Air Pollution and Health: The India case

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First World NCD Congress
PGIMER, Chandigarh
November 5, 2017
Delhi’s pollution in 2016 – note effects of
1) the holiday (Diwali) and
2) crop residue burning
PM2.5 concentrations in μg/m³

box plot = measured hourly avgs from all public continuous monitoring stations
ribbon plot = WRF-CAMx model forecasted hourly avgs for ~2000 1km x 1km grids over Delhi

In 2017 -- now
PM2.5 concentrations in μg/m³

box plot = measured hourly avgs from all public continuous monitoring stations
ribbon plot = WRF-CAMx model forecasted hourly avgs for ~2000 1km x 1km grids over Delhi
Particle deposition

Figure 4: Compartmental deposition of particulate matter
An Association between Air Pollution and Mortality in Six U.S. Cities

Fine-Particulate Air Pollution and Life Expectancy in the United States

Other Effects - examples

- Low birth weight
- Pre-term birth
- BMI
- Diabetes
A meta-analysis of exposure to particulate matter and adverse birth outcomes

Dirga Kumar Lamichhane¹, Jong-Han Leem², Ji-Young Lee¹, Hwan-Cheol Kim²

A meta-analysis of exposure to particulate matter and adverse birth outcomes

Dirga Kumar Lamickhane¹, Jong-Han Leem², Ji-Young Lee¹, Hwan-Cheol Kim³

Preterm Birth

from random effects analysis
Adjusted Mean BMI z Score vs. Prenatal Ambient Air PAH Exposure (ng/m^3)

Rundle et al., Am J Epidemiol 2012
Air Pollution and Diabetes

• Several studies have shown associations between diabetes in adults and exposure to traffic-related air pollution (TRAP)
• Evidence also building for children
Potential Mechanism

- Air pollution can induce oxidative stress and systemic inflammation
- PM$_{2.5}$ induced adipose tissue inflammation and insulin resistance in a mouse model of diet-induced obesity (Sun et al. Circulation 2009)
- Hypothesis:
  - Exposure to air pollution *in utero* and in early childhood increases risk of obesity and abnormal glucose metabolism later in childhood
The three major solid fuels
Population Cooking with Solid Fuels in 2010 (%)
Toxic Pollutants in Wood Smoke from Simple (poor) Combustion

- Small particles, CO, NO₂
- Hydrocarbons
  - 25+ saturated hydrocarbons such as n-hexane
  - 40+ unsaturated hydrocarbons such as 1,3 butadiene
  - 28+ mono-aromatics such as benzene & styrene
  - 20+ polycyclic aromatics such as benzo(a)pyrene
- Oxygenated organics
  - 20+ aldehydes including formaldehyde & acrolein
  - 25+ alcohols and acids such as methanol
  - 33+ phenols such as catechol & cresol
  - Many quinones such as hydroquinone
  - Semi-quinone-type and other radicals
- Chlorinated organics such as methylene chloride and dioxin

Typical chulha releases

400 cigarettes per hour worth of smoke

Source: Naeher et al, J Inhal Tox, 2007
First person in human history to have her exposure measured doing the oldest task in human history

Kheda District, Gujarat, 1981

Emissions and concentrations, yes, but what about exposures?

~5000 ug/m³ during cooking
>500 ug/m³ 24-hour

Indian standard 40 ug/m³

Kheda District, Gujarat, 1981
State-wise estimates of 24-h kitchen concentrations of PM2.5 in India

Solid-fuel using households

Balakrishnan et al. 2013 (SRU group)
Burnett et al., EHP. 2014, Integrated Exposure-Response Functions
Table 2. Adjusted relative risk estimates\(^a\) for various increments of exposure from cigarette smoking (versus never smokers), second hand cigarette smoke, and ambient air pollution from the present analysis and selected comparison studies.

