Air Quality and Health: Beyond the Lungs and Heart

Jay R. Turner

Energy, Environmental and Chemical Engineering
Washington University in St. Louis / USA

East-West Gateway Council of Governments
Air Quality Advisory Committee

Image: power plant stacks and plumes as seen from aloft, wintertime in Ulaanbaatar, Mongolia
Quantifying Burden of Disease
Disability Adjusted Life Year (DALY)

DALY
Disability Adjusted Life Year is a measure of overall disease burden, expressed as the cumulative number of years lost due to ill-health, disability or early death.

\[ \text{DALY} = \text{YLD} + \text{YLL} \]

- \( \text{YLD} \): Years Lived with Disability
- \( \text{YLL} \): Years of Life Lost

Healthy life  
Disease or Disability  
Early death  
Expected life years
Air Quality in Context - China

Burden of disease attributable to 15 leading risk factors in 2010, expressed as a percentage of China's GBD DALYs.

Top Five Risk Factors

DALY = disability adjusted life years

84 risk factors, 481 risk-outcome pairs

Top five risk factors account for 44% of total burden

Air pollution (ambient and household combined) ranks 5th with ~7% of DALYs

After stratifying by socio-demographic index (SDI), air pollution ranks are:
- High SDI – 10th
- Middle SDI – 6th
- Low SDI – 2nd

Data from E. Gakidou et al. (2017) Lancet 390: 1345-1422
Fine Particulate Matter Air Pollution
Annual Average (2005)

Spectrum of Particulate Matter (PM) Health Effects

Historical focus…

• Pulmonary
• Cardiovascular
• Cardiopulmonary

• **exposures**: short term (acute) versus long term
• **endpoints**: mortality [death] vs. morbidity [disease]
Respiratory Emergency Department Visits and Ambient Air Pollutants in St. Louis

Asthma/Wheeze

June 2001 – April 2003

**Gases**
- O$_3$ = ozone (8-hr max)
- CO = carbon monoxide (1-hr max)
- NO$_2$ = nitrogen dioxide (1-hr max)
- SO$_2$ = sulfur dioxide (1-hr max)

**Fine Particles (PM2.5) (24-hr avg)**
- PM2.5 = total mass
- SO$_4$ = sulfate ion
- NO$_3$ = nitrate ion
- OC = organic carbon
- EC = elemental carbon

Risk ratio per interquartile range:
- O$_3$: 0.90
- CO: 0.95
- NO$_2$: 1.00
- SO$_2$: 1.05
- PM2.5: 1.10
- SO$_4$: 1.15
- NO$_3$: 1.20
- OC: 1.25
- EC: 1.30

Cardiovascular Emergency Department Visits and Ambient Air Pollutants in St. Louis

Congestive Heart Failure

June 2001 – April 2003

Gases
O3 = ozone (8-hr max)
CO = carbon monoxide (1-hr max)
NO2 = nitrogen dioxide (1-hr max)
SO2 = sulfur dioxide (1-hr max)

Fine Particles (PM2.5) (24-hr avg)
PM2.5 = total mass
SO4 = sulfate ion
NO3 = nitrate ion
OC = organic carbon
EC = elemental carbon ("soot")

Ambient PM and Cardiovascular Effects

Numerous mechanisms, e.g.
- Proinflammatory responses, e.g. plasma fibrinogen formation
- Reactive oxidant species (ROS) causing oxidative stress

Leading to numerous impacts, e.g.
- Chronic: systemic inflammation $\rightarrow$ atherosclerosis
- Acute: systemic inflammation $\rightarrow$ blood clots

Long-term exposure to PM$_{2.5}$ increases the risk of nonaccidental mortality by 6% per a 10 $\mu$g/m$^3$ increase, independent of age, gender, and geographic region (Chen et al., 2008)
Air Pollution and Neurodegenerative Effects: Dementia (including Alzheimer’s Dementia)

Epidemiology Studies

- Cognitive level
- Neuroimaging marker status
- Cognitive change
- Incident dementia or poor cognition
- Time series and hospital admissions

Biological Plausibility

- PM can reach the brain via circulation (bypass blood-brain-barrier) or by direct translocation through the olfactory bulb
- Cardiovascular and cerebrovascular disease appear to promote cognitive decline and dementia

Review by Power et al. (2016)
Air Pollution and Neurodegenerative Effects: Dementia (including Alzheimer’s Dementia)

Example...

Cognitive decline in older women (70-81 years old) in the Nurses’ Health Study Cognitive Cohort

Conclusion: “a 10-μg/m3 increment in long-term PM exposure is cognitively equivalent to aging by approximately 2 years”

Weuve et al. (2012)
Airborne Manganese and Motor/Cognitive Impacts

oxides of manganese particles

Dr. Brad Racette, Washington University School of Medicine, Project Principal Investigator
Air Pollution and Neurodevelopmental Effects: Autism Spectrum Disorder (ASD)

- Evidence of toxicity scale
  - evidence of lack of toxicity
  - inadequate evidence of toxicity
  - limited evidence of toxicity
  - sufficient evidence of toxicity

- Currently “limited evidence” for early life exposure to air pollution as a whole and diagnosis of ASD

- The strongest evidence between prenatal exposure to particulate matter and ASD (PM$_{10}$, n=6; PM$_{2.5}$, n=3)

Review and meta-analysis by Lam et al. (2016)
More Broadly: Air Pollution and Birth Outcomes

Associations between maternal PM$_{2.5}$ exposures and:

- Pre-term birth
- Term low birth weight

Example

- Prenatal PM$_{2.5}$ exposure and *intrauterine inflammation*, a risk factor for preterm birth and neurodevelopmental outcomes (for example, affecting development of the placenta)

Nachman *et al.* (2016)
Air Pollution and Intrauterine Inflammation (Boston Birth Cohort)

Odds ratios by PM$_{2.5}$ exposure quartile

Nachman et al. (2016)
**Air Pollution and Kidney Disease**

Dr. Ziyad Al-Aly group, Washington University School of Medicine (among other affiliations)

**Particulate Matter Air Pollution and the Risk of Incident CKD and Progression to ESRD**

**METHODS**
- Observational cohort of 2,482,737 US Veterans followed for 8.52 years.
- Fine particulate matter (<2.5 μm in aerodynamic diameter (PM$_{2.5}$)) exposure data:
  - EPA ground-based air monitoring stations
  - NASA satellites spaceborne sensors

**OUTCOMES**
- Increase in Risk of Kidney Outcomes for Every 10 Increase in PM$_{2.5}$ (μg/m$^3$)
- National Burden of Incident CKD Attributable to PM$_{2.5}$ Exposure Above the EPA recommended level of 12 μg/m$^3$

CONCLUSION: Our findings demonstrate a significant association between exposure to ambient PM$_{2.5}$ and risk of incident CKD, eGFR decline, and ESRD.

B. Bowe et al. (2017) Journal of the American Society of Nephrology, 28 (preprint)
In the Recent Press…

Does Eating Right Protect You From Air Pollution?

Moises Velasquez-Manoff
New York Times
October 19, 2017

Credit: Kelsey Wroten for the New York Times