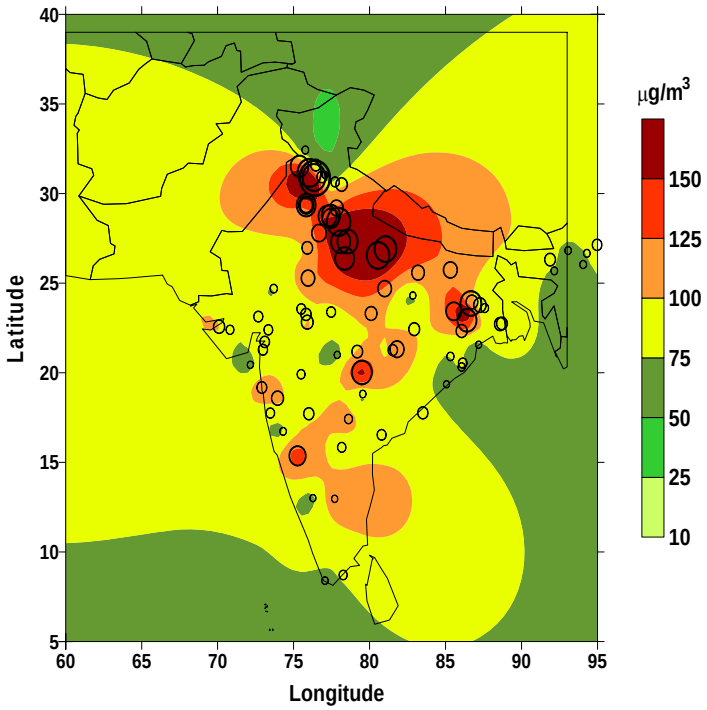
Simple Interactive Models for Better Air Quality

Particulate Matter (PM) Pollution in India in 2007

Dr. Sarath Guttikunda

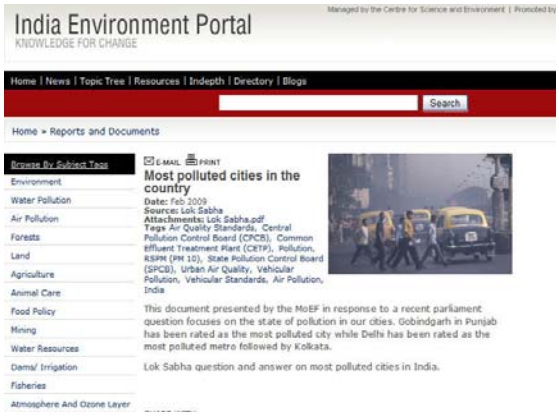
November, 2009



SIM-air Working Paper Series: 27-2009

Particulate Matter (PM) Pollution in India in 2007

This paper presents a review of Particulate (PM) pollution in India based on monitoring data published by the Central Pollution Control Board (CPCB) for 2007 and presented by the Ministry of Environment and Forests (MoEF) of Government of India to the Lok Sabha Parliament in February 2009[1].



PM Pollution and Standards

PM is a growing environmental problem in the developed and developing countries of the world[2]. Among the many pollutants, the impacts of PM pollution on human health and ecology are the largest and its impacts in the urban and rural

[1] The document is available on "India Environment Portal" (pictured above) titled "Most Polluted Cities in the Country". The report also discusses the PM pollution in year 2007.
Details @ http://www.indiaenvironmentportal.org.in/content/most-polluted-cities-country

