Health Impact Assessment for Air Pollution

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HEI Workshop
Nairobi, Kenya

March 31, 2023

colorado school of public health

WARNING

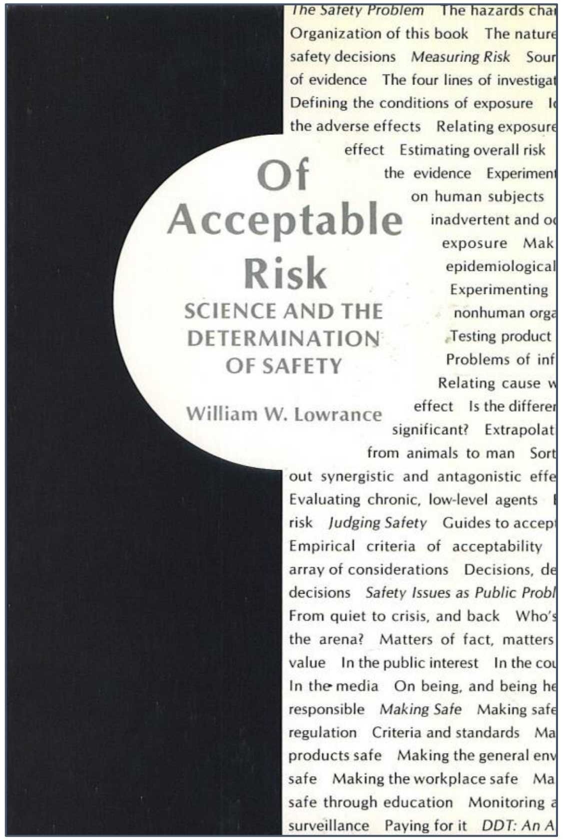
YOU MUST PARTICIPATE

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)

The Goal: Reducing Risks to Acceptable Levels

Of Acceptable Risk (Lowrance)



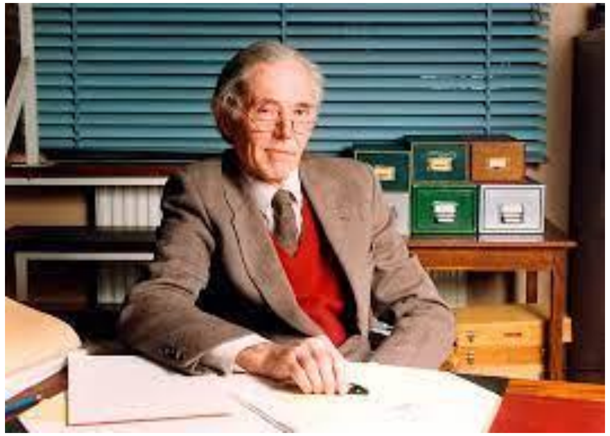
William Lowrance
1977

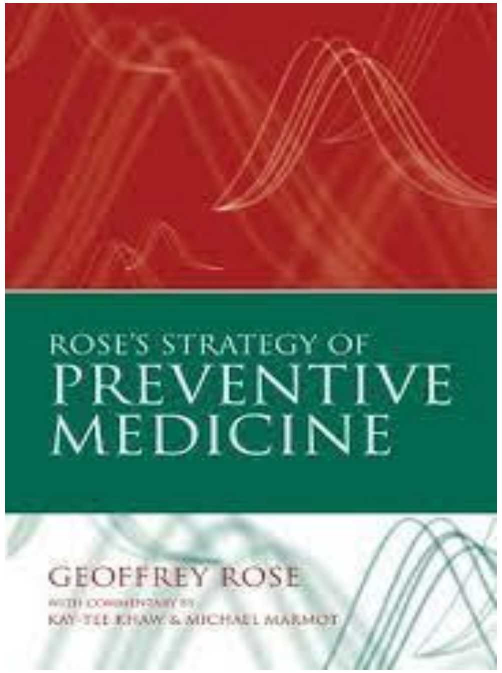
"A thing is safe if its risks are judged to be acceptable."