<table>
<thead>
<tr>
<th>Source of risk estimate</th>
<th>Increments of Exposure</th>
<th>Lung Cancer (95% CI)</th>
<th>IHD (95% CI)</th>
<th>CVD (95% CI)</th>
<th>CPD (95% CI)</th>
<th>Estimated Daily Dose PM(_{2.5}) (µg)(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS- present analysis</td>
<td>&lt;3 (1.5) cigs/day</td>
<td>10.44 (7.30-14.94)</td>
<td>1.61 (1.27-2.03)</td>
<td>1.58 (1.32-1.89)</td>
<td>1.72 (1.46-2.03)</td>
<td>18</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>4-7 (5.5) cigs/day</td>
<td>8.03 (5.89-10.96)</td>
<td>1.64 (1.37-1.96)</td>
<td>1.73 (1.51-1.97)</td>
<td>1.84 (1.63-2.08)</td>
<td>66</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>8-12 (10) cigs/day</td>
<td>11.63 (9.51-14.24)</td>
<td>2.07 (1.84-2.31)</td>
<td>2.01 (1.84-2.19)</td>
<td>2.10 (1.94-2.28)</td>
<td>120</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>13-17 (15) cigs/day</td>
<td>13.93 (11.04-17.58)</td>
<td>2.18 (1.89-2.52)</td>
<td>1.99 (1.77-2.23)</td>
<td>2.08 (1.87-2.32)</td>
<td>180</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>18-22 (20) cigs/day</td>
<td>19.88 (17.14-23.06)</td>
<td>2.36 (2.19-2.55)</td>
<td>2.42 (2.28-2.56)</td>
<td>2.52 (2.39-2.66)</td>
<td>240</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>23-27 (25) cigs/day</td>
<td>23.82 (18.80-30.18)</td>
<td>2.29 (1.91-2.75)</td>
<td>2.33 (2.02-2.69)</td>
<td>2.33 (2.03-2.67)</td>
<td>300</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>28-32 (30) cigs/day</td>
<td>26.82 (22.54-31.91)</td>
<td>2.22 (1.97-2.49)</td>
<td>2.17 (1.98-2.38)</td>
<td>2.39 (2.19-2.60)</td>
<td>360</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>33-37 (35) cigs/day</td>
<td>26.72 (18.38-38.44)</td>
<td>2.58 (1.91-3.47)</td>
<td>2.52 (1.98-3.19)</td>
<td>2.83 (2.28-3.52)</td>
<td>420</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>38-42 (40) cigs/day</td>
<td>30.63 (25.79-36.38)</td>
<td>2.30 (2.05-2.59)</td>
<td>2.37 (2.16-2.59)</td>
<td>2.61 (2.40-2.84)</td>
<td>480</td>
</tr>
<tr>
<td>ACS- present analysis</td>
<td>43+ (45) cigs/day</td>
<td>39.16 (31.13-49.26)</td>
<td>2.00 (1.62-2.48)</td>
<td>2.17 (1.84-2.56)</td>
<td>2.37 (2.04-2.76)</td>
<td>540</td>
</tr>
<tr>
<td>ACS-air pol. original</td>
<td>24.5 µg/m(^3) ambient PM(_{2.5})</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>1.31(1.17-1.46)</td>
</tr>
<tr>
<td>ACS-air pol. extend.</td>
<td>10 µg/m(^3) ambient PM(_{2.5})</td>
<td>1.14(1.04-1.23)</td>
<td>1.18(1.14-1.23)</td>
<td>1.12(1.08-1.15)</td>
<td>1.09(1.03-1.16)</td>
<td>0.18</td>
</tr>
<tr>
<td>HSC-air pol. original</td>
<td>18.6 µg/m(^3) ambient PM(_{2.5})</td>
<td>1.21(0.92-1.69)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>1.37(1.11-1.68)</td>
</tr>
<tr>
<td>HSC-air pol. extend.</td>
<td>10 µg/m(^3) ambient PM(_{2.5})</td>
<td>1.21(0.92-1.69)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.18</td>
</tr>
<tr>
<td>WHI-air pol.</td>
<td>10 µg/m(^3) ambient PM(_{2.5})</td>
<td>1.21(0.92-1.69)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.18</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Low- moderate SHS exp.</td>
<td>-----</td>
<td>-----</td>
<td>1.16(1.03-1.32)</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Moderate-high SHS exp.</td>
<td>-----</td>
<td>-----</td>
<td>1.26(1.12-1.42)</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Live with smoking spouse</td>
<td>1.21(1.13-1.30)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.36</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Work with SHS exposure</td>
<td>1.22(1.13-1.33)</td>
<td>1.24(1.17-1.32)</td>
<td>-----</td>
<td>-----</td>
<td>0.72</td>
</tr>
<tr>
<td>INTERHEART</td>
<td>1-7 hrs/wk SHS exp.</td>
<td>-----</td>
<td>-----</td>
<td>1.28(1.12-1.47)</td>
<td>-----</td>
<td>0.54</td>
</tr>
<tr>
<td>INTERHEART</td>
<td>Live with smoking spouse</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.54</td>
</tr>
</tbody>
</table>

