Health Effects of Air Pollution

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PARTICULATE MATTER

- Complex heterogeneous mixture of solid and liquid components

- Sources:
  - Power plants and industry
  - Motor vehicles
  - Domestic coal burning
  - Natural sources (volcanoes, dust storms)
  - Secondary small particles from gases (nitrates and sulfates)
Particulate matter - definitions

A complex mixture of airborne solid and liquid particles, including soot, organic material, sulfates, nitrates, other salts, metals, biological materials.

- PM\(_{10}\) -- inhalable particles
- PM\(_{2.5}\) -- fine particles
- PM\(_{10}\)-PM\(_{2.5}\) -- coarse particles
- PM\(_{0.1}\) -- ultrafine particles
**Ultrafines (\(<0.1 \mu m\)**)

- Local combustion
- Long-distance transport
- Soil

Particle aerodynamic diameter, \(\mu m\)
Particulate Matter

Fine fraction (PM$_{2.5}$)

- Elemental and Organic Carbon
- Sulphate
- Nitrate
- Ammonium
- Chloride
- Insoluble minerals
- Na, K, Mg, Ca

Coarse fraction (PM$_{2.5}$-PM$_{10}$)
SIZE MATTERS

- Coarse particles (2.5–10 microns) deposited in the upper respiratory tract and large airways

- Fine particles (< 2.5 microns) may reach terminal bronchioles and alveoli
Annual average PM\textsubscript{10} concentrations observed in selected cities worldwide, 2000-2004
Global Estimates of Ambient Fine Particulate Matter Concentrations from Satellite-Based Aerosol Optical Depth: Development and Application

Aaron van Donkelaar,1 Randall V. Martin,1,2 Michael Brauer,3 Ralph Kahn,4 Robert Levy,4 Carolyn Verduzco,1 and Paul J. Villeneuve5,6

Satellite-derived map of PM$_{2.5}$ averaged over 2001-2006. Credit: Dalhousie University, Aaron van Donkelaar
Fig 2. PM10 2007 Satellite

Annual PM$_{10}$
($\mu g/m^3$)

- $\leq 12$
- $>12$ - $16$
- $>16$ - $20$
- $>20$ - $24$
- $>24$ - $28$
- $>28$ - $32$
- $>32$

Inset 1: London
Inset 2: Rome

Transect Distance (km)

Measured PM$_{10}$ ($\mu g/m^3$)

Modelled PM$_{10}$ ($\mu g/m^3$)

$R^2=0.47;\ n=325$
y$=1.07x+1.36$
AIR POLLUTION MAPS, ITALY, 2006-2012

Maps of PM$_{10}$ in Italy at high resolution using satellite data (1 Km grid)

Stafoggia et al, Env Int, 2016
Industrial sites in Italy

61 industrial sites
(44 municipalities)

European Pollutant Release and Transfer Register (E-PRTR)

"Revealing the costs of air pollution from industrial facilities in Europe"
European Environmental Agency, 2011
## WHO AQG Summary (2005)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging time</th>
<th>AQG value</th>
<th>EU standard (target or limit value)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particulate matter</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>1 year 24 hour (99$^{\text{th}}$ percentile)</td>
<td>10 $\mu$g/m$^3$ 25 $\mu$g/m$^3$</td>
<td>25 $\mu$g/m$^3$ --</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>1 year 24 hour (99$^{\text{th}}$ percentile)</td>
<td>20 $\mu$g/m$^3$ 50 $\mu$g/m$^3$</td>
<td>40 $\mu$g/m$^3$ 50 $\mu$g/m$^3$***</td>
</tr>
<tr>
<td><strong>Ozone, O$_3$</strong></td>
<td>8 hour, daily maximum</td>
<td>100 $\mu$g/m$^3$</td>
<td>120 $\mu$g/m$^3$***</td>
</tr>
<tr>
<td><strong>Nitrogen dioxide, NO$_2$</strong></td>
<td>1 year 1 hour</td>
<td>40 $\mu$g/m$^3$ 200 $\mu$g/m$^3$</td>
<td>40 $\mu$g/m$^3$ 200 $\mu$g/m$^3$***</td>
</tr>
<tr>
<td><strong>Sulfur dioxide, SO$_2$</strong></td>
<td>24 hour 10 minute</td>
<td>20 $\mu$g/m$^3$ 500 $\mu$g/m$^3$</td>
<td>125 $\mu$g/m$^3$*** 350 $\mu$g/m$^3$*** (1 hr)</td>
</tr>
</tbody>
</table>

