Comparative Risk Assessment and the Burden of Disease from Indoor Air Pollution

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How Much Ill-Health is Attributable to Air Pollution?

Need to define:

• Ill-health
• Attributable
• Air pollution
Only recently there has been a $C^4$ Database for health

- **Complete**
  - Much of the world was unrepresented
  - Many important disabilities were unaccounted

- **Consistent definitions of disease states**

- **Coherent**
  - Deaths by disease add to total
  - Statistics match by age and sex

- **Combined mortality and morbidity**
Combined Measure of Ill-health

• Death is most common
  – Easy to determine
  – Commonly tabulated

• Severe problems
  – Everyone dies
  – Health never achieved
  – Age is clearly important

• Deaths + Disability = ?
Combined Measure

- Most fundamental deprivation is loss of time: life length shared by all humans
- Can be used for disabilities, but need to weight relative severity of disabilities
- Other issues common to any measure
  - Count impacts differently in different groups?
    - No, only age and sex counts
  - What about impacts in different times?
    - 3% discount rate applied
Quality Adjusted Life Years
QALY

• Basically the number of fully healthy life years lost to a particular disease or risk factor.
• Considers the age at which the disease or death occurs and the duration and severity of any disability created.
Global Burden of Disease Database

- Developed at Harvard University originally for the World Bank
- Extended greatly in the mid-1990s and now adopted by the World Health Organization
- Dozens of countries, states, and cities now have National Burdens of Disease
- Uses a variation of QALY, the DALY
World - Deaths

- Heart
- Cancer
- Stroke
- ARI
- COPD
- HIV
- Perinatal
- Diarrhea
- TB
- Child Cluster
- Road Traffic
- Malaria

Percent of Total

2000
Characteristics of Attributable Risk

• All attributable risks for a disease often add up to much more than 100%
• Size of attributable risk for a particular risk factor depends on order that different factors are examined
• Presumes the existence of a feasible intervention (counterfactual level) to lower exposure.
840,000 ARI Deaths in Children Under 5

- Malnutrition: 35%
- Breastfeeding: 10%
- Measles: 10%
- Diarrhea: 20%
- Breastfeeding: 10%
- Malnutrition: 35%
- Better Housing: 40%
- Air Pollution: 30%
- Case-management: 65%
- Vaccines: 25%

UCB - KR Smith et al
Global Burden of Disease in 1995

Major Risk Factors
Risk Factors in GBD-2000
Comparative Risk Assessment

- Hypertension
- Cholesterol
- Physical inactivity
- Unsafe sex
- Lack of fruit & veg
- Malnutrition
- Unsafe injection
- Child sexual abuse
- Obesity/BMI
- Lack of breast feeding
- Illicit drugs
- Active Smoking
- Alcohol
- Lead
- Indoor air pollution
  - ETS
  - Solid fuel use
- Outdoor air pollution
- Water/hygiene/sanitation
- Climate change
- Occupational hazards
CRA Method

- Estimate prevalence of exposure
  \[(\text{Actual} - \text{Counterfactual}) \times \text{Exposures} = \text{Pe}\]
- Relative risk estimates from epidemiological studies = \text{RR}
- Population Attributable Risk (PAR)
  \[\text{PAR} = \frac{\text{Pe}(\text{RR}-1)}{1 + \text{Pe}(\text{RR}-1)}\]
- Morbidity and Mortality, preferably from a Burden of Disease study (\(C^4\) compatible) = \text{M}
- \text{Burden} = \text{PAR} \times \text{M}
- Sum over exposure levels (distribution) and age-sex groups
Estimating Exposure Levels (what is air pollution?)
Pollutants in Biomass Smoke
(many hundred)

- Small particles, CO, NO$_2$
- Formaldehyde, Acrolein, Benzene, 1,3-Butadiene, Toluene, Styrene, etc.
- Polyaromatic hydrocarbons
- **Coal** has all the above plus SO$_2$ and toxic elements such as As, Pb, Hg, and Fl.
- Both produce significant non-CO$_2$ greenhouse gases (GHGs), such as CH$_4$
## Indoor pollution from Indian chula burning wood

<table>
<thead>
<tr>
<th>Component</th>
<th>Mechanisms of health effects</th>
<th>WHO guidelines (mg/ m³)</th>
<th>(mg/ m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>▪ Absorption into blood from lungs ▪ ↑ HbCO levels ▪ ↓ oxygen to body tissues ▪ Possible impact on lung clearance</td>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td>Particulates</td>
<td>▪ Inhalation into respiratory system ▪ Deposition in respiratory tract irritation and toxicity</td>
<td>0.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Benzene</td>
<td>▪ Absorption into blood from lungs ▪ Leukaemia</td>
<td>0.002</td>
<td>0.8</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>▪ Irritation of mucosa ▪ Toxicity to cilia ▪ Reduction in lung clearance ability ▪ Possible carcinogen</td>
<td>0.1</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**Note:** Emissions from 1 kg of wood / hr in 40 m³ kitchen
Distribution of 24-hour PM$_{10}$ measurements in North Indian village households

