The Burden of Disease from Air Pollution

Michael Brauer

Air quality impacts on health: Beyond the heart and lungs. 13th Annual Air Quality and Health Workshop Vancouver, February 10, 2016
Although shark attacks, plane crashes, and terrorist attacks might be the stuff of our collective nightmares, there’s one thing that kills way more people both worldwide and in the U.S. than any of those things combined. And there’s no way to hide from it.

... *air pollution is killing way more people than we previously thought* — over 3 million people around the world die prematurely from it every single year. By comparison, an average of just six people die worldwide from shark attacks every year — and generally only one of those takes place in the U.S.

The number of deaths caused by plane crashes is slightly bigger: Last year (2014) was one of *the worst years for plane crashes* in the last decade. An estimated 1,328 people died in plane crashes worldwide...
Air pollution and health

• Ambient air pollution (individual) risk is small…but large exposed population = large population risk
  – Smoking: Larger risk, smaller exposed population
• Major impacts are on chronic disease progression
• Diseases impacted by air pollution are multifactorial…
• …Air pollution as a contributing risk factor
What is air pollution?

Source perspective

Processed emissions

Waste burning

Biogenic Sources

Agri-culture

Agricultural & forest fires

Stationary power generation

Crustal material

Residential heating

Residential cooking

Petro-chemical industry

Metal industry

Road transportation

Off-road transportation

Solvent and paint use

Agricultural & forest fires

Natural processes

Fate and transport

Metal industry
What is air pollution?

Component perspective

- **Aerosol**
  - EC and Organic Matter
  - Metals
  - Crustal materials
  - Salts & H2O

- **Gas-Phase SVOCs**

- **VOCs**

- **Gaseous N-compounds**
  - Oxidants (O3, H2O2)

- **gaseous S-compounds**

- **Other Gases**

- **CO**
Particulate Matter

- **PM$_{2.5}$**: Combustion particles, organic compounds, metals, etc.
  - < 2.5 μm (microns) in diameter

- **PM$_{10}$**: Dust, pollen, mold, etc.
  - < 10 μm (microns) in diameter

HUMAN HAIR
50-70 μm (microns) in diameter

FINE BEACH SAND
90 μm (microns) in diameter

Image courtesy of the U.S. EPA
WHO REVIEW (2013)
Cardiovascular and Respiratory Mortality and Morbidity

Growing evidence for birth outcomes and childhood respiratory disease

Possible links with neurodevelopment and cognitive function, diabetes

IARC (2013)
Air pollution (and PM specifically) carcinogenic (lung cancer)
But how bad is it really?
What is the Global Burden of Disease?

• Systematic quantification of health loss due to diseases, injuries and risk factors

• Disease, injury, & risk burden estimates for 1990 – 2013 using comparable methods for 188 countries (+ sub-country analyses)
  – incidence and prevalence of 301 diseases and injuries and 2,337 relevant disabling sequelae, stratified by sex and 20 age groups
  – Role of 79 modifiable risk factors

• Global collaboration coordinated by Institute for Health Metrics and Evaluation + ~1000 volunteers....

• Annual updates beginning in 2016

http://www.healthdata.org/gbd
Exposure to Outdoor Air Pollution

PM$_{2.5}$

Ozone

Worldwide Health Evidence

Country-Specific Mortality, Disease

Concentration – Response Relationships

Baseline Incidence

Global Burden, DALYs, Mortality

Population Attributable fraction $\times$ Deaths (cause-specific)

Population Attributable fraction $\times$ DALYs (cause specific)
Theoretical minimum risk exposure level

Exposure that would yield the lowest population risk (0, or some theoretically feasible value)

- $\text{PM}_{2.5}$ Uniform distribution: 5.9 - 8.7 $\mu g/m^3$ (min/5th %)
- $O_3$ Uniform distribution: 33.3 - 41.9 $\mu g/m^3$
Measurements

Annual average PM2.5 (µg/m³)
- 0.0 - 8.4
- 8.4 - 13.0
- 13.0 - 18.1
- 18.1 - 25.3
- 25.3 - 34.1
- 34.1 - 46.2
- 46.2 - 61.0
- 61.0 - 75.6
- 75.6 - 141.5
- 141.5 - 193.9
• Final estimates based on average of (1.4 million) grid cell values (SAT, TM5) and calibrated (regression model) with measurements
  • 0.1° x 0.1° resolution
  • extrapolated to 2013 using 2010-2011 trend in SAT
• Incorporate variance between two estimates and measurements in uncertainty assessment
• Unique contributions from each approach

