Respiratory Effects of Air Pollution

J. Daryl Thornton, MD, MPH

March 3, 2021

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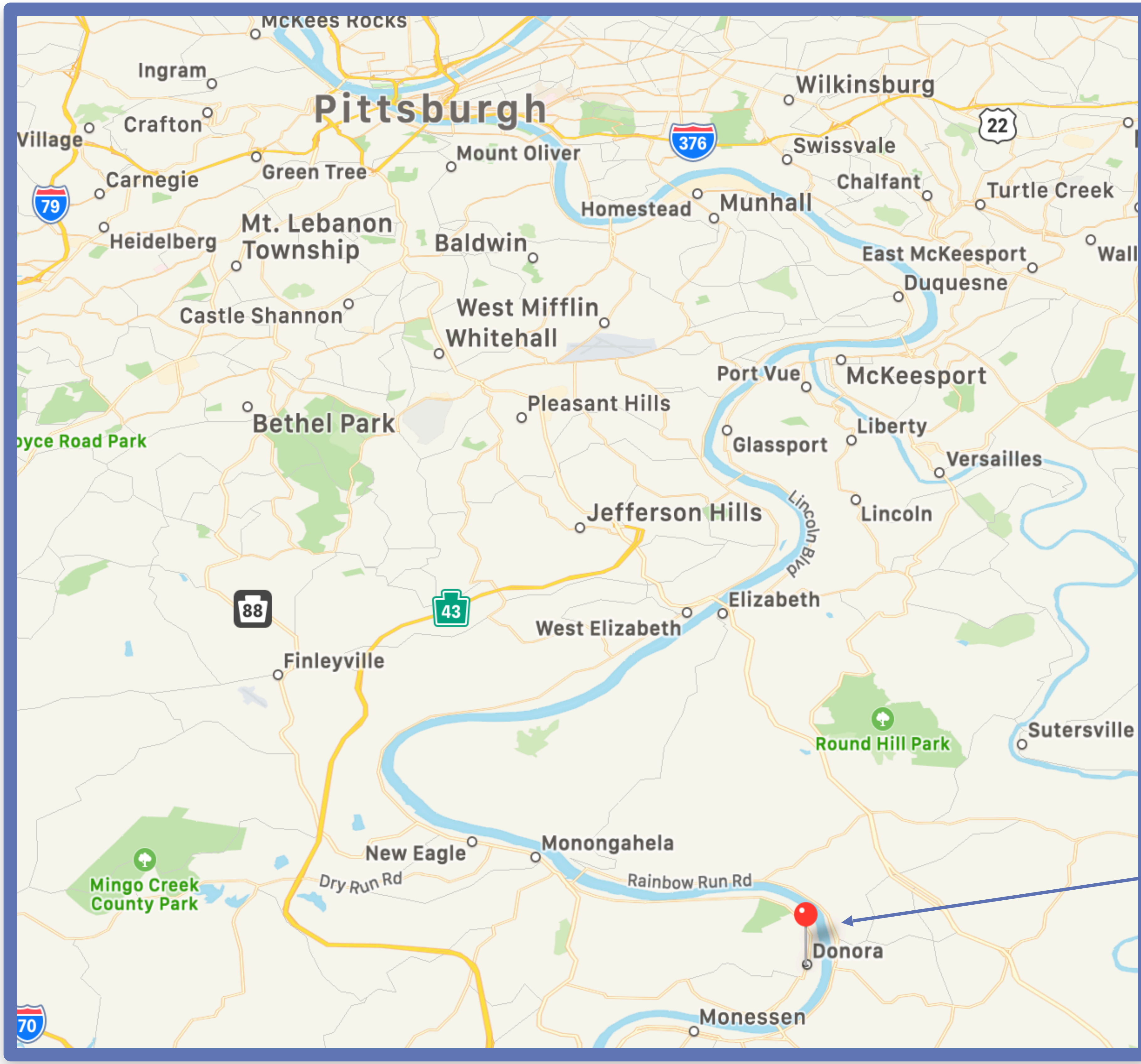

Monogahela River

Donora, Pennsylvania

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Donora, Pennsylvania
Home to zinc plant and steel mill both run by the US Steel Corporation
January 1, 1948

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https://www.npr.org/templates/story/story.php?storyId=103359330, 4/22/2009

Donora Smog

- October 26, 1948
- Temperature inversion: 5 days of thick-yellow fog
  - ½ town developed acute respiratory difficulties and almost 40 died (28%)
  - Steel mill stopped operations on October 30 as the weather improved
- Hotel became a secondary hospital and morgue
- State DOH, United Steelworkers, Donora Borough Council and US Public Health Service (PHS) jointly met
  - First coordinated US effort to document health impacts of air pollution
- Key in creation of 1970 Clean Air Act & EPA
- US Steel & PHS conducted air analysis during the fog
  - No records are available from either group

http://old.post-gazette.com/magazine/19981029smog1.asp, 10/29/1998
https://www.npr.org/templates/story/story.php?storyId=103359330, 4/22/2009

What is Air Pollution?

- The introduction of chemicals, particulate matter, or biologic materials that cause harm or discomfort to humans or other living organisms, or damage the natural environment, into the atmosphere.

- Both indoor and outdoor air pollution contribute to adverse effects on lung health in humans (adults and children).

Ko *Clin Pulm Med* 2010; 17:300

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Environmental Protection Agency (EPA)

- 1970, President Nixon presented Congress with a 37-point message on the environment requesting:
  - $4 billion for improvement of water treatment
  - National air quality standards and guidelines to reduce motor vehicle emissions
  - Clean-up of federal facilities that fouled air and water
  - Legislation to end dumping of wastes into the Great Lakes
  - Tax on lead additives to gas
  - National Contingency Plan for treatment of oil spills
  - Consolidation of federal environmental responsibilities into 1 agency

Air Quality Index (AQI)

- EPA's index for reporting and forecasting daily air quality
- Reports on the 4 most common ambient air pollutants that are regulated under the Clean Air Act
  1. Ground-level ozone
  2. Particle pollution (PM_{10} & $PM_{2.5}$)
  3. Carbon monoxide (CO)
  4. Sulfur dioxide (SO_2)
- Focuses on health effects that may be experienced within a few hours or days after breathing polluted air

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"Learn About Particle Pollution and Your Patient's Health Course" 2021 (www.epa.gov/pmcourse)

Air Quality Index
(Continued)

- Created 1976, last updated 1999
- Populations > 350,000 required to report it daily

AQI Basics for Ozone and Particle Pollution

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

- Runs from 0 to 500

www.AirNow.gov 2021

Clean Air Act

- Originally passed in 1963 to fund the study and cleanup air pollution
  - No comprehensive federal response
- Revised in 1970
  - Regulates air emissions from stationary and mobile sources
  - Authorizes EPA to establish National Ambient Air Quality Standards (NAAQS)
    - Goal to set and achieve NAAQS in every state by 1975
      - Amended in 1977 and again in 1990 to set new deadlines since many areas of the country failed to meet them

www.epa.gov 2021

Legacy of the Clean Air Act

Since 1970...

- Pros
  - 6 commonly found air pollutants have decreased by 50%
  - Air toxins from large industrial sources have decreased by 70%
  - New cars are 90% cleaner
  - Production of most ozone-depleting chemicals has ceased
- Cons
  - Energy consumption has increased by 50%
  - Vehicle use has increased by 200%

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Who is Most Affected by Pollution?

- < 18 years of age or > 65 years of age
- Co-morbid conditions
    - Heart or lung diseases (e.g. asthma & COPD)
    - Diabetes
- Lower socio-economic status

Air Pollution is Deadly!

- Air pollution contributes to 6% of total mortality
  - 40,000 attributable cases each year
  - 50% of mortality from air pollution is due to motorized traffic
- Morbidity
  - 25,000 cases of chronic bronchitis in adults
  - 290,000 episodes of bronchitis in children
  - 500,000 asthma attacks
  - > 16 million person-days of restricted activity

Künzli *Lancet* 2000; 356:795

Global Burden of Unhealthy Environments

- 13.7 million (24% of all estimated) global deaths are linked to the environment
- 3.8 million deaths every year as a result of exposure to indoor smoke from cooking fuels
- 4.2 million deaths every year as a result of exposure to fine particulate matter

www.who.int/gho/data/themes/public-health-and-environment 2021

Pollutants

Ground-level Ozone

- Primary component of smog
- Main ingredients:
  - *Volatile organic compounds (VOCs)*
    - Released by cars burning gasoline, petroleum refineries, chemical manufacturing plants, & other industrial facilities
    - Paint solvents and other consumer / business products
    - 1990 Clean Air Act resulted in changes to reduce VOC
  - *Nitrogen oxides (NO_x)*
    - Reddish-brown color of smog
    - Produced when cars and other sources burn fuels
    - High doses acutely causes lung injury & decreased pulmonary defense
    - Low indoor exposure can potentiate allergen exposure

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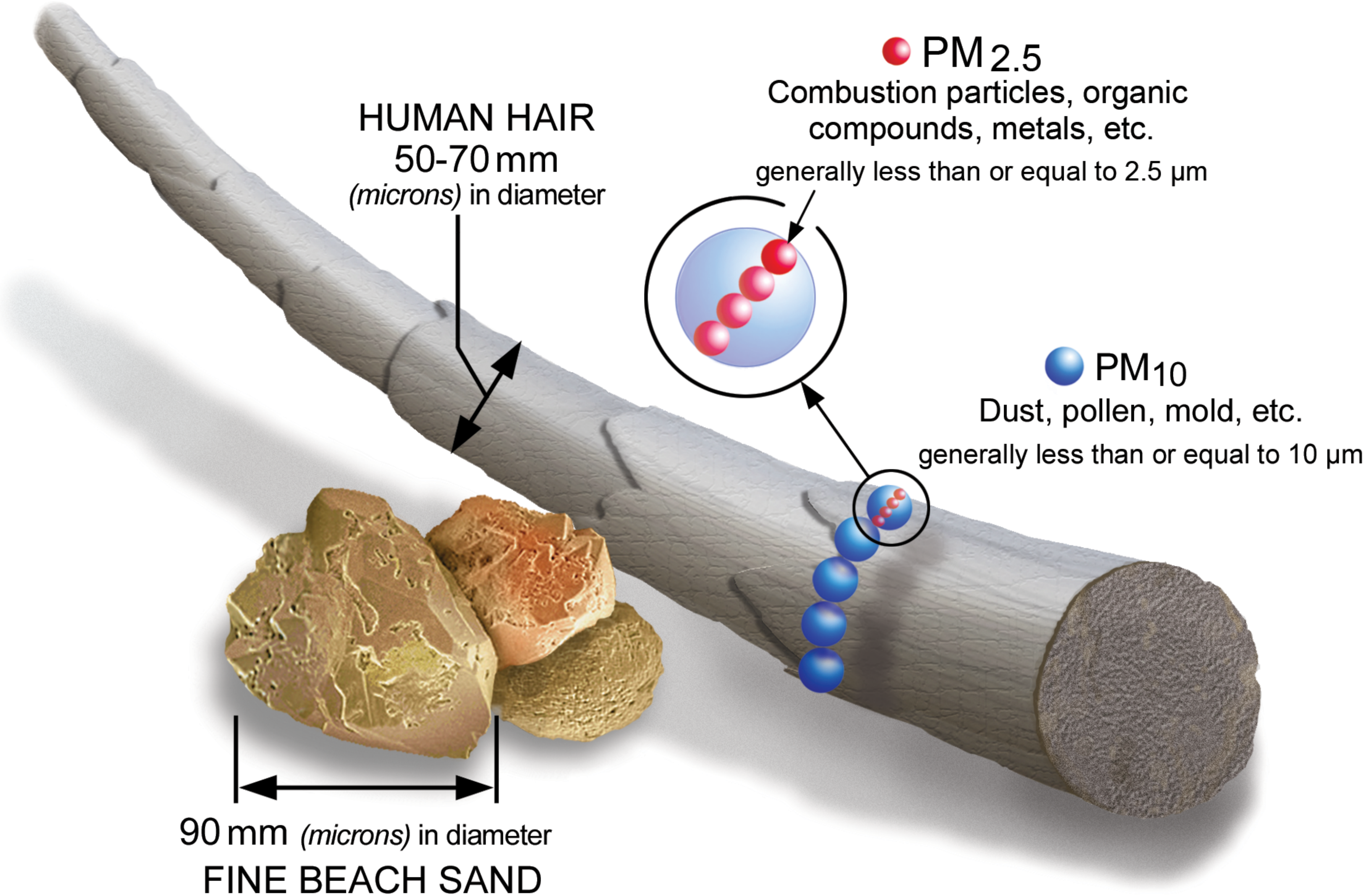
Particulate Matter (PM)
AKA Particle Pollution

- Very small (< 10 micron diameter), fine (< 2.5 micron diameter) or ultra fine (< 0.1 micron) particles
  - Size allows them to can get deep into the lungs, brain, & heart
- Includes the very fine dust, soot, smoke, and droplets produced when fuels (coal, wood, or oil) are burned
  - Created when SO_2 and NO_2 from motor vehicles, electric power generation, & industrial facilities react with sunlight and water vapor to form particles
  - May come from fireplaces, wood or gas stoves, unpaved roads, crushing and grinding operations, or wind
- Cause haze by reducing visibility
- Can travel extremely long distances


PM 2.5
Combustion particles, organic compounds, metals, etc.
generally less than or equal to 2.5 µm
HUMAN HAIR
50-70 mm
(microns) in diameter
PM10
Dust, pollen, mold, etc.
generally less than or equal to 10 µm
90 mm (microns) in diameter
FINE BEACH SAND