US Standard 50 µg/m$^3$

Saksena & Smith, 2000
Pyramid of Exposure Assessment

- Biomarkers
- Personal monitoring
- Microenvironmental monitoring
- Questionnaires
- Secondary information

Uncertainty
Emissions Along the Household Energy Ladder

![Graph showing emissions along the household energy ladder. The x-axis represents different energy sources: Dung, Crop Residues, Wood, Kerosene, Gas, Electricity. The y-axis represents grams per meal. The emissions range from clean to dirty, with CO and PM10 indicated.]
Estimating Risk Factor Levels:  *Solid Fuel Use*

**Binary classification of exposure**

- **Exposed:**
  - Households using solid fuels (wood, dung, agricultural residues, coal, charcoal) as primary source of energy for cooking
- **Unexposed:**
  - Households not using solid fuels as primary cooking fuel (counterfactual level)
National Burden of Disease from IAP in India

Households Using Biomass Fuels

*Source: Census of India 1991

<table>
<thead>
<tr>
<th>Percentage of Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-24</td>
</tr>
<tr>
<td>25-49</td>
</tr>
<tr>
<td>50-74</td>
</tr>
<tr>
<td>75-100</td>
</tr>
<tr>
<td>unknown</td>
</tr>
</tbody>
</table>
Obtaining estimates where data exist: Household Fuels Database

- 52 countries in 10 WHO regions
- Sources of data include: national population and housing censuses, household energy surveys, FAO
- Estimates for each region are population weighted averages of available data
Household Fuel-Use Prediction Model

As countries develop, people shift from solid to cleaner fuels

- All countries with 1999 GNP/capita >$5000 assumed to have made complete transition to cleaner cooking fuels
- Avoid over-extrapolation of model: highest 1999 GNP/capita in household fuels database: Brazil ($4420)
Fuel Prediction Model:

**Modelling Technique:**
- Stepwise linear regression

**Criteria for Model Parameters:**
- Stable over a several year period (solid fuel use patterns are relatively stable over several years)
- Available on a national level for most countries across most regions
- Routinely updated
- From a reliable source
Final Fuel Prediction Model

• Parameters:

<table>
<thead>
<tr>
<th>Standardized Coefficients</th>
<th>95% Confidence Interval for B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>t</td>
</tr>
<tr>
<td>(Constant)</td>
<td>3.1926</td>
</tr>
<tr>
<td>RURAL</td>
<td>0.3527</td>
</tr>
<tr>
<td>EMR</td>
<td>-0.2838</td>
</tr>
<tr>
<td>LNGNP</td>
<td>-0.2646</td>
</tr>
<tr>
<td>per capita Petroleum Use</td>
<td>-0.2244</td>
</tr>
</tbody>
</table>

• Model Summary:
  – R: 0.8637
  – \( R^2 \): 0.7460
  – Adjusted \( R^2 \): 0.7244
  – Standard Error of the Estimate: 0.1891

• Model meets assumptions of normalcy, constant variance.
• Collinearity and Tolerance also assessed.
Indoor air pollution defined here as unventilated use of household use of solid fuels

What are the Exposure-Response Relationships?
FIG 1—Incidence of ischaemic heart disease, age adjusted with 95% confidence intervals, according to fifths of distribution of serum cholesterol concentration in 10 cohort studies.
Diseases for which we have quantitative risk data

- Pneumonia
- Asthma
- Low birth weight
- Early infant death
- Chronic obstructive lung disease
- Lung cancer
- Blindness
- Tuberculosis
- Heart disease?
**Evidence of Causality**

<table>
<thead>
<tr>
<th>Criteria for Causality</th>
<th>Acute Lower Respiratory Infections (ARI)</th>
<th>Chronic Obstructive Pulmonary Disease (COPD)</th>
<th>Lung Cancer (coal)**</th>
<th>Lung Cancer (biomass)</th>
<th>Asthma</th>
<th>Blindness (cataracts)</th>
<th>Tuberculosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>INC*</td>
<td>INC*</td>
<td>INC*</td>
<td>INC*</td>
</tr>
<tr>
<td>Strength of association?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Specificity?</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dose-response relationship?</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Temporal relationship?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Biological plausibility?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Coherence?</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>INC*</td>
<td>YES</td>
<td>INC*</td>
<td>INC*</td>
</tr>
<tr>
<td>Experiment?</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Evidence</td>
<td>STRONG</td>
<td>STRONG</td>
<td>STRONG</td>
<td>MODERATE</td>
<td>MODERATE</td>
<td>MODERATE</td>
<td>MODERATE</td>
</tr>
</tbody>
</table>

UCB - KR Smith et al
Strong Evidence: Active & passive smoking; urban air pollution, biochemical/laboratory studies, and multiple studies of solid-fuel use in developing countries

Selection Criteria for ARI Studies

- Primary
- Developing-country
- Biomass-using households
- Children under 5
- Standard measure of outcome
- Odds ratio calculated
- Adjustment/evaluation of potential confounders
- Written in English, German, or French