[2] "Urbanization: 95% Of The World's Population Lives On 10% Of The Land", Science Daily (2008)
@ http://www.sciencedaily.com/releases/2008/12/081217192745.htm
"Urban Air Quality Management Strategy in Asia – Guidebook", The World Bank (1997)
@ http://go.worldbank.org/CS76F4GWD0
"EMEP/EEA air pollutant emission inventory guidebook", European Environment Agency (2009)
@ http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009
"Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)", IIASA, Austria (2009)
@ http://gains.iiasa.ac.at
"Megacities and atmospheric pollution" (2004) J. Air Waste Management Assoc. 54(6):644-680
"North American Research Strategy for Tropospheric Ozone (NARSTO)" (2009)
@ http://www.narsto.org/
"Cost of Pollution in China" (2007), published by the World Bank, Washington DC, USA
@ http://go.worldbank.org/FFCJVBTP40
"Air pollution, greenhouse gases and climate change", Ramanathan, et al., 2009, Atmospheric Environment
@ http://dx.doi.org/10.1016/j.atmosenv.2008.09.063
"Clear Sky Visibility Over Land Has Decreased Globally, Indicative Of Increased Particulate Matter"
@ http://www.sciencedaily.com/releases/2009/03/090312140850.htm
"Regional atmospheric pollution and transboundary air quality management" (2005)
@ http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.energy.30.050504.144138
"UN reports pollution threat in Asia" (2008)
@ http://www.nytimes.com/2008/11/14/world/14cloud.html
"Air pollution and health in rapidly developing countries", Published by Earthscan
@ http://www.earthscan.co.uk/?tabid=994
"Urban Air Pollution in Asian Cities: Status Challenge and Management", Published by SEI
@ http://www.sei.se/publications.html?task=view&catid=1&id=698
"Managing air quality in a rapidly developing China", Fang et al., 2009, Atmospheric Environment
@ http://dx.doi.org/10.1016/j.atmosenv.2008.09.064
"Atmospheric Chemistry and Physics" by Sienfeld and Phadnis
@ http://www.amazon.com/Atmospheric-Chemistry-Physics-Pollution-Climate/dp/0471178160

(focusing on indoor air pollution) areas is studied and documented the most[3]. Since, the absolute PM is a combination of contributions from many pollutants – primary emissions and secondary contribution from sulfur dioxide and nitrogen oxides emissions, the urban air pollution strategies have evolved around this pollutant[4].

Among the size fractions of PM pollution, the PM_{10} (also referred to as "coarse") with an aerodynamic diameter less than 10 micron meter is the harmful fraction and also commonly measured size fraction. The health studies suggest that the $PM_{2.5}$ (also referred to as "fine") with an aerodynamic diameter of 2.5 micron meter is more harmful. At present, only the developed countries have health and alert standards for $PM_{2.5}$. **Figure 1** presents a summary of the PM pollution standards across the world. The World Health Organization (WHO) proposes three interim targets (IT) and a global standard of 20 $\mu g/m^3$ for annual PM_{10} concentrations. Nepal, Japan, and Indonesia have only 24 hr (daily) limits for PM_{10}. Though $PM_{2.5}$ is now considered more critical for health impacts, only a few countries have adopted a standard. The US EPA maintains an annual standard for $PM_{2.5}$ at 15 $\mu g/m^3$.

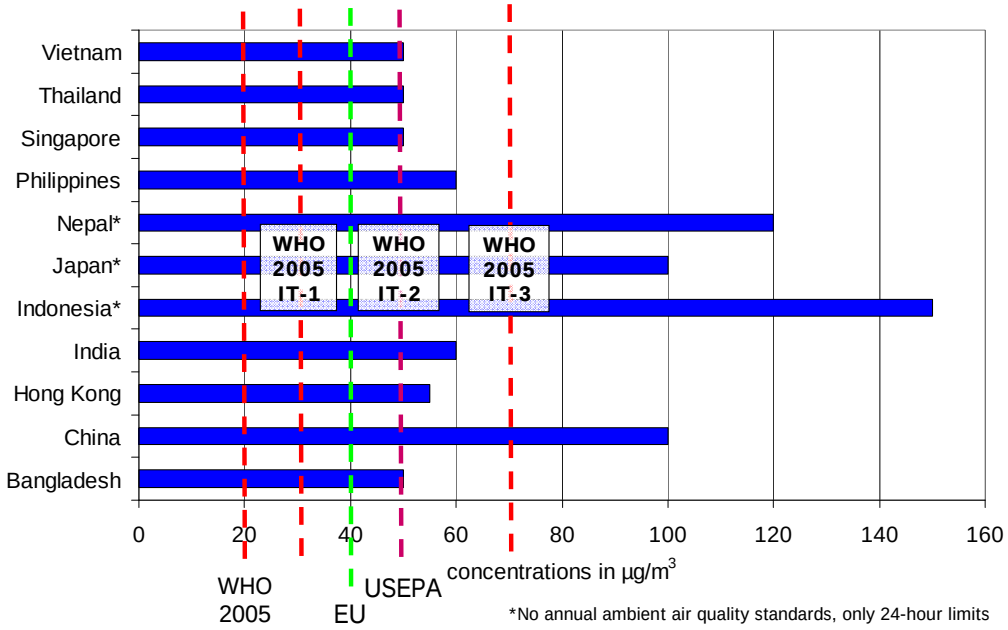


Figure 1: Ambient PM_{10} standards in Asian Countries[5]

