Climate change and air pollution in megacities: A challenge for interdisciplinary research

Peter Suppan¹
Bhola R. Gurjar²

¹Institute for Meteorology and Climate Research (IMK-IFU), KIT Campus Alpine, Germany
²Department of Civil Engineering, Indian Institute of Technology Roorkee, INDIA
Overview

✔ Problems and Facts
✔ Interdisciplinary Research
✔ Regional Climate Change Modeling
✔ Human Health Impact
✔ Conclusions
Some urban facts (I)

- In 1974 a UNEP and WHO declaration concerning air pollution was released.
- In order to reduce human exposure and health risks in 1992 a EU-report about a more effective planning on energy requirements and transportation was published.
- Since 2007 more than 50 % of worlds population live in urban agglomerations.
- India is different: by 2030 40% of the country’s total projected population (590 million) will live in cities.
- Urban agglomerations in China increased from 19.6 % to 40.5 % (between 1980-2005).
Chinas cities produce about 65 % of the GDP

Indian cities will account for nearly 58% of the GDP in 2008 and 70% in 2030

170 cities in China have more than 1 Mill. inhabitants

In 2030 India will have 68 "million-plus" cities, 13 "four million-plus" cities and six megacities of over 10 million population (McKinsey)

Peak vehicular densities are likely to reach as high as 330 vehicles per lane kilometers. At such densities, an average journey may take up to five hours in peak morning traffic. (Source: McKinsey report)

Per capita water supply could drop from 105 litres currently to 65 in 2030
Geographical Situation

[Map showing the geographical situation of megacities around the world, with different sizes of circles indicating urban populations of 5-8 million, 8-10 million, and ≥10 million.]

Source: UN 2002
Draft and Copyright: F. Kraas
Cartography: R. Spohner
Anthropogenic Emissions

Emissions from megacities of China, Japan, India (2000)

Guttikunda et al. Impact of Asian megacity emissions on regional air quality during Spring 2001
Aerosol Pollution

Beijing

Stefan Norra
Institute of Mineralogy and Geochemistry (IMG) of KIT

European Geosciences Union, General Assembly 2010, Vienna, Austria, 02 – 07 May 2010
AS3.7 Megacities: Air Quality and Climate Impacts from Local to Global Scales
Atmospheric Brown Clouds (ABC)

- Around 13 megacities have been identified as ABC hotpots: Bangkok, Beijing, Cairo, Dhaka, Karachi, Kolkata, Lagos, Mumbai, New Delhi, Seoul, Shanghai, Shenzhen and Tehran

- Soot levels are 10% of the total mass of anthropogenic particles

- Overall effect of ABCs is to make 'hot spot' cities darker or dimmer (10-25%)

- For India as a whole, the dimming trend has been running at about 2% per decade between 1960 and 2000 - more than doubling between 1980 and 2004

- In China the observed dimming trend from 1950s to 1990s was about 3-4% per decade, with larger trends after 1970s

- ABCs masking the impact of Climate Change

- Atmospheric Brown Clouds. Regional Assessment Report with Focus on Asia. UNEP
Atmospheric Brown Clouds (ABC)


Beijing

Shanghai

NASA/GODDARD / NYT
Variation in Annual Mean Temperature

Trend of observational temperature data obtained on urban sites

Source: Kataoka et al., 2009. Urban warming trends in several large Asian cities over the last 100 years. Science of the Total Environment, 407, 3112-3119
Driving Force: Health Impact

Health Impact Pyramid

- mortality
- hospital admissions
- emergency room visits
- physician office visits
- reduced physical performance
- medication use
- symptoms
- impaired pulmonary function
- Sub-clinical (subtle) effects