Adjusted $R^2$: 0.64
$N = 4,073$
$PM_{2.5} = \exp[0.41765 + (0.86953 \times \ln(Avg))]$

approximate location
$PM_{2.5}$ calculated (from $PM_{10}$)
unspecified monitor type
1990 – 2013 Change in Annual Average PM$_{2.5}$

1990 – 2013 Change in O$_3$
Diseases affected by air pollution: 4 of the top 5 causes of the global burden of disease in 2013

Outdoor air pollution

• Ischemic Heart Disease mortality/incidence: PM
• Stroke mortality/incidence: PM
• COPD mortality: PM, ozone
• Lung Cancer mortality: PM
• ALRI mortality/incidence: PM

<table>
<thead>
<tr>
<th>Leading causes 2013</th>
<th>Rank 2013</th>
<th>Age-standardised % change 2005-2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ischemic heart disease</td>
<td>1-0 (1-1)</td>
<td>-11% (-15 to -6%)</td>
</tr>
<tr>
<td>2 Cerebrovascular disease</td>
<td>2-2 (2-3)</td>
<td>-14% (-17 to -10%)</td>
</tr>
<tr>
<td>3 Lower respiratory infections</td>
<td>3-4 (3-4)</td>
<td>-22% (-28 to -15%)</td>
</tr>
<tr>
<td>4 Low back &amp; neck pain</td>
<td>3-5 (2-5)</td>
<td>0% (-1 to 3%)</td>
</tr>
<tr>
<td>5 COPD</td>
<td>5-2 (5-7)</td>
<td>-11% (-15 to -6%)</td>
</tr>
<tr>
<td>6 Diarrheal diseases</td>
<td>7-2 (5-11)</td>
<td>-32% (-38 to -26%)</td>
</tr>
<tr>
<td>7 Road injuries</td>
<td>7-3 (5-10)</td>
<td>-14% (-18 to -9%)</td>
</tr>
<tr>
<td>8 Neonatal preterm birth</td>
<td>9-0 (5-14)</td>
<td>-24% (-32 to -17%)</td>
</tr>
<tr>
<td>9 HIV/AIDS</td>
<td>9-3 (6-12)</td>
<td>-32% (-35 to -27%)</td>
</tr>
<tr>
<td>10 Malaria</td>
<td>10-6 (6-15)</td>
<td>-36% (-45 to -22%)</td>
</tr>
<tr>
<td>11 Depressive disorders</td>
<td>11-4 (5-17)</td>
<td>1% (-2 to 4%)</td>
</tr>
<tr>
<td>12 Diabetes</td>
<td>11-8 (9-14)</td>
<td>1% (-2 to 4%)</td>
</tr>
<tr>
<td>13 Sense organ diseases</td>
<td>12-1 (5-16)</td>
<td>-3% (-5 to -2%)</td>
</tr>
<tr>
<td>14 Neonatal encephalopathy</td>
<td>13-5 (10-17)</td>
<td>-18% (-27 to -7%)</td>
</tr>
<tr>
<td>15 Congenital anomalies</td>
<td>13-6 (10-17)</td>
<td>-5% (-15 to 2%)</td>
</tr>
<tr>
<td>16 Tuberculosis</td>
<td>15-7 (13-18)</td>
<td>-27% (-32 to -21%)</td>
</tr>
<tr>
<td>17 Iron-deficiency anemia</td>
<td>17-5 (14-21)</td>
<td>-12% (-14 to -10%)</td>
</tr>
<tr>
<td>18 Skin diseases</td>
<td>18-5 (13-24)</td>
<td>0% (-2 to 2%)</td>
</tr>
<tr>
<td>19 Lung cancer</td>
<td>18-5 (17-21)</td>
<td>-7% (-12 to -3%)</td>
</tr>
<tr>
<td>20 Chronic kidney disease</td>
<td>20-4 (18-23)</td>
<td>0% (-4 to 4%)</td>
</tr>
<tr>
<td>21 Self-harm</td>
<td>21-0 (18-25)</td>
<td>-17% (-25 to -8%)</td>
</tr>
<tr>
<td>22 Falls</td>
<td>24-0 (22-28)</td>
<td>-13% (-18 to -9%)</td>
</tr>
<tr>
<td>23 Neonatal sepsis</td>
<td>24-2 (17-36)</td>
<td>-6% (-21 to 13%)</td>
</tr>
<tr>
<td>24 Alzheimer disease</td>
<td>25-2 (23-28)</td>
<td>-2% (-6 to 1%)</td>
</tr>
<tr>
<td>25 Migraine</td>
<td>26-0 (18-39)</td>
<td>1% (-2 to 3%)</td>
</tr>
</tbody>
</table>