[3] "Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review", Health Effects Institute, USA @ http://pubs.healtheffects.org/view.php?id=3
"PAPA – Public Health and Air Pollution in Asia", Clean Air Initiative for Asian Cities @ http://www.cleanairnet.org/caiasia/1412/article-48844.html
"Methodology for Estimating Premature Deaths Associated with Long-term Exposure to Fine Airborne Particulate Matter in California", California Air Resources Board (2008) @ http://www.arb.ca.gov/research/health/pm-mort/pm-mort.htm
The first coordinated Asian multi city study of air pollution and health (2008), published in the *Journal of Environmental Health Perspectives (EHP)* and conducted by the Health Effects Institute @ http://www.ehponline.org/docs/2008/116-9/toc.html
[4] "What is PM?" SIM-air working paper series No. 10 @ http://urbanemissions.info/simair/simseries.html
[5] Clean Air Initiative for Asian Cities @ http://www.cleanairnet.org/caiasia/1412/article-71311.html

In India, the standards were first introduced under the clean air act in 1980 and revised twice in 1986 and 1994, based on different land-use categories i.e. industrial, residential, and sensitive areas. The standards are revised in November, 2009, which abolished the distinction between industrial, residential, and sensitive areas, and also added newer pollutants to the list, such as fine PM and additional carcinogenic volatile organic compounds[6].

PM_{10} Monitoring in Urban India in 2007

The CPCB operates, in collaboration with the State Pollution Control Boards (SPCBs), 347 monitoring stations over 128 cities across the country. **Figure 2** presents an overview of the monitoring stations in India. The network presented includes stations neither utilized by the independent research groups, including academia, nor the routine monitoring conducted by various industrial units for environmental clearances. The pollution control boards also operate 48 continuous monitoring stations in 16 cities[7].

In this paper, the analysis is presented using PM_{10} measurements only. **Table 1** presents the city average annual PM_{10} measurements from 85 cities. Only the cities exceeding the national standard of 60 $\mu g/m^3$ are presented.

Figure 2: National ambient monitoring stations in India

This implies that out of 128 cities, **on average 66% (85 cities) exceeded the national standards in 2007**. Among the metro stations, Delhi and Noida (part of the National Capital Region) ranks the most polluted at 160 $\mu g/m^3$ and Kanpur ranks the most polluted among the growing secondary cities at 193 $\mu g/m^3$. On top of the list are Gobindgarh and Ludhiana (both from the Punjab state) at 250 $\mu g/m^3$ and 200 $\mu g/m^3$ respectively. It is important to note that the mix of pollution is these cities range from transported in Kanpur to industrial in Ludhiana to a mix of sources in Delhi and Noida.

[6] Central Pollution Control Board, New Delhi, India
@ http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

[7] Monitoring data from continuous monitoring sensors at ITO station in Delhi was utilized to study the photochemistry of the air pollution. The diurnal and seasonal variations, impacts of the pollution source mix, and a review of the photochemistry using the monitoring data is presented SIM-air working paper No.25
@ http://urbanemissions.info/simair/simseries.html

Although other pollutants are also measured at these stations, the data is available for PM_{10} only. Also, given the health implications and the source mix, PM_{10} is considered vital for regulatory and policy discussions.

Table 1: National ambient annual averages of PM_{10} in 2007 in India[8]