WHO levels are recommended to be achieved everywhere in order to significantly reduce the adverse health effects of pollution.
THE EFFECTS OF AIR POLLUTION ON HEALTH ARE OFTEN CONVENIENTLY CLASSIFIED:

In short-term and long-term effects

although there is probably a continuum of effects in the time scale, which are not yet fully understood.
Acute effects
Temporal differences

Chronic effects
Spatial differences
Short-term health effects
Deaths from London Smog, December 1952
Long-term health effects
Long-term exposure and mortality

Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution

POPE ET AL, JAMA 2002
Figure 2. Nonparametric Smoothed Exposure Response Relationship

A. All-Cause Mortality

B. Cardiopulmonary Mortality

C. Lung Cancer Mortality

D. All Other Cause Mortality

Vertical lines along x-axes indicate rug or frequency plot of mean fine particulate pollution; PM$_{2.5}$, mean fine particles measuring less than 2.5 μm in diameter; RR, relative risk; and CI, confidence interval.
Adjusted mortality relative risks (RR) associated with 10μg/m³ change in PM$_{2.5}$*

(Pope et al, 2002)

<table>
<thead>
<tr>
<th>Cause of mortality</th>
<th>RR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cause</td>
<td>1.06 (1.02 – 1.11)</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>1.14 (1.04 – 1.23)</td>
</tr>
<tr>
<td>Cardiopulmonary</td>
<td>1.09 (1.03 – 1.16)</td>
</tr>
<tr>
<td>All other cause</td>
<td>1.01 (0.95 – 1.06)</td>
</tr>
</tbody>
</table>

*Adjusted for age, sex, race, smoking, education, marital status, body mass, alcohol consumption, occupational exposure, diet.
Possible biological mechanisms linking PM with cardiovascular diseases

Brook et al, 2004. AHA
Ischemic and Thrombotic Effects of Dilute Diesel-Exhaust Inhalation in Men with Coronary Heart Disease

Nicholas L. Mills, M.D., Håkan Törnqvist, M.D., Manuel C. Gonzalez, M.D., Elen Vink, B.Sc., Simon D. Robinson, M.D., Stefan Söderberg, M.D., Ph.D., Nicholas A. Boon, M.D., Ken Donaldson, Ph.D., Thomas Sandström, M.D., Ph.D., Anders Blomberg, M.D., Ph.D., and David E. Newby, M.D., Ph.D.
Atherosclerosis: A Progressive Process

Normal → Fatty Streak → Fibrous Plaque → Occlusive Atherosclerotic Plaque → Plaque Rupture/Fissure & Thrombosis

Prenatal and early childhood exposures
Endothelial dysfunction and plaque progression due to risk factor exposure
Effort Angina or Claudication

Blood levels of inflammatory markers (e.g., CRP)

Clinically silent 10 → Clinically apparent 40

Increasing age (years) 10 → 20 → 30 → 40 → 50+

Unstable Angina
MI
Coronary Death
Stroke
Critical Leg Ischemia
Diet, air pollution and atherosclerosis

Mice on normal diet

Mice on high-fat diet

Filtered air  PM2.5  Filtered air  PM2.5

Recent statements and publications on air pollution
World Health Assembly closes, passing resolutions on air pollution and epilepsy

New release

May 26, 2015

26 MAY 2015 | GENEVA - The World Health Assembly closed today, with Director-General Dr Margaret Chan noting that it had passed several “landmark resolutions and decisions”. Three new resolutions were passed today: one on air pollution, one on epilepsy and one laying out the next steps in finalizing a framework of engagement with non-State actors.