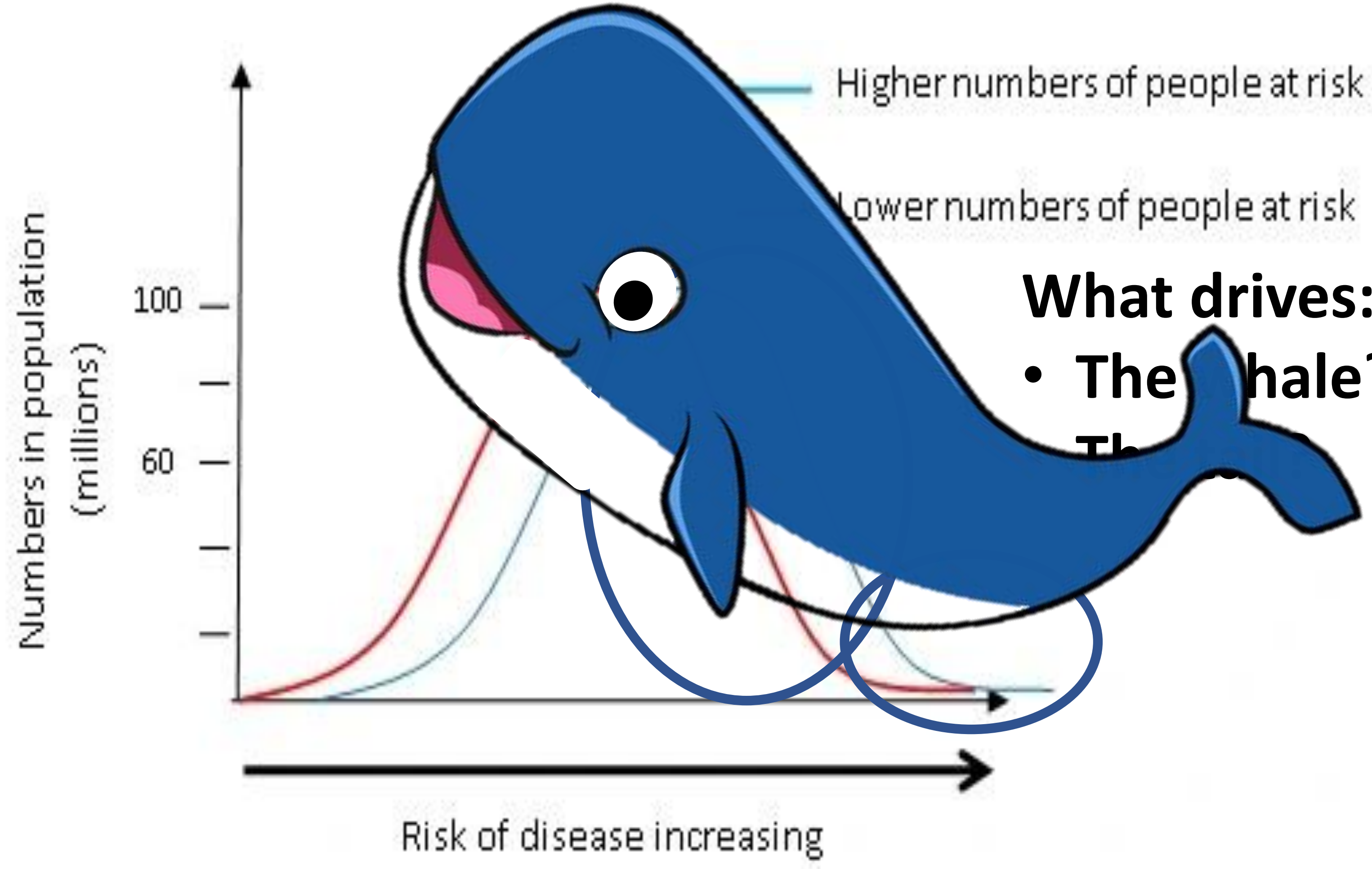
Therefore

- 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 hale?**

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.

Causation in an individual

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

Ella Kissi-Debrah lived within 30 metres of London's South Circular road. Photograph: PA

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.

The “new tobacco”?

