Health Impact Assessment for Air Pollution

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HEI Workshop
Nairobi, Kenya

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WARNING

YOU MUST PARTICIPATE
Goals for the workshop

• Introduce the concept of burden estimation
  • The underlying assumption of the *counterfactual* comparison
• Data needed for health impact assessment (HIA)
• Tools for HIA for air pollution
• Using HIA for decision-making
• Burden estimates for ambient and household air pollution (Carradee)
• Uncertainties associated with HIAs for air pollution
  • Limitations for policy purposes
• Communicating about results of HIA
• Experiences with HIA in the region (Abera and Otienoh)
A thing is safe if its risks are judged to be acceptable.

Therefore

- We need to have sufficiently certain estimates of risk
- And, we need to have a judgment on acceptability of risk.
Geoffrey Rose: *Sick Individuals and Sick Populations—Re-Imagined*

What drives:
- The whale?
- The tail?

Diagram showing the relationship between risk of disease increasing and numbers in population (millions), with higher and lower numbers of people at risk.
Causation and Policy

• By causation, we mean that exposure to the causal factor increases risk for disease.

• If an environmental agent acts to increase risk for an adverse event, then we want to know:
  • By how much is increased, i.e., the relative risk.
  • The nature/form of the exposure/risk relationship.
  • How much disease is caused by the agent, i.e., the population attributable risk.

• For policy purposes, we want to know how much risk can be reduced by taking various actions.
Air pollution a cause in girl's death, coroner rules in landmark case

Coroner says failure to reduce pollution levels to legal limits was factor in death of Ella Kissi-Debrah, who had severe asthma

A coroner has made legal history by ruling that air pollution was a cause of the death of a nine-year-old girl.

Philip Barlow, the inner south London coroner, said Ella Kissi-Debrah’s death in February 2013 was caused by acute respiratory failure, severe asthma and air pollution exposure.
Air pollution is the “new tobacco”, the head of the World Health Organization has warned, saying the simple act of breathing is killing 7 million people a year and harming billions more.
Dr Tedros Adhanom Ghebreyesus speaks at a press conference in 2017. Photograph: Fabrice Coffrini/AFP/Getty Images

Air pollution is the “new tobacco”, the head of the World Health Organization has warned, saying the simple act of breathing is killing 7 million people a year and harming billions more.

Imagine that you are Dr. Tedros

A reporter asks: Dr. Tedros, what do you mean when you say that air pollution causes 7 million deaths each year?

Your answer?
The Counterfactual

What does this mean—6.7 million deaths attributable to air pollution?

The “real world?”

The “counterfactual” world

Figure 3. Global and regional distributions of population as a function of annual (2013) average ambient PM$_{2.5}$ concentration for the world’s 10 most populous countries. Plotted data reflect local smoothing of bin width normalized distributions computed over 400 logarithmically spaced bins. Equal-sized plotted areas would reflect equal populations. Dashed vertical lines indicate World Health Organization Interim Targets (IT) and the Air Quality Guidelines (AQG).
The Counterfactual Concept

Definition: The counterfactual is contrary to the facts

• The counterfactual assumed is for a world that does not exist, but theoretically could.
• The counterfactual value generally has some basis for selection.
• Explaining the concept is critical for communication about burden estimates and health impact assessments.
Attributable vs Avoidable
Johns Hopkins Epidemiology Department, circa 1935-36

Morton Levin
Estimating the Attributable Burden of Lung Cancer

**TABLE V.**

Lung Cancer and Smoking. Indicated Incidence and Proportion Attributable to Smoking in Four Studies.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Lung Cancer Cases (a)</th>
<th>Per Cent Cigarette Smokers among</th>
<th>Ratio of Incidence</th>
<th>Indicated per cent of all lung cancer attributable to smoking <em>b(r-1) + 1</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(b)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Doll &amp; Hill (5)</td>
<td>99.7</td>
<td>96.0</td>
<td>1.04</td>
<td>13.8</td>
</tr>
<tr>
<td>2) Wynder &amp; Graham (11)</td>
<td>98.7</td>
<td>85.4</td>
<td>1.16</td>
<td>12.9</td>
</tr>
<tr>
<td>3) Breslow (2)</td>
<td>91.0</td>
<td>68.5</td>
<td>1.31</td>
<td>4.4</td>
</tr>
<tr>
<td>4) Levin et al. (1)</td>
<td>78.2</td>
<td>49.9</td>
<td>1.57</td>
<td>3.6</td>
</tr>
<tr>
<td>5) Levin et al. (*) adjusted to (3)</td>
<td>91.0</td>
<td>58.1</td>
<td>1.57</td>
<td>7.3</td>
</tr>
<tr>
<td>6) Doll &amp; Hill (*) excluding 1-4 cigarette smokers</td>
<td>96.0</td>
<td>89.2</td>
<td>1.07</td>
<td>2.8</td>
</tr>
</tbody>
</table>

(1) Adjusted to age distribution of data of (1) Doll and Hill.