Legend:
Communicable, maternal, neonatal and nutritional
Non-communicable
Injuries
Together contributed to 10% of global mortality in 2013 – the 4th highest global risk factor

### Ambient PM$_{2.5}$
- 2.9 Million deaths in 2013

### Ozone
- 217,000 deaths in 2013
8,800 deaths/yr PM$_{2.5}$  680 deaths/yr ozone

Among top risk factors (#10 deaths, #11 DALYs)

BC Crude Estimate (population proportion):
1147 PM$_{2.5}$ + 87 Ozone


[http://vizhub.healthdata.org/gbd-compare](http://vizhub.healthdata.org/gbd-compare)
Avoidable deaths

<table>
<thead>
<tr>
<th>City</th>
<th>Deaths/yr</th>
<th>% attrib</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quebec</td>
<td>400</td>
<td>8</td>
<td>5 – 11</td>
</tr>
<tr>
<td>Montreal</td>
<td>1540</td>
<td>9</td>
<td>5 – 12</td>
</tr>
<tr>
<td>Ottawa</td>
<td>340</td>
<td>7</td>
<td>4 - 9</td>
</tr>
<tr>
<td>Toronto</td>
<td>1840</td>
<td>10</td>
<td>6 – 13</td>
</tr>
<tr>
<td>Hamilton</td>
<td>460</td>
<td>10</td>
<td>7 - 14</td>
</tr>
<tr>
<td>Windsor</td>
<td>260</td>
<td>9</td>
<td>6 - 12</td>
</tr>
<tr>
<td>Calgary</td>
<td>400</td>
<td>8</td>
<td>5 - 11</td>
</tr>
<tr>
<td>GVRD</td>
<td>680</td>
<td>5</td>
<td>3 – 7</td>
</tr>
<tr>
<td>Total</td>
<td>5900</td>
<td>8</td>
<td>5 - 11</td>
</tr>
</tbody>
</table>

• Anthropogenic air pollution
• Short & long-term (~ 70%) exposures
• 8 major Canadian cities

Health Canada, 2005
Estimates of Annual Mortality Burden of Air Pollution in BC (excludes radon)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>82</td>
<td>25-250</td>
<td>115-402</td>
<td>644</td>
<td>NA</td>
<td>71-110 (6)</td>
</tr>
</tbody>
</table>

$85 million annual healthcare costs

Table 5.6: Comparison of the Low-Intermediate Estimate Range for the Burden of Air Pollution and Other Causes of Mortality in British Columbia

<table>
<thead>
<tr>
<th>Cause</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor Air Pollution</td>
<td>25 - 250</td>
</tr>
<tr>
<td>Indoor Air Pollution</td>
<td>5 - 45</td>
</tr>
<tr>
<td>ETS Estimate (1998)</td>
<td>108</td>
</tr>
<tr>
<td>Total Air Pollution</td>
<td>138 - 403</td>
</tr>
<tr>
<td>Homicide</td>
<td>37</td>
</tr>
<tr>
<td>Cervical Cancer</td>
<td>43</td>
</tr>
<tr>
<td>AIDS</td>
<td>104</td>
</tr>
<tr>
<td>Motor Vehicle Accidents</td>
<td>399</td>
</tr>
<tr>
<td>Lung Cancer</td>
<td>2015</td>
</tr>
<tr>
<td>Female Breast Cancer</td>
<td>600</td>
</tr>
<tr>
<td>Cardiovascular Diseases (ICD I00-I51)</td>
<td>6893</td>
</tr>
<tr>
<td>Work-Related Deaths*</td>
<td>149</td>
</tr>
</tbody>
</table>

*Note: Work-related deaths reported by the Workers' Compensation Board (2003).
Global, Deaths attributable to Ambient particulate matter pollution
Both sexes, All ages, 2013