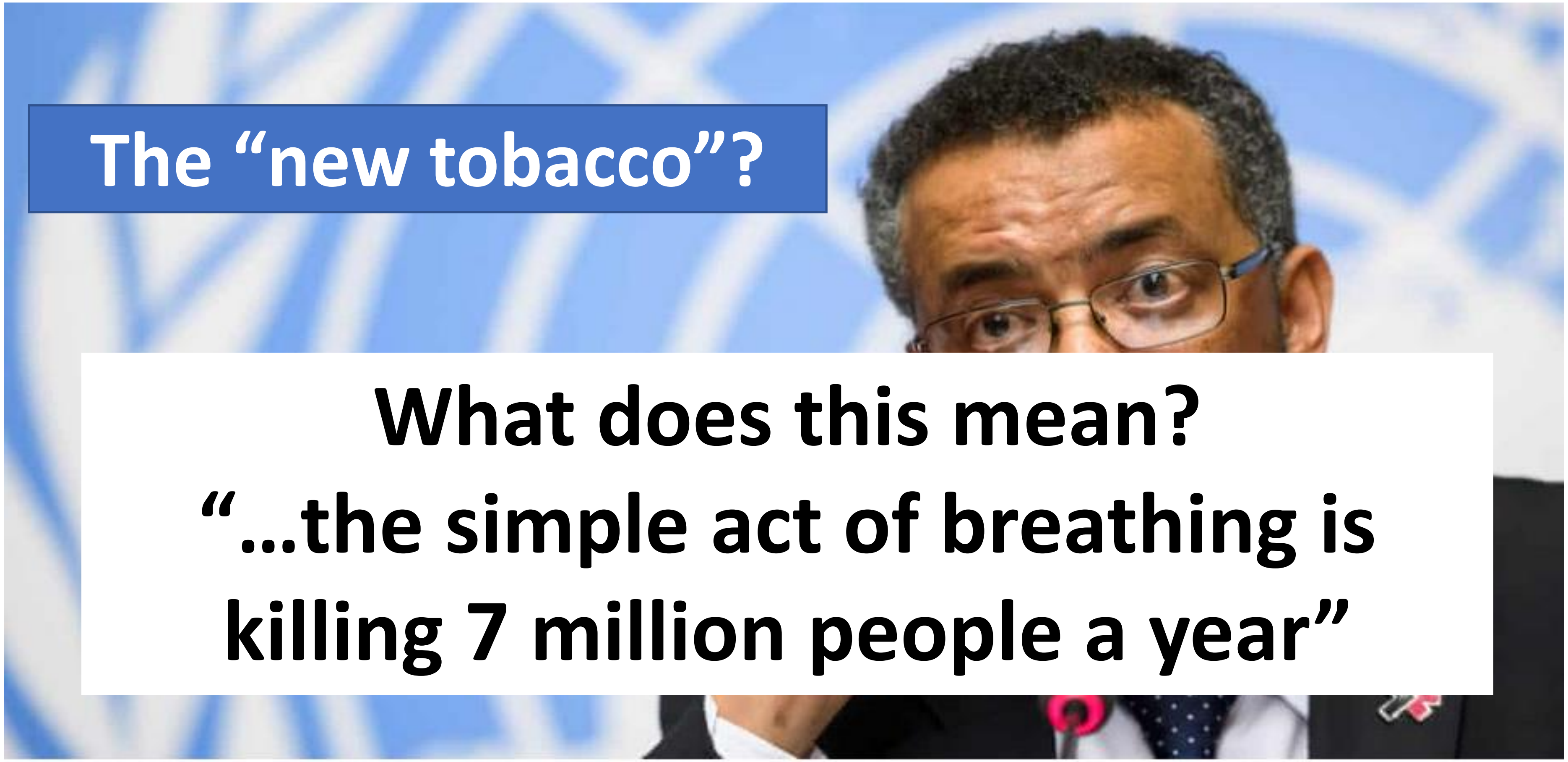
Do burden estimates motivate action?

▲ 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.

https://www.theguardian.com/environment/2018/oct/27/air-pollution-is-the-new-tobacco-warns-who-head

The “new tobacco”?



What does this mean?

“…the simple act of breathing is killing 7 million people a year”

▲ Dr Tedros Adhanom Ghebreyesus speaks at a press conference in 2017. Photograph: Fabrice Coffrini/AFP/Getty Images

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https://www.theguardian.com/environment/2018/oct/27/air-pollution-is-the-new-tobacco-warns-who-head

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?