*Abbreviations: RR relative risk, HR hazard ratio, CI confidence interval, CPD cardiopulmonary disease, PM particulate matter.*
Pope et al.  
*Environmental Health Perspectives*  
2011, in press
Generalized Exposure-Response: Outdoor Air, SHS, and Smoking

IHD risks from combustion particles
Annual average PM2.5 in ug/m3

Relative Risk

Smokers

Solid Fuel Zone

Secondhand Tobacco Smoke

Outdoor Air Pollution
Household Air Pollution and Blood Pressure In Yunnan

Baumgartner et al. Environmental Health Perspectives 2011, Oct
Intervention to Lower Household Wood Smoke Exposure in Guatemala Reduces ST-Segment Depression on Electrocardiograms

John McCracken,1,2 Kirk R. Smith,2 Peter Stone,3 Anaité Díaz,4 Byron Arana,4 and Joel Schwartz1

1Department of Environmental Health, Harvard School of Public Health, Boston, Massachusetts, USA; 2Environmental Sciences Division, University of California, Berkeley, California, USA; 3Brigham and Women’s Hospital, Boston, Massachusetts, USA; 4Center for Health Studies, Universidad del Valle, Guatemala City, Guatemala

Table 3. Odds ratios (ORs) for nonspecific ST-segment depression (30-min average ≤ −1 mm, regardless of slope) associated with chimney-stove intervention compared with open fire from two study designs: between-groups and before-and-after analyses.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Crude OR (95% CI)</th>
<th>p-Value</th>
<th>Adjusted OR (95% CI)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-groups</td>
<td>0.34 (0.15, 0.81)</td>
<td>0.015</td>
<td>0.26 (0.08, 0.90)*</td>
<td>0.033</td>
</tr>
<tr>
<td>Before-and-after (only control group)</td>
<td>0.41 (0.24, 0.70)</td>
<td>0.001</td>
<td>0.28 (0.12, 0.63)b</td>
<td>0.002</td>
</tr>
</tbody>
</table>

*Adjusted for age (quadratic), BMI (quadratic), asset index category, ever smoking, SHS, owning a wood-fired sauna, recent use of wood-fired sauna, and time of day (natural spline with 5 degrees of freedom). ^Adjusted for age (quadratic), day of week, season (wet/dry), daily average temperature and relative humidity, daily rainfall, interactions of weather variables with season, recent use of wood-fired sauna, and time of day (natural spline with 5 degrees of freedom).
 Estimated Burden of Disease for India - 2016
Satellite-based ambient PM$_{2.5}$

29% from households in India

van Donkelaar et al, EHP 2010
India
All causes attributable to Ambient particulate matter pollution
Both sexes, All ages
Remember

• GBD numbers are highly uncertain – these are central estimates
• And change with new models and databases
• Some health outcomes not included
  – Low birth weight/prematurity
  – TB/asthma
  – Other cancers: cervical, etc.
  – Diabetes, arthritis, low IQ, BMI
Neurodevelopmental performance among school age children in rural Guatemala is associated with prenatal and postnatal exposure to carbon monoxide, a marker for exposure to woodsmoke

Linda Dix-Cooper, Brenda Eskenazi, Carolina Romero, John Balmes, Kirk R. Smith

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Center for Environmental Research and Children’s Health (CERCH), School of Public Health, University of California, Berkeley, CA, USA
Centro de Estudios en Salud Universidad Del Valle, Guatemala
Division of Occupational and Environmental Medicine, Department of Medicine, University of California, San Francisco, CA, USA
Exposure is a much better metric for understanding and controlling health risk than concentrations in fixed locations.