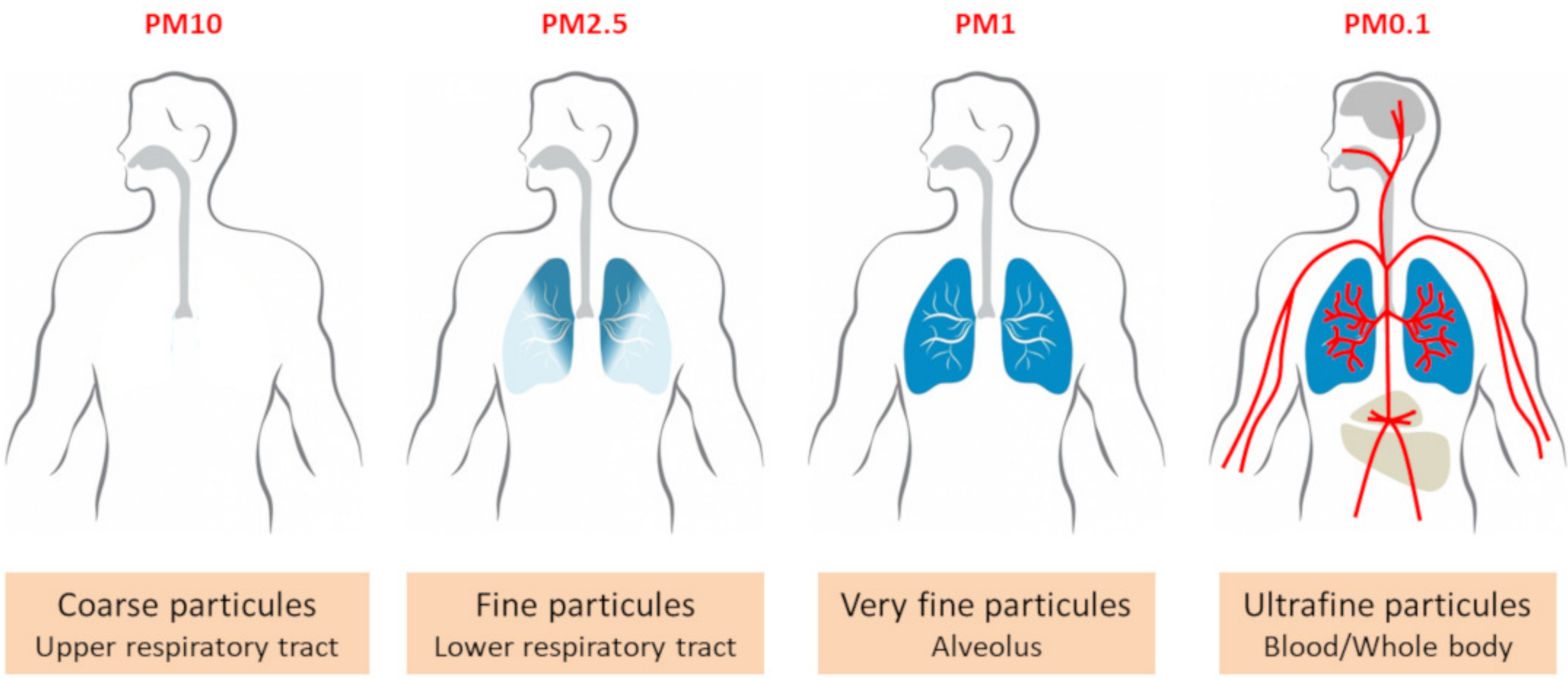
Standards of Pollutants

National Ambient Air Quality Standards

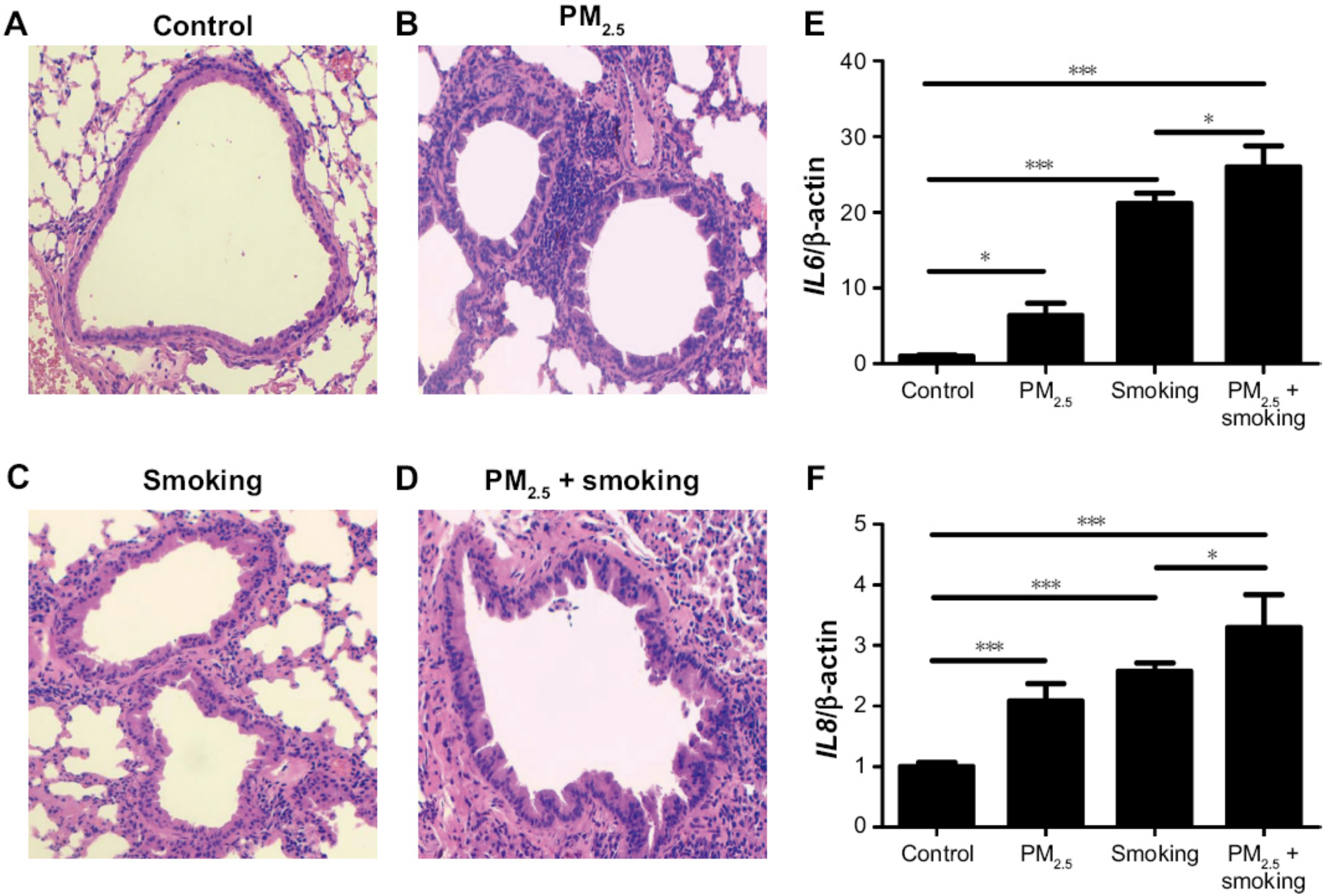
Pollutant	Level
Carbon Monoxide	35 ppm (1 hour)
Nitrogen Dioxide (NO_2)	53 ppb (1 year)
Ozone (O_3)	70 ppb (8 hours)
Particulate Matter	
$PM_{2.5}$	12 µg/m^3 (1 year)
$PM_{2.5}$	35 µg/m^3 (24 hours)
PM_{10}	150 µg/m3 (24 hours)
Sulfur Dioxide (SO_2)	75 ppb (1 hour)

- In the US, 50% of people live in urban areas exceeding recommended $PM_{2.5}$ & ozone

www.epa.gov/criteria-air-pollutants 2021
Berger *NEJM* 2017; 376 (26): 2591



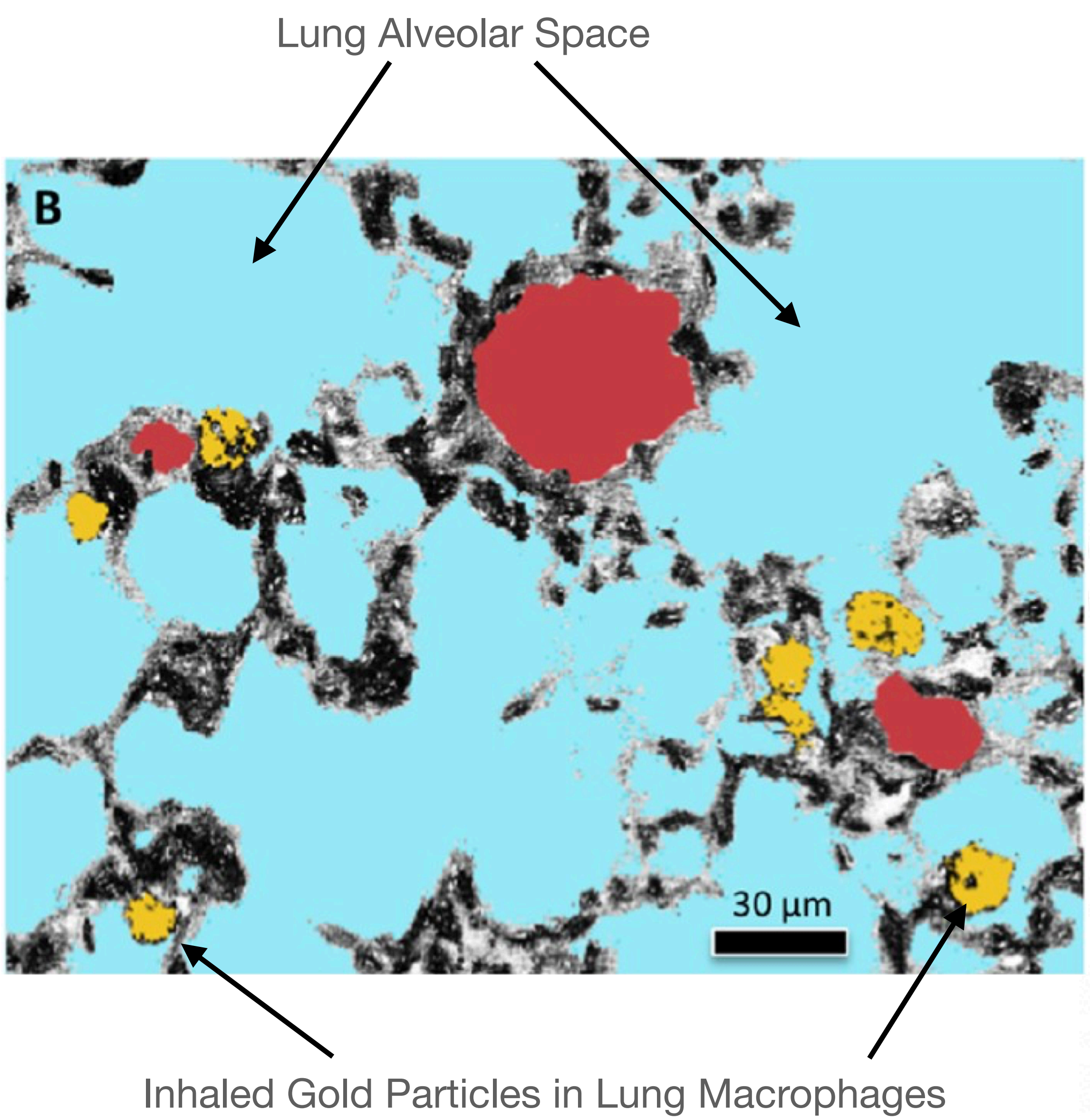
https://www.encyclopedie-environnement.org/en/health/airborne-particulate-health-effects/ 2021