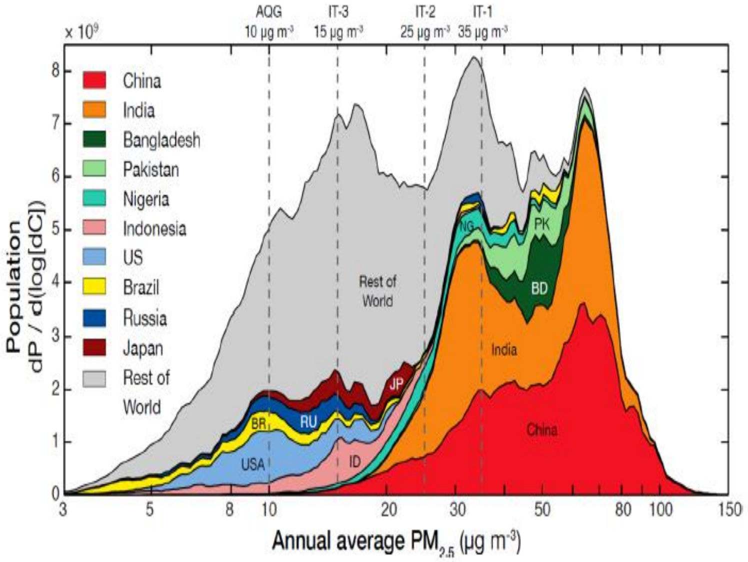
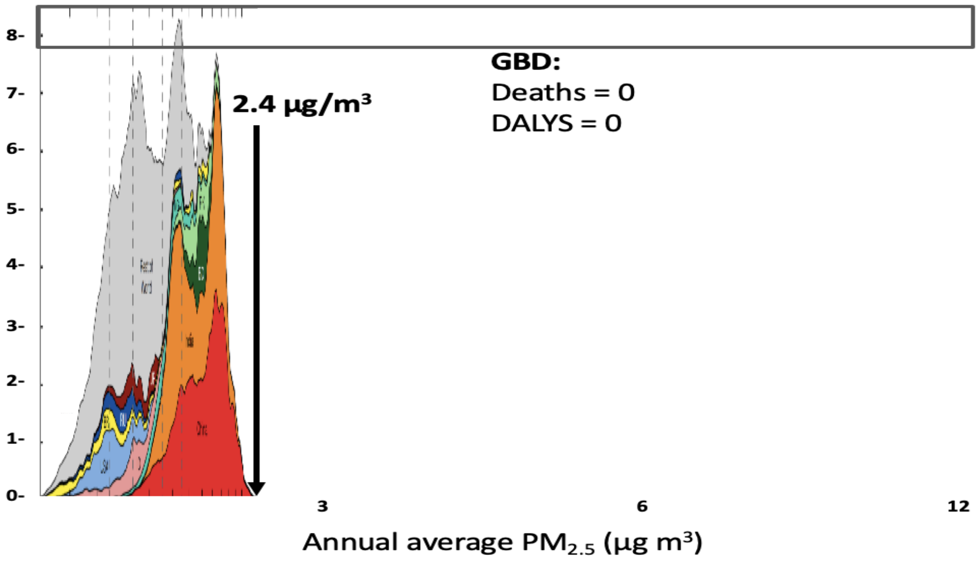


Figure 3. Global and regional distributions of population as a function of annual (2013) average ambient $PM_{2.5}$ concentration for the world's 10 most populous countries. Plotted data reflect local smoothing of bin-width normalized distributions computed over 400 logarithmically spaced bins; equal-sized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

The "real world?