State	City	PM_{10}	State	City	PM_{10}
Andhra Pradesh	Visakhapatnam	95	Maharashtra	Chandrapur	173
Andhra Pradesh	Vijayawada	85	Maharashtra	Pune	109
Andhra Pradesh	Kurnool	80	Maharashtra	Nagpur	99
Andhra Pradesh	Hyderabad	77	Maharashtra	Solapur	95
Andhra Pradesh	Ramagundam	65	Maharashtra	Mumbai	92
Assam	Guwahati	99	Maharashtra	Lote	82
Assam	Sibasagar	90	Maharashtra	Aurangabad	77
Assam	Golaghat	67	Maharashtra	Kolhapur	66
Assam	Tezpur	66	Maharashtra	Amravati	63
Bihar	Patna	123	Meghalaya	Shilong	67
Chandigarh	Chandigarh	93	Nagaland	Dimapur	68
Chattisgarh	Raipur	125	Orissa	Rourkela	101
Chattisgarh	Korba	100	Orissa	Cuttack	82
Chattisgarh	Bhilai	88	Orissa	Angul	71
Delhi	Delhi	159	Orissa	Bhubaneshwar	71
Gujarat	Jamnagar	103	Orissa	Berhampur	62
Gujarat	Ankleshwar	90	Orissa	Balasore	62
Gujarat	Surat	87	Punjab	Gobindgarh	252
Gujarat	Ahmedabad	86	Punjab	Ludhiana	201
Gujarat	Vadodara	83	Punjab	Khanna	196
Gujarat	Rajkot	76	Punjab	Jalandhar	157
Gujarat	Vapi	63	Himachal Pradesh	Naya Nangal	94
Haryana	Faridabad	146	Rajasthan	Jodhpur	132
Haryana	Hissar	114	Rajasthan	Alwar	130
Himachal Pradesh	Paonta Sahib	81	Rajasthan	Kota	121
Himachal Pradesh	Damtal	68	Rajasthan	Jaipur	98
Himachal Pradesh	Parwanoo	62	Rajasthan	Udaipur	72
Jharkhand	Jharia	180	Tamil Nadu	Tuticorin	78
Jharkhand	Jamshedpur	166	Uttar Pradesh	Khurja	201
Jharkhand	Ranchi	136	Uttar Pradesh	Kanpur	193
Jharkhand	Dhanbad	107	Uttar Pradesh	Lucknow	187
Karnataka	Hubli-Dharwad	145	Uttar Pradesh	Firozabad	175
Karnataka	Bangalore	63	Uttar Pradesh	Agra	167
Karnataka	Hassan	62	Uttar Pradesh	Jhansi	165
Kerala	Thiruvananthapuram	65	Uttar Pradesh	Noida	162
Madhya Pradesh	Gwalior	166	Uttar Pradesh	Meerut	120
Madhya Pradesh	Satna	122	Uttar Pradesh	Varnasi	114
Madhya Pradesh	Indore	108	Uttrakhand	Dehradun	105
Madhya Pradesh	Jabalpur	107	West Bengal	Asansol	112
Madhya Pradesh	Ujjain	96	West Bengal	Howrah	103
Madhya Pradesh	Bhopal	84	West Bengal	Kolkata	99
Madhya Pradesh	Nagda	84	West Bengal	Durgapur	74
Madhya Pradesh	Singrauli	63			

[8] The document is available on "India Environment Portal" (pictured above) titled "Most Polluted Cities in the Country". The table includes only cities above the annual standard of 60 $\mu g/m^3$
Details @ http://www.indiaenvironmentportal.org.in/content/most-polluted-cities-country

Mapping PM_{10} Pollution in India

While the measurements provide an insight for air pollution in each of the cities, the story is more interesting when the same are mapped over the region. **Figure 3** presents a map of interpolated PM_{10} concentrations across the nation. The circles are scaled to indicate measured annual averages of PM_{10} in $\mu g/m^3$ from **Table 1**.