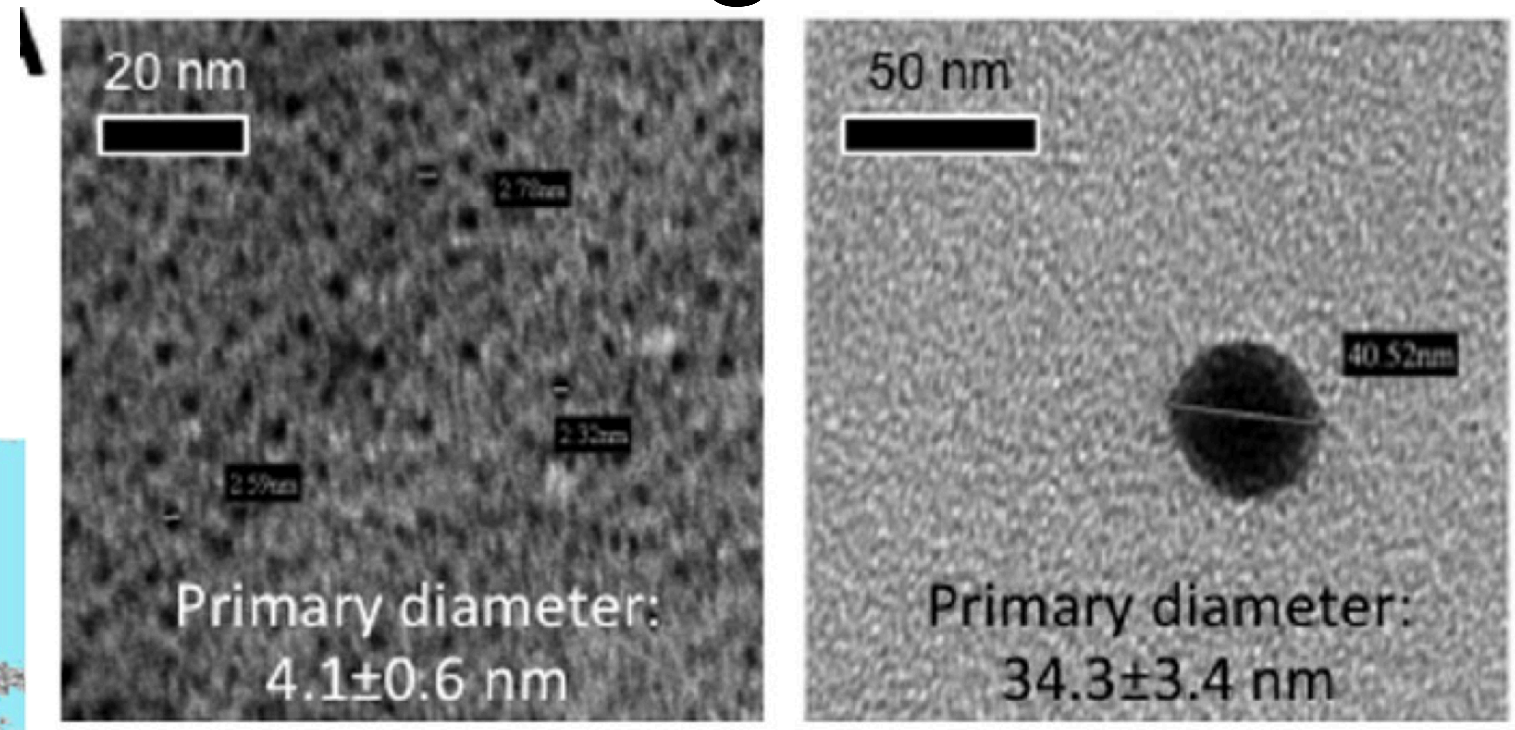


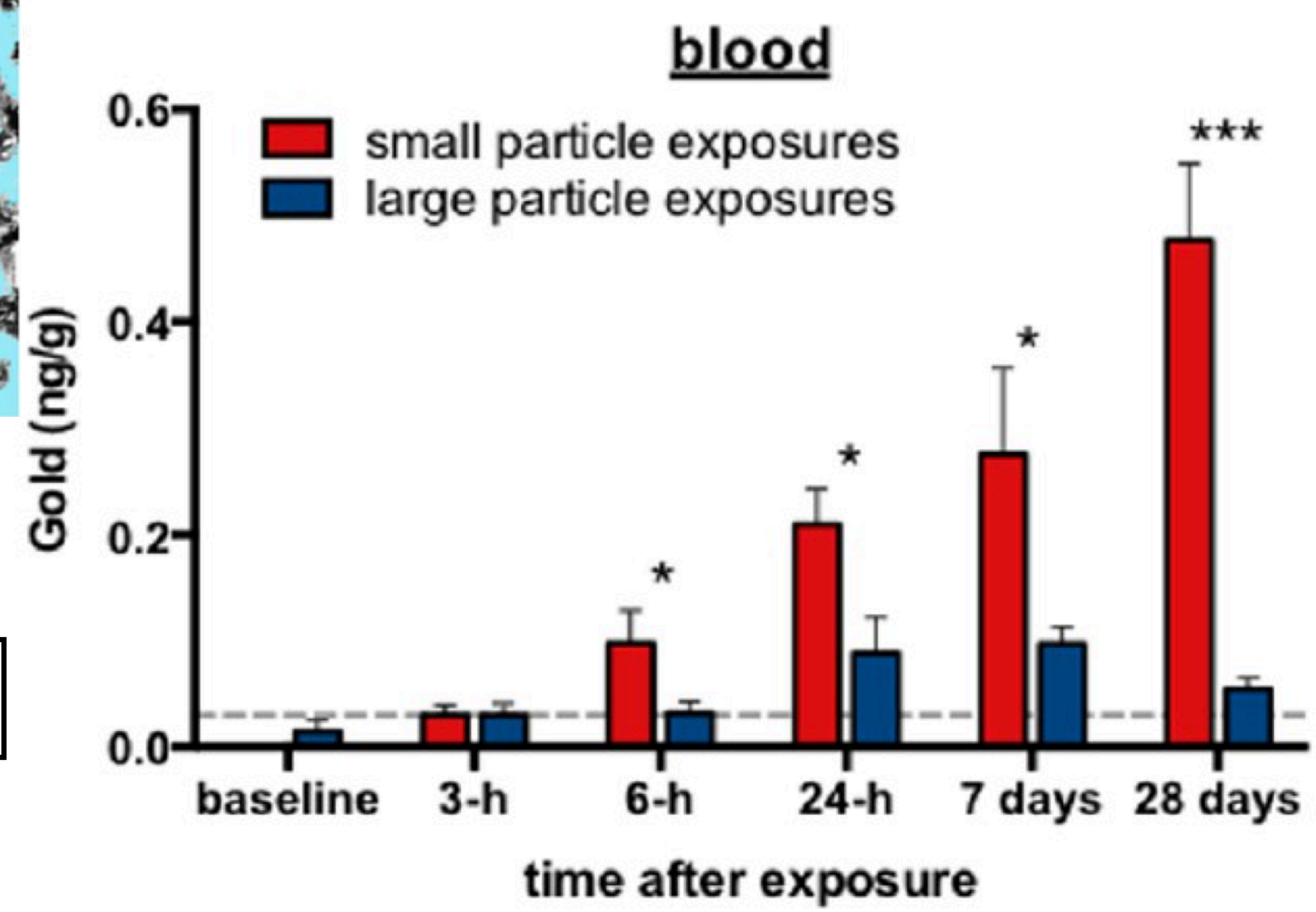
The Influence of Particulate Matter and Smoking on Lung Inflammation in Mice

Wang *International Journal of Chronic Obstructive Pulmonary Disease* 2019 14: 979

Translocation of PM from Lung to Blood



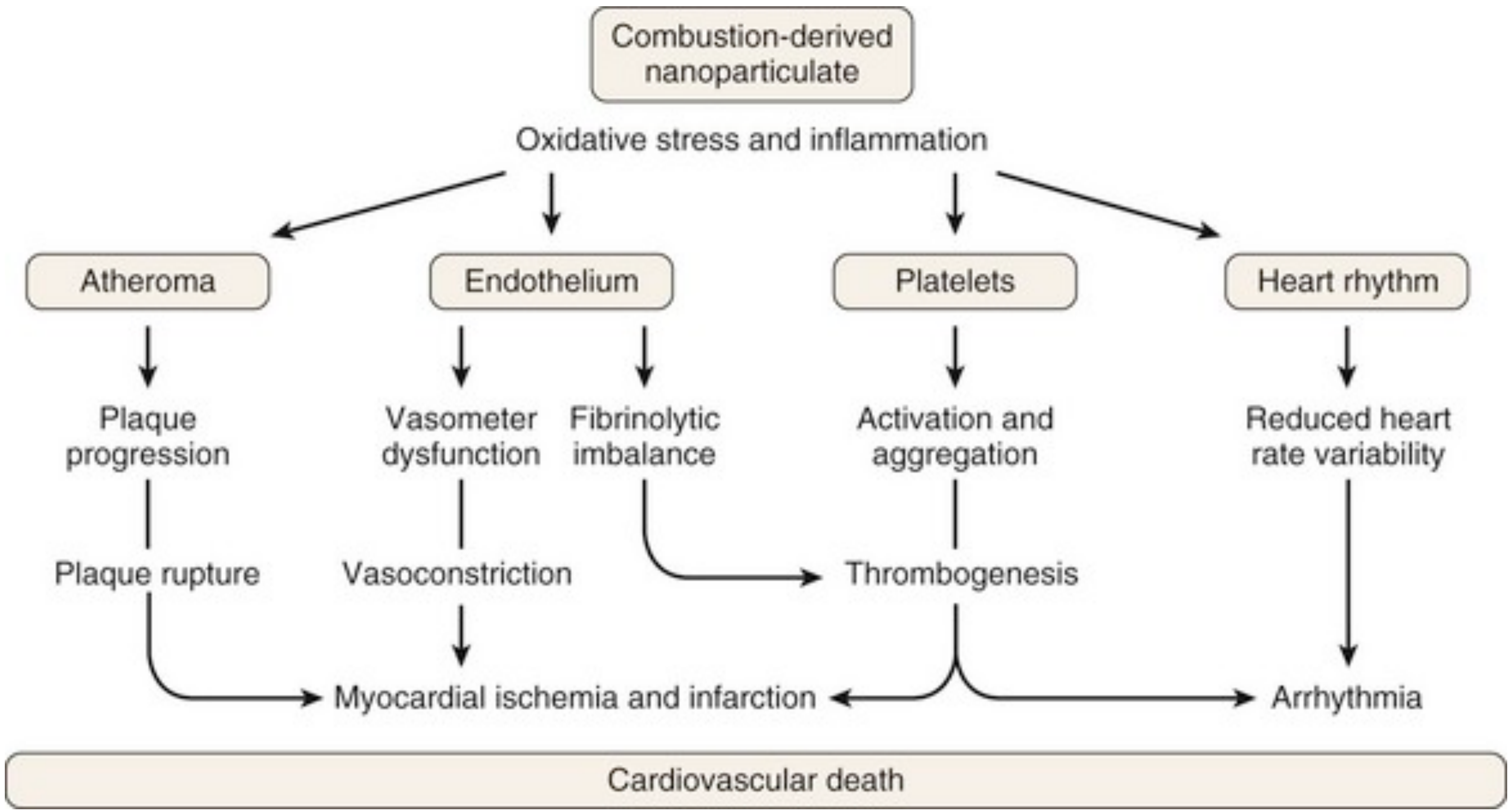




Particles Move from lung to blood to sites of inflammation such as atheromatous plaques

Miller *ACS Nano* 2017, 11:4542

Cardiovascular Effects of PM



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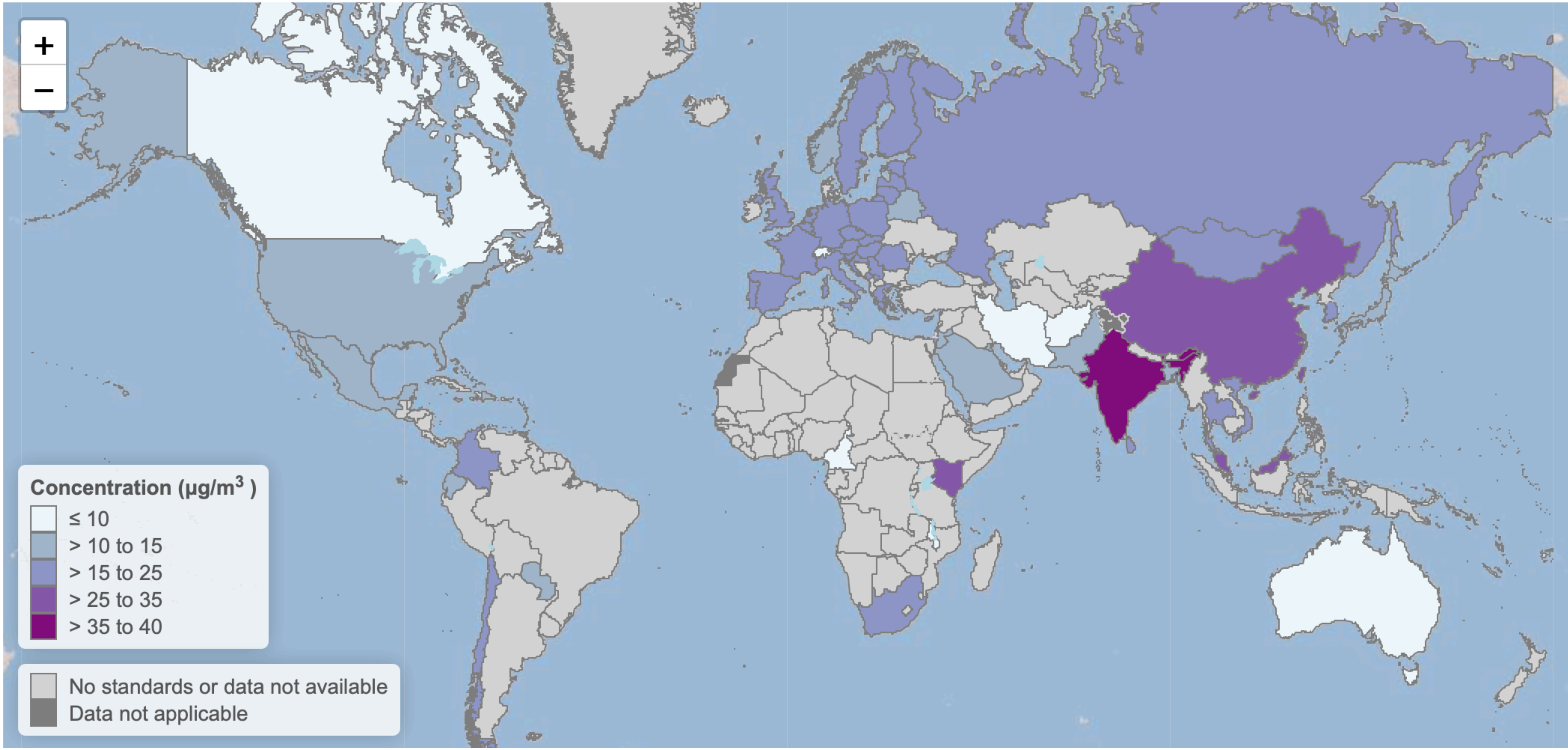
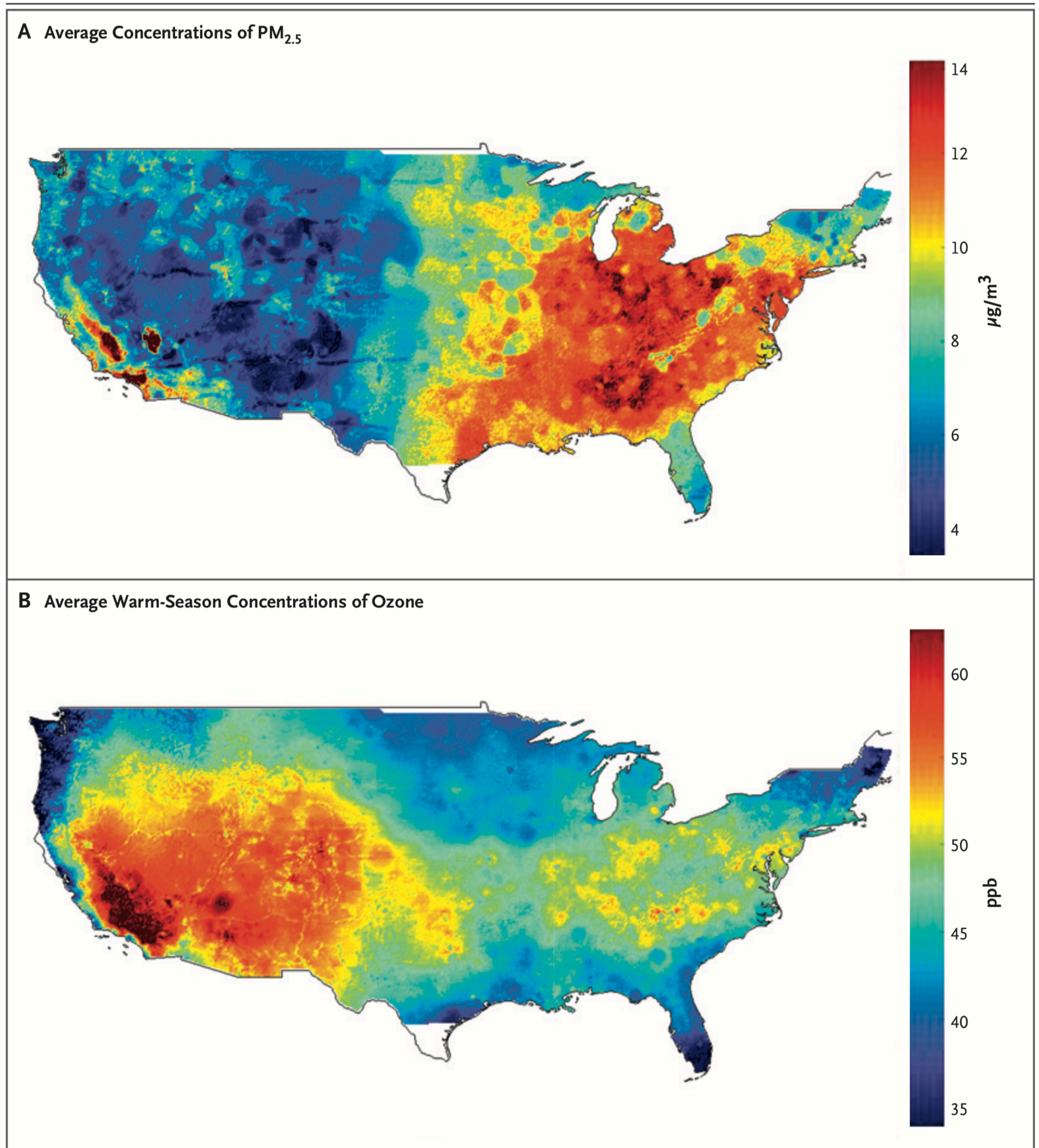