The "counterfactual" world

The Counterfactual Concept

Definition: The counterfactual is contrary to the facts

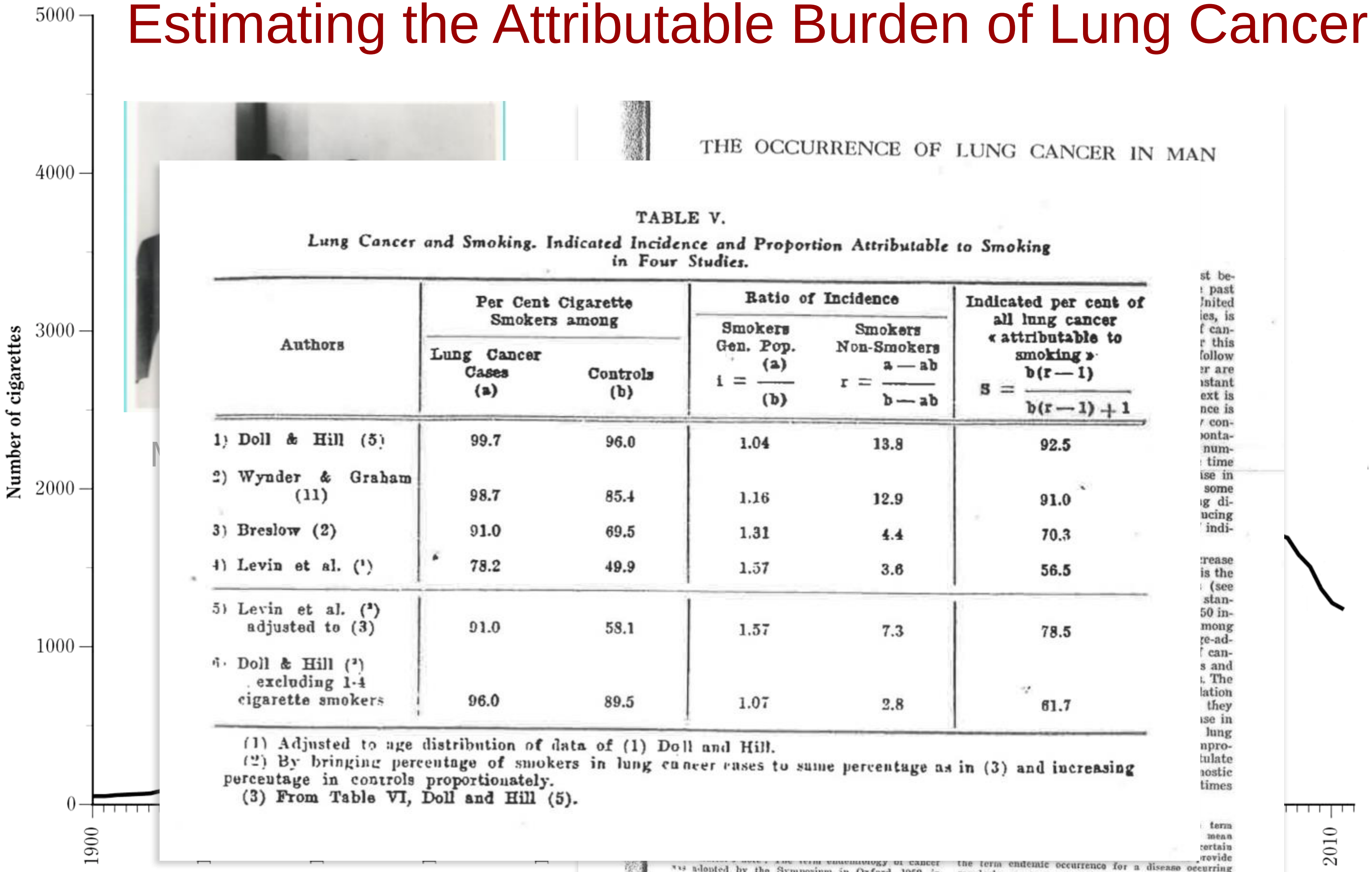
- The counterfactual assumed is for a world that does not exist, but theoretically could.
- The counterfactual value generally has some basis for selection.
- Explaining the concept is critical for communication about burden estimates and health impact assessments.

Attributable vs Avoidable

Johns Hopkins Epidemiology Department, circa 1935-36

Morton Levin

Estimating the Attributable Burden of Lung Cancer



THE OCCURRENCE OF LUNG CANCER IN MAN

TABLE V.

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

Authors	Per Cent Cigarette Smokers among: Lung Cancer Cases (a)	Per Cent Cigarette Smokers among: Controls (b)	Ratio of Incidence: Smokers / Gen. Pop. $i = \frac{(a)}{(b)}$	Ratio of Incidence: Smokers / Non-Smokers $r = \frac{a - ab}{b - ab}$	Indicated per cent of all lung cancer « attributable to smoking » $s = \frac{b(r-1)}{b(r-1)+1}$
1) Doll & Hill (5)	99.7	96.0	1.04	13.8	92.5
2) Wynder & Graham (11)	98.7	85.4	1.16	12.9	91.0
3) Breslow (2)	91.0	69.5	1.31	4.4	70.3
4) Levin et al. (1)	78.2	49.9	1.57	3.6	56.5
5) Levin et al. (1) adjusted to (3)	91.0	58.1	1.57	7.3	78.5
6) Doll & Hill (2) excluding 1-4 cigarette smokers	96.0	89.5	1.07	2.8	61.7

