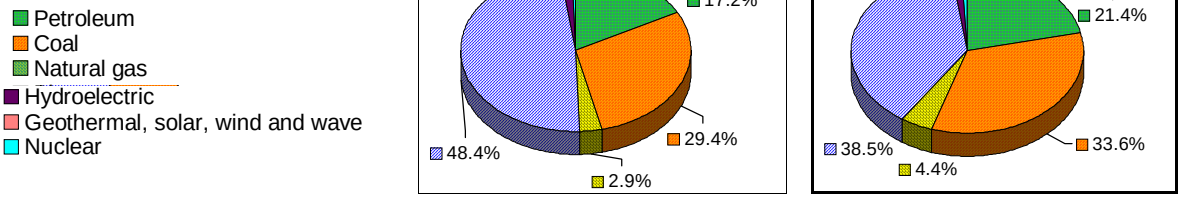
Industrialization has also helped to bring the green revolution to India. The agricultural output has increased, though total arable and permanent cropland is almost same since 1960. The agricultural output (crop yield) has risen since 1960 (total cereal production) with increases in the demand for fertilizers and pesticides (Fig. 4). The fertilizer industry is energy intensive and rising indigenous production implies greater pressure on existing sources of energy like coal, natural gas and petroleum (faostat.fao.org).

The energy consumption (petroleum products) has also increased tremendously in the transportation sector with increasing numbers of vehicles especially in major cities. 'Two wheelers' and cars account for more than 80 percent of the vehicular population in major cities (e.g. 90% in Kanpur and 95% in cities like Hyderabad and Bangalore). India has more than 33 cities with a population greater than 1 million (Fig. 5). The population growth trend of urban agglomerations with 750,000 inhabitants or more in 2000 is shown in Figure 5. In terms of the total population residing in each urban agglomeration since 1950, Delhi and Mumbai are the fastest growing cities of India. The vehicular population growth (in millions) since 1950 is shown in Figure 6. Mumbai is now the largest city in terms of total population, and Delhi is the largest city in terms of total registered motor vehicles (Figs. 5&6). Figure 6 shows the alarming rate of growth in vehicular traffic that is concentrated mainly in the major cites of India. Delhi which contains 1.4 percent of population, accounts for 7% of all motor vehicles in India. Emission of air pollutants from vehicles is one of the major causes for degrading air quality in cities.

Figure 3.
Percent share of energy consumption by major countries (or group) since 1990 (top row).



The percent share of major energy sources in India in 1990 and 2000 (lower row).



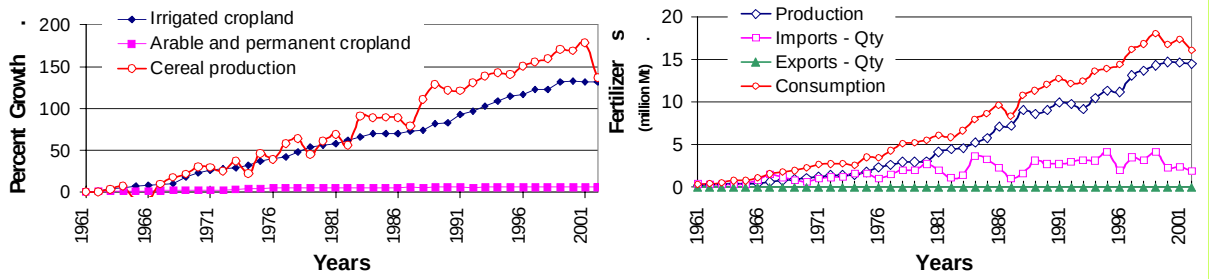


Figure 4. Increase of total cereal production since 1961 (left) is supported by corresponding increase in irrigated land and use of fertilizers (indigenous production by fertilizer industries) (right).