$PM_{2.5}$ Pollutants Averaged Over 1 Year

whoairquality.shinyapps.io/AirQualityStandards 2021

Average US PM2.5 & Ozone Concentrations

2000 - 2012



Di *NEJM* 2017; 37(26): 2513

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There is No Safe Level of PM!

- 60,925,443 Medicare Beneficiaries 2000 - 2012
- Annual averages of $PM_{2.5}$ and ozone
- Assessed risk of death for each increase of 10 of $PM_{2.5}$ & ozone
  - All cause mortality increased by 7.3%
- When analysis was restricted to $PM_{2.5}$ < 12 μg/m^3 & O_3 < 50 ppm
  - Risk of death increased by 13% ($PM_{2.5}$) & 1% (O_3)
- Risk greatest for men, blacks (3x > white), & Medicaid eligible
  - **NO SAFE LEVEL --** Risk continued until 5 μg/m^3 $PM_{2.5}$ and 30 ppb O_3

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Di *NEJM* 2017; 37(26): 2513

Hospital Admission and PM

- 95,277,169 Medicare claims for all US urgent/emergent hospital admissions from 1/1/2000 - 12/31/12
- Mean $PM_{2.5}$ on the same & previous days of each admission
- CHF, pneumonia, COPD, acute MI, arrhythmias, respiratory failure, Parkinson's disease, DM, and thromboembolism were confirmed to be associated with $PM_{2.5}$ exposure
- Sepsis, fluid / electrolyte disorders, acute kidney injury, UTIs, and skin infections were new disorders found to be associated with $PM_{2.5}$ exposure
- Results did not change when analysis was restricted to daily $PM_{2.5}$ $\leq 25\ \mu g/m^3$

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Wei *BMJ* 2019; 367: l6258

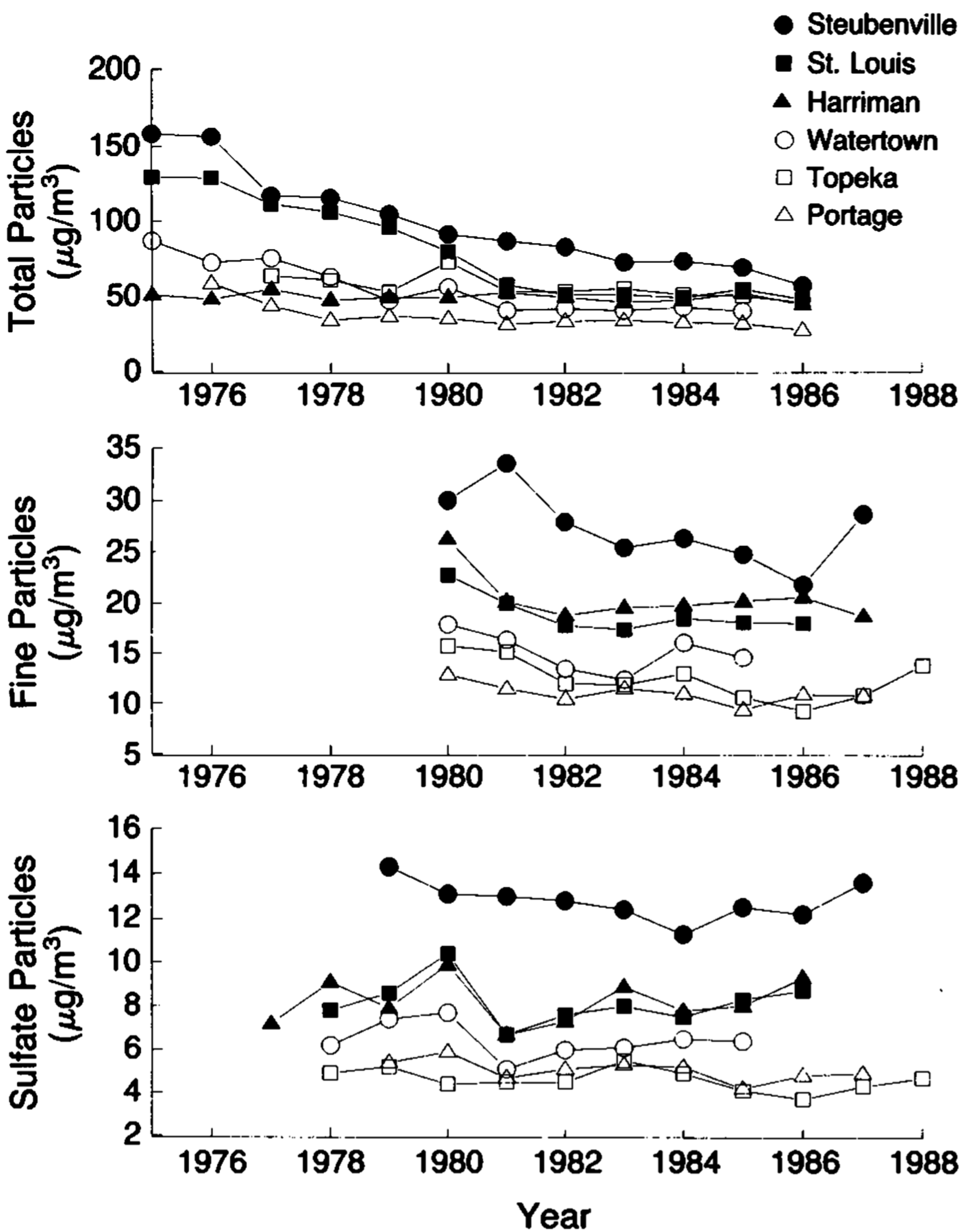
Harvard Six Cities Study

1974-1989

- Evaluated long-term pollution exposure & survival
- 8,111 whites between 25 & 74 years of age
- PM, SO_2, O_3 in each city
    - Watertown, MA
    - Harriman, TN
    - St. Louis, MO
    - Stubenville, OH
    - Portage, WI
    - Topeka, KS

Characteristic	Portage, Wis.	Topeka, Kans.	Watertown, Mass.	Harriman, Tenn.	St. Louis	Steubenville, Ohio
No. of participants	1,631	1,239	1,336	1,258	1,296	1,351
Person-years of follow-up	21,618	16,111	19,882	17,836	17,715	17,914
No. of deaths	232	156	248	222	281	291
Deaths/1000 person-years	10.73	9.68	12.47	12.45	15.86	16.24
Female sex (%)	52	56	56	54	55	56
Smokers (%)	36	33	40	37	35	35
Former smokers (%)	24	25	25	21	24	23
Average pack-years of smoking						
Current smokers	24.0	25.6	25.2	24.5	30.9	28.0
Former smokers	18.0	19.7	21.8	21.1	22.0	25.0
Less than high-school education (%)	25	12	22	35	45	30
Average age (yr)	48.4	48.3	48.5	49.4	51.8	51.6
Average body-mass index	26.3	25.3	25.5	25.1	26.0	26.4
Job exposure to dust or fumes (%)	53	28	38	50	40	48
Total particles ($\mu g/m^3$)	34.1	56.6	49.2	49.4	72.5	89.9
Inhalable particles ($\mu g/m^3$)	18.2	26.4	24.2	32.5	31.4	46.5
Fine particles ($\mu g/m^3$)	11.0	12.5	14.9	20.8	19.0	29.6
Sulfate particles ($\mu g/m^3$)	5.3	4.8	6.5	8.1	8.1	12.8
Aerosol acidity ($nmol/m^3$)	10.5	11.6	20.3	36.1	10.3	25.2
Sulfur dioxide (ppb)	4.2	1.6	9.3	4.8	14.1	24.0
Nitrogen dioxide (ppb)	6.1	10.6	18.1	14.1	19.7	21.9
Ozone (ppb)	28.0	27.6	19.7	20.7	20.9	22.3