(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

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)

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

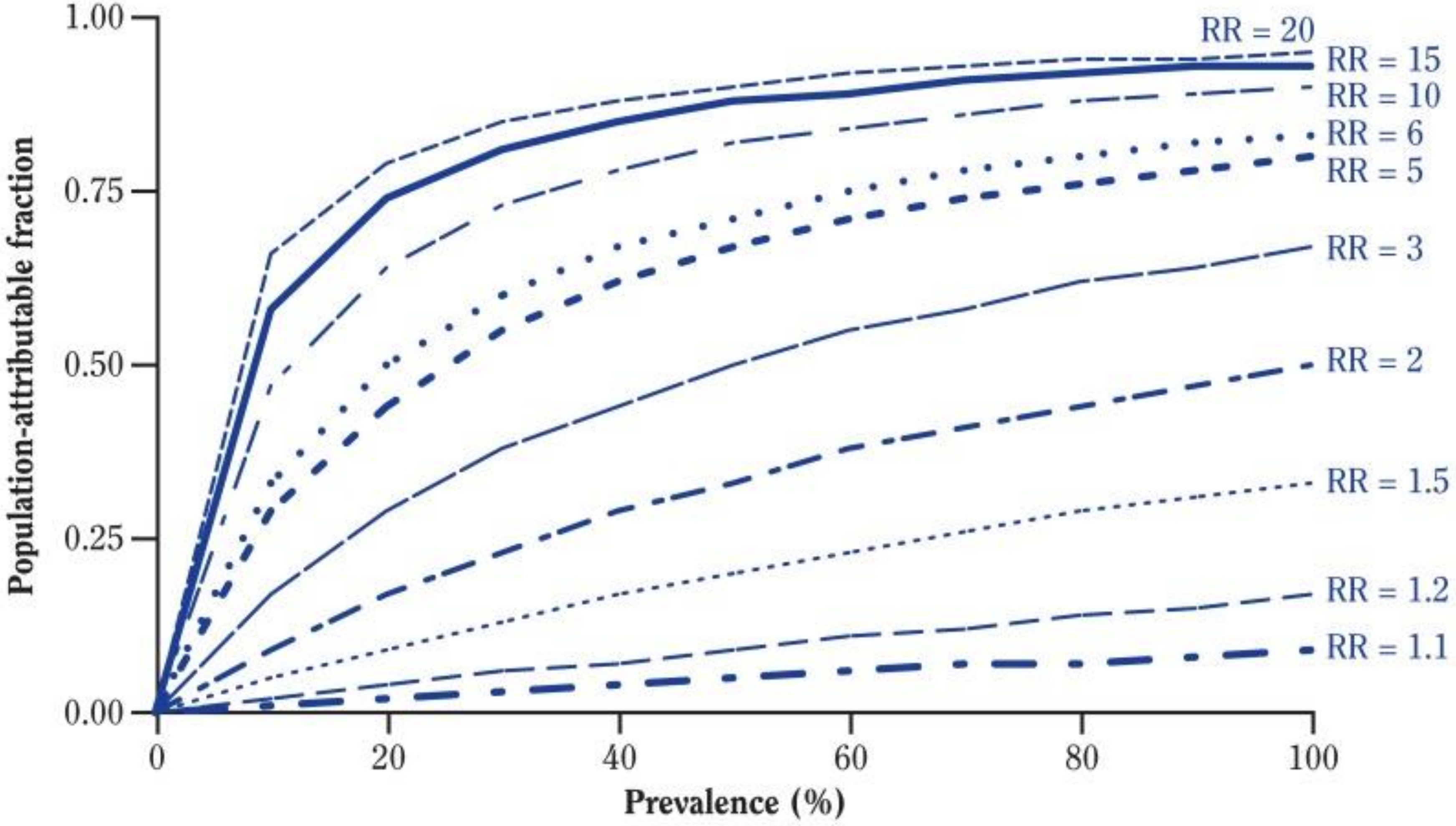
where P is exposure prevalence

PAR ranges from 0.0 to 1.00

Population Attributable Risk

Relative Risk	Prevalence (%)	PAR = Proportion of disease in the total population that is the result of exposure	PAR (%)
1.5	10	0.05	4.76
1.5	80	0.29	28.57
5	10	0.29	28.57
5	50	0.67	66.67
10	10	0.47	47.37
10	50	0.82	81.82

