Estimating the Health Impact from Air Pollution: An Overview of Modelling Tools

Daven K. Henze
University of Colorado, Boulder

Horowitz et al. (2006)
How are the health impacts (premature deaths) estimated for long-term exposure to PM$_{2.5}$ and O$_3$?

Three main ingredients:

**Concentrations**
- Long-term averages (6 - 12 m)
- PM$_{2.5}$ and O$_3$
- Surface level

**Population and health data**
- Age stratified, km-scale or less
- Mortality rates

**Concentration-response functions**
- Quantify incidence of health outcomes from exposure
- Use statistical or functional epidemiological relationships:
  - $M = f(C, \text{pop}, \text{rate})$

![Maps showing population distribution and concentration levels](image1.png)

![Graph showing concentration-response function](image2.png)
How are the health impacts (premature deaths) estimated for long-term exposure to PM$_{2.5}$ and O$_3$?

Computational recipe:

1. Population and health data
2. Concentrations PM$_{2.5}$, O$_3$
3. Concentration Response Function $M=f(C,p,r)$
4. Health impacts
How are the health impacts (premature deaths) estimated for long-term exposure to PM$_{2.5}$ and O$_3$?

Computational recipe:
First global estimates of anthropogenic impacts on human health

Exposure estimated using model simulations alone (MOZART, 2.8° x 2.8°, Horowitz et al., 2006)

0.7 million from O₃ and 3.7 million from PM₂.₅ (Anenberg et al., EHP, 2010)

Significantly more than previous estimates of 0.8 million from Cohen et al. (2004) based on urban PM monitoring
Global estimates of PM$_{2.5}$ health impacts from satellite-derived exposure estimate

Hoff and Christopher (JAWMA, 2009) “Remote sensing of particulate pollution from space: have we reached the promised land?” – uncertainty in AOD-derived PM$_{2.5}$ reaching ~30%.

First estimates of global PM$_{2.5}$ health impacts from satellite-derived PM2.5 (van Donkelaar et al., 2010) reported in in Evans et al. (ER, 2013): 2.4 million cause-specific premature deaths in 2004.
Advanced fusion of satellite and model-based PM$_{2.5}$ estimates

PM$_{2.5}$ from Shaddick et al. (2018): hierarchical Bayesian synthesis of satellite-derived products, surface observations, geostatistical information.

Provides exposure estimates for GBD 2015 (Cohen et al., Lancet, 2017): 4.2 (3.7 – 4.8) million premature deaths
How are the health impacts (premature deaths) estimated for long-term exposure to PM$_{2.5}$ and O$_3$?
How are the health impacts (premature deaths) estimated for changes to pollutant emissions?
How are the health impacts (premature deaths) estimated for air quality policy?
How are the health impacts (premature deaths) estimated for air quality policy?

Concentration Response Function:

\[ M = f(C, p, r) \]

- Policy
- Emissions
- Concentrations (PM$_{2.5}$, O$_3$)
- Population and health data
- Health impacts

Integrated assessment tool + emissions allocation & processing
Chemical transport model (CTM)
Algebraic computations

E.g. GAINS + ECLIPSE → GEOS-Chem → Algebraic computations

“Rigorous calculations”
- requires wide range of expertise
- CTM requires workstation or supercomputer
- not amenable to exploration of myriad scenarios
How are the health impacts (premature deaths) estimated for air quality policy?

Many parts packaged into a variety of policy, decision support, and research tools.

Note: illustrative but not comprehensive set shown here. For more exhaustive review of tools: Anenberg et al. (2016)
Given concentrations, what are the health impacts?

**BenMAP and AirQ+:** input concentrations (gridded or tabulated, modeled or measured), estimate health burden

**BenMAP-CE example**

From Davidson et al., ERL, 2020: deaths due to PM$_{2.5}$ and ozone from the on-road sectors in 2011 and 2025. Concentrations from CAMx (AQ model)

These types of tools often consider additional health impacts (mortality, morbidity, DALY,...) and options (alternative CRF’s) for how they are estimated.
Comparisons: BenMAP-CE and AirQ+

### Similarities

**Table 3.** Comparison of Estimated Benefits of Meeting the World Health Organization (WHO) Air Quality Guideline (AQG) Annual PM$_{2.5}$ value of 10 μg/m$^3$ Using BenMAP—CE and AirQ+.

<table>
<thead>
<tr>
<th>Results</th>
<th>BenMAP—CE</th>
<th>Air Q+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subregion 1</td>
<td>Subregion 2</td>
</tr>
<tr>
<td>Estimated Attributable</td>
<td>8.9 (6.0–11.7)</td>
<td>11.1 (7.5–14.5)</td>
</tr>
<tr>
<td>Proportion (%)$^1$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Number of</td>
<td>965 (652–1271)</td>
<td>1278 (867–1677)</td>
</tr>
<tr>
<td>Attributable Cases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Number of</td>
<td>83.5 (56.4–109.9)</td>
<td>91.9 (62.3–120.5)</td>
</tr>
<tr>
<td>Attributable Cases per 100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population at Risk$^2$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Results represent the central estimate and 95% confidence intervals. $^1$ Estimated Attributable Proportion (%) = (Estimated Number of Attributable Cases/[(Population per 100,000) × (Mortality Rate per 100,000)])

$^2$ Estimated Number of Attributable Cases per 100,000 Population at Risk = (Estimated Number of Attributable Cases/Population) × 100,000.