Dockery *NEJM* 1993; 329:1753



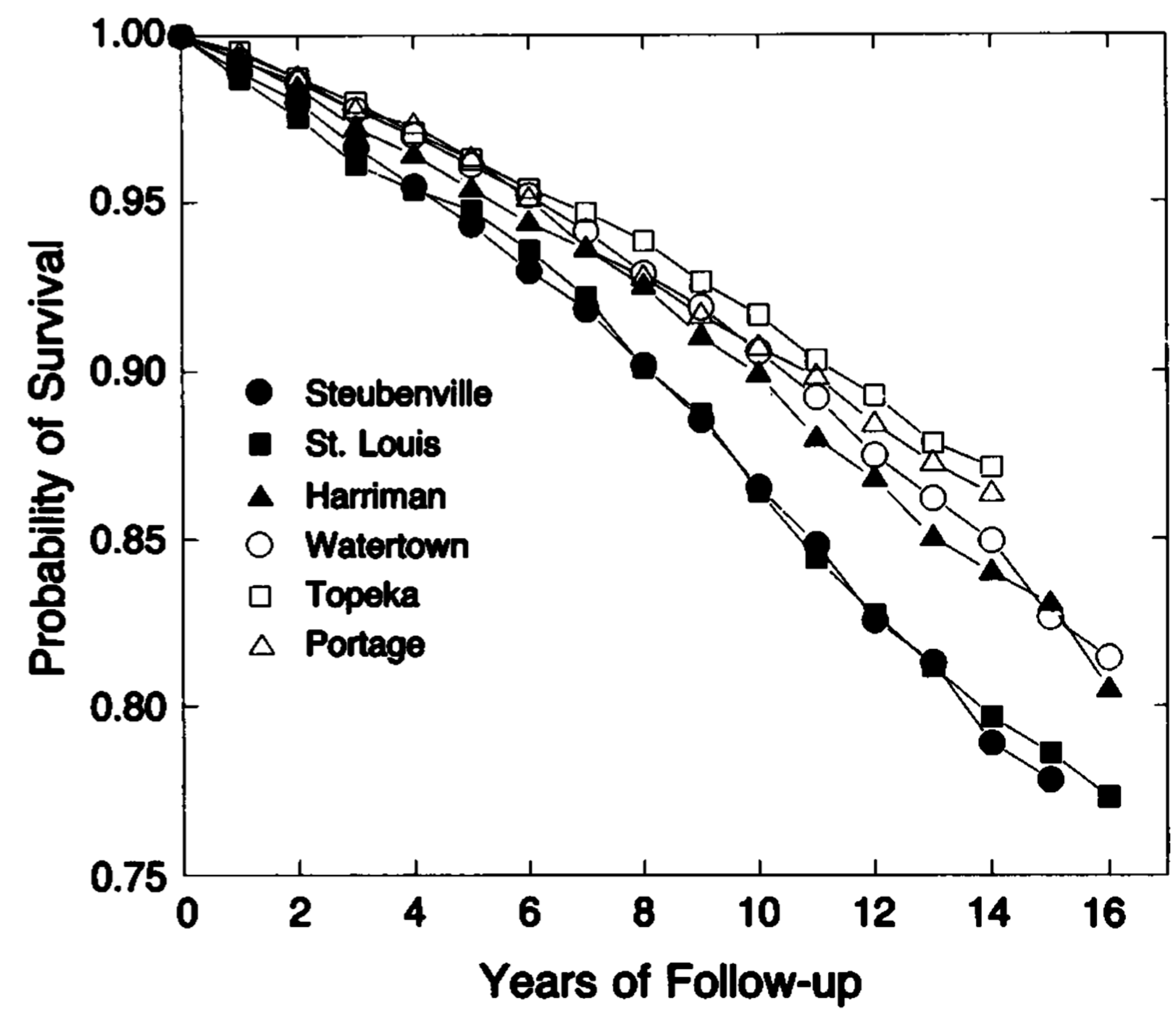
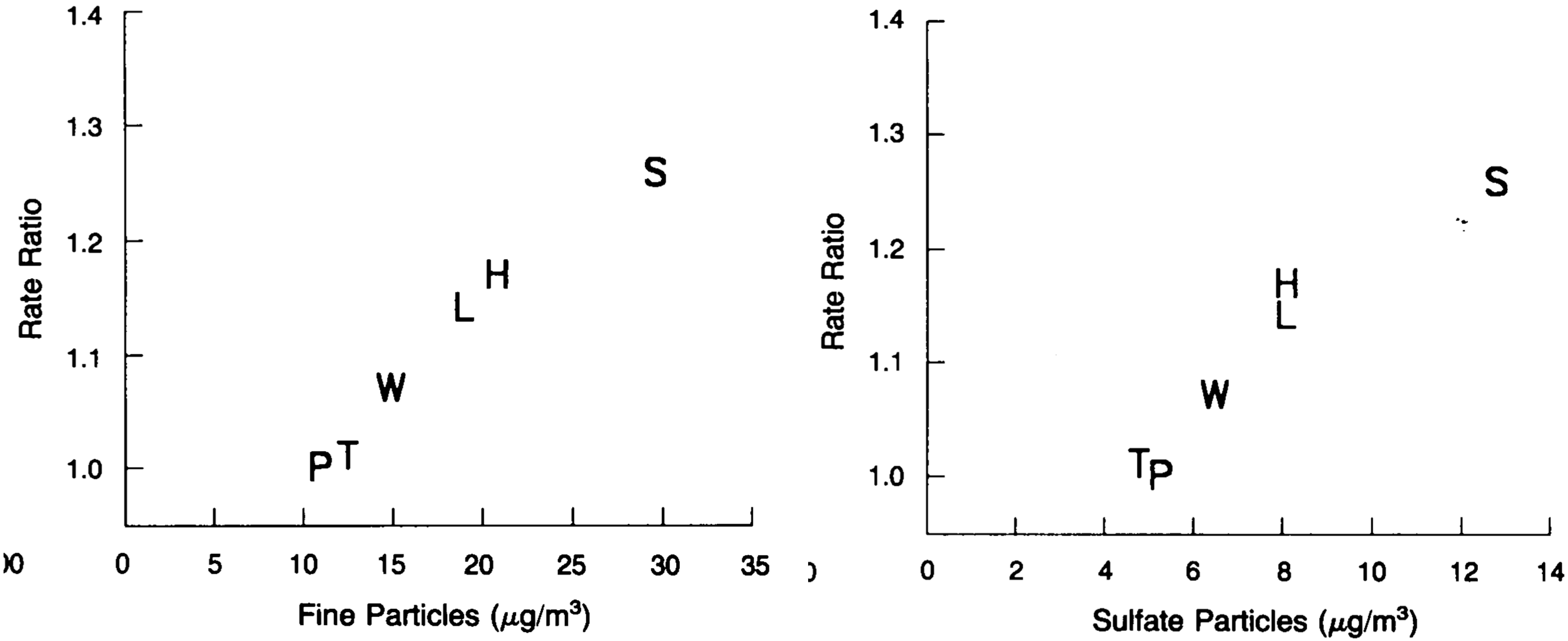
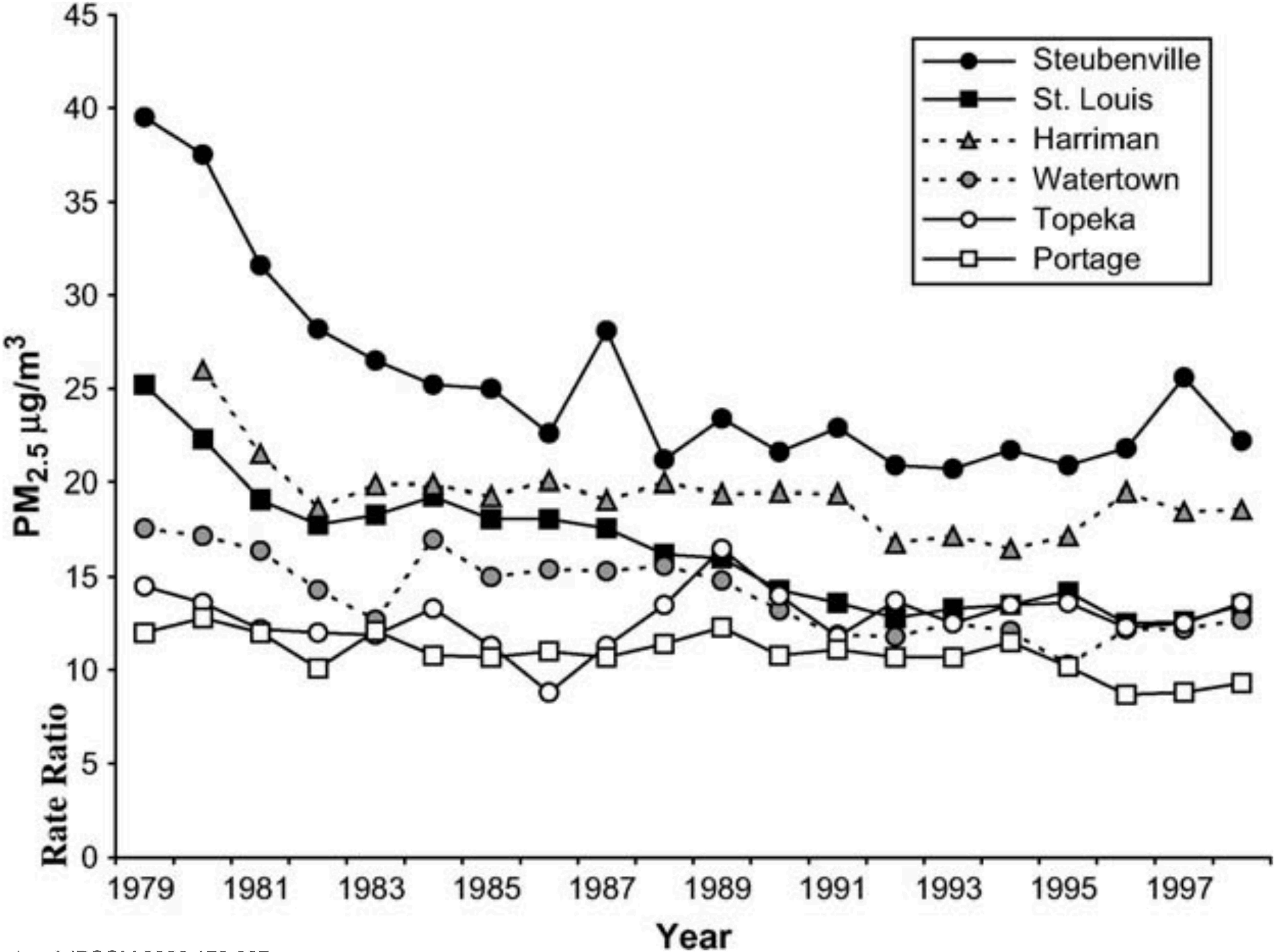


Figure 2. Crude Probability of Survival in the Six Cities, According to Years of Follow-up.

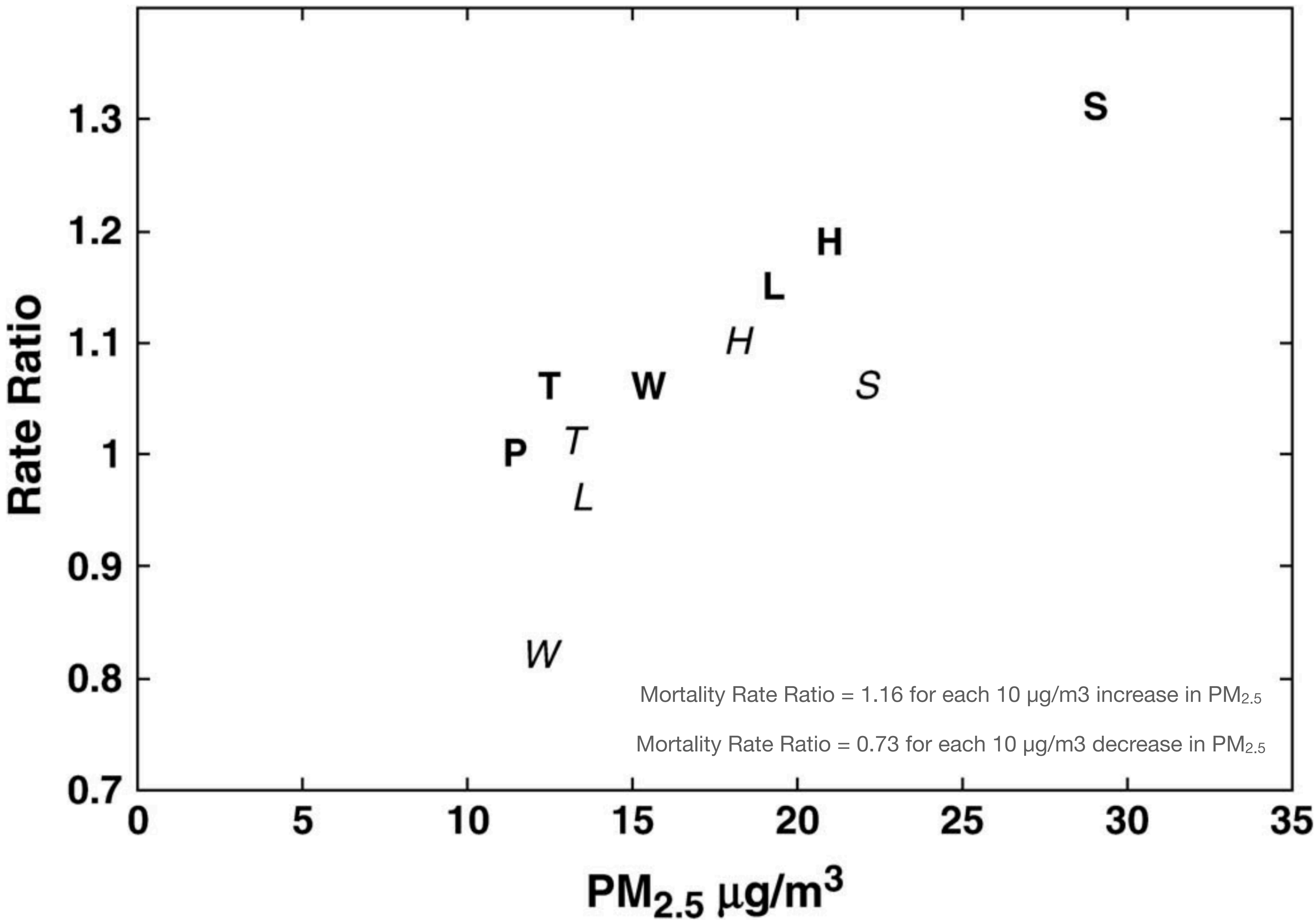


Mortality Rate Ratio = 1.13 (1.04 - 1.73)

for each 10 μg/m3 increase in city-specific $PM_{2.5}$ concentrations



Laden *AJRCCM* 2006 173:667



Bold letters = 1974 - 1989 *Italic letters* = 1990 - 1998

Air Pollution Affects Lung Development

Children's Health Study

- 1759 children with mean age 10 in 12 Southern California communities

- FEV1 & FVC annually for 8 years

- Exposure to higher levels of ozone (O_3), acid vapor, nitrogen dioxide (NO_2), and particulate matter (PM) had deficits in FEV1 attained by age 18 compared to children with lower levels of exposure

- 4.9x greater risk of having low FEV1 at highest level of $PM_{2.5}$ exposure compared to lowest level

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Gauderman *NEJM* 2004 351(11): 1057

Air Pollution Affects Lung Function in Children

- In Rome, among 2,107 children aged 9 - 14 from 40 schools, NO_2 exposure related to traffic was associated with lower FEV1/ FVC (-0.62%, 95%CI -1.05 – -0.19) and peak expiratory flow (-85 mL/s (95% CI -135 – -35)

- Among 3,677 children from 12 Southern California followed for 8 years

  - Those who lived within 500m of a motorway had lower FEV1 (mean -81 mL, 95%CI -143 – -18) [97% predicted] and maximal mid-expiratory flow rates (-127 mL/s, 95%CI -243 – -11) [93% predicted] compared to children living at least 1500 m from a motorway

Rosenlund *Thorax* 2009 64:573
Guaderman *Lancet* 2007 269: 571

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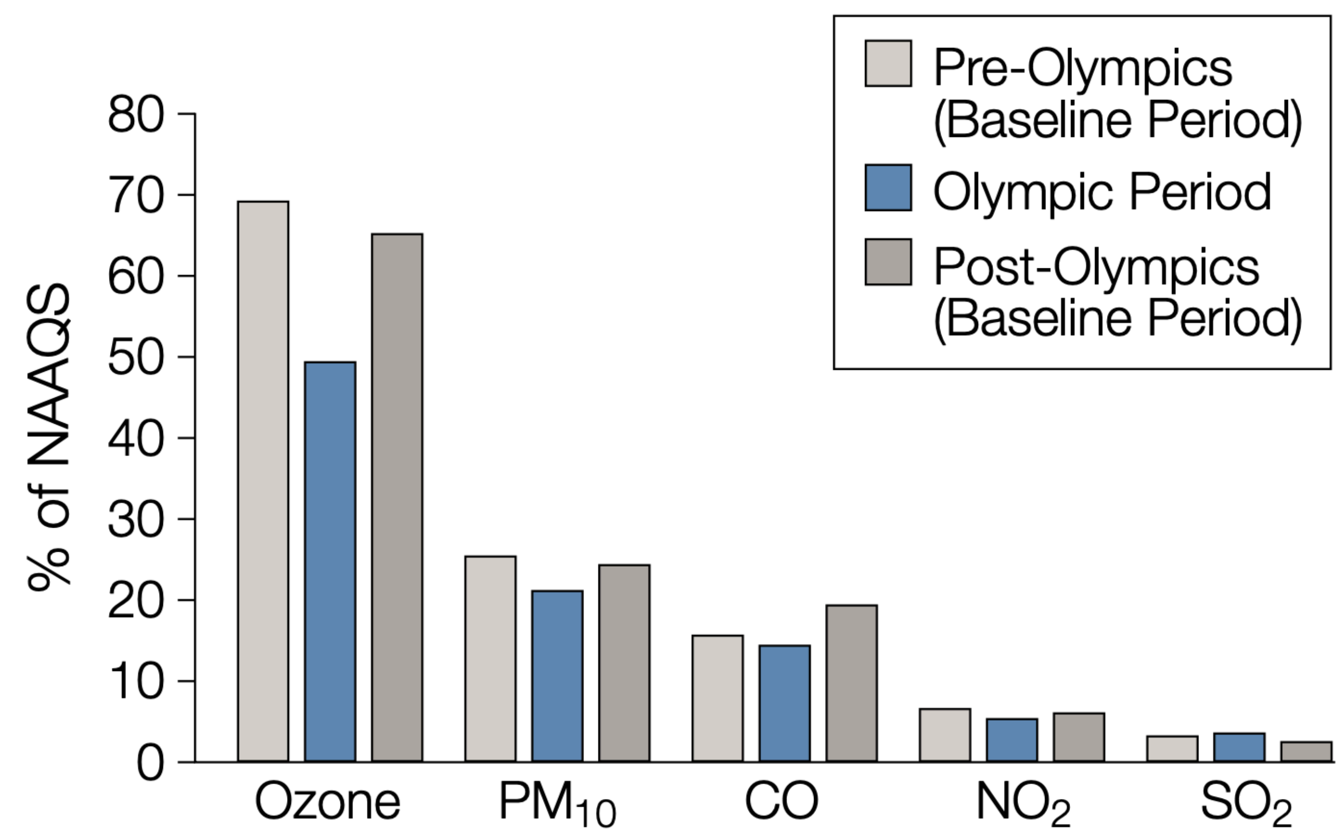
1996 Summer Olympics in Atlanta