(2) By bringing percentage of smokers in lung cancer cases to same percentage as in (3) and increasing percentage in controls proportionately.

(3) From Table VI, Doll and Hill (5).
A Reminder: RR and PAR

Relative Risk (RR)

\[ RR = \frac{\text{Risk in those exposed}}{\text{Risk in those not exposed}} \]

- RR = 1 indicates no increase
- RR > 1 indicates increased risk

Population Attributable Risk (PAR)

\[ PAR = \frac{P(RR-1)}{1 + P(RR-1)} \]

where P is exposure prevalence

PAR ranges from 0.0 to 1.00

Calculations for you

- P=0.5 and RR=1.5
- P=0.5 and RR=20
- P=0.1 and RR=1.5
- P=0.7 and RR=1.5
### Population Attributable Risk

\[
PAR = \text{Proportion of disease in the total population that is the result of exposure}
\]

<table>
<thead>
<tr>
<th>Relative Risk</th>
<th>Prevalence (%)</th>
<th>PAR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>10</td>
<td>0.05</td>
</tr>
<tr>
<td>1.5</td>
<td>80</td>
<td>0.29</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>0.29</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>0.67</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>0.47</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>0.82</td>
</tr>
</tbody>
</table>
The relationship of relative risk (RR) to the population-attributable fraction at different prevalence levels

Source: Surgeon General, 2014
Attributable is not the same as Avoidable

Figure 3. Global and regional distributions of population as a function of annual (2013) average ambient PM$_{2.5}$ concentration for the world’s 10 most populous countries. Plotted data reflect local smoothing of bin-width normalized distributions computed over 400 logarithmically spaced bins; equal-sized plotted areas would reflect equal populations. Dashed vertical lines indicate World Health Organization Interim Targets (IT) and the Air Quality Guideline (AQG).
Health Impact Assessment and Burden Estimation
US National Academies: Definition of HIA

HIA is a systematic process that uses an array of data sources and analytic methods and considers input from stakeholders to determine the potential effects of a proposed policy, plan, program, or project on the health of a population and the distribution of those effects within the population. HIA provides recommendations on monitoring and managing those effects.

WHO Health Impact Assessment Definition

Health Impact Assessment (HIA) is a practical approach used to judge the potential health effects of a policy, programme or project on a population, particularly on vulnerable or disadvantaged groups. Recommendations are produced for decision-makers and stakeholders, with the aim of maximising the proposal's positive health effects and minimising its negative health effects. The approach can be applied in diverse economic sectors and uses quantitative, qualitative and participatory techniques.

https://www.who.int/health-topics/health-impact-assessment#tab=tab_1
# Health Impact Assessment

## Phases
1. **Policy and programme development phase for prospective assessments**
   - **Steps:** Screening, Scoping, Appraisal, Reporting, Monitoring
   - **Questions:**
     - **Screening:** Who should carry out screening? How to carry out the screening?
     - **Scoping:** What is the geographical boundary of the HIA? What is the timeframe for the HIA to deliver? What skills are there in the HIA team?
     - **Appraisal:** Does the policy have the potential to affect environmental or social determinants that impact health outcomes? If so, which specific health determinants will be assessed? Would health inequities be impacted? Is the project impacts to health likely to be significant in terms of the number of individuals impacted, the magnitude, and/or immediacy of impacts? Are methods, expertise and evidence available to assess health impacts of the policy?
     - **Reporting:** What needs to be monitored after the proposal is implemented to check the estimates of the HIA? Are there any particular aspects that require careful consideration in case of early intervention? Did the policy decision change in a way that was consistent with the recommendations of the HIA?
   - **Actions:** Contact stakeholders and decision-makers. Identify resources.

2. **Stakeholders participation**
   - **Steps:** Screening, Scoping
   - **Questions:**
     - **Screening:**
     - **Scoping:** What is the geographical boundary of the HIA? What is the timeframe for the HIA to deliver? What skills are there in the HIA team?
   - **Actions:** Define roles. Use local data, expert opinion.

