9B: Outdoor Air

Meghan F. Davis, DVM MPH PhD
Assistant Professor
Environmental Health and Engineering
mdavis65@jhu.edu
Learning Objectives

• Describe differences between indoor and outdoor air
• Identify typical outdoor air pollutants and their sources
• Describe diseases linked to outdoor air pollution
Time spent outdoors (2019, n=187)

The class spent 6% more time outdoors on a weekend (Sat-Sun) than a weekday, but this was not statistically significant.
Daily steps (2019, \( n=187 \))

The class took, on average, 1939 more steps for a weekend day (Sat-Sun) versus a weekday (Mon-Fri), \( p<0.03 \).
PM$_{2.5}$ exposures (2019, $n=187$)

There were no significant differences in ambient PM$_{2.5}$ for weekend versus weekday reports, but many exposures were high.
West Coast U.S., July 21, 2018

Wildfire Smoke Plume

Fire Conditions
www.airnow.gov
Beijing smog

Pre-Olympics

During 2008 Summer Olympics

Image: Princeton
Air Pollution

• Group 1 known human carcinogen (IARC/WHO 2013)
• Cause of mortality for one in nine total global deaths
  • ~7 million people died prematurely (WHO 2014)
Outdoor vs. Indoor Air

Indoor air pollution-caused deaths:
• 34% - stroke
• 26% - ischemic heart disease
• 22% - COPD
• 12% - acute lower respiratory infections in children
• 6% - lung cancer

Outdoor air pollution-caused deaths:
• 40% – ischemic heart disease
• 40% – stroke
• 11% – chronic obstructive pulmonary disease (COPD)
• 6% – lung cancer
• 3% – acute lower respiratory infections in children
Outdoor vs. Indoor Air

Indoor air pollution-caused deaths:

• 34% - stroke
• 26% - ischemic heart disease
• 22% - COPD
• 12% - acute lower respiratory infections in children
• 6% - lung cancer

Outdoor air pollution-caused deaths:

• 40% – ischemic heart disease
• 40% – stroke
• 11% – chronic obstructive pulmonary disease (COPD)
• 6% – lung cancer
• 3% – acute lower respiratory infections in children
Mortality from air pollution

REGIONAL ESTIMATES ACCORDING TO WHO REGIONAL GROUPINGS:

- Over 2 million in South-East Asia Region
- Over 2 million in Western Pacific Region
- Nearly 1 million in Africa Region
- About 500,000 deaths in Eastern Mediterranean Region
- About 500,000 deaths in European Region
- More than 300,000 in the Region of the Americas

CLEAN AIR FOR HEALTH #AirPollution
Sources of air pollution

Biogenic sources

Outdoor air pollution affects urban and rural areas and is caused by multiple factors:

- Industry & Energy Supply
- Transport
- Waste Management
- Dust
- Agricultural Practices
- Household Energy

Anthropogenic sources
Prelude to regulation

Great Smog of London (1952)
• Prior “Pea Souper” events
• Worst air pollution event in U.K.
• Climate x pollution emissions
• 4,000-12,000 people died
• Led to the U.K. Clean Air Act of 1956


Image: The Guardian
Inversion layer

Arrows show air flow in normal conditions on the left and during temperature inversion on the right. In normal conditions, warm air rises and normal convective patterns persist. During temperature inversion, the warm air acts as a cap, effectively shutting down convection and trapping smog over the city.

Image: Weather Understory
London Fog (December 1952)

Pollution Concentration (mg/m³)

Deaths per day

- Smoke (mg/m³)
- Sulfur Dioxide
- Deaths/Day

10,000 excess deaths

December 1952
U.S. Clean Air Act

- Classified air pollutants
- Criteria Air Pollutants (CAPs)
  - PM, SO$_2$, NO$_2$, O$_3$, CO, Pb
  - Ubiquitous (wide-spread)
  - Less toxic
Criteria Air Pollutants (CAPs)

- Many sources of emissions
  - Both mobile and stationary sources
- Ubiquitous
  - Large number of people exposed
- Assumption that the adverse health events are non-cancerous
  - Dose-response relationship
  - Threshold
- Regulated via NAAQS
  - National Ambient Air Quality Standards
- Require “adequate” margins of safety
## NAAQS Standards 1

