Health Effects of Air Pollution

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Varenna, July 22 2019

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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), e.g. from agriculture
Particulate matter - definitions

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

- $\text{PM}_{10}$ -- inhalable particles
- $\text{PM}_{2.5}$ -- fine particles
- $\text{PM}_{10-2.5}$ -- coarse particles
- $\text{PM}_{0.1}$ -- ultrafine particles
**Ultrafines**

(<0.1 µm)

Particle aerodynamic diameter, µm

mass, dm/dlogDp, µg/m³

Local combustion

Long-distance transport

Soil

PM2.5

Elements:
- Al
- Ca
- Fe
- O
- Si

Elements in Ultrafines:
- C
- SO₄
- NH₄
- NO₃
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$_{10}$)
Sources of air pollutants in the EU\textsuperscript{11}

\begin{center}
\begin{tabular}{|c|c|c|c|c|c|}
\hline
 & Household heating & Road transport & Energy & Industry & Agriculture & Other \\
\hline
PM\textsubscript{10} & 42\% & 11\% & 10\% & 17\% & 15\% & 5\% \\
PM\textsubscript{2.5} & 57\% & 11\% & 12\% & 10\% & 4\% & 6\% \\
NO\textsubscript{x} & 14\% & 39\% & 31\% & 3\% & 5\% & 8\% \\
SO\textsubscript{x} & 13\% & & 78\% & 7\% & & 2\% \\
\hline
\end{tabular}
\end{center}

## 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&lt;sub&gt;2.5&lt;/sub&gt;</td>
<td>1 year</td>
<td>10 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>25 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>24 hour (99&lt;sup&gt;th&lt;/sup&gt; percentile)</td>
<td>25 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>20 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>PM&lt;sub&gt;10&lt;/sub&gt;</td>
<td>1 year</td>
<td>20 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>40 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>24 hour (99&lt;sup&gt;th&lt;/sup&gt; percentile)</td>
<td>50 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>50 µg/m&lt;sup&gt;3&lt;/sup&gt;***</td>
</tr>
<tr>
<td><strong>Ozone, O&lt;sub&gt;3&lt;/sub&gt;</strong></td>
<td>8 hour, daily maximum</td>
<td>100 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>120 µg/m&lt;sup&gt;3&lt;/sup&gt;***</td>
</tr>
<tr>
<td><strong>Nitrogen dioxide, NO&lt;sub&gt;2&lt;/sub&gt;</strong></td>
<td>1 year</td>
<td>40 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>40 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td>200 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>200 µg/m&lt;sup&gt;3&lt;/sup&gt;***</td>
</tr>
<tr>
<td><strong>Sulfur dioxide, SO&lt;sub&gt;2&lt;/sub&gt;</strong></td>
<td>24 hour</td>
<td>20 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>125 µg/m&lt;sup&gt;3&lt;/sup&gt;***</td>
</tr>
<tr>
<td></td>
<td>10 minute</td>
<td>500 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>350 µg/m&lt;sup&gt;3&lt;/sup&gt;*** (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.
Ambient Air Quality Directives

PM10 concentration
In red: above EU limit values

Percentage of the EU’s urban population exposed to exceeding PM10 limits

Annual mean particulate matter (PM$_{10}$) 2010, based on daily average with percentage of valid measurements ≥ 75% in μg/m$^3$.

EU air quality standards

% of urban population exposed to air pollution exceeding acceptable EU air quality standard

WHO air quality guidelines

% of urban population exposed to air pollution exceeding WHO air quality guidelines

Source: EEA Air Quality report 2012
Figure 5 – PM\(_{10}\) and NO\(_2\) concentrations in 2015
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
Estimation of daily PM$_{10}$ concentrations in Italy (2006–2012) using finely resolved satellite data, land use variables and meteorology

Massimo Stafoggia $^{a,b,*}$, Joel Schwartz $^c$, Chiara Badaloni $^a$, Tom Bellander $^{b,d}$, Ester Alessandrini $^a$, Giorgio Cattani $^e$, Francesca de' Donato $^a$, Alessandra Giugliano $^g$, Meytar Sorek-Hamer $^{g,h}$, Kees de Hoogh $^{i,j}$, Qian Di $^c$, Fr...
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
Exposure assessment – Spatial