3. **Policy implementation phase**
   - **Steps:** Appraisal, Reporting, Monitoring
   - **Questions:**
     - **Appraisal:** Does the policy have the potential to affect environmental or social determinants that impact health outcomes? If so, which specific health determinants will be assessed? Would health inequities be impacted? Is the project impacts to health likely to be significant in terms of the number of individuals impacted, the magnitude, and/or immediacy of impacts? Are methods, expertise and evidence available to assess health impacts of the policy?
     - **Reporting:** What needs to be monitored after the proposal is implemented to check the estimates of the HIA? Are there any particular aspects that require careful consideration in case of early intervention? Did the policy decision change in a way that was consistent with the recommendations of the HIA?
   - **Actions:** Communicate HIA findings. Identify goals for the monitoring process.

## Methods
- Document review
- Secondary data review
- Surveys, interviews, and focus groups
- Field observations
- Statistical analysis/GIS mapping
- Interpretation analysis of data collection
- Identify evidence-based mitigations and recommendations

## Additional Notes
- Ensure stakeholder engagement throughout the process.
- Regular review and adjustment of the HIA as needed.
- Continuous monitoring and evaluation to refine future policy implementations.
Burden Estimation: A Component of HIA

- Estimates the **attributable burden**, the share of the burden of a disease that can be estimated to occur due to exposure to a particular risk factor, and the

- **Avoidable burden**, the reduction in future disease burden if observed levels of risk factor exposure were decreased to a counterfactual level.

- We measure disease burden as:
  - Years of life expectancy lost
  - DALYs: Disability-adjusted life-years
GBD Methods for Ambient Air Pollution

Flowchart

Risk factor estimation

Exposure
- WHO ambient air pollution cities database
- Government monitoring sites
- Global emission inventories
- GEOS-Chem chemical transport model
- Satellite retrievals 2006-2017
- Estimated grid cell surface PM2.5
- Grid cell population estimates
- Bayesian hierarchical calibration model
- Grid cell exposure estimates of ground monitor PM2.5

Relative risks
- Ambient air pollution
  - Cohort studies
  - Case-control studies
- Household solid fuel use
  - Cohort studies
  - Case-control studies
- Secondhand smoke
  - Cohort studies
  - Case-control studies
- Ambient air pollution exposure
- Calculate location-specific relative risks
- Set the year calculation
- Proportional split

Birthweight and Gestational Age
Household solid fuel use
- Cohort studies
- Case-control studies
- Randomized-controlled trials
- Ambient air pollution exposure
- Convert RR and OR to linear shift
- MR-BRT Spline fitting

Final burden estimation
- Deaths, YLLs, YLDs, DALYs for each disease and injury by age, sex, year, geography
- Population attributable fractions by risk, cause, age, sex, and geography
- Application of mediation factors where applicable
- Population attributable fractions by risk, age, sex, and geography
The TMREL was assigned a uniform distribution with lower/upper bounds given by the average of the minimum and fifth percentiles of outdoor air pollution cohort studies' exposure distributions, conducted in North America, with the assumption that current evidence was insufficient to precisely characterise the shape of the concentration-response function below the fifth percentile of the exposure distributions. The TMREL was defined as a uniform distribution rather than a fixed value in order to represent the uncertainty regarding the level at which the scientific evidence was consistent with adverse effects of exposure. The specific outdoor air pollution cohort studies selected for this averaging were based on the criteria that their fifth percentiles were less than that of the American Cancer Society Cancer Prevention II (CPSII) cohort’s fifth percentile of 8.2 based on Turner and colleagues (2016).\textsuperscript{10} This criterion was selected since GBD 2010 used the minimum, 5.8, and fifth percentile solely from the CPS II cohort. The resulting lower/upper bounds of the distribution for GBD 2019 were 2.4 and 5.9. This has not changed since GBD 2015.
- **Ambient Air Pollution**
  - **Cardiovascular Disease:**
    - 2,475,395 deaths
    - (4.38% of global deaths)
  - **Chronic Respiratory Disease:**
    - 695,071 deaths
    - (1.23% of global deaths)
  - **Neoplasms:**
    - 307,680 deaths
    - (0.54% of global deaths)
  - **Respiratory & TB:**
    - 326,365 deaths
    - (0.58% of global deaths)

- **Household Air Pollution**
  - **Cardiovascular Disease:**
    - 1,069,765 deaths
    - (1.89% of global deaths)
  - **Chronic Respiratory Disease:**
    - 398,386 deaths
    - (0.7% of global deaths)
  - **Neoplasms:**
    - 79,763 deaths
    - (0.14% of global deaths)
  - **Respiratory & TB:**
    - 422,887 deaths
    - (0.75% of global deaths)

- **Ozone**
  - **Chronic Respiratory Disease:**
    - 365,222 deaths
    - (0.65% of global deaths)

- ~6.66 million deaths (11.79% of global deaths)
- 4th ranking risk factor

Source: GBD
What do we need for burden estimation?