Emission scenario and its impact on air quality

Major greenhouse-related gases are carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), nitrogen oxide (NO_x), and sulfur dioxide (SO_2). Sulfur emissions and aerosols especially black carbon have been recognized as a crucial radiative forcing factors other than CO_2 (Kiehl and Briegleb, 1993; Menon et al., 2002). India ranks fifth in terms of Global Greenhouse Gas Emissions (506.04 MtC, million metric onnes of carbon equivalent) after United States, China, European Union, and Russian Federation. Per capita emission (Tons of C per person) in India is only 0.5 compared to 6.6 in USA. Kyoto Protocol signatories including India have agreed to limit and reduce their emissions of greenhouse gases between 2008 and 2012.

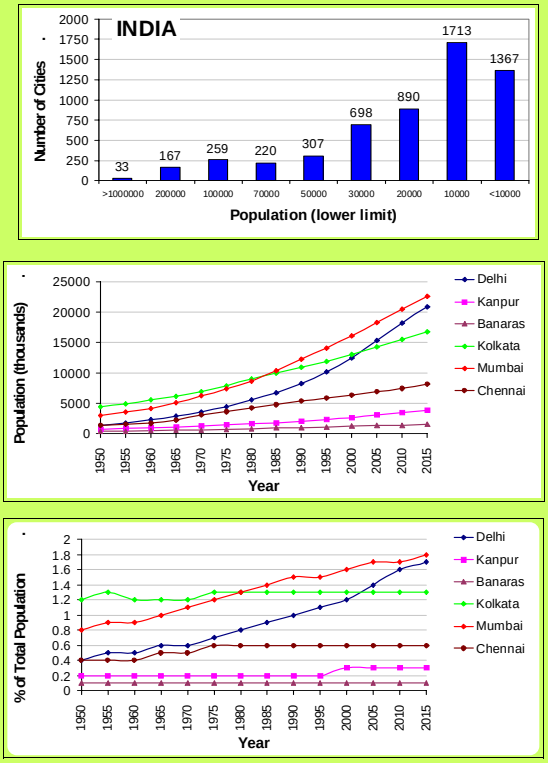
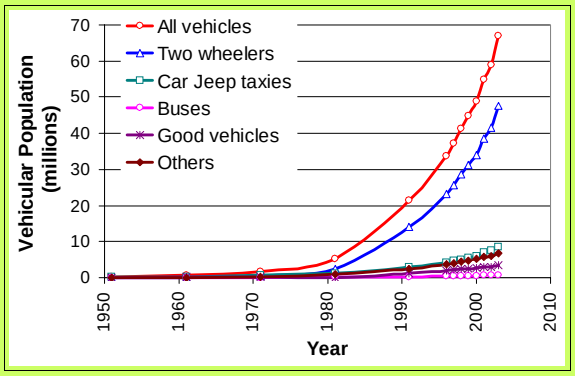


Figure 5. Population class and Number of cities (top), Population of urban agglomerations with 750,000 inhabitants or more in 2000 (middle). Percentage of the total population residing in each urban agglomeration (bottom).

The quality of air in cities is a major environmental concern. It indirectly affects climatic conditions and directly affects the health of the community. Major air pollutants are gaseous (SO_X, NO_X), lead, CO, ozone, respirable suspended particulate matter (RSPM) and aerosols. The highest concentrations of air pollutants are found in the urban areas (Fig. 7, NO_2, SO_2, RSPM) due to congestion of traffic, poor quality of fuel, inefficient engines and bad maintenance of motor vehicles (Central Pollution Control Board, CPCB). Recently, the IG basin has been found to have high aerosol optical depth (>0.4) throughout the year based on ground (Aerosol Robotic Network, AERONET) and satellite data (Polarization and Directionality of the Earth's Reflectances (POLDER), Total Ozone Mapping Spectrometer (TOMS), Moderate Resolution Imaging Spectroradiometer (MODIS), Multiangle Imaging Spectro-Radiometer (MISR)) (Goloub et al., 2001; Massie et al., 2004; Singh et al., 2004; Di Girolamo et al., 2005; Prasad et al., 2004, 2005; Ramanathan and Ramana, 2005) (Figs. 9, 10). A statistically significant increase in aerosols, up to 10.6 ± 4.9% per decade, is calculated for the India region (Massie et al., 2004) based on TOMS aerosol record (1979-2000). The major cause of high aerosol optical depth (AOD) in the IG basin, other than major emission sources (transport, power plants, industrial sector, biomass burning, pre-monsoon dust storms), relates to its unique low topography flanked by the towering Himalayas in the north, compounded with favorable meteorology and wind fields. Sulfur dioxide, nitrogen dioxide and ozone cause a decrease in crop yield,