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging Time</th>
<th>Level</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carbon Monoxide (CO)</strong></td>
<td>8 hours</td>
<td>9 ppm</td>
<td>Not to be exceeded more than once per year</td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td>35 ppm</td>
<td></td>
</tr>
<tr>
<td><strong>Lead (Pb)</strong></td>
<td>Rolling 3 month average</td>
<td>0.15 μg/m³ (1)</td>
<td>Not to be exceeded</td>
</tr>
<tr>
<td><strong>Nitrogen Dioxide (NO₂)</strong></td>
<td>1 hour</td>
<td>100 ppb</td>
<td>98th percentile of 1-hour daily maximum concentrations, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>53 ppb (2)</td>
<td>Annual Mean</td>
</tr>
<tr>
<td><strong>Ozone (O₃)</strong></td>
<td>3 hours</td>
<td>0.5 ppm</td>
<td>Not to be exceeded more than once per year</td>
</tr>
</tbody>
</table>
# NAAQS Standards 2

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging Time</th>
<th>Level</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particle Pollution (PM)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>1 year</td>
<td>12.0 μg/m$^3$</td>
<td>annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>15.0 μg/m$^3$</td>
<td>annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>24 hours</td>
<td>35 μg/m$^3$</td>
<td>98th percentile, averaged over 3 years</td>
</tr>
<tr>
<td><strong>PM$_{10}$</strong></td>
<td>24 hours</td>
<td>150 μg/m$^3$</td>
<td>Not to be exceeded more than once per year on average over 3 years</td>
</tr>
<tr>
<td><strong>Sulfur Dioxide (SO$_{2}$)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td>75 ppb $^{(4)}$</td>
<td>99th percentile of 1-hour daily maximum concentrations, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>3 hours</td>
<td>0.5 ppm</td>
<td>Not to be exceeded more than once per year</td>
</tr>
</tbody>
</table>
PM$_{2.5}$ exposures (2019, $n=187$)

NAAQS PM2.5 24-hour standard

88% above NAAQS
U.S. Clean Air Act

- Classified air pollutants
- Criteria Air Pollutants (CAPs)
  - PM, SO₂, NO₂, O₃, CO, Pb
  - Ubiquitous (wide-spread)
  - Less toxic
- Hazardous Air Pollutants (HAPs)
  - Sources more limited (industry specific)
  - More toxic
  - Hundreds of chemicals
    - Benzene, formaldehyde, many more
Hazardous Air Pollutants (HAPs)

- More toxic than CAPs
  “may reasonably be expected to result in serious irreversible disease, including cancer”
- 188 chemicals specified via a 1990 amendment to the CAA
  - Heavy metals (e.g. chromium)
  - Organics (e.g. benzene)
- Establish site-specific emissions standards
  - Require “ample” (not merely “adequate”) margins of safety
  - CAPs are (differently) regulated via air concentration standards
U.S. Clean Air Act

- Classified air pollutants
- Criteria Air Pollutants (CAPs)
  - PM, SO$_2$, NO$_2$, O$_3$, CO, Pb
  - Ubiquitous (wide-spread)
  - Less toxic
- Hazardous Air Pollutants (HAPs)
  - Sources more limited (industry specific)
  - More toxic
  - Hundreds of chemicals
    - Benzene, formaldehyde, many more
- Uniform standards that protect susceptible subpopulations
Susceptible subpopulations

• Sulfur dioxide (SO₂) – CAP
  • Persons with increased airway reactivity
  • Respiratory irritation
• Carbon monoxide (CO) – CAP
  • Persons with coronary artery disease
  • Fatigue, headache
• Lead (Pb) – CAP
  • Fetuses and children
  • Developmental disorders
Transport & Transformation of Air Pollutants

Sources
   Area
   Point-source
   Mobile

Primary Pollutants
   SO$_2$, NO$_2$, CO, PM

Secondary Pollutants
   O$_3$, Acid Aerosols
Air Pollutant Transformation

Ozone Formation

$\text{Hydrocarbons (VOCs)} + \text{NO}_2 \xrightarrow{\text{sunlight}} \text{O}_3$

Formation of Fine Particles (droplet aerosols)

$\text{SO}_2$ gas $\xrightarrow{\text{atmospheric oxidation}} \text{H}_2\text{SO}_4$ particle
Wet v. Dry Deposition

- Emissions
- SO₂
- Various reactions lead to the formation of acids
- Acids are incorporated into clouds
- Precipitation or rain-out
- Wet Deposition
Accumulation of pollutants
Global African Dust Transport
U.S. Dust Bowl

- 1930s
- Great Depression
- Drought + high winds
- Agricultural mechanization
  - Ecosystem destruction

Size of Particulate Matter (PM)

- Fine Particles
  - pollen
  - milled flour
  - coal dust
  - fly ash
  - insecticide dusts
  - cement dust
  - bacteria
  - paint pigments
  - sea salt nuclei
  - oil smoke
  - combustion nuclei
  - tobacco smoke
  - photochemical smog
  - carbon black
  - viruses
  - metallurgic dust and fumes