• Estimates of the exposure or exposure distribution for the population
  • Based on monitoring and models for air pollution
• An exposure-response relationship to estimate the risks of exposure
  • Based on external epidemiological data, the IER
• Population demographics
  • From national census data
• Population mortality (morbidity) statistics
  • From national vital statistics and other sources for morbidity
What do we need for burden estimation?

• Estimates of the exposure or exposure distribution for the population
  • *Based on monitoring and models for air pollution: From global models or local data*

• An exposure-response relationship to estimate the risks of exposure
  • *Based on external epidemiological data, the IER: External epidemiological studies and risk modeling*

• Population demographics
  • *From national census data: Available from government*

• Population mortality (morbidity) statistics
  • *From national vital statistics and other sources for morbidity: Potential challenge for cause-specific mortality and hospital morbidity*
### New WHO Global Air Quality Guidelines

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Time</th>
<th>2005 levels</th>
<th>New 2021 levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PM$_{2.5}$</strong></td>
<td>Annual</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>24-hour</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td><strong>PM$_{10}$</strong></td>
<td>Annual</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>24-hour</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td><strong>O$_3$</strong></td>
<td>Peak season</td>
<td>-</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>8-hour</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>NO$_2$</strong></td>
<td>Annual</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>24-hour</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td><strong>SO$_2$</strong></td>
<td>24-hour</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td><strong>CO</strong></td>
<td>24-hour</td>
<td>-</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: Values in microns ($\mu g / m^3$), 3-4 years, percentiles ($\%$).

WHO global air quality guidelines.
Environmental Public Health Tracking

![Confidence in/availability of local data diagram](image)

**Fig. 1**

Conceptual model for staged development of air pollution health impact assessment for environmental public health tracking

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2805788/
SOGA: AFRICA
THE STATE OF AIR QUALITY AND HEALTH IMPACTS IN AFRICA

A REPORT FROM THE STATE OF GLOBAL AIR INITIATIVE

2022

The State of Global Air is a collaboration between the Health Effects Institute and the Institute for Health Metrics and Evaluation's Global Burden of Disease project.
### TABLE 2 Death rates linked to PM$_{2.5}$ across African regions in 2019

<table>
<thead>
<tr>
<th>Region/Focus Country</th>
<th>PM$_{2.5}$ Death Rate* (UI)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Africa</td>
<td>55.8 (46.7–65.1)</td>
</tr>
<tr>
<td>Egypt</td>
<td>91.4 (67.5–118)</td>
</tr>
<tr>
<td>Southern Africa</td>
<td>38.6 (29.8–47.3)</td>
</tr>
<tr>
<td>South Africa</td>
<td>44.6 (35.4–53.8)</td>
</tr>
<tr>
<td>Western Africa</td>
<td>27.4 (16.7–40.7)</td>
</tr>
<tr>
<td>Ghana</td>
<td>39.8 (25.5–56.2)</td>
</tr>
<tr>
<td>Central Africa</td>
<td>15.6 (7.9–27)</td>
</tr>
<tr>
<td>Democratic Republic of the Congo</td>
<td>12.6 (5.3–23.8)</td>
</tr>
<tr>
<td>Eastern Africa</td>
<td>9.8 (5.3–15.8)</td>
</tr>
<tr>
<td>Kenya</td>
<td>10.9 (6.5–17)</td>
</tr>
</tbody>
</table>

*Death rate refers to the number of deaths per 100,000 people per year. **UI - Uncertainty interval refers to the 95% uncertainty interval.
FIGURE 9 Distribution of air pollution–linked deaths in 2019 by age (years, except neonatal [0 to 27 days]). Note that the number of deaths is on a different scale for each country.
# SOGA Africa: Cause-Specific Deaths Linked to PM$_{2.5}$

## TABLE 4 Percentage of cause-specific deaths linked to air pollution for the five focus countries in 2019

<table>
<thead>
<tr>
<th>Country</th>
<th>Diabetes</th>
<th>COPD</th>
<th>Stroke</th>
<th>Ischemic Heart Disease</th>
<th>Lung Cancer</th>
<th>Lower Respiratory Infections</th>
<th>Neonatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>30 (17–30)</td>
<td>46 (35–58)</td>
<td>33 (29–36)</td>
<td>30 (26–33)</td>
<td>29 (22–37)</td>
<td>39 (28–50)</td>
<td>22 (20–24)</td>
</tr>
</tbody>
</table>
SOGA Africa: Trends in Death Rates Attributable to Household Air Pollution