Proportion of population affected

severity of effect
### Mortality rates on PM$_{10}$ increase

<table>
<thead>
<tr>
<th>Region</th>
<th>Percentage change</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>0.49% (0.23-0.76)</td>
<td>HEI, 2004</td>
</tr>
<tr>
<td>Europe</td>
<td>0.60% (0.40-0.80)</td>
<td>Katsouyanni, 2001</td>
</tr>
<tr>
<td>Latin America</td>
<td>0.61% (0.16-1.07)</td>
<td>PAHO, 2005*</td>
</tr>
<tr>
<td>United States</td>
<td>0.21% (0.09-0.33)</td>
<td>Dominici, 2003</td>
</tr>
<tr>
<td>Worldwide</td>
<td>0.65% (0.51-0.76)</td>
<td>Stieb, 2002</td>
</tr>
</tbody>
</table>

*Based on studies in Mexico City, São Paulo, Santiago de Chile

PAN American Health Organization, 2005
Reduction benefit is 10 times higher as for ozone, e.g. Mexico City about $2 Bill.

Molina and Molina, 2002
Heat waves and mortality

Vandentorren et al. 2004
The complex chemical interactions of emissions – transmission - air pollution – deposition / exposure needs detailed investigations on the causal chain, e.g.

- Source apportionment
- Particle interaction / composition
- Deposition rates / accumulation
- (real) Exposure

Climate Change Impact on these topics

Only interdisciplinary approaches allow a holistic analysis

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Research Project

Risk Habitat Megacity

Local Stakeholders

Cross-Cutting Concept: Governance

Cross-Cutting Concept: Risk

Cross-Cutting Concept: Sustainable Development

Programme Coordinator
Programme Steering Group

Land-use management
Socio-spatial differentiation
Energy system
Transportation
Air quality and health
Water resources and services
Waste management

Development and Dissemination of Knowledge
Methods
Indicators
Toolkits
Scenarios

Capacity Building
Scientific training
Training of practitioners
Workshops

Scientific Advisory Board

¿sostenibilidad en riesgo?
Integrating Approach

Urban Development

Measurement Data

Traffic Data

Air Quality

Scenario

Indicator

WRF Chem

Air Quality & Climate Change Approach

Mortality

Subclinical Effects

Health Impact

Stakeholder
Impact on Air Quality

- Land use

Mexico City
Natural Land Use Change (Impact)

1: Beijing
2: Desert Gobi
3: Desert Takla Makan

Source: Stefan Norra, University Karlsruhe (IMG)
Dust Storms

Beijing

18.04.2006

Photos by Stefan Norra
Land Use Change

<table>
<thead>
<tr>
<th></th>
<th>Santiago de Chile</th>
<th>Mexico City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population 2002</td>
<td>6.061.000</td>
<td>19.410.000</td>
</tr>
<tr>
<td>Urbanized area (km²)</td>
<td>641</td>
<td>1800</td>
</tr>
<tr>
<td>Population density (p / km²)</td>
<td>9.500</td>
<td>10.800</td>
</tr>
<tr>
<td>Population growth (% / y)</td>
<td>~1,32</td>
<td>~1,28</td>
</tr>
</tbody>
</table>

Source: U. Weiland, E. Banzhaf, A. Ebert, A. Kindler, R. Höfer (UFZ)

Source: Poduje 2005 (Santiago de Chile) APERC 2007 (Mexico City)
Effect of land use change

Temperature difference with and without urban sprawl

Diurnal variation of ozone concentrations considering land use change

Renate Forkel (IMK-IFU)
Impact on Air Quality

- Land use
- Energy

Cities: Beijing, Mumbai
## Urban energy distribution

<table>
<thead>
<tr>
<th></th>
<th>Industry</th>
<th>Transport</th>
<th>Residential</th>
<th>Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>62%</td>
<td>8%</td>
<td>17%</td>
<td>13%</td>
</tr>
<tr>
<td>Shanghai</td>
<td>80%</td>
<td>10%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>Seoul</td>
<td>18%</td>
<td>25%</td>
<td>37%</td>
<td>20%</td>
</tr>
<tr>
<td>Tokyo</td>
<td>11%</td>
<td>37%</td>
<td>22%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Global final energy consumption

Source: REN21, Renewables 2007, Global Status Report
Bioenergy from N⁺Plants

Crutzen et al., 2008

Increase of GHG-emissions

Reduction of GHG-emissions

CO₂-Eq-Bioenergy / CO₂-Savings

Plant N content [g N kg⁻¹ DW]