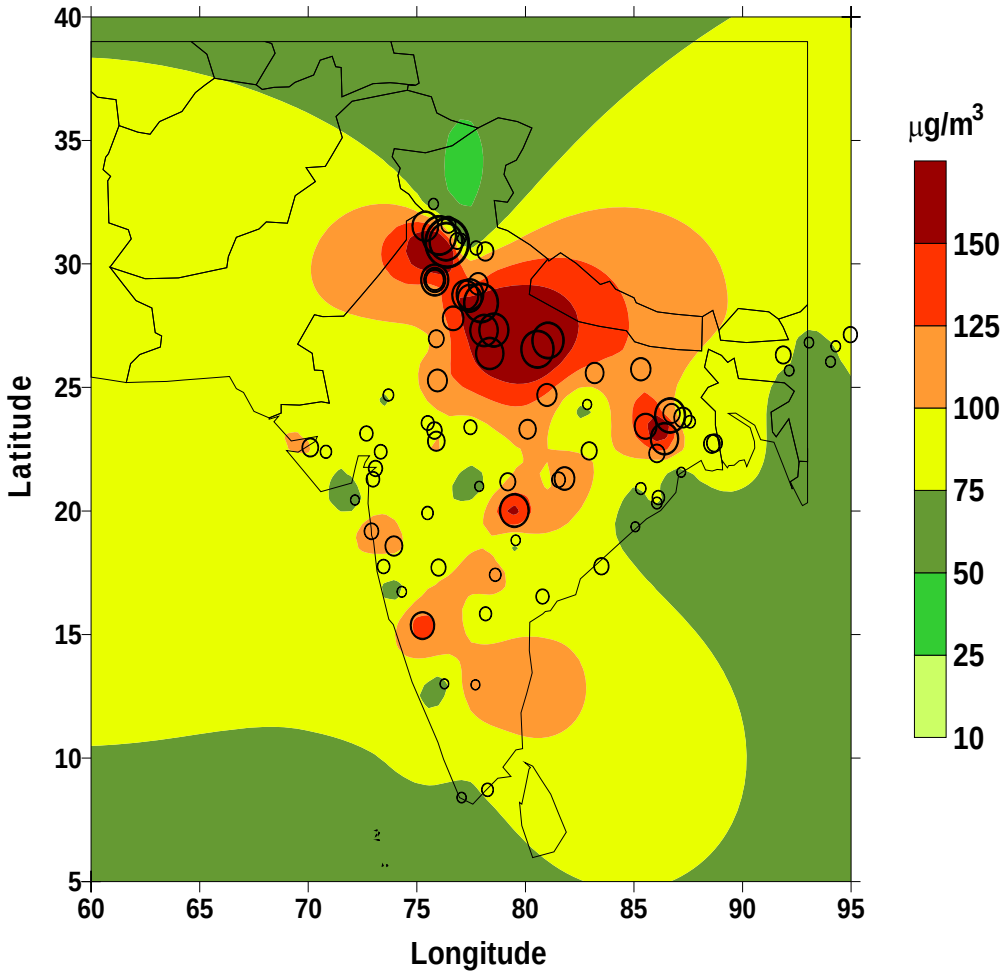


Figure 3: Map of Interpolated PM_{10} concentrations in India in 2007

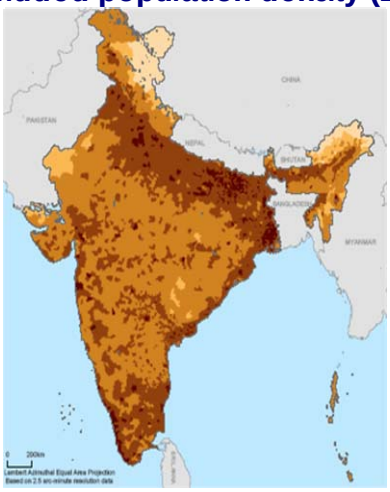
The interpolated contours in **Figure 3** are calculated using the Kriging method (in Surfer - Golden Software) at 0.5° x 0.5 ° resolution.

It is important to note that this is an interpolated map created using only 85 measurement points spread across the nation and NOT a representation of modeled air pollution. While there are limitations to this method, the results present an overview of the mix of local pollution and possible dispersion of pollution between the cities. The mapping of pollution via this methodology is more reliable with more measurement points spread across the country.

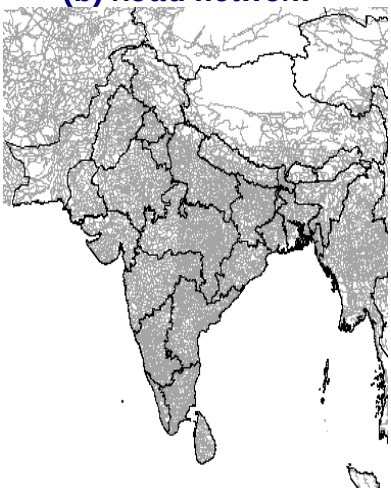
Spatial Nexus between Pollution & Energy Consumption

While **Figure 3** presents a possible spatial spread of the PM_{10} pollution based on the monitoring data, this is best interpreted using the energy consumption patterns. **Figure 4** presents one such proxy – population density. The gridded population density presents visually a close fit to where people live, which is also an indication of the highest consumption patterns – domestically, energy is consumed the most where people live and very like to experience the pollution levels.