**FIGURE 8** Trends in death rates linked to household air pollution across Africa between 2010 and 2019.
HIA ETHIOPIA
Fine particulate pollution concentration in Addis Ababa exceeds the WHO guideline value

Results of 3 years of continuous monitoring and health impact assessment

Abera Kenewa, Abera Kayene, Weldegebriel Zewdie, Tsadik Worku, Teferi Tewodros, Arega Afarsu, Gemechu Gudina, Mekdes Melkamu, Meka Yosef, Dejene Kebede, Mekdes Tadesse

Background: Fine particulate pollution (PM$_{2.5}$) is a major health concern in Ethiopia. High PM$_{2.5}$ levels are associated with respiratory and cardiovascular diseases, particularly among elderly and vulnerable populations.

Methods: PM$_{2.5}$ concentrations were measured using a centrally-located Beta Attenuation Mass Monitor (BAM) for 3 years (1 April 2017 to 31 March 2020), with data downloaded biweekly. Deaths attributable to current PM$_{2.5}$ concentration levels were estimated using the AirQ+ tool. The daily average was estimated using hourly data.

Results: The daily mean (SD) PM$_{2.5}$ concentration was 42.4 µg/m$^3$ (15.98). Two daily extremes were observed: morning (high) and afternoon (low). Sundays had the lowest PM$_{2.5}$ concentration, while Mondays to Thursdays saw a continuous increase; Fridays showed the highest concentration. Seasons showed marked variation, with the highest values during the wet season. Concentration spikes reflected periods of intensive fuel combustion. A total of 502 deaths (4.44%) were attributable to current air pollution levels referenced to the 35 µg/m$^3$ WHO interim target annual level and 2,043 (17.7%) at the WHO 10 µg/m$^3$ annual guideline.

Conclusions: PM$_{2.5}$ daily levels were 1.7 times higher than the WHO-recommended 24-hour guideline. The current annual mean PM$_{2.5}$ concentration results in a substantial burden of attributable deaths compared to an annual mean of 10 µg/m$^3$. The high PM$_{2.5}$ level and its variability across days and seasons calls for citywide interventions to promote clean air.

Keywords: Fine particulate matter; Ambient air pollution; Beta Attenuation Mass Monitor; Impact of air pollution
PM$_{2.5}$ Monitoring in Addis Ababa: 3/2017-3/2020

1. Peaks Wet/ rainy months vs non-rainy months
2. Daily mean: 42.4 μg/m$^3$ >>> 25 μg/m$^3$ >>> 15 μg/m$^3$ (WHO 2021)
3. 3-year average: 42.4 μg/m$^3$ >>> 10 μg/m$^3$ >>> 5 μg/m$^3$ (WHO 2021)
The total population of Addis Ababa in 2020 was taken from UN population data sources (4.8 mln). We considered that 34% of the total population was adult of 30 years old and above (Addis Ababa Health Bureau, personal communication, February 2, 2021). The annual mortality for the year 2020 was taken from Addis Ababa Mortality Surveillance Program. A 7% of the incidence of injury was taken from published articles addressing the mortality surveillance program. We used the three WHO annual interim target options and the WHO annual mean air quality guideline as cut-off reference values to estimate the excess deaths because of PM2.5 pollution as measured by the three BAMs separately.
Premature deaths – AirQ+ (WHO)
11539 deaths in 2020, aged >30yrs

<table>
<thead>
<tr>
<th>BAM location</th>
<th>PM$_{2.5}$ µg/m$^3$ (2017-2020)</th>
<th>Annual Attributable deaths with 95 CI, # (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WHO AI 1 (35 µg/m$^3$)</td>
<td>WHO AI 2 (25 µg/m$^3$)</td>
</tr>
<tr>
<td></td>
<td># (95%CI)</td>
<td>%</td>
</tr>
<tr>
<td>“TASH”</td>
<td>42.4</td>
<td>502 (330-661)</td>
</tr>
<tr>
<td>Internl School</td>
<td>34.7</td>
<td>0 (330-661)</td>
</tr>
<tr>
<td>US Embassy</td>
<td>24.2</td>
<td>0 (403-805)</td>
</tr>
</tbody>
</table>

Remark: “0” shows the current level is below the WHO cut off with zero risk; AI - Annual Interim

If the 42.4 µg/m$^3$ is reduced to 10 µg/m$^3$, 2043 premature deaths could be saved.
FIGURE 5 Contribution of key sources to PM$_{2.5}$ exposures in 2019.