- Medium Particles
  - Nose
  - Lung Parenchyma
  - Trachea and Bronchi

- Large Particles

Graph showing the percentage deposited for different particle diameters.
PM

Nucleation → Condensation → Coagulation → Vapor

Mechanically generated

Nuclei mode → Accumulation mode → Coarse mode

Fine particles → Total suspended particulate matter → Coarse particles

Half-life: <1/2 hour → 1-2 weeks → <1 hour

A CENTURY OF SAVING LIVES—MILLIONS AT A TIME 1916/2016

© 2015/2016, Johns Hopkins University. All rights reserved.
Respiratory Deposition of PM

Adapted from Annals of American Conference of Governmental Hygienists, Vol. 11
Mechanisms of PM Deposition

A. Sedimentation

B. Inertia

C. Diffusion
### Particle Deposition in the Lung

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Respiratory rate</th>
<th>Deposition process</th>
<th>Deposition site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>High</td>
<td>Impaction</td>
<td>Large airways</td>
</tr>
<tr>
<td>Coarse</td>
<td>Low</td>
<td>Sedimentation</td>
<td>Large and smaller airways</td>
</tr>
<tr>
<td>Fine</td>
<td>High</td>
<td>Diffusion</td>
<td>Large and smaller airways</td>
</tr>
<tr>
<td>Fine</td>
<td>Low</td>
<td>Diffusion</td>
<td>Alveoli</td>
</tr>
</tbody>
</table>
PM$_{2.5}$ Exposure

Scott L. Zeger, Francesca Dominici, Aidan McDermott, Jonathan M. Samet
PM$_{2.5}$ Mortality

**Table 3.** Percentage increase (95% CI) in mortality rate per 10-$\mu$g/m$^3$ increase in PM$_{2.5}$ from the log-linear regression model and stratified by three regions, and relative risks for three levels of adjustment for demographic and socioeconomic variables.

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>Eastern ($n = 2,938$ ZIP codes)</th>
<th>Central ($n = 990$ ZIP codes)</th>
<th>Western ($n = 640$ ZIP codes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>15.5 (13.0 to 18.0)</td>
<td>17.8 (13.3 to 22.2)</td>
<td>0.3 (−1.9 to 2.5)</td>
</tr>
<tr>
<td>Age + SES</td>
<td>10.5 (8.4 to 12.5)</td>
<td>8.9 (5.2 to 12.5)</td>
<td>−0.3 (−2.2 to 1.6)</td>
</tr>
<tr>
<td>Age + SES + COPD</td>
<td>6.8 (4.9 to 8.7)</td>
<td>13.2 (9.5 to 16.9)</td>
<td>−1.1 (−3.0 to 0.8)</td>
</tr>
</tbody>
</table>

Scott L. Zeger, Francesca Dominici, Aidan McDermott, Jonathan M. Samet
Global Urban PM$_{2.5}$

Concentration of particulate matter with an aerodynamic diameter of 2.5 µm or less (PM2.5) in nearly 3000 urban areas*, 2008–2015

* The mean annual concentration of fine suspended particles of less than 2.5 microns in diameters is a common measure of air pollution.

The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Information Evidence and Research (IER)
World Health Organization

© WHO 2016. All rights reserved.
Other health effects of PM

• Acute
  • Lung function decrements (FEV₁)
  • Cardiovascular
  • Respiratory irritation
• Chronic
  • Impaired lung growth (spirometry)
  • Accelerated lung aging
• Cancer
Good news: regulation works

The Trump Administration and the Environment—Heed the Science
Jonathan Samet, Thomas Burke, and Bernard Goldstein
NEJM 2017

Figure 1. Changes in Concentrations of Criteria Pollutants, 1990–2015.
Data are from the EPA (https://gispub.epa.gov/air/trendsreport/2016/).
NAAQS denotes National Ambient Air Quality Standards.
Key Points

• Air pollutants may be man-made or of natural origin
• Particulates are aerosols (suspensions of particle or liquid droplets in air) and include dust, mist, smoke, and smog
• The U.S. Clean Air Act focuses on protection of susceptible subpopulations
• Criteria Air Pollutants are ubiquitous but not very toxic
  • PM, SO₂, NO₂, O₃, CO, Pb
  • Primary pollutants can be precursors to secondary pollutants
• Hazardous Air Pollutants are less widespread but more toxic
• Particle size and respiratory rate influence where particles deposit in the airways and by what mechanism