- Interventions
  - Road traffic was minimized (downtown sector closed to private travel)
  - Public transportation ran 24 hours daily
  - 1000 buses for park-and-ride
  - Local businesses allowed telecommuting



Friedman *JAMA* 2001 285:897

2008 Summer Olympics in Beijing

- July 1 - Sept 20, 2008 vehicle restrictions implemented
  - No trucks that failed emission standards
  - Registered vehicles allowed only every other day
  - August 8, Olympics began and transpiration was curtailed

Periods	Asthma (Events/Day)	$PM_{2.5}$	O_3	RR of Asthma Visit
June	12.5	78.8	65.8	Ref
July	16.5	72.3	74.6	1.12 (0.85 - 1.5)
August	7.3	46.7	61.0	0.54 (0.39 - 0.75)

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Li *Science of the Total Environment* 2009: 1226

Acute Asthma Events & 3-Day O_3

Data Source	Ozone <60 ppb†		Ozone 60-89 ppb†		Ozone ≥90 ppb†	
	Mean Daily Asthma Events	RR	Mean Daily Asthma Events	RR (95% CI)	Mean Daily Asthma Events	RR (95% CI)
Georgia Medicaid claims file	2.20	1.00	3.85	1.61 (1.13-2.30)‡	5.11	1.88 (1.24-2.83)‡
Health maintenance organization	1.07	1.00	1.15	1.11 (0.63-1.96)	1.50	1.33 (0.68-2.61)
Pediatric emergency departments	3.00	1.00	4.65	1.33 (0.98-1.81)	6.00	1.46 (1.02-2.09)§
Georgia Hospital Discharge Database	1.67	1.00	2.15	1.19 (0.77-1.84)	1.72	1.03 (0.58-2.11)

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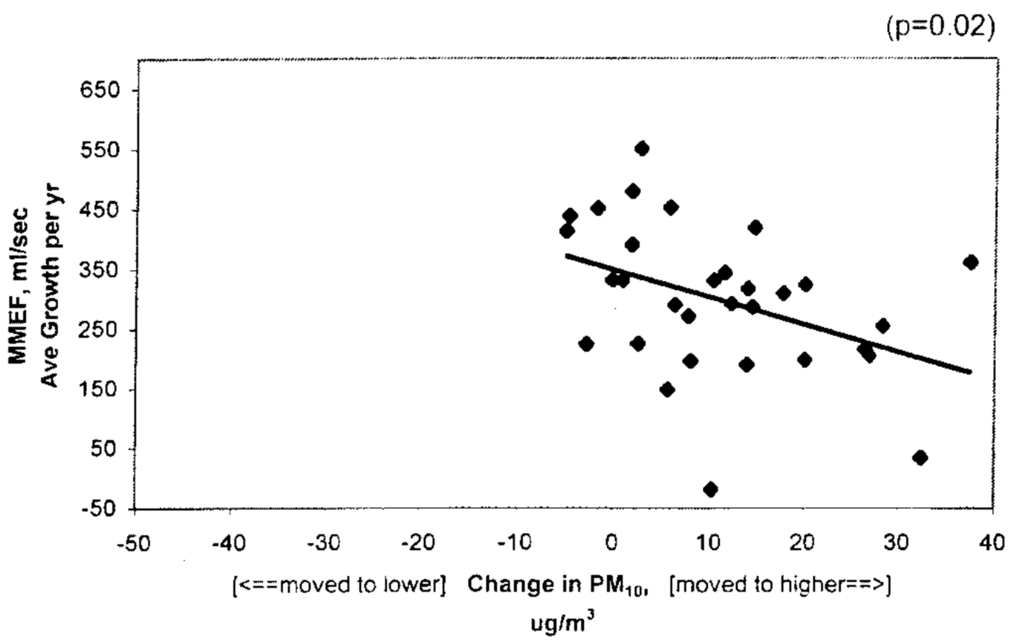
The Effect of Moving on Lung Function

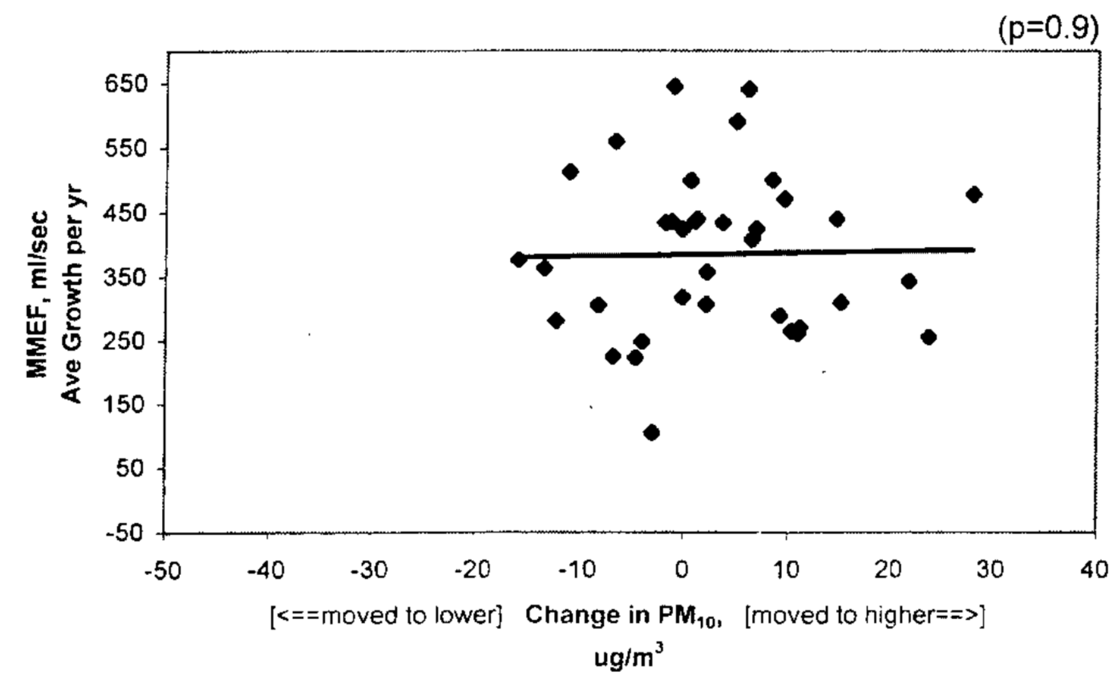
"Low" PM_{10} communities (15 to 22 ug/m^3)

Lompoc, Santa Maria, Atascadero, Lake Gregory



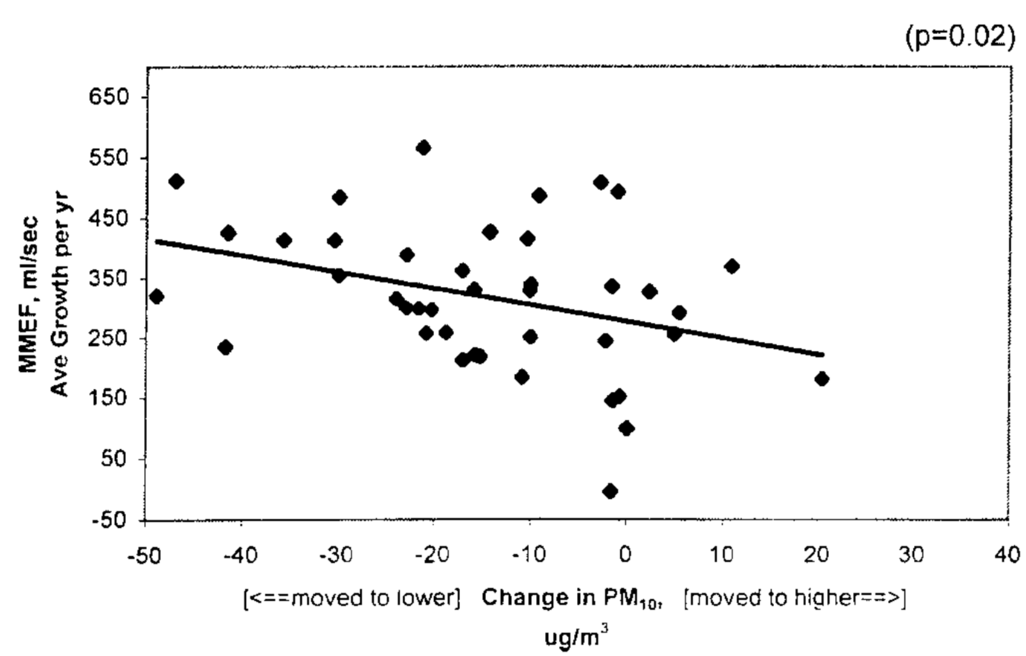
"Moderate" PM_{10} communities (23 to 37 ug/m^3)

Alpine, Lancaster, Lake Elsinore, San Dimas



"High" PM_{10} communities (38 to 67 ug/m^3)