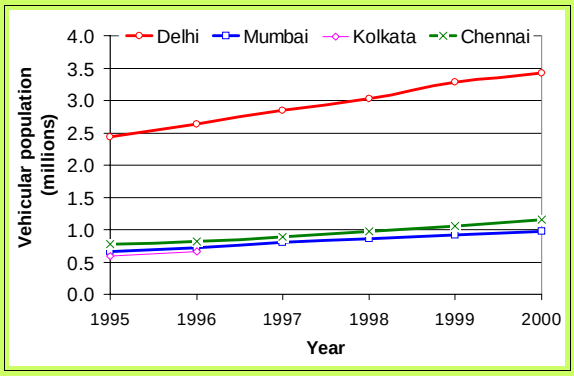
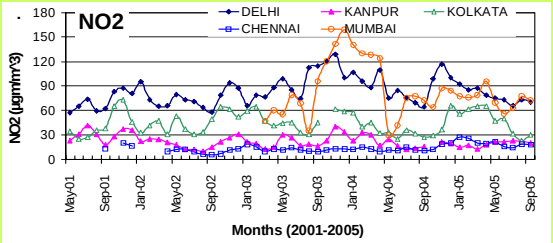
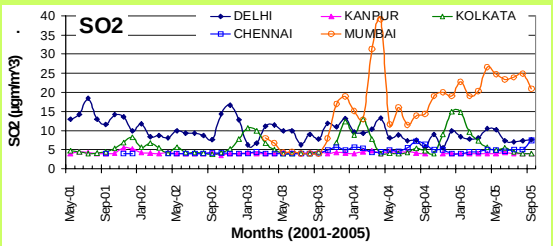


Figure 6. Vehicular population growth (in millions) since 1950 (left) and Registered number of vehicles (in millions) in major cities (right)

acidification of lakes, damage to human-made materials etc. For example, SO_X and NO_X combine with water vapor present in the air to form weak nitric and sulfuric acids to produce acid rain which affects building and monuments (for example, Taj Mahal, Agra). Also, the unique meteorology of India (wind pattern) facilitates transport of pollution far away from the source, causing acidification of soil, lakes, pond etc. thereby damaging





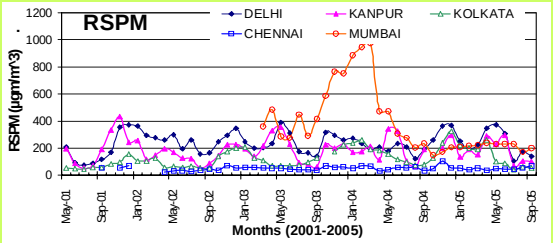


Figure 7. Monthly variation of near surface concentration of air pollutants (NO_2, SO_2 and RSPM) for the major cities of India (CPCB, 2001-2005).