Addresses

PM10 Concentration
- Green: 0.00 - 16.80
- Light Green: 16.80 - 27.78
- Yellow: 27.78 - 32.62
- Orange: 32.62 - 37.60
- Red: 37.60 - 49.77
Exposure assessment – Temporal

Exposure parameters:
- PM$_{10}$ μg/m$^3$
- Date

Graph showing temporal exposure assessment with PM$_{10}$ concentration over years 2006 to 2012.
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.
Health Effects of Particulate Matter

- Short-term increase in mortality
- Short-term increase in morbidity (cardiovascular and respiratory conditions)
- Decreased survival
- Increased lung cancer risk
Acute and chronic effects of air pollution on children’s respiratory health

**Acute effects**
- Increase in respiratory symptoms
- Increase in respiratory illnesses
- Exacerbation of asthma

**Chronic effects**
- Impaired functional lung growth
- Chronic respiratory diseases and asthma
Acute effects

Temporal differences

Chronic effects

Spatial differences
Short-term health effects
Deaths from London Smog, December 1952

Graph showing the increase in deaths per day and smoke levels during the London Smog event in December 1952.

JONATHAN M. SAMET, M.D., FRANCESCA DOMINICI, Ph.D., FRANK C. CURRIERO, Ph.D., IVAN COURSA, M.S., AND SCOTT L. ZEGER, Ph.D.
APHEA RESULTS

Percentage increase in the daily number of deaths associated with 10 \( \text{ug/m}^3 \) increase in \( PM_{10} \) measurements for each city.

Katsouyanni, 2001
Sorveglianza epidemiologica dell'inquinamento atmosferico
EPIAIR1:

- **Study period:** 2001-2005
- **Study population:** 10 cities
- **Focus on** $\text{PM}_{10}$, $\text{NO}_2$ and $\text{O}_3$
- Natural and cardio-respiratory mortality, cardio-respiratory hospital admissions
- **Socio-demographic characteristics and clinical conditions** (based on previous 2-year hospitalizations) evaluated as effect modifiers
## EPIAIR2 – Health data

<table>
<thead>
<tr>
<th>MORTALITY</th>
<th>N (range)</th>
<th>Daily mean (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural causes</td>
<td>422,723</td>
<td>9.9 (1.4 - 57.4)</td>
</tr>
<tr>
<td>Cardiac causes</td>
<td>113,358</td>
<td>2.5 (0.4 - 17.3)</td>
</tr>
<tr>
<td>Cerebrovascular causes</td>
<td>42,805</td>
<td>1.0 (0.1 - 5.1)</td>
</tr>
<tr>
<td>Respiratory causes</td>
<td>31,008</td>
<td>0.7 (0.1 - 3.6)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HOSPITALIZATIONS</th>
<th>N (range)</th>
<th>Daily mean (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac diagnosis</td>
<td>438,618</td>
<td>9.5 (1.8 - 56.3)</td>
</tr>
<tr>
<td>Cerebrovascular diagnosis</td>
<td>161,212</td>
<td>3.4 (0.6 - 21.1)</td>
</tr>
<tr>
<td>Respiratory diagnosis</td>
<td>331,289</td>
<td>7.2 (1.1 - 36.9)</td>
</tr>
</tbody>
</table>

Colais et al, Epidemiology 2011
MED-PARTICLES: the cities
### Associations between Fine and Coarse Particles and Mortality in Mediterranean Cities: Results from the MED-PARTICLES Project

Evangelia Samoli,1 Massimo Stafoggia,2 Sophia Rodopoulou,1 Bart Ostro,3,4 Christophe Declercq,5 Ester Alessandrini,2 Julio Diaz,6 Angeliki Karanasiou,4,7 Apostolos G. Kelessis,8 Alain Le Tertre,5 Paolo Pandolfi,9 Giorgia Randi,10 Cecilia Scarinzi,11 Stefano Zauli-Sajani,12 Klea Katsouyanni,1 and Francesco Forastiere2; the MED-PARTICLES Study Group