(a) Gridded population density (2005)[9]



(b) Road network[10]



(c) Large and medium power plants[11]

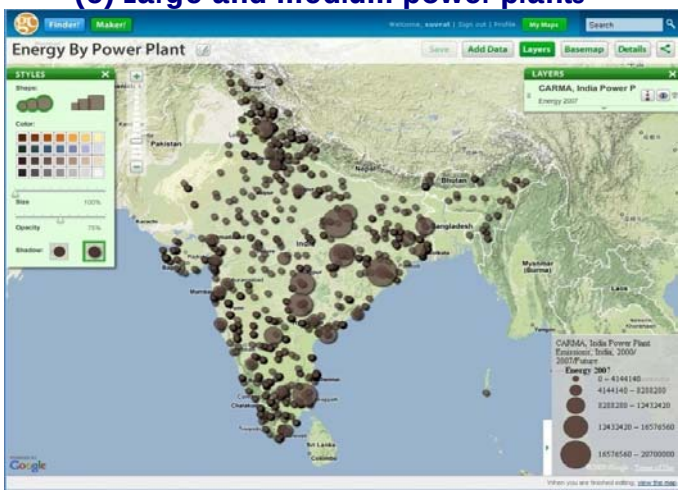


Figure 4: Spatial distribution of the population and energy generation in India

[9] Gridded Population of the World (GPW) by SEDAC @ http://sedac.ciesin.columbia.edu/gpw/global.jsp?file=gpwv3&data=pdens&type=ascii&resolut=25&year=00

[10] From Prof. Jung-hun Woo, Korea. Email: woojh21@gmail.com

[11] Carbon Monitoring for Action (CARMA) by CGD, Washington DC, USA @ http://carma.org/ and mapped using geocommons by Dr. Suvrat Kher. Geocommons @ http://www.geocommons.com/

For example, pockets of transport emissions and pollution due to transport are concentrated in the urban centers. The transport sector is considered the largest contributor of the air pollution in the cities (at least 30 percent in the megacities of India) (**Figure 5**) and the contributions are also increasing in a growing number of secondary and tertiary cities. **Figure 4(b)** presents the road network spread across the country but the emissions from the transport sector are more likely to follow the population density, leading us to the likely spread observed in **Figure 3**.

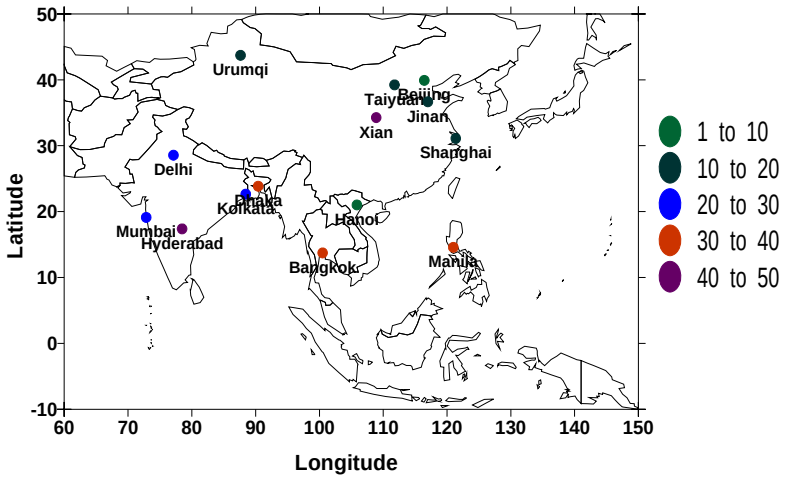


Figure 5: The share of transport emissions contributing to the measured ambient air quality in Asia[12]