Air pollution

Delegates at the World Health Assembly adopted a resolution to address the health impacts of air pollution – the world’s largest single environmental health risk. Every year 4.3 million deaths occur from exposure to indoor air pollution and 3.7 million deaths are attributable to outdoor air pollution. This was the first time the Health Assembly had debated the topic.
IARC: DIESEL ENGINE EXHAUST CARCINOGENIC

Lyon, France, June 12, 2012 — After a week-long meeting of international experts, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), today classified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer.

INDOOR EMISSIONS FROM HOUSEHOLD COMBUSTION OF COAL

Indoor combustion of coal was considered by a previous IARC Working Group in 2006 (IARC, 2010a). Since that time, new data have become available, these have been incorporated into the Monograph, and taken into consideration in the present evaluation.

1. Exposure Data

1.1 Constituents of coal emissions from household use of coal

1.1.1 Types and forms of coal

Coal is a highly variable fuel, which ranges from high heating-value anthracite through sub-bituminous to lignite. It is composed of inorganic (mineral) matter and organic (carbon) matter. This organic matter is made up of hydrocarbons (water soluble) and other substances.

1.1.2 Constituents of coal emissions

When using small and simple combustion devices such as household cooking and heating stoves, coals are difficult to burn without substantial emission of pollutants principally due to the difficulty of completely pre-mixing the fuel and air during burning. Consequently, a substantial fraction of the fuel carbon is converted to products of incomplete combustion. For example,
IARC: Outdoor air pollution a leading environmental cause of cancer deaths

Lyon/Geneva, 17 October 2013 – The specialized cancer agency of the World Health Organization, the International Agency for Research on Cancer (IARC), announced today that it has classified outdoor air pollution as *carcinogenic to humans* (Group 1).

After thoroughly reviewing the latest available scientific literature, the world’s leading experts convened by the IARC Monographs Programme concluded that there is *sufficient evidence* that exposure to outdoor air pollution causes lung cancer (Group 1). They also noted a positive association with an increased risk of bladder cancer.

Particulate matter, a major component of outdoor air pollution, was evaluated separately and was also classified as *carcinogenic to humans* (Group 1).

The IARC evaluation showed an increasing risk of lung cancer with increasing levels of exposure to particulate matter and air pollution. Although the composition of air pollution and levels of exposure can vary dramatically between locations, the conclusions of the Working Group apply to all regions of the world.

1. Exposure Data

1.1 Constituents of coal emissions from household use of coal

1.1.1 Types and forms of coal

Coal is a highly variable fuel, which ranges from high heating-value anthracite through subbituminous coals to bituminous coal. The properties of coal, such as the type of ash (silica, alumina, and/or iron oxide), sulfur content, and mineral component, can vary significantly.

1.1.2 Constituents of coal emissions

When using small and simple combustion devices such as household cooking and heating stoves, coals are difficult to burn without substantial emission of pollutants principally due to the difficulty of completely pre-mixing the fuel and air during burning. Consequently, a substantial fraction of the fuel carbon is converted to products of incomplete combustion. For example...
GBD 2010: Air pollution is a major risk factor for public health


Lancet, 2012
Health effects of particulate air pollution

- Respiratory Disease Mortality
- Respiratory Disease Morbidity
- Lung Cancer
- Pneumonia
- Upper and lower respiratory symptoms
- Airway inflammation
- Decreased lung function
- Decreased lung growth

- Insulin Resistance
- Type 2 diabetes
- Type 1 diabetes
- Bone metabolism

- High blood pressure
- Endothelial dysfunction
- Increased blood coagulation
- Systemic inflammation
- Deep Venous Thrombosis

- Stroke
- Neurological development
- Mental Health
- Neurodegenerative diseases

- Cardiovascular Disease Mortality
- Cardiovascular Disease Morbidity
- Myocardial Infarction
- Arrhythmia
- Congestive Heart Failure
- Changes in Heart Rate Variability
- ST-Segment Depression
- Skin Aging

- Premature Birth
- Decreased Birth Weight
- Decreased foetal growth
- In uterine growth retardation
- Decreased sperm quality
- Preclampsia

Joint ERS / ATS statement (ERJ, 2016)
Original Article

Air Pollution and Mortality in the Medicare Population

Qian Di, M.S., Yan Wang, M.S., Antonella Zanobetti, Ph.D., Yun Wang, Ph.D., Petros Koutrakis, Ph.D., Christine Choirat, Ph.D., Francesca Dominici, Ph.D., and Joel D. Schwartz, Ph.D.