Long Beach, Riverside, Upland, Mira Loma



Avol *AJRCCM* 2001 164:2067

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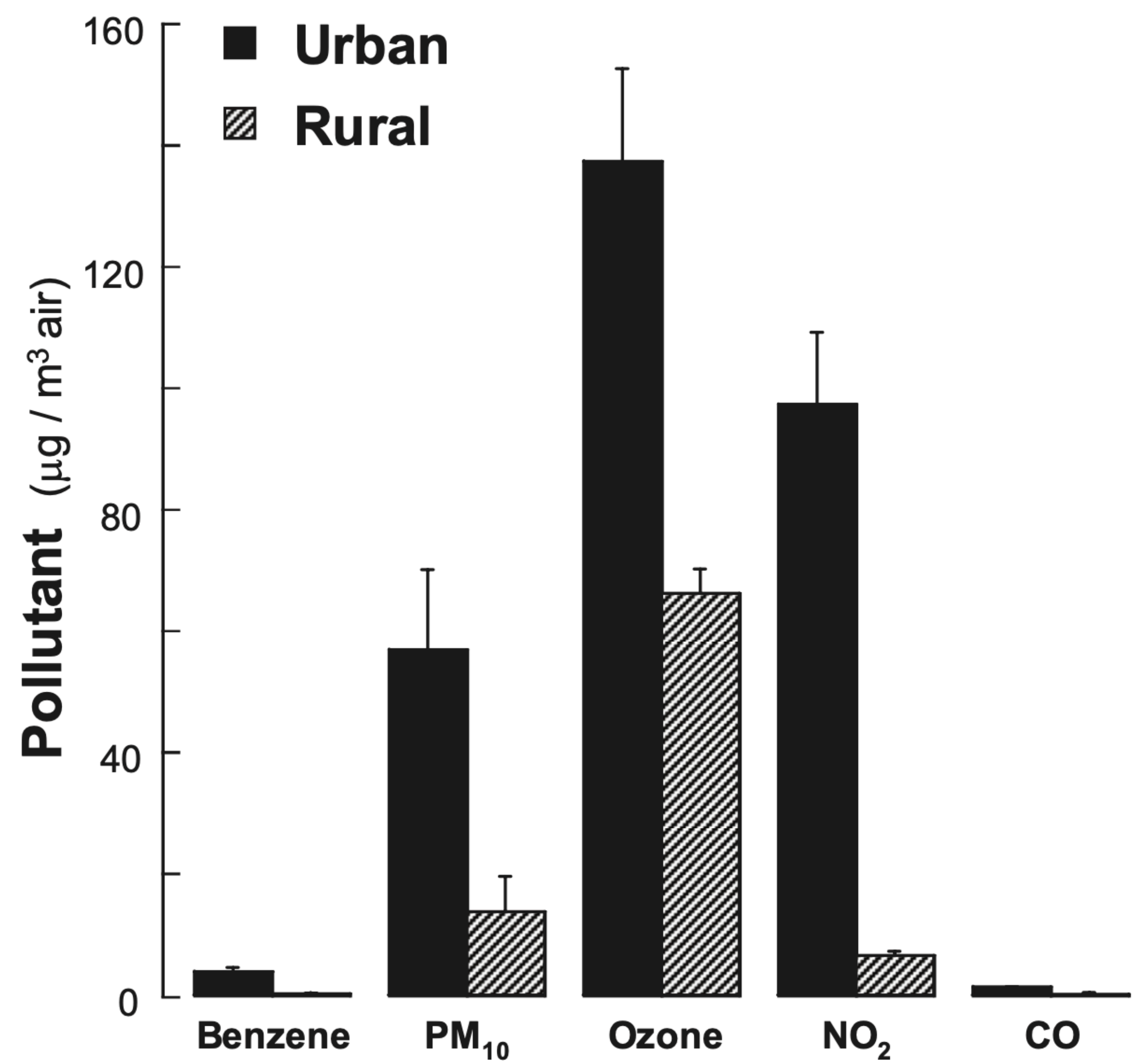
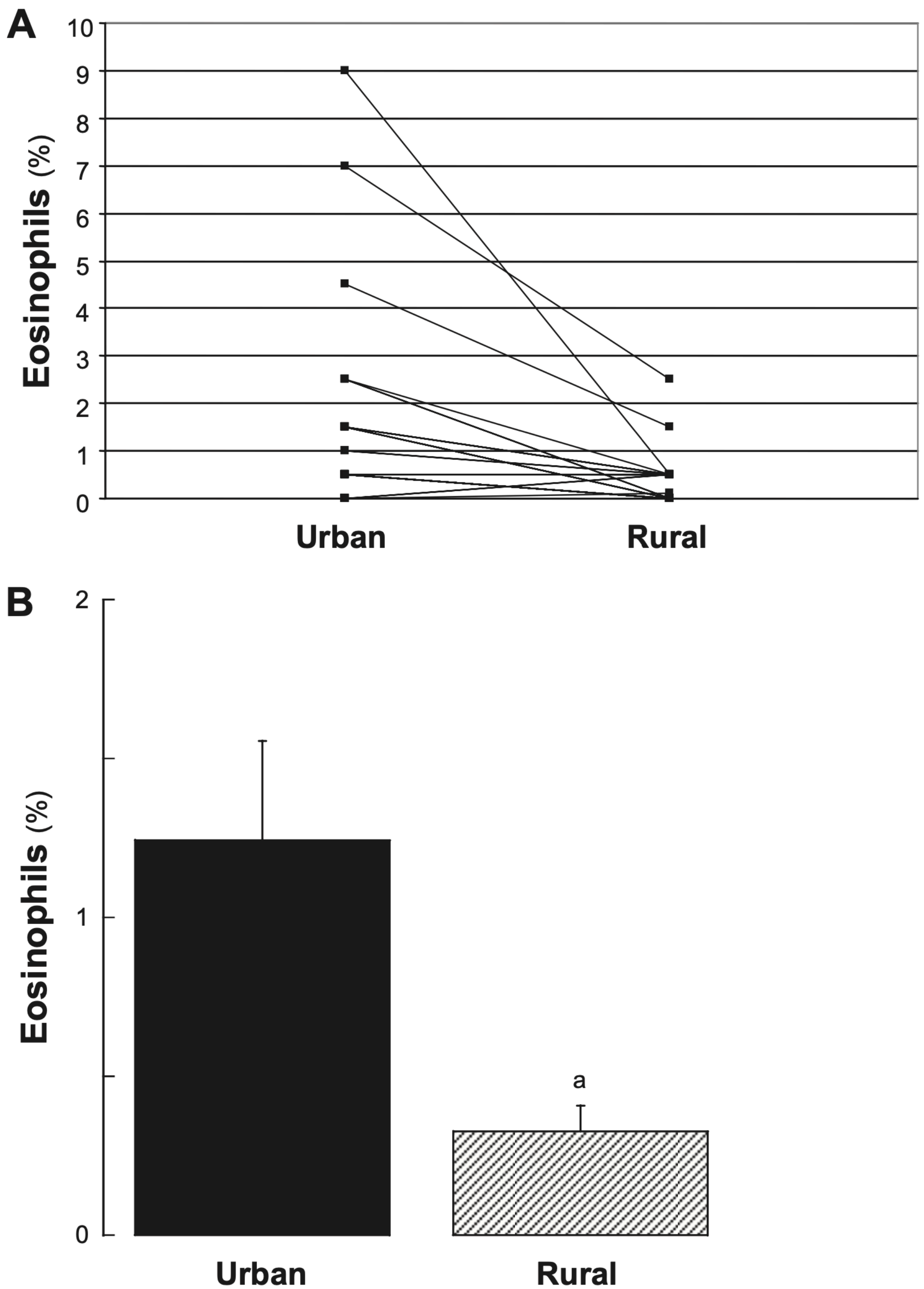
Relocation & Rapid Improvement in Lung Function

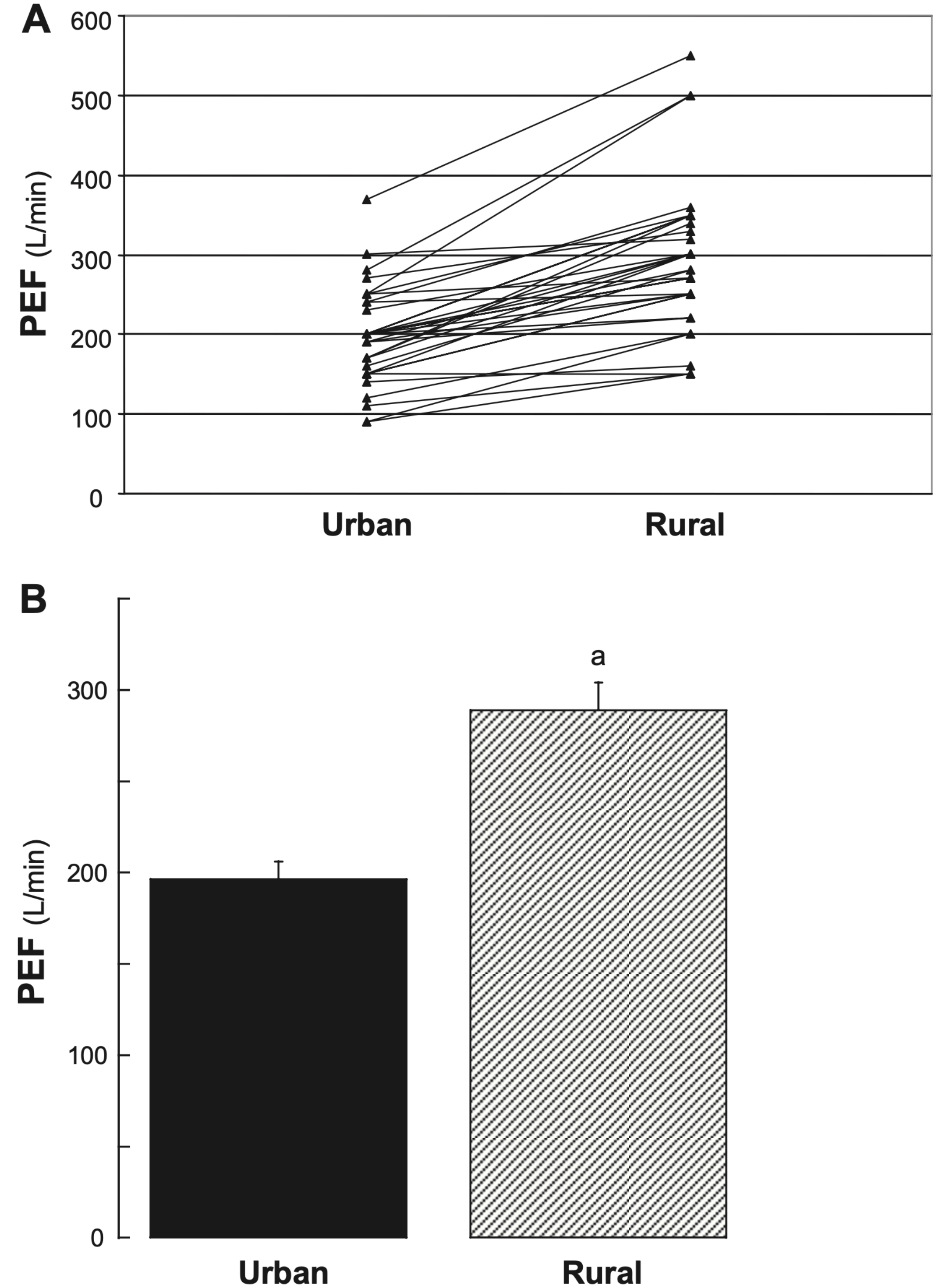
- 37 untreated children with allergic rhinitis and mild persistent asthma
- Moved from highly polluted urban environment to less polluted urban environment
- Nasal eosinophils, exhaled nitric oxide, peak flow, and urinary leukotrienes measured in urban setting and 7 days after moving



Renzetti *Pediatrics* 2009 123:1051

Eosinophils & Peak Flow

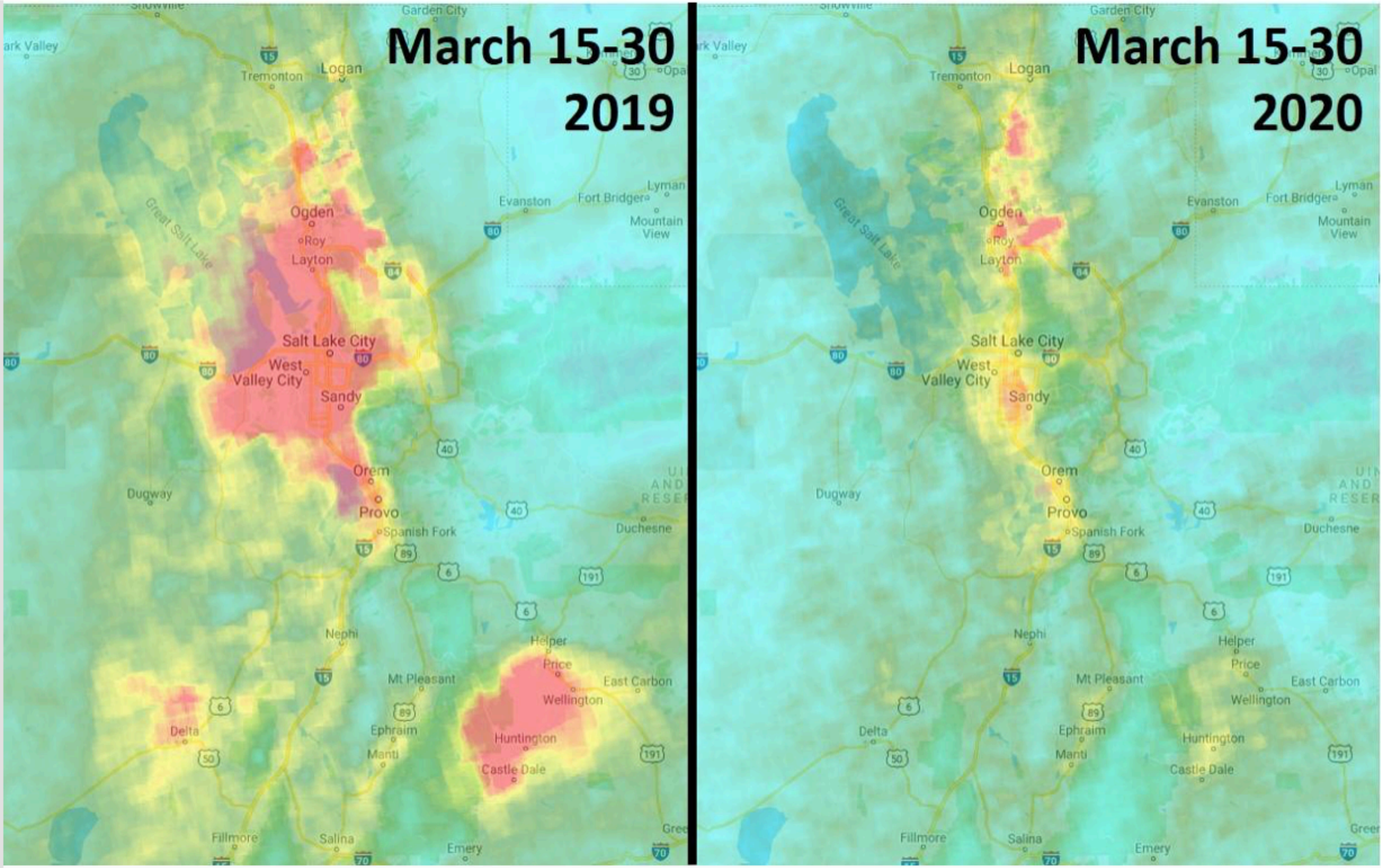




COVID-19 Pandemic and AQI

Utah March 2020

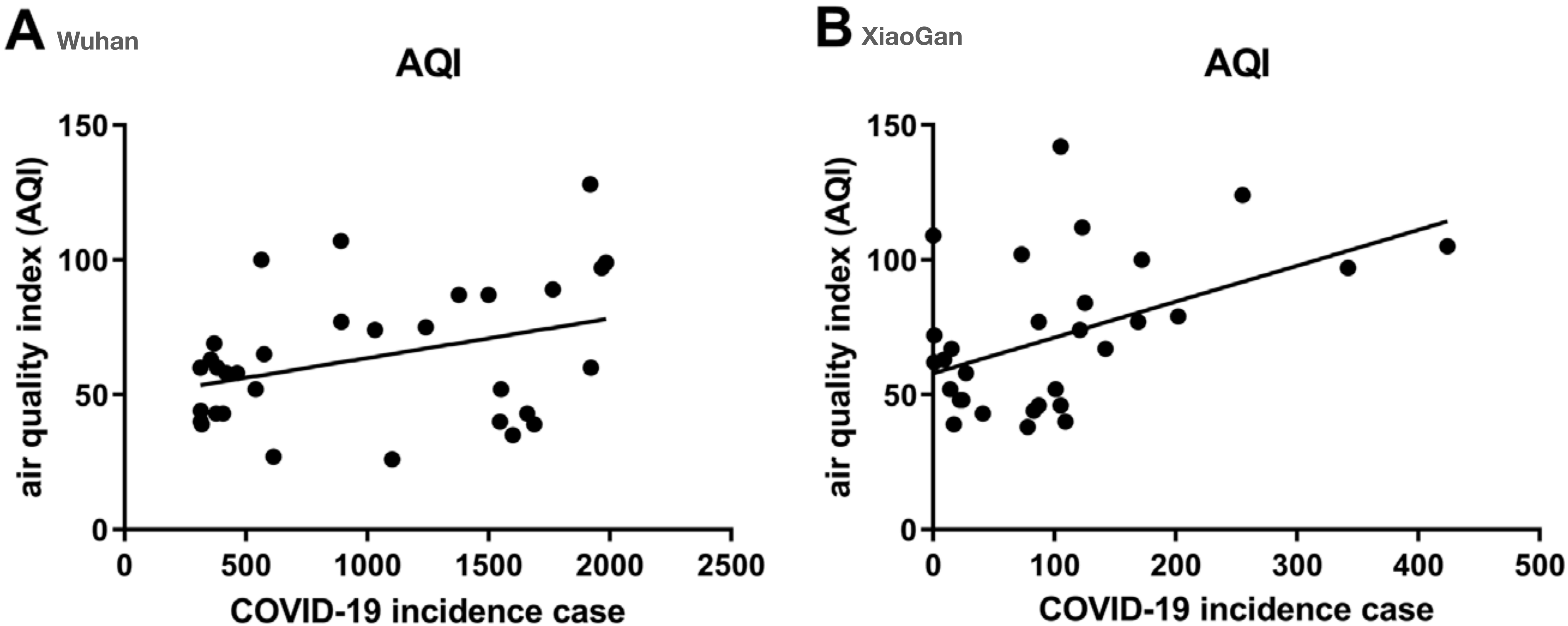
- AQI generally good, but in 2020 was better than ever
  - 40 - 50% reduction in traffic
    - Similar to 40 - 50% of cars being electric
  - Lower NO_2
  - Similar O_3
  - PM lower than average, particularly at night
  - CO2 lower than average