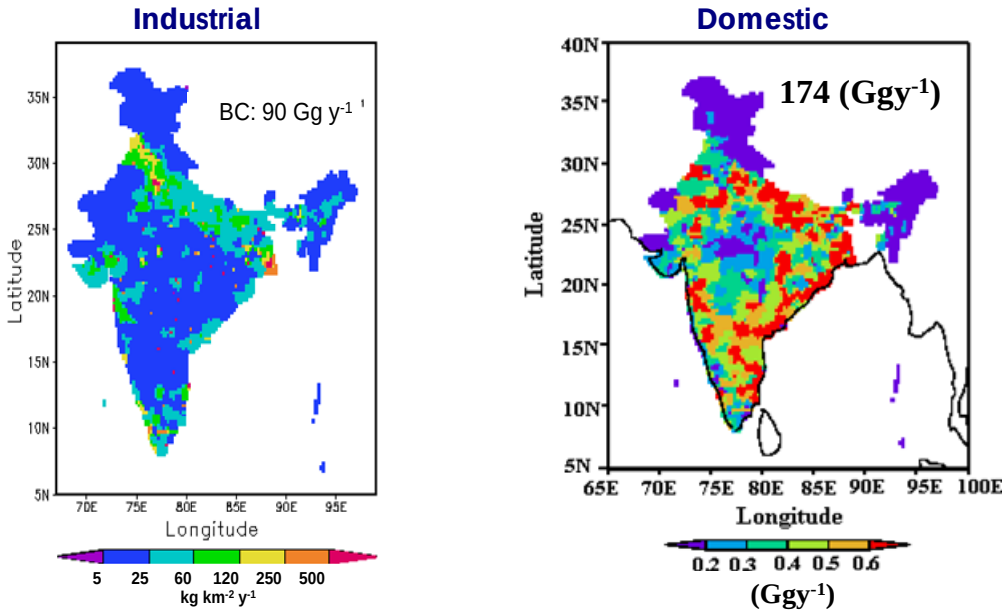


Figure 6: Spatial distribution of black carbon emissions (2000) from industrial and domestic sectors in India[13]

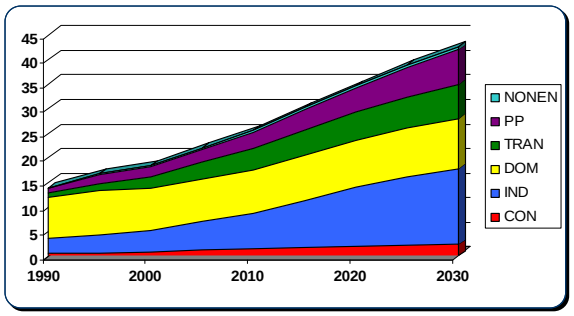
[12] SIM-air working paper series "SIM-10-2008: What is PM" and "SIM-16-2009: Urban Particulate Pollution Source Apportionment" and references within @ http://urbanemissions.info/simair/simseries.html

[13] Personal communication: Prof. Chandra Venkataraman, Indian Institute of Technology, Mumbai, India. Email: chandra@iitb.ac.in

Highest densities of population and pollution are observed in the north, northeastern and south, and along the northwestern and eastern coastlines. Compare this with the energy consumption from major power and industrial estates presented in **Figure 4(c)**. The northern belt with one of the high industrial density is also experiencing the highest PM pollution levels >150 μg/m^3 in the region.

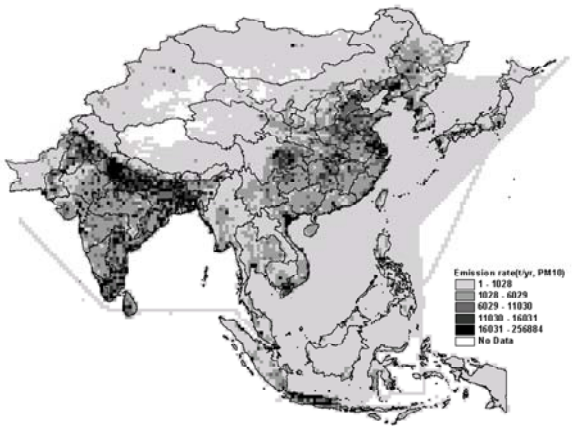
One of the important components of the PM pollution is Black Carbon and **Figure 6** presents the spatial spread of the BC emissions from industrial and domestic sector in India, based on an inventory developed by the Indian Institute of Technology, Mumbai, India. For the distribution of the emissions, the population density was utilized as a proxy, which is again reflected in the pollution map in **Figure 3**.

(a) Energy consumption in India[14]



NONEN = non-energy sources; PP = power plants; TRAN = transport; DOM = domestic; IND = industrial; CON = conventional fuels

(b) PM_{10} Emissions Inventory[15]



(c) Modeled annual average PM_{10} concentrations (2000)[16]