NEJM  June 2017
Average PM$_{2.5}$ and Ozone Concentrations in the Continental United States, 2000 through 2012.
Risk of Death Associated with an Increase of 10 μg per Cubic Meter in PM$_{2.5}$ or an Increase of 10 ppb in Ozone Concentration.

Table 2. Risk of Death Associated with an Increase of 10 μg per Cubic Meter in PM$_{2.5}$ or an Increase of 10 ppb in Ozone Concentration.*

<table>
<thead>
<tr>
<th>Model</th>
<th>PM$_{2.5}$</th>
<th>Ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>hazard ratio (95% CI)</td>
<td></td>
</tr>
<tr>
<td>Two-pollutant analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main analysis</td>
<td>1.073 (1.071–1.075)</td>
<td>1.011 (1.010–1.012)</td>
</tr>
<tr>
<td>Low-exposure analysis</td>
<td>1.136 (1.131–1.141)</td>
<td>1.010 (1.009–1.011)</td>
</tr>
<tr>
<td>Analysis based on data from nearest monitoring site (nearest-monitor analysis)†</td>
<td>1.061 (1.059–1.063)</td>
<td>1.001 (1.000–1.002)</td>
</tr>
<tr>
<td>Single-pollutant analysis‡</td>
<td>1.084 (1.081–1.086)</td>
<td>1.023 (1.022–1.024)</td>
</tr>
</tbody>
</table>

* Hazard ratios and 95% confidence intervals were calculated on the basis of an increase of 10 μg per cubic meter in exposure to PM$_{2.5}$ and an increase of 10 ppb in exposure to ozone.
† Daily average monitoring data on PM$_{2.5}$ and ozone were obtained from the Environmental Protection Agency Air Quality System. Daily ozone concentrations were averaged from April 1 through September 30 for the computation of warm-season averages. Data on PM$_{2.5}$ and ozone levels were obtained from the nearest monitoring site within 50 km. If there was more than one monitoring site within 50 km, the nearest site was chosen. Persons who lived more than 50 km from a monitoring site were excluded.
‡ For the single-pollutant analysis, model specifications were the same as those used in the main analysis, except that ozone was not included in the model when the main effect of PM$_{2.5}$ was estimated and PM$_{2.5}$ was not included in the model when the main effect of ozone was estimated.
Concentration–Response Function of the Joint Effects of Exposure to PM$_{2.5}$ and Ozone on All-Cause Mortality.

A Exposure to PM$_{2.5}$

B Exposure to Ozone
The Lancet, May 2017

Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015


Findings Ambient PM$_{2.5}$ was the fifth-ranking mortality risk factor in 2015. Exposure to PM$_{2.5}$ caused 4.2 million (95% uncertainty interval [UI] 3.7 million to 4.8 million) deaths and 103.1 million (90.8 million to 115.1 million) disability-adjusted life-years (DALYs) in 2015, representing 7.6% of total global deaths and 4.2% of global DALYs, 59% of these in east and south Asia. Deaths attributable to ambient PM$_{2.5}$ increased from 3.5 million (95% UI 3.0 million to 4.0 million) in 1990 to 4.2 million (3.7 million to 4.8 million) in 2015. Exposure to ozone caused an additional 254 000 (95% UI 97 000–422 000) deaths and a loss of 4.1 million (1.6 million to 6.8 million) DALYs from chronic obstructive pulmonary disease in 2015.

4.2 million deaths attributable to PM2.5 in 2015
Deaths attributable to ambient particulate matter pollution in 2015