CANADA

<table>
<thead>
<tr>
<th>Cause</th>
<th>Deaths</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>IHD</td>
<td>4,229</td>
<td>8.0%</td>
</tr>
<tr>
<td>Stroke</td>
<td>1,214</td>
<td>6.9%</td>
</tr>
<tr>
<td>COPD</td>
<td>188</td>
<td>1.5%</td>
</tr>
<tr>
<td>Lung Cancer</td>
<td>2,515</td>
<td>12%</td>
</tr>
<tr>
<td>ALRI</td>
<td>651</td>
<td>7.5%</td>
</tr>
<tr>
<td>Total</td>
<td>8,796</td>
<td></td>
</tr>
</tbody>
</table>
What’s Missing?
Diseases on the cusp

- Asthma (2012 Workshop)
- Low birthweight / Pre-term birth
- Diabetes
Traffic-related air pollution (2009, 2015 Workshops)

Traffic-related air pollution and health in Canada

Michael Brauer ScD, Conor Reynolds PhD, Perry Hystad PhD
Near Roadway Air Pollution

Environ Health Perspect. 2015
300,000 Adult Canadians (CCHS) 8 – 11 year follow-up

No evidence of threshold above 1 μg/m³ minimum level

Policy Implications

• As a HEALTH issue, air pollution is among the leading modifiable risk factors
• Burden will increase with aging population and high prevalence of chronic diseases affected by air pollution
  – Future emphasis on identifying other high prevalence diseases affected by air pollution
• Steep exposure-response relationships down to near-background levels imply continued benefits of further improving air quality
Air pollution and climate co-benefits

• Air quality regulations benefit:cost ratios
  ~4:1 – 30:1
• Clean air rules responsible for majority of ALL estimated benefits (and costs) generated by Federal regulation
EXTRA SLIDES
Air pollution and health

• On **days** with worse air quality, more people die*
• In **more polluted cities**, people die earlier than in less polluted cities…
• …and, in the **most polluted areas** of cities, there is an increased risk of dying

*out-of-hospital, >65 yrs
2.5 million Canadians, 16-year follow-up (1991 – 2006)

300,000 Adult Canadians (CCHS)
8 – 11 year follow-up

No evidence of threshold above 1 µg/m³ minimum level

2.1 million non-immigrant Canadians
(1991 long-form Census)

Mortality

Total
(Nonaccidental)

Cardiovascular

IHD

Cerebrovascular

2013 Annual Average PM$_{2.5}$

87% global population in areas exceeding WHO Air Quality Guideline (10 μg/m$^3$ PM$_{2.5}$ annual average)
1990 – 2013 Change in Annual Average PM$_{2.5}$
2013 Seasonal Maximum O$_3$

Seasonal (3-month) hourly maximum ozone concentration (ppb)

- 0 - 15
- 15 - 30
- 30 - 45
- 45 - 60
- 60 - 75
General approach

- Define risk factor (exposure metrics: $PM_{2.5}$, $O_3$)
- Estimate exposure ($P$)
- Select health outcomes
  - Systematic reviews
  - Weight of evidence
  - Meta analyses
- Exposure – response functions (RR)
- Counterfactual ($P'$)

\[
P_{AF} = \frac{\int_{x=0}^{m} RR(x)P(x)dx - \int_{x=0}^{m} RR(x)P'(x)dx}{\int_{x=0}^{m} RR(x)P(x)dx}
\]
Population attributable fraction

\[ PAF = \frac{\int_{x=0}^{m} RR(x)P(x)dx - \int_{x=0}^{m} RR(x)P'(x)dx}{\int_{x=0}^{m} RR(x)P(x)dx} \]

- RR, relative risk at each exposure level
- \( m \), maximum exposure level
- \( P \), proportion of population at each exposure level
- \( P' \), counterfactual proportion of population at each exposure level