Table 2. Percent increase (95% CI) in mortality outcomes associated with 10-μg/m³ increase in PM for different cumulative lag structures.~

<table>
<thead>
<tr>
<th>Association under investigation</th>
<th>Lag 0–1</th>
<th>Lag 2–5</th>
<th>Lag 0–5</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause mortality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>0.55 (0.27, 0.84)</td>
<td>0.51 (0.07, 0.96)</td>
<td>0.70 (0.22, 1.18)</td>
</tr>
<tr>
<td>PM₂.₅–₁₀</td>
<td>0.30 (–0.10, 0.69)</td>
<td>–0.03 (–0.70, 0.64)*</td>
<td>0.07 (–0.75, 0.90)*</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>0.32 (0.13, 0.52)</td>
<td>0.19 (–0.18, 0.56)*</td>
<td>0.28 (–0.14, 0.71)*</td>
</tr>
<tr>
<td>Cardiovascular mortality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>0.57 (0.07, 1.08)</td>
<td>0.77 (0.20, 1.34)</td>
<td>0.86 (0.15, 1.57)</td>
</tr>
<tr>
<td>PM₂.₅–₁₀</td>
<td>0.28 (–0.37, 0.93)</td>
<td>0.33 (–0.59, 1.26)</td>
<td>0.33 (–0.78, 1.46)</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>0.31 (–0.01, 0.62)</td>
<td>0.41 (0.04, 0.79)</td>
<td>0.54 (0.09, 0.99)</td>
</tr>
<tr>
<td>Respiratory mortality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>0.72 (–0.11, 1.55)</td>
<td>1.63 (0.62, 2.65)</td>
<td>1.91 (0.71, 3.12)</td>
</tr>
<tr>
<td>PM₂.₅–₁₀</td>
<td>–0.13 (–1.25, 1.01)</td>
<td>0.72 (–0.31, 1.76)</td>
<td>0.76 (–0.70, 2.25)</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>0.23 (–0.35, 0.81)</td>
<td>1.14 (0.28, 2.00)</td>
<td>1.12 (0.29, 1.95)</td>
</tr>
</tbody>
</table>
Saharan dust: frequency of events

African dust frequency (% over annual days)

Pey et al. *Atmos Chemistry Physics* (2013)
### Effects of two PM$_{10}$ sources: Anthropogenic and Saharan dust

Percent increase (95% CI) in mortality and hospital admissions associated with 10 μg/m$^3$ increase in anthropogenic/desert PM$_{10}$: Results of two-pollutant models

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Lag</th>
<th>Percent change (95% CI)</th>
<th>I$^2$</th>
<th>$X^2$</th>
<th>p value</th>
<th>Percent change (95% CI)</th>
<th>I$^2$</th>
<th>$X^2$</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mortality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural</td>
<td>0-1</td>
<td>0.53 (0.23, 0.83)</td>
<td>32</td>
<td>0.147</td>
<td></td>
<td>0.66 (0.27, 1.06)</td>
<td>0</td>
<td>0.748</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>0-5</td>
<td>0.47 (-0.39, 1.33)</td>
<td>46</td>
<td>0.045</td>
<td></td>
<td>1.10 (0.15, 2.05)</td>
<td>0</td>
<td>0.766</td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>0-5</td>
<td>2.43 (0.94, 3.95)</td>
<td>41</td>
<td>0.073</td>
<td></td>
<td>1.28 (-0.42, 3.01)</td>
<td>0</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td><strong>Hospital admissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiovascular, age 15+</td>
<td>0-1</td>
<td>0.36 (-0.02, 0.75)</td>
<td>59</td>
<td>0.016</td>
<td></td>
<td>0.23 (-0.30, 0.76)</td>
<td>0</td>
<td>0.503</td>
<td></td>
</tr>
<tr>
<td>Respiratory, age 15+</td>
<td>0-5</td>
<td>0.67 (0.14, 1.19)</td>
<td>21</td>
<td>0.266</td>
<td></td>
<td>0.67 (-0.48, 1.83)</td>
<td>10</td>
<td>0.352</td>
<td></td>
</tr>
<tr>
<td>Respiratory, age 0-14</td>
<td>0-5</td>
<td>1.76 (0.60, 2.94)</td>
<td>24</td>
<td>0.235</td>
<td></td>
<td>2.38 (0.09, 4.71)</td>
<td>9</td>
<td>0.363</td>
<td></td>
</tr>
</tbody>
</table>