### Differences

- BenMAPS health impacts functions are specific to US policy applications, whereas AirQ+ is a decision support tool for public health specialists.

Comparison of GBD ambient AQ health impacts across the years (Ostro et al., 2018)

Sources of uncertainties: concentrations vs CRFs

Δ updating concentration: 8% and 12%
Δ updating CRF (IER): 27%

Also, ranges around central estimate for any single CRF often ~30%
How are the health impacts (premature deaths) estimated for air quality policy?

- Policy
- Emissions
- Concentrations $\text{PM}_{2.5}$, $\text{O}_3$
- Concentration Response Function $M = f(C, p, r)$
- Health impacts

Many parts packaged into a variety of policy, decision support, and research tools.

- Satellite data
- In situ data
- Geographical info
- AQ models
- Population and health data

Note: illustrative but not comprehensive set shown here. For more exhaustive review of tools: Anenberg et al. (2016)
Given emissions, what are the health impacts?

What do you know about the emissions?
- individual sources (EASIUR)
- county, stack height (APX)
- gridded emissions inventories (InMAP, FATE, FASST)

Where do you evaluate health impacts?
- spatially disaggregated impacts
  - grid scale, global (InMAP, GBD Maps)
  - US (EASIUR w/APSCA)
- aggregated impacts
  - city (SHERPA)
  - county (APX)
  - national (FATE, FASST, EASIUR)

Emissions: point sources to global scenarios

Impacts: $\Delta PM_{2.5}$, $\Delta O_3$, premature deaths, $\$/ton...
Emissions to concentration is most expensive step in an explicit health impact calculation

- Different tools use different approaches to approximate this step
- Most approximations are linear (1st order) estimates
- When applied to the same emissions changes (right), tools show widest diversity for a vehicle emission scenario
- In contrast, range was much smaller when considering the response of only primary EC

IEC, 2019
Evaluating reduced form tools for estimating air quality benefits
Comparisons: emissions → impacts

Gilmore et al. (ERL, 2019) Marginal social costs for ground-level emissions for each US county by pollutant and by air quality model (in USD per tonne).

Given policy, what are the health impacts?

National and international scale policies

LEAP-IBC:
- detailed energy planning tool (LEAP: policy $\rightarrow$ emissions)
with Integrated Benefits Calculator (IBC: emissions $\rightarrow$ impacts)

Example: short-lived climate pollutant mitigation co-benefits
- $\sim$10,000 avoided deaths, 60% of which from SLCP mitigation
- $\sim$20,000 in concert with global initiatives
- Total burden rises from pop growth

City policies

Pathways:
- estimates of benefits from urban scale initiatives in $\sim$100 cities world-wide
- urban energy planning coupled with InMAP (emissions $\rightarrow$ concentrations)

These tools require detailed datasets describing current emissions controls, energy sources, transportation, etc., specific to the areas in question.

Kuylenstierna et al., 2020
What is under the hood?

The emission concentration from substantial (100’s to 1000’s of hrs of workstation or supercomputer simulations):

- APX: National-scale Gaussian dispersion model (CRDM; Latimer 1996), tuned to AQS
- EASIUR: Regression based on ensemble of CMAQ runs
- InMAP: Flexible grid re-calculation of annual averages from WRF-Chem (US) and GEOS-Chem (global) simulations
- TM5-FASST: Ensemble of emission perturbation simulations with TM5
- GBD-MAPS: Ensemble of emission perturbation simulations with GEOS-Chem
- LEAP-IBC, FATE: Ensemble of GEOS-Chem adjoint simulations

Tools may include:
- bias correction using in situ or remote sensing data
- downscaling of source locations or exposure using proxy data or remote sensing
Availability and complexity

- EASIUR: web-based or data-file download
- TMF-FASST: web-based, data-file download, or script
- Pathways: Spreadsheet (TBD)
- APX: MATLAB scripts
- FATE: Python scripts (TBD)
- BenMAP-CE, AirQ+: Desktop software, open access
- LEAP-IBC: Desktop software
- InMAP: Workstation software, open access
References and links


• BenMAP-CE: https://www.epa.gov/benmap


Summary

• Wide range of decision support tools and models exist to help relate policy to health impacts

• Key differences: inputs (policy, emissions, or concentrations), resolution (points, aggregates, gridded maps), and coverage (city to global)

• Air quality models used for estimation of exposure and processing of remote sensing data, as well as for decision support tools.

• Large diversity owing to emissions → concentration approximations, and large uncertainty from the concentration response function and health data

• Remote sensing, in situ data, and other proxy information used to calibrate and downscale

• Tools range from spreadsheets to heavier sets of scripts and executables, and all much faster than running grid-based AQ models
Thanks!