Population Attributable Fraction: sex, age, country, time
<table>
<thead>
<tr>
<th>Study</th>
<th>PM$_{2.5}$ Mean (µg/m$^3$)</th>
<th>PM$_{2.5}$ Min (µg/m$^3$)</th>
<th>IHD HR /10 µg/m$^3$ (95% CI)</th>
<th>CEV HR /10 µg/m$^3$ (95% CI)</th>
<th>COPD HR /10 µg/m$^3$ (95% CI)</th>
<th>LC HR /10 µg/m$^3$ (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Cancer Society$^a$</td>
<td>14.2</td>
<td>5.8</td>
<td>1.26 (1.16-1.38)</td>
<td>1.12 (1.01-1.24)</td>
<td>1.05 (0.95-1.17)</td>
<td>1.14 (1.06-1.23)</td>
</tr>
<tr>
<td>(ACS)</td>
<td>N=486133</td>
<td></td>
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<tr>
<td>Six City$^b$ (SCS)</td>
<td>17.8</td>
<td>8.7</td>
<td>1.33 (1.16-1.52)</td>
<td>0.89 (0.67-1.18)</td>
<td>1.17 (0.85-1.62)</td>
<td>1.37 (1.07-1.75)</td>
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<tr>
<td>N=8096</td>
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<tr>
<td>California Teachers$^c$ (CTS)</td>
<td>15.6</td>
<td>3.1</td>
<td>1.20 (1.02-1.41)</td>
<td>1.16 (0.92-1.46)</td>
<td>1.21 (0.88-1.68)</td>
<td>0.95 (0.70-1.38)</td>
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<tr>
<td>N=73,498</td>
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<tr>
<td>Adventist Study of Health and Smog$^d$ (ASHSmog)</td>
<td>29.0</td>
<td>12.9</td>
<td>15.0/45.1 (0.87-1.15)</td>
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<tr>
<td>N=3,230</td>
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<tr>
<td>Dutch Study of Diet and Cancer$^e$ (DSDC)</td>
<td>28.3</td>
<td>23.0</td>
<td>24.8/31.8 (0.75-1.22)</td>
<td>1.62 (1.07-2.44)</td>
<td>1.06 (0.82-1.38)</td>
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<tr>
<td>N=120,852</td>
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<tr>
<td>Male Health Professionals$^f$ (MHP)</td>
<td>17.9</td>
<td>5.8</td>
<td>12.3/23.4 (0.71-1.36)</td>
<td>0.98 (0.71-1.36)</td>
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<td>N=17,545</td>
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<tr>
<td>Nurses Health$^g$ (NHS)</td>
<td>13.9</td>
<td>5.8</td>
<td>10.0/17.8 (1.07-3.78)</td>
<td>2.02 (1.17-4.16)</td>
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<tr>
<td>N=66,250</td>
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<tr>
<td>Women’s Health Initiative$^h$ (WHI)</td>
<td>13.5</td>
<td>3.4</td>
<td>7.4/19.6 (1.17-4.16)</td>
<td>2.21 (1.11-3.00)</td>
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<tr>
<td>N=65,893</td>
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<tr>
<td>Canadian Census Health &amp; Environment Cohort$^i$ (CanCHEC)</td>
<td>8.7</td>
<td>2.1</td>
<td>3.6/13.8 (1.18-1.43)</td>
<td>1.30 (0.93-1.16)</td>
<td>1.04 (0.95-1.26)</td>
<td></td>
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<tr>
<td>N=2,145,400</td>
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</tr>
<tr>
<td>Canadian National Enhanced Cancer Surveillance System Cohort (NECSS)$^j$</td>
<td>11.9</td>
<td>3.8</td>
<td>6.7/16.8 (0.81-1.29)</td>
<td>1.43 (1.00-1.79)</td>
<td></td>
<td>1.29 (0.85-1.62)</td>
</tr>
<tr>
<td>N=5458</td>
<td></td>
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</tr>
<tr>
<td>English Cohort$^k$ (ENDOCC)</td>
<td>12.9</td>
<td>5.8</td>
<td>10.6/15.2 (0.81-1.29)</td>
<td>1.00 (0.81-1.29)</td>
<td>1.43 (1.00-1.79)</td>
<td>1.11 (0.88-1.43)</td>
</tr>
<tr>
<td>N=835,607</td>
<td></td>
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</tr>
<tr>
<td>Agricultural Health Study$^l$</td>
<td>5.7</td>
<td>3.1</td>
<td>7.3/12.6 (1.04-6.87)</td>
<td>2.68 (1.04-6.87)</td>
<td>0.78 (0.72-4.42)</td>
<td>0.75 (0.34-1.65)</td>
</tr>
</tbody>
</table>
Key assumption
Risk is function of PM$_{2.5}$ inhaled dose regardless of source

Extrapolation model
• reflect change in risk observed in cohort studies at low concentrations
• near-linear at low concentrations
• predict risk for highest PM$_{2.5}$ consistent with risks from smoking (Pope et al. 2011)