Stafoggia et al, EHP 2015
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.
Early Studies on the Mechanisms linking Air-Pollution to Cardiovascular Conditions

<table>
<thead>
<tr>
<th>Authors</th>
<th>Observed association with PM exposure</th>
<th>Physiologic endpoints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peters et al. 1997</td>
<td>Increased risk of elevated blood plasma viscosity</td>
<td>Plasma viscosity</td>
</tr>
<tr>
<td>Pope et al. 1999</td>
<td>Increased mean heart rate and odds of a substantially elevated heart rate</td>
<td>Heart rate</td>
</tr>
<tr>
<td>Peters et al. 1999</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liao et al 1999</td>
<td>Changes in cardiac rhythm.</td>
<td>Heart rate variability</td>
</tr>
<tr>
<td>Pope et al. 1999</td>
<td>Decrease in overall heart rate variability</td>
<td></td>
</tr>
<tr>
<td>Gold et al. 2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pekkanen et al, 2000</td>
<td>Increased mean plasma fibrinogen</td>
<td>Plasma fibrinogen</td>
</tr>
<tr>
<td>Ibald-Mulli et al. 2001</td>
<td>Increase in systolic blood pressure</td>
<td>Blood pressure</td>
</tr>
<tr>
<td>Peters et al, 2001</td>
<td>Increased odds of elevated C-reactive protein</td>
<td>C-reactive protein</td>
</tr>
</tbody>
</table>
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.
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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 20 30 40 50+

Increasing age (years)

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

Ambient Air Pollution and Atherosclerosis in Los Angeles

Figure 2. Mean CIMT ± 1 SE among quartiles of the PM$_{2.5}$ distribution. The y-axis shows mean CIMT levels at the population average of the adjustment covariates (age, sex, education, and income). The first quartile is the reference group.

carotid intima-media thickness (CIMT),

Kunzli et al, EHP 2005
European Studies
## Air pollution and mortality in the Rome Longitudinal Study

### Long-Term Exposure to Urban Air Pollution and Mortality in a Cohort of More than a Million Adults in Rome

*Giulia Cesaroni,1 Chiara Badaloni,1 Claudio Gariazzo,2 Massimo Stafoggia,1 Roberto Sozzi,3 Marina Davoli,1 and Francesco Forastiere1*

1Department of Epidemiology, Lazio Regional Health Service, Rome, Italy; 2Italian Workers’ Compensation Authority (INAIL), Rome, Italy; 3Regional Environmental Protection Agency, Rome, Italy

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Cases</th>
<th>HR</th>
<th>95% CI</th>
<th>HR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ug/m³ NO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Non accidental mortality</td>
<td>144,441</td>
<td>1.03</td>
<td>1.02</td>
<td>1.03</td>
<td>1.04</td>
</tr>
<tr>
<td>Cardiovascular mortality</td>
<td>60,318</td>
<td>1.03</td>
<td>1.02</td>
<td>1.04</td>
<td>1.06</td>
</tr>
<tr>
<td>IHD mortality</td>
<td>22,562</td>
<td>1.05</td>
<td>1.03</td>
<td>1.06</td>
<td>1.10</td>
</tr>
<tr>
<td>Respiratory mortality</td>
<td>8,825</td>
<td>1.03</td>
<td>1.00</td>
<td>1.06</td>
<td>1.03</td>
</tr>
</tbody>
</table>

| 10 ug/m³ PM2.5          |           |      |         |      |         |
| Non accidental mortality| 144,441   |      |         |      |         |
| Cardiovascular mortality| 60,318    |      |         |      |         |
| IHD mortality           | 22,562    |      |         |      |         |
| Respiratory mortality   | 8,825     |      |         |      |         |
Long-Term Exposure to Urban Air Pollution and Mortality in a Cohort of More than a Million Adults in Rome