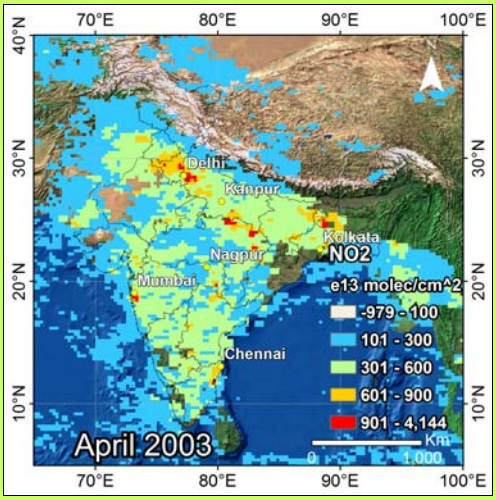


Figure 8. Spatial distribution of NO_2 measured by Sciamachy during January 2004.

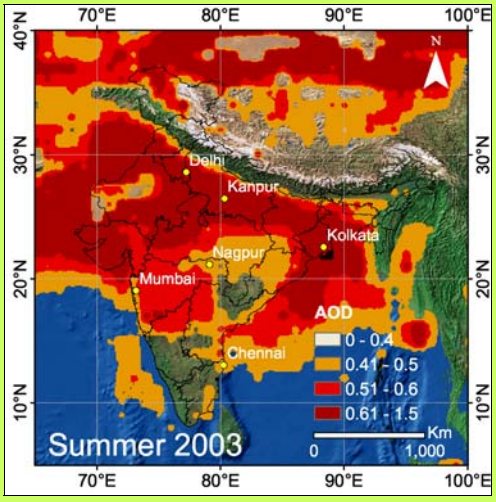
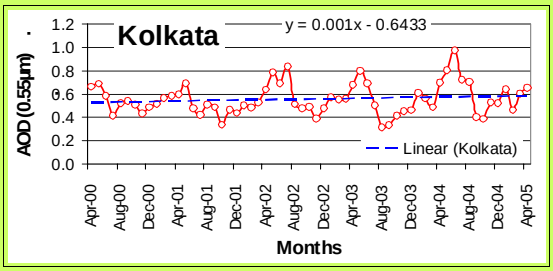
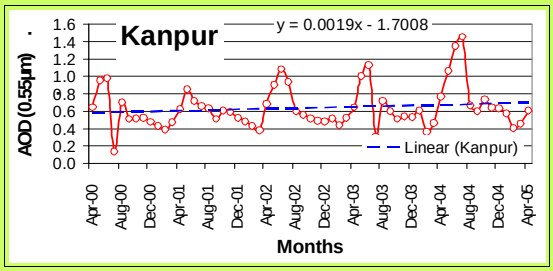
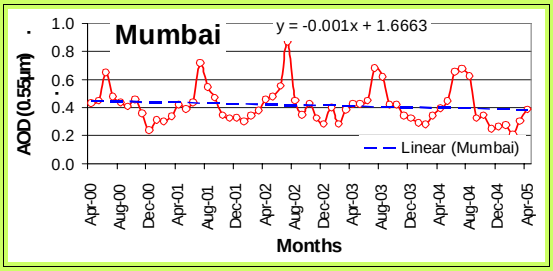
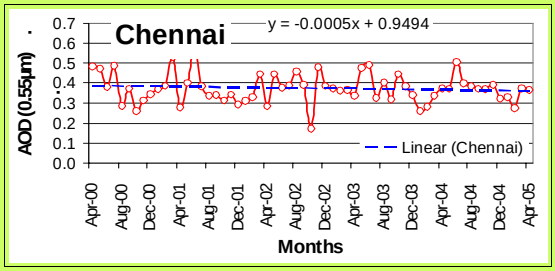


Figure 9. Spatial distribution of MODIS TERRA aerosol optical depth (AOD) over India during the summer (mean of April, May and June months) season.