Sugar cane
Wheat/Barley
Maize/root crops etc.
Rapeseed

Crutzen et al., 2008
Emission Reduction Strategies

Olympic Games Beijing

Energy & Technology Assessment Disciplines

Time Period:
15.10.2007 – 01.02.2009

Stefan Norra
Institute of Mineralogy and Geochemistry (IMG) of KIT
Impact on Air Quality

- Land use
- Energy
- Mobility

São Paulo

Bogotá
Traffic

Source: US Dept. of Energy, 2000

Economical background of vehicle ownership
Vehicle purchase max GDP 3000-4000 $
Which will be reached in China in about 20 y
Coupling of Scales

Micro-scale modelling
e.g. NO\textsubscript{x} with GRAL

Santiago de Chile
NO\textsubscript{x} \(\mu g/m^3\) yearly mean

Transportation Sciences

Meso-scale modeling
e.g. NO\textsubscript{2} with MCCM
Impact on Air Quality

- Land use
- Energy
- Mobility
- Climate Change

![Graph showing global surface warming over time.](image)
Consequences of Climate Change

Climate Change

Resolution too coarse for regional impact analysis!
Regional Climate Simulations

Problem of comparing time slices: long term trends - short time trends

Solution: transient simulations
Dynamical Downscaling

Validation of the simulation results by comparing simulated observed precipitation

Yearly Mean Precipitation 1961-1975
Regional Climate Change Impact

High resolution climate-chemistry simulations - Mexico -

Renate Forkel (IMK-IFU)
Regional Climate Change Impact

Setup: 60-20 km grid
2x10 years period
Southern Germany

Source: R. Forkel (IMK-IFU)
Impact on Air Quality

- Land use
- Energy
- Mobility
- Climate Change

- Air Quality
- Health Impact

Integrated Approach
Temporal Distribution of ARI cases and Diarrhea cases between July 2006 and March 2009

Burkart and Endlicher. Bio-meteorological and air pollution conditions in the Megacity of Dhaka, Bangladesh and their effects on public health of urban poor population groups. The seventh International Conference on Urban Climate, 29 June - 3 July 2009, Yokohama, Japan.
Health Effects

Size dependent health effects of airborne particles

Odeh SF, PhD Thesis 2006
Health Impact

EU-average 2000 vs 2020:
- Life expectancy reduction of 9 months – reduced to 6 months
- Annual loss of 4 Mio. life years – reduced to 2.3 Mio
- Annually 386,000 premature deaths – reduced to 251,000
- Annually 110,000 serious hospital admissions – reduced to 63,000

Source: CAFÉ (Clean Air for Europe), 2005 by support of Alexandra Schneider (HMGU)
Conclusions

- Air quality & Climate Change issues need an holistic and interdisciplinary approach

- Strong links to
  - Regional and Spatial Planning Sciences
  - Energy & Technology Assessment Disciplines
  - Transportation Sciences
  - Health / Epidemiological Disciplines
  - Social Sciences

- Link between these fields tackles central problems in mega cities

- Complex system of mega cities, needs further process studies in each discipline

- Air quality and health impact assessment studies are essential prerequisites for mitigation and adaptation strategies and for reducing e.g.
  - environmental risks (air pollution, climate change impact, congestion, waste, ...)
  - social risks (spatial segregation, health problems, ...)
  - costs (healthcare system, transportation, production, ...)
Thank you for your attention

Cooperation Partner

Stefan Norra
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Ulrich Franck
Annette Peters, Josef Cyrys

Institute of Mineralogy and Geochemistry (IMG) of KIT, Karlsruhe
Chinese Academy of Sciences (CAS), Beijing
Chinese University of Mining and Technology (CUMTB), Beijing
Universidad Nacional Autonoma de Mexico (UNAM)
Universidad de Chile, Santiago de Chile (UdC)
Helmholtz Zentrum für Umweltforschung (UFZ)
Helmholtz Zentrum München (HMGU)