Giulia Cesaroni, Chiara Badaloni, Claudio Gariazzo, Massimo Stafoggia, Roberto Sozzi, Marina Davoli, and Francesco Forastiere

A

Nonaccidental causes

Cardiovascular disease

EU Limit Value

EU Limit Value

In-HRs

NO₂ (µg/m³)

EHP 2013
ESCAPE study areas in EUROPE

PM+NOx

NOx only
Air pollution measurements ~400 PM, ~1,500 NOx locations

Measurement of fine particles with pump and sampling head

Measurement of nitrogen oxides with passive samplers
The ESCAPE project

Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project


Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE)

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Long-Term Exposure to Ambient Air Pollution and Incidence of Cerebrovascular Events: Results from 11 European Cohorts within the ESCAPE Project

Massimo Stafoggia,1 Giulia Cesaroni,1 Annette Peters,2 Zoe J. Andersen,3,4 Chiara Badaloni,5 Rob Beelen,5 Barbara Caracciolo,6 Josef Cyrys,2,7 Ulf de Faire,8 Kees de Hoogh,9 Kirsten T. Eriksen,2 Laura Fratiglioni,6,10,11 Claudia Galassi,12 Bruna Gigante,13 Atsuo Havelin,12 Frauke Hennig,16 Agnete Hilding,15 Gerard Hooij,5 Barbara Hoffmann,14,16 Danny Houthuijs,7 Michal Korek,8 Timo Lanki,18 Karin Leander,8 Patrik K. Magnusson,19 Christa Meisinger,3,20 Enrica Miglioretti,5 Kim Ovendal,21,22 Clas Goran Östenson,15 Nancy L. Pedersen,16 Juna Pekkanen,16 Johanna Penell,9 Goran Pershagen,10 Nooren Pundt,23 Andriy Pyko,9 Ole Raaschou-Nielsen,2 Andrea Ranzi,25 Fulvio Ricceri,25 Carlotta Sacerdote,12 Wilm J. Swart,17 Anu W. Turren,18 Paolo Vineis,9,25 Christian Weimar,26 Gudrun Weinmayr,16,27 Kathrin Wolf,2 Bert Brunekreef,2 and Francesco Forastiere1
## The ESCAPE project

<table>
<thead>
<tr>
<th></th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(10 ug/m$^3$)</td>
<td>(5 ug/m$^3$)</td>
</tr>
<tr>
<td>Non accidental mortality</td>
<td>1.04 (1.00–1.09)</td>
<td>1.07 (1.02–1.13)</td>
</tr>
<tr>
<td>CV mortality</td>
<td>1.02 (0.92–1.14)</td>
<td>0.99 (0.91–1.08)</td>
</tr>
<tr>
<td>Incidence of acute coronary events</td>
<td>1.12 (1.04-1.28)</td>
<td>1.13 (0.98-1.30)</td>
</tr>
<tr>
<td>Incidence of stroke</td>
<td>1.02 (0.90-1.16)</td>
<td>1.19 (0.88-1.62)</td>
</tr>
<tr>
<td>Lung cancer incidence</td>
<td>1.22 (1.03–1.45)</td>
<td>1.18 (0.96–1.46)</td>
</tr>
</tbody>
</table>
Recent statements and publications on air pollution
World Health Assembly closes, passing resolutions on air pollution and epilepsy

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: 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 bituminous, sub-bituminous, to lignite coals. Depending on its composition and the amount of air supplied during combustion, the degree of complete burnout varies, leading to incomplete combustion and the generation of emissions, generally in the form of gases and particulates. Incomplete combustion products are the result of fuel combustion in which not all fuel components are converted to gaseous by-products.