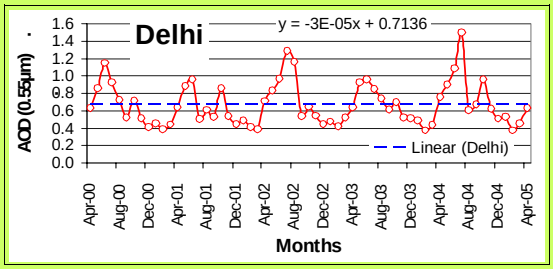


Figure 10. Monthly mean MODIS aerosol optical depth (AOD) at 0.55µm over major cities (2001-2005).

the fisheries and affecting animal and human heath. Excess of Nitrogen Dioxide near the costal environment causes algae blooms which destabilizes marine ecosystem (fisheries, coral reef and sea organisms).

Recent Climate Trends

Changes in hydrological cycle: Increasing air pollution and climatic change in the region is having an impact on the monsoon circulation (severe drought during 2002 and 2004) and increases in the magnitude and frequency of extreme events (for instance, the extreme rainfall event of July 26, 2005 over Mumbai, Prasad and Singh, 2005) etc. On average, annual flood waters cover ~7.7 million ha and ~3.1 million ha in India and Bangladesh, respectively (GOI, 1992; Mirza et al., 2005), primarily due to riverine and flash floods during the monsoon season. Water resources, agriculture, forestry, glaciers, ecosystems and biodiversity are under stress due to rapid changes in climate associated with a phenomenal rise in the use of fossil fuel (coal and petroleum) with increasing industrialization.

Changes in Temperature and Precipitation: Mean surface temperatures have increased by 0.3-0.8° C over the Tropical Asian region in the last 100 years. The southwest monsoon in India has shown changes in the period 1961-1990 compared to 1901-1930 or 1931-1960. However, no consistent longer-term trend in precipitation has been found. GCM models (Whetherald and Manabe, 1986; Whetton et al., 1993; Murphy and Mitchell, 1995; Mirza, 1997) predict large increases in river discharge (as high as 42% and 13% for Ganga and Brahmaputra river, respectively) due to rises in global mean temperature by 2-6°C associated with rising air pollution and emission of greenhouse gases. Lal et al. (1995) have suggested a future decline in surface runoff throughout the region after taking into account the combined effects of GHGs and aerosols. The Ganga river has a very high ratio of monsoon-to-dry-season runoff (nearly 6:1). Any large deviation as predicted by GCM models will adversely affect agriculture, navigation, fisheries, industrial and domestic water supply in the densely populated IG basin (Divya and Mehrotra, 1995; Mirza and Dixit, 1997).

Atmospheric Brown Cloud over the IG basin

The annual tropical weather in the Ganga plain further contributes to the enhancement of the anthropogenic pollution during winter season, due to intense haze and fog, forming inversion layers in

the upper boundary layer, trapping anthropogenic gaseous emission and aerosols. In the summer season, frequent dust storms bring large amounts of dust aerosol particles (size, radius >1µm), which act as suitable condensation nuclei for gas to particle reactions (Singh et al., 2004). Vehicular and Industrial emissions play an important role in Brown cloud formation. Brown cloud is a haze of smoke, brownish in color, three-kilometers thick seen over the Tropical Indian Ocean of south, southeast and east-Asia (Ramanathan and Ramana, 2003; Ramanathan and Crutzen, 2003). The haze consists of organic carbon, sulfates, nitrates, fly ash and many other harmful chemicals. Through both fossil fuel combustion and biomass burning, cites contribute a significantly large ratio to this brown cloud formation. Brown cloud, by scattering and absorbing solar radiation, reduces up to 10% of solar energy over oceans and 10-20% over land, thereby cooling land and ocean and heating the atmosphere. This cut in radiance over land and heating of atmosphere causes spatial gradients of atmospheric temperatures thereby altering the monsoon precipitation pattern. This effect was seen in regional monsoon rainfall over India, due to which N-E India Nepal and Bangladesh received intense rain and flooding whereas precipitation was reduced over N-W India and Pakistan.