Classic air pollution control focuses on concentrations in fixed locations.
Source – Exposure Relationships

Vehicles

Power plants

Stoves

How different? Does it matter?
Ministry of Health and Family Welfare
Air Pollution Task Force - 2015

• First Ministry of Health in world to treat AP as one of its major priorities and consider along with other risk factors in its mission

• First government agency in the world not to address AP by location, but by total exposure – a true health focus

• Thus, not indoor/household, not outdoor, but by what will give the most health benefit
MoHFW AP Task Force

- Total exposure approach requires utilizing estimates of relation between emissions of each source category and exposure.
- Emissions weighted essentially by proximity to population
- Goal is to change source apportionment to exposure apportionment
- Several analytic approaches now available – new research agenda to make viable for policy
Emissions – PM$_{2.5}$

MOHFW Report, 2015 estimates by Guttikunda
## Ambient Intake Fractions in Hyderabad

ppm – grams inhaled per tonne emitted

<table>
<thead>
<tr>
<th>Source</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Households</td>
<td>175</td>
<td>97</td>
</tr>
<tr>
<td>Construction</td>
<td>175</td>
<td>93</td>
</tr>
<tr>
<td>Waste bum</td>
<td>140</td>
<td>74</td>
</tr>
<tr>
<td>Veh. exhaust</td>
<td>130</td>
<td>64</td>
</tr>
<tr>
<td>Gen. sets</td>
<td>123</td>
<td>53</td>
</tr>
<tr>
<td>Industries</td>
<td>65</td>
<td>17</td>
</tr>
<tr>
<td>Dust</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Power plants</td>
<td>7.4</td>
<td>7.0</td>
</tr>
<tr>
<td>Brick.kilns</td>
<td>6.8</td>
<td>1.9</td>
</tr>
</tbody>
</table>
Emissions – PM$_{2.5}$

Draft MOHFW Report estimates by Guttikunda
Vehicles

Power plants

Stoves

How different?
Does it matter?

Yes, a factor of 100 different!
Classic air pollution control focuses on concentrations in fixed locations. Integrated exposure allows for more nuanced and efficient air pollution control that weights sources by their impact on exposure and health, rather than environmental quality.
Summary

• Eventually, we wish to control all sources of air pollution, all the time, everywhere.
• But we cannot afford to do so immediately.
• What metric gives the optimal pathway such that the most health protection is occurring at each stage of investment?
• Metrics of exposure are the way to do so.
India

- Still with ~two-thirds of households using solid cookfuels
- Most polluted cities in the world, but also major amounts of ambient pollution in rural areas
- Highest burden of disease from air pollution in the world
- Highest total air pollution burden/capita of all middle-income countries – 2x China
Joint Activity of
Indian Institute of Technology Delhi
Sri Ramachandra University Chennai
The Energy and Resources Institute (TERI)
University of California Berkeley
and
UrbanEmissions.com – knowledge partner
Mission

• The CCAPC
  – evaluates, and compares policy options for dealing with India’s health-damaging air pollution of all types,
  – provides a platform for institutions to work together to solve problems and recommend policy, and
  – works to develop capacity to address the policy implications of air pollution in the country.
NIMBY versus MIMBY

- Not in my backyard (NIMBY) is a well known issue in environmental health
- But MIMBY (Must be in my backyard) is a more fundamental problem
- Local data are obviously valuable
- But we cannot repeat every study in every part of the world
- When do we have enough information for policy?
- In particular for HAP risk for CVD outcomes; these now come from ambient and other data only?
Risk Modifiers

- Age
- Sex
- Race/ethnicity
- Socioeconomic status
- Neighborhood
- Stress
- Diet
- Obesity
- Diabetes
- Other exposures (e.g., tobacco smoke, biomass smoke, occupational vapors, dusts, fumes)
Many thanks

For publications & presentations:
Just “Google”
Kirk R. Smith

For the new Centre
http://www.ccapc.org.in/