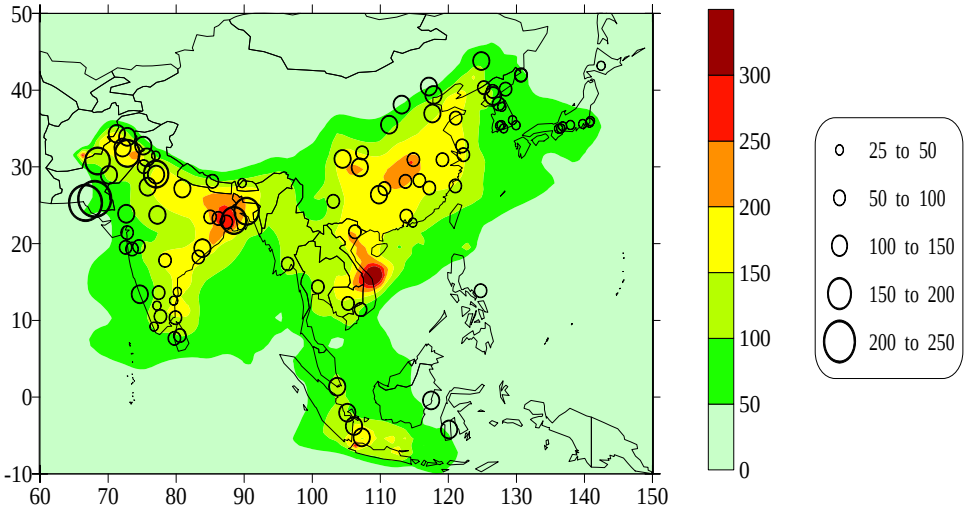


Figure 7: Modeled energy (TJ/yr), emissions (t/yr), and pollution (μg/m³) in India

[14] RAINS-Asia/GAINS developed and published by IIASA, Austria @ http://www.iiasa.ac.at/rains/index.html
[15] Master thesis by Mr. James Dorwart, The University of Iowa, USA
[16] SIM-air working paper No.20 "Particulate Pollution in Asia: Part 1 - Multi-pollutant Modeling, Contributions, & Health Impacts" @ http://www.urbanemissions.info/simair/simseries.html

Each of the maps presented here help better the visual understanding of the air pollution linked to what is being measured in India. However, the best information is available when either monitoring and dissemination of the monitoring data is increased a few folds or an open bottom-up air pollution modeling based on the energy consumption, emissions inventories and dispersion modeling. While this paper addresses the use of monitoring data for analyzing monitoring data spatially, **Figure 7** presents results from a bottom-up study. A health impacts analysis in Asia for 2000 (**Figure 7(c)**) estimates ~902,000 premature death due to air pollution[17].

What's Next

Key to a successful air quality management program at the national, regional, or urban level is access to information. Most often programs don't get implemented to the level possible because of lack of information, an easy excuse for inaction. While in some cases, information is available, either it is not enough or not reliable.

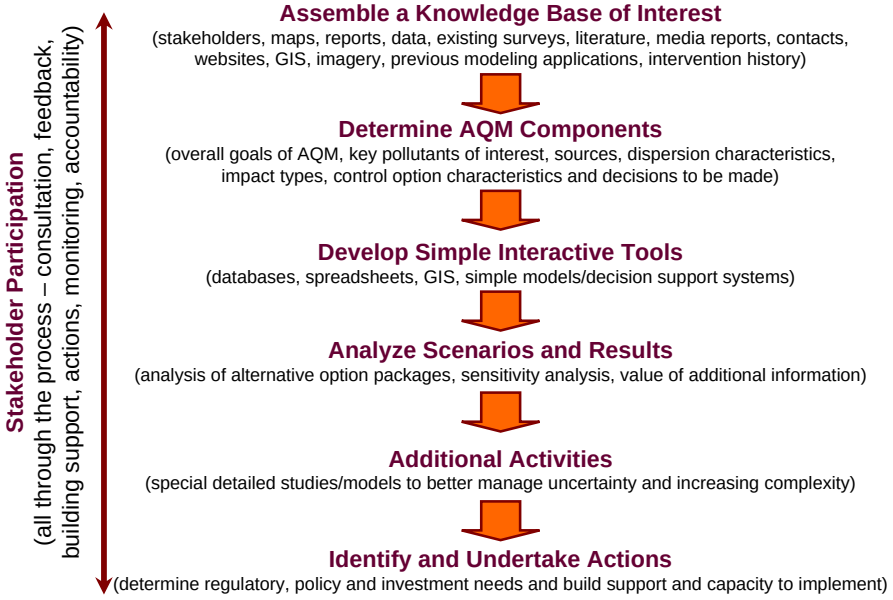


Figure 8: Steps to managing information resources for air quality management

In this paper, a visual correlation between the pollution measured across India is presented along with various indicators ranging from energy to emissions. A step further (**Figure 8**) will provide a plethora of information to better understand the pollution sources and for an informed air quality management plan.

[17] Details of the study including the emissions inventory used for the dispersion modeling and methodology to estimate health impacts is presented in the SIM-air working paper No.20 "Particulate Pollution in Asia: Part 1 - Multi-pollutant Modeling, Contributions, & Health Impacts" and SIM-air working paper No.6 "Estimating Health Impacts of Urban Air Pollution" @ http://www.urbanemissions.info/simair/simseries.html