IAP and Childhood ARI

- **9 Case-control:** South Africa, Zimbabwe, *Nigeria, Tanzania, Gambia, *Brazil, *India, Argentina 6 adjusted for confounders; \( n = 4311 \); Odds Ratios = 2.2-9.9

- **3 Cohort:** Nepal, Gambia 2 adjusted for confounders; \( n = 910 \); Odds Ratios = 2.2-6.0

- **1 Case-fatality:** Nigeria Hospitalized patients; \( n = 103 \); Odds Ratio = 8.2

- **2 US Case-control:** \( n = 206 \) Adjusted for confounders. Odds Ratios = 4.8

- **Result of meta-analysis:** 2.3 (CI 95%: 1.9, 2.7).
COPD

• **3 Case-control studies**: Saudi Arabia; Columbia; Mexico 2 adjusted for confounders; 2 show exposure response with years of cooking; $n = 498$
  
  Odds Ratios = 3.3 - 15

• **5 Cross-sectional studies**: Nepal; India; Bolivia
  
  All partly adjusted; 2 show exposure-response with years of cooking; $n = 5528$
  
  Odds Ratios = 1.4 - 7.9

• **Women**: 3.2 (CI 95%: 2.3, 4.8).

• **Men**: 1.8 (CI 95%: 1.0, 2.8).

UCB - KR Smith et al
Meta-analysis: Graph coal use studies - lung cancer

Women: 1.94 (CI 95%: 1.09, 3.47).
Men: 1.5 (CI 95%: 1.0, 2.5).

UCB - KR Smith et al
Moderate Evidence: active smoking, animal studies, and at least 3 studies of solid fuel use in LDCs

- **Blindness**: Cataracts have been associated with biomass use in one national survey and two case-control studies in India. OR: 1.3-1.6

- **TB**: Shown to be associated with biomass use in one national and one local study in India and one case-control study in Mexico (occasionally reported to be associated with outdoor air pollution) OR: 1.5-2.7
Weak Evidence: difficult to assign causality and to diagnose, but some studies available in LDC households

- **Asthma**: Associated with urban outdoor and indoor pollution in MDCs. Typical solid-fuel smoke exposures are much higher. 3 studies in LDC solid fuel households. OR: 1.4-2.5
**Suggestive Evidence:** active and passive smoking, urban air pollution, physiological mechanisms being elucidated, but inadequate number of studies yet in LDC solid-fuel using households

- **Heart disease (ischaemic):** Thought to be a major impact of smoking and urban pollution. Typical solid-fuel smoke exposures are intermediate. No LDC indoor studies.

**OR:** Cannot quantify
Suggestive Evidence (cont.)

• **Adverse Pregnancy Outcomes** (stillbirth, low birthweight (LBW), neo-natal death, etc.): Stillbirth and LBW have been associated with biomass smoke exposure in pregnant women in India and Latin America. LBW and early infant death have been associated with much lower levels of urban air pollution in China and several developed countries.

OR: Not possible to quantify
Indoor Air Pollution Compared to Other Major Risk Factors in India
Currently not included

• Indoor environments
  – Schools, vehicles, shops, workplaces, etc.
• Population groups
  – Men and Youth (5-15)
• Pollutants/Sources
  – Radon
  – Arsenic and fluorine in coal
  – Incense and mosquito coils
  – Biological agents (mold, mites, etc.)
Not included (cont.)

- Disease endpoints
  - Adverse Pregnancy Outcomes
  - Aero-digestive cancer
  - Cor Pulmonale
  - Interstitial lung disease
  - Trachoma
  - Initiation/trIGGERING of asthma
  - Coronary heart disease
Not included (cont.)

• Sequelae
  – TB in the HIV-positive
  – ARI during perinatal period
  – Excess deaths in the blind
  – ARI-Malnutrition-Diarrhea connections

• Indirect Causal Pathways
  – Low birth weight
  – (Un) Healthy mother effect

• Counterfactual level not actual minimum
  – Liquid and gaseous fuels produce exposures
The Unhealthy Mother Effect

Solid Fuel Use → Smoke → Child ARI ← Child Health

Fuel Harvesting → Maternal Health → Maternal Time and Energy
Cost-Effectiveness of Health Interventions
Improved Biomass Stoves in India

Net Present Cost of Improved Stoves (including all program costs) per Healthy Life Year
Extended

$NPV Per DALY

Stove Lifetime - Years

3.0% Discount Rate
10% Discount Rate
Attributable versus Avoidable
Version 2

Baseline Changes Due to Shifts in
- Exposure due to economic growth
- Population distribution
- Competing risks

Attributable
Avoidable

Intervention

Risk and Uncertainty

Avoidable Risk

Attributable Risk

Indoor Air Pollution

Outdoor Air Pollution

UCB - KR Smith based on Murray
Risk and Uncertainty

Avoidable Risk

Attributable Risk

Tobacco

Malnutrition

Indoor Air Pollution

Outdoor Air Pollution

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Risk and Uncertainty

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Climate Change

Tobacco

Malnutrition

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Thank you