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,
Figure 1. Global ranking of risk factors by total number of deaths from all causes for all ages and both sexes in 2016.
GBD 2015 Italy

What risk factors drive the most death and disability combined?

Top 10 causes of DALYs with key risk factors, 2015
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>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</td>
<td>1.061 (1.059–1.063)</td>
<td>1.001 (1.000–1.002)</td>
</tr>
<tr>
<td>monitoring site (nearest-monitor analysis)</td>
<td></td>
<td></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$_{2.5}$

- Hazard Ratio vs. PM$_{2.5}$ (µg/m$^3$)

**B** Exposure to Ozone

- Hazard Ratio vs. Ozone (ppb)
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
Effects of fossil fuel and total anthropogenic emission removal on public health and climate

J. Lelieveld\textsuperscript{a,b,1}, K. Klingmüller\textsuperscript{a}, A. Pozzer\textsuperscript{a}, R. T. Burnett\textsuperscript{c}, A. Haines\textsuperscript{d}, and V. Ramanathan\textsuperscript{e}

Table 1. Excess mortality rate attributed to air pollution in the top 15 ranking countries

<table>
<thead>
<tr>
<th>Countries</th>
<th>Excess deaths, ( \times 10^3/y )</th>
<th>YLL, ( \times 10^6/y )</th>
<th>All sources</th>
<th>Fossil-fuel-related</th>
<th>Total anthropogenic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Avoidable deaths, ( \times 10^3/y )</td>
<td>Unavoidable warming, °C</td>
<td>Avoidable deaths, ( \times 10^3/y )</td>
</tr>
<tr>
<td>China</td>
<td>2,799</td>
<td>61.9</td>
<td>1,554</td>
<td>0.92</td>
<td>2,204</td>
</tr>
<tr>
<td>India</td>
<td>1,853</td>
<td>55.0</td>
<td>692</td>
<td>0.38</td>
<td>1,140</td>
</tr>
<tr>
<td>USA</td>
<td>283</td>
<td>5.7</td>
<td>194</td>
<td>0.88</td>
<td>230</td>
</tr>
<tr>
<td>Pakistan</td>
<td>233</td>
<td>7.9</td>
<td>29</td>
<td>0.44</td>
<td>73</td>
</tr>
<tr>
<td>Japan</td>
<td>203</td>
<td>3.1</td>
<td>84</td>
<td>1.03</td>
<td>117</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>186</td>
<td>4.3</td>
<td>114</td>
<td>1.07</td>
<td>152</td>
</tr>
<tr>
<td>Nigeria</td>
<td>181</td>
<td>9.1</td>
<td>6</td>
<td>0.10</td>
<td>33</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>175</td>
<td>5.1</td>
<td>73</td>
<td>0.80</td>
<td>130</td>
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<tr>
<td>Indonesia</td>
<td>174</td>
<td>5.3</td>
<td>35</td>
<td>0.19</td>
<td>88</td>
</tr>
<tr>
<td>Sudan + South</td>
<td>126</td>
<td>5.5</td>
<td>6</td>
<td>0.45</td>
<td>11</td>
</tr>
<tr>
<td>Sudan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>124</td>
<td>2.1</td>
<td>76</td>
<td>0.91</td>
<td>115</td>
</tr>
<tr>
<td>Egypt</td>
<td>120</td>
<td>3.4</td>
<td>19</td>
<td>1.03</td>
<td>21</td>
</tr>
<tr>
<td>Brazil</td>
<td>102</td>
<td>2.7</td>
<td>16</td>
<td>0.35</td>
<td>65</td>
</tr>
<tr>
<td>Vietnam</td>
<td>88</td>
<td>2.2</td>
<td>35</td>
<td>0.35</td>
<td>61</td>
</tr>
<tr>
<td>Italy</td>
<td>81</td>
<td>1.2</td>
<td>41</td>
<td>0.84</td>
<td>50</td>
</tr>
<tr>
<td>World</td>
<td>8,793</td>
<td>233</td>
<td>3,608</td>
<td>0.35</td>
<td>5,554</td>
</tr>
</tbody>
</table>