March 15-30
2019
March 15-30
2020
Garden City
Logan
Tremonton
Ogden
Roy
Layton
Great Salt Lake
Evanston
Fort Bridger
Lyman
Mountain View
Salt Lake City
West Valley City
Sandy
Orem
Provo
Spanish Fork
Dugway
Duchesne
Nephi
Helper
Price
East Carbon
Wellington
Mt Pleasant
Ephraim
Manti
Delta
Huntington
Castle Dale
Fillmore
Salina
Emery

Air Pollution and COVID-19 Incidence

Wuhan and XiaoGan, China

- Correlation between AQI, PM_{10}, $PM_{2.5}$, NO_2 and COVID-19 incidence



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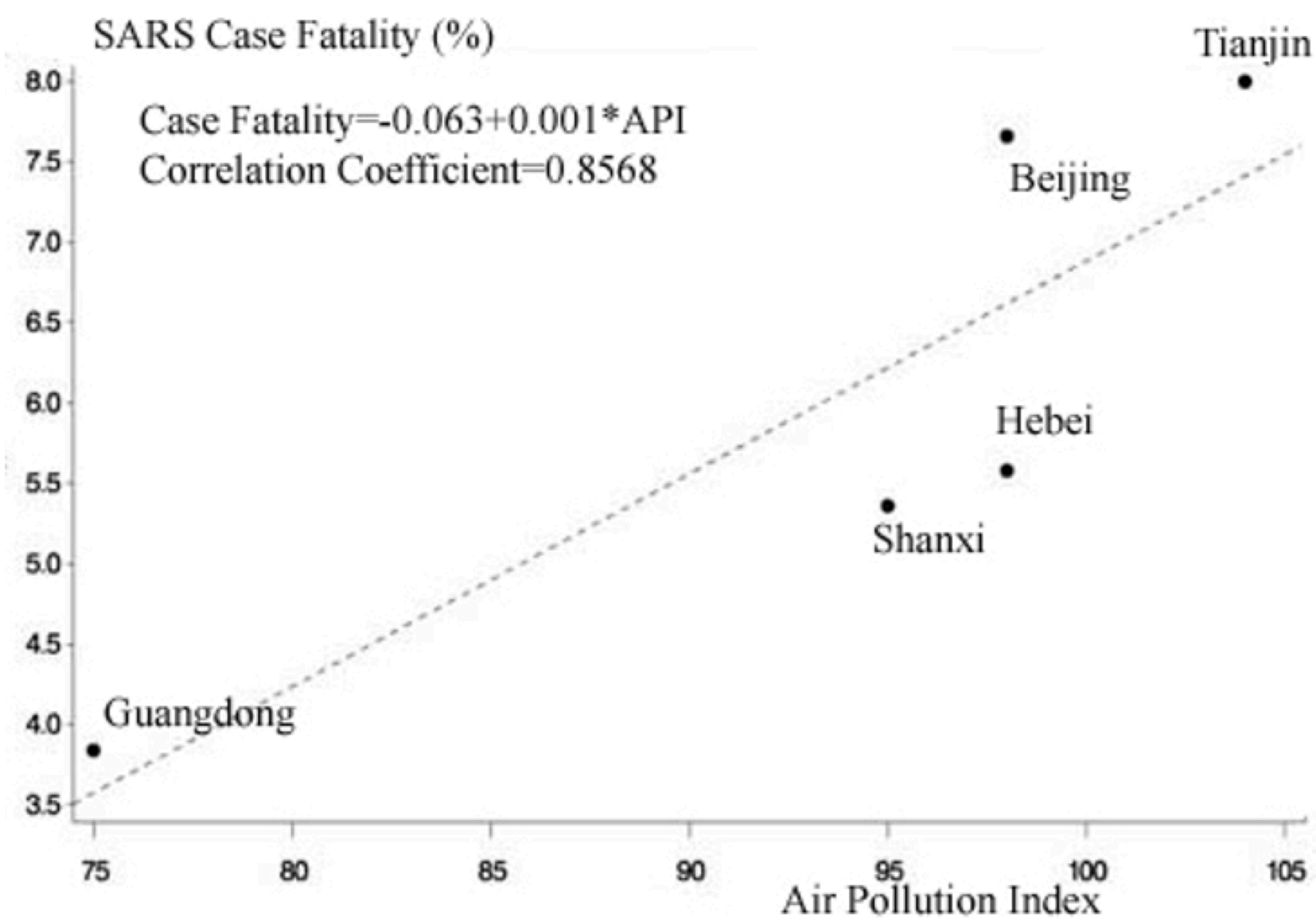
Li International Journal of Infectious Diseases 2020 97:278

SARS Mortality and Air Pollution

- Risk of dying from SARS in cities with moderate pollution: 1.84
- Risk of dying from SARS in cities with high pollution: 2.18



Cui *Environmental Health* 2003, 2:15

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Indoor Air Pollutants And Asthma

Baltimore, MD

- 180 students recruited from a school-based asthma education program
  - Air pollution sampling over 72 hours in the sleeping room of the child
    - Average NO_2 concentration = 32 ± 40
    - Average $PM_{2.5}$ = 45 ± 37 μg/m^3
    - Average ozone = 3 ± 8 ppb
  - Smoking households had higher $PM_{2.5}$ concentrations
    - Smoking added 1 μm/m^3 to $PM_{2.5}$
- 150 2 - 6 year olds with physician-diagnosed asthma
  - 72 hour monitoring in children's bedrooms at baseline, 3, and 6 months
  - Sources of increased NO_2 = Gas stoves and space heaters
  - Increased NO_2 concentrations associated with asthma exacerbations but not health care utilization

Breysse *Environmental Research* 2005; 98:167
Hansel *Environmental Health Perspectives* 2008; 116 (10): 1428

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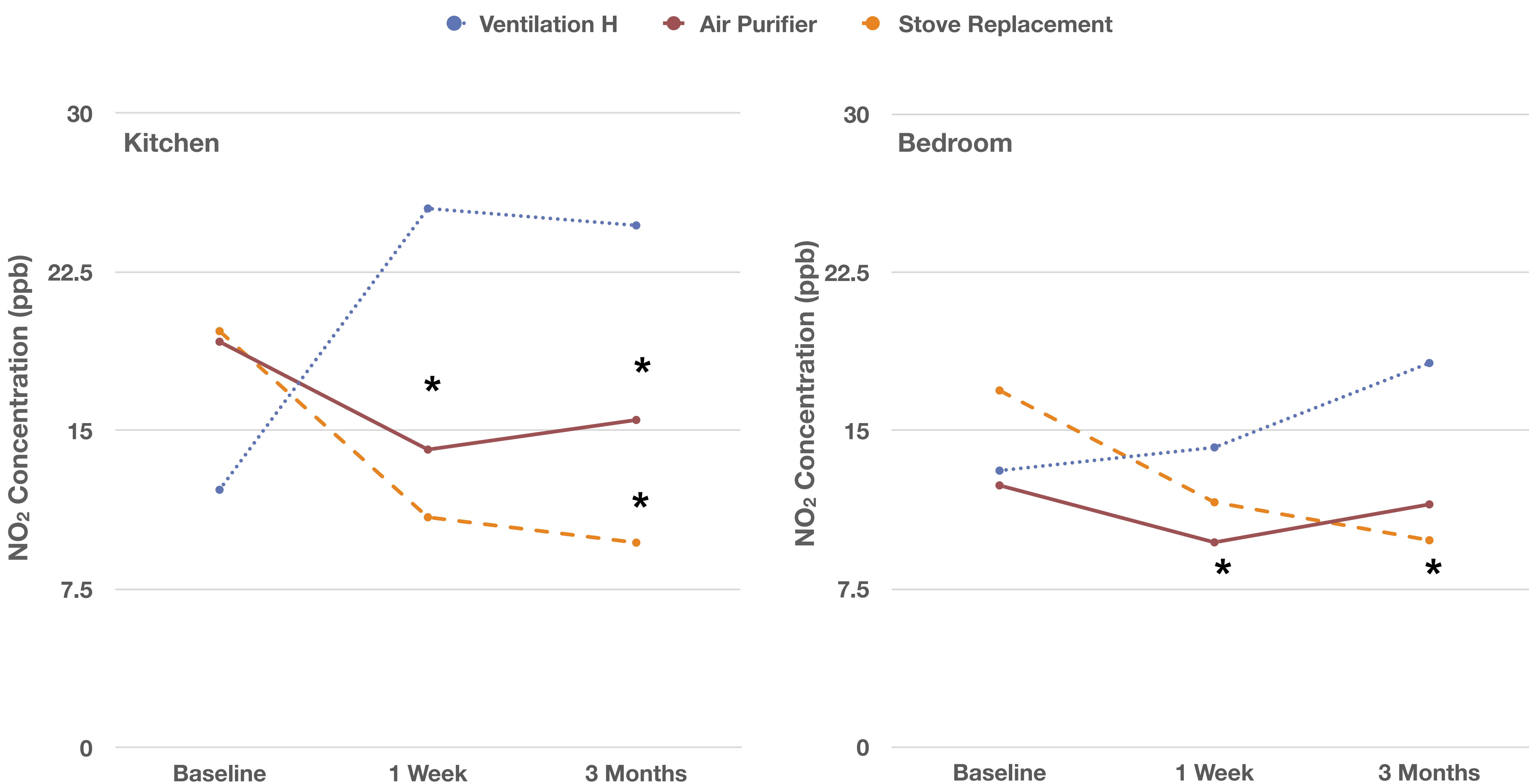
Decreasing Household NO_2 Concentrations

- 100 Baltimore homes with unvented gas stoves
- 3-arm RCT in a 2:1:1 design
    - Placement of air purifiers with HEPA and carbon filters ($500)
    - Installation of a ventilation hood over the gas stove ($65)
    - Replacement of the gas stove with an electric stove ($390)
- Home inspection and NO_2 monitoring at 1 week pre-intervention, 1 week and 3 months post-intervention

Paulin *Indoor Air* 2014; 24: 416

Home Intervention Results



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Paulin *Indoor Air* 2014; 24: 416

HEPA Filters

High-efficiency particulate air

- Must remove 99.95% (European) or 99.97% (US) of particles with diameters = 0.3 μm
- Mats of randomly arranged fibers (generally fiberglass) with diameter 0.5 - 2 μm
  - Holes between fibers are usually > 0.3 μm
- Work by:
  - *Diffusion* - Particles < 0.1 μm collide with gas molecules and are impeded or delayed in their path through the filter
  - *Interception* - 0.1 μm - 1μm particles adhere to fibers when they travel along air stream
  - *Impaction* - > 1 μm particles are unable to avoid fibers by following the curved contours of the air stream
- Can be combined with a pre-filter to extend the HEP filter life by removing larger dust PM_{10} and pollen from air

Respirators

N95 and KN95

- N95 respirators use a fine mesh of non woven polypropylene fabric that filters out at least 95% of airborne particles
  - Not effective against gases or vapors
  - Authentic respirators are marked with “NIOSH” or the logo, “N95”, and a TC approval number
  - KN95 are made in China and meet at least 95% filtration
    - US FDA require KN95s that do not filter 95% to be called “face masks”
  - Surgical masks do not provide tight seals and are not as effective

Understanding the Difference

	Surgical Mask	N95 Respirator
Testing and Approval	Cleared by the U.S. Food and Drug Administration (**FDA**)	Evaluated, tested, and approved by **NIOSH** as per the requirements in 42 CFR Part 84
Intended Use and Purpose	Fluid resistant and provides the wearer protection against large droplets, splashes, or sprays of bodily or other hazardous fluids. Protects the patient from the wearer's respiratory emissions.	Reduces wearer's exposure to particles including small particle aerosols and large droplets (**only non-oil aerosols**).
Face Seal Fit	Loose-fitting	Tight-fitting
Fit Testing Requirement	No	Yes
User Seal Check Requirement	No	Yes. Required each time the respirator is donned (put on)
Filtration	Does NOT provide the wearer with a reliable level of protection from inhaling smaller airborne particles and is not considered respiratory protection	Filters out at least 95% of airborne particles including large and small particles
Leakage	Leakage occurs around the edge of the mask when user inhales	When properly fitted and donned, minimal leakage occurs around edges of the respirator when user inhales
Use Limitations	Disposable. Discard after each patient encounter.	Ideally should be discarded after each patient encounter and after aerosol-generating procedures. It should also be discarded when it becomes damaged or deformed; no longer forms an effective seal to the face; becomes wet or visibly dirty; breathing becomes difficult; or if it becomes contaminated with blood, respiratory or nasal secretions, or other bodily fluids from patients.

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Research Needs

- More information about how humans are affected by air pollution
  - What other organ systems and what is the mechanism?
- What is the relationship between air pollution and infections?
- What other substances are responsible?
  - Does it matter how the substances are created?
- What interventions are most successful in reducing the harmful effects of pollution?

Conclusion

- Pollution has had a devastating effect on human health
- Indoor air pollution is important to consider particularly during the winter
- More multidisciplinary research is needed
- Effective interventions are not necessarily costly, but require behavioral change