Conclusion

The quality of air is affecting the health of communities especially in cities and also climatic conditions around us. Rising anthropogenic air pollution is a direct threat to our environment and is accelerated by growing population with increasing dependency on coal and petroleum as energy source. The impact of pollutants on climate such as carbon dioxide, sulfur dioxide, aerosols, and black carbon is increasingly visible as changes in hydrological cycle, temperature, precipitation etc. Adoption of cleaner sources of energy like natural gas, nuclear, wind, geothermal etc and new technology can help to reduce growing anthropogenic pollution.

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IAUC NEWSLETTER

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President's Column

IAUC Luke Howard Award: I am very pleased to announce that the IAUC Awards Committee have selected **Professor Ernesto Jáuregui** of the National University of Mexico (UNAM), Mexico City as this year's recipient of the IAUC's Luke Howard Award (see further details p21). This award honors an individual who has made outstanding contributions to the field of urban climatology in a combination of research, teaching, and/or service to the international community of urban climatologists. Clearly, Ernesto has made profound contributions in each of these realms. His own work in Mexico City, and with the WMO, have served to enhance understanding and focus attention on urban climates in tropical cities. Please join me in congratulating him on this highly deserved recognition. The award will be presented at the ICUC-6 meeting in Göteborg, Sweden, 2006. I would like to thank the Awards committee for all of their work and particularly those who submitted and wrote in support of nominations.

New IAUC Awards created: I am also very pleased to announce two new IAUC Awards. First, the **Japan Prize** ($1000 US) to be awarded to up to three researchers from developing countries who are judged to have given the best papers at an ICUC conference. Second, **The William P. Lowry Memorial Awards** also to be awarded in conjunction with ICUC meetings: *The William P. Lowry Graduate Student Prize* ($200) for the graduate student author/presenter of the best oral presentation (or poster) in urban biometeorology/bioclimatology; *The William P. Lowry Methodology Prize* ($200) to the author/presenter of a paper (or poster) that incorporates the best conceptual or experimental methodology; and *The William P. Lowry African Student Travel Award* ($300) to help defray travel expense to the ICUC meetings for a graduate student traveling from the continent of Africa. More details on all of these awards, and procedures and criteria to be followed, can be found on the IAUC Awards Policy Document (follow the links from Committees; Awards Committees). Further details will be sent out via the UrbClim email list. I would like to thank all those who were involved in the creation and approval of these Awards.

ICUC6: An excellent set of submissions have been received for the ICUC6 conference; over 345 abstracts were submitted from 43 countries. Currently, the IAUC Board is putting together the scientific program. I want to thank Prof Sven Lindqvist and Maria Lindqvist, along with all members of the Local Organizing Committee at Göteborg University, for creating and managing such a smooth submission process for the abstracts. We hope to be contacting authors in about a month with notification of the acceptance of papers or posters and with details of the conference program. At that stage information will also be distributed on pre-prints.

Changes: A number of changes are occurring at the moment for the IAUC. First, the location of the urban climate **email list** moved recently. From now on you should email messages that you want distributed to: met-urbclim@lists.reading.ac.uk. I want to thank *Janet Barlow* and her group at University of Reading for all their help in this transition. *John Arnfield* and The Ohio State University deserve special recognition and thanks for hosting the email list for the last few years. ***Website****:* In the very near future the IAUC website location address will change. If you use www.urban-climate.org then your links will remain the same. Otherwise you will need to update the address you use to www.urban-climate.org. *James Voogt* remains the Webmaster. I would like to thank Indiana University for hosting the site. King's College London will take up this role. Finally, I am moving! Effective January 1, 2006, I will take up a position at King's College London. Should you wish to contact me, my new email is Sue.Grimmond@kcl.ac.uk. Address: Environmental Monitoring and Modelling Group, Department of Geography, King's College London, The Strand, London WC2R 2LS, United Kingdom; phone 44 20 7848 2275, fax 44 20 7848 2287, www.kcl.ac.uk/ip/suegrimmond/.

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