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*

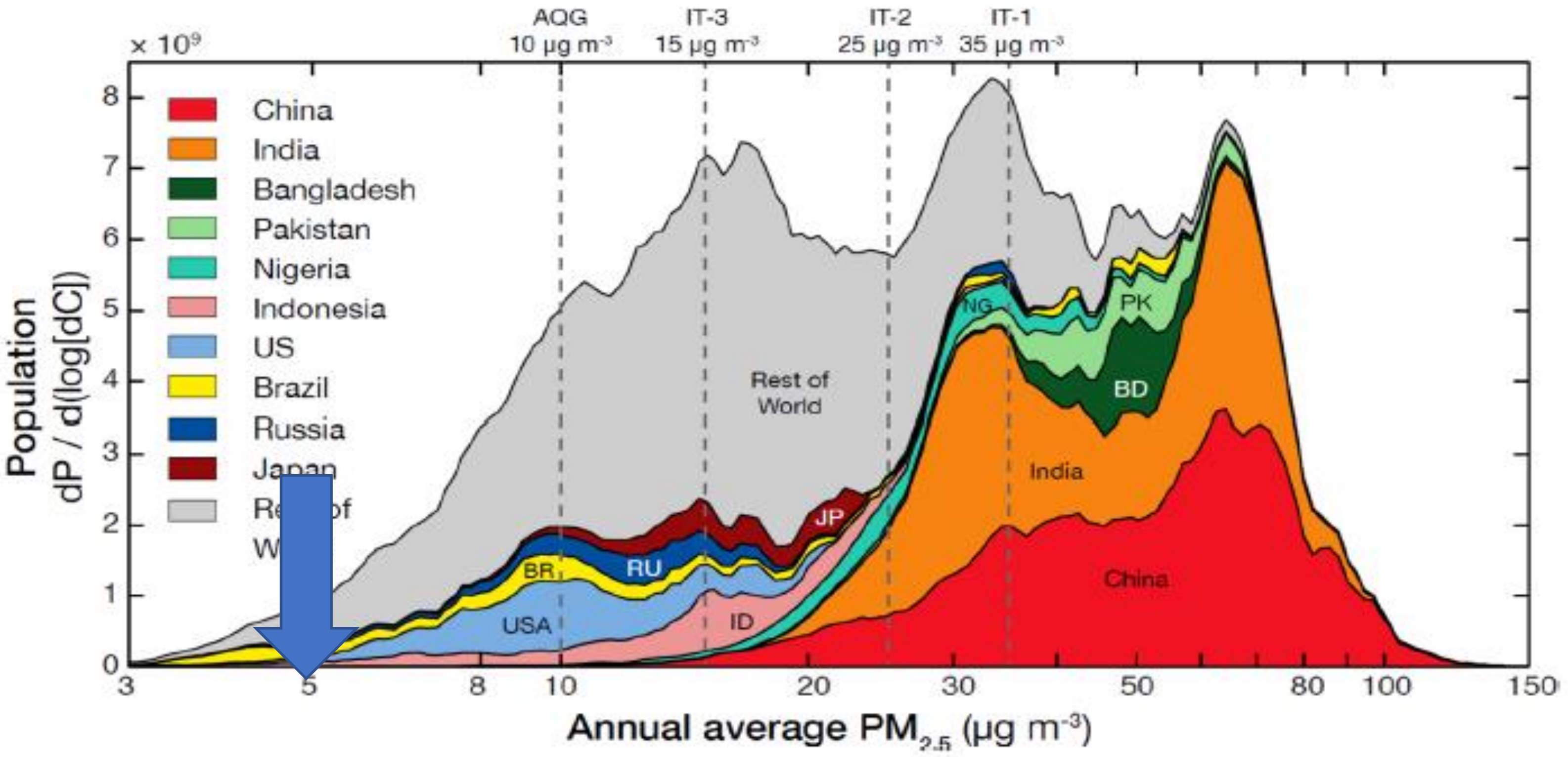


Figure 3. Global and regional distributions of population as a function of annual (2013) average ambient $PM_{2.5}$ concentration for the world's 10 most populous countries. Plotted data reflect local smoothing of bin-width normalized distributions computed over 400 logarithmically spaced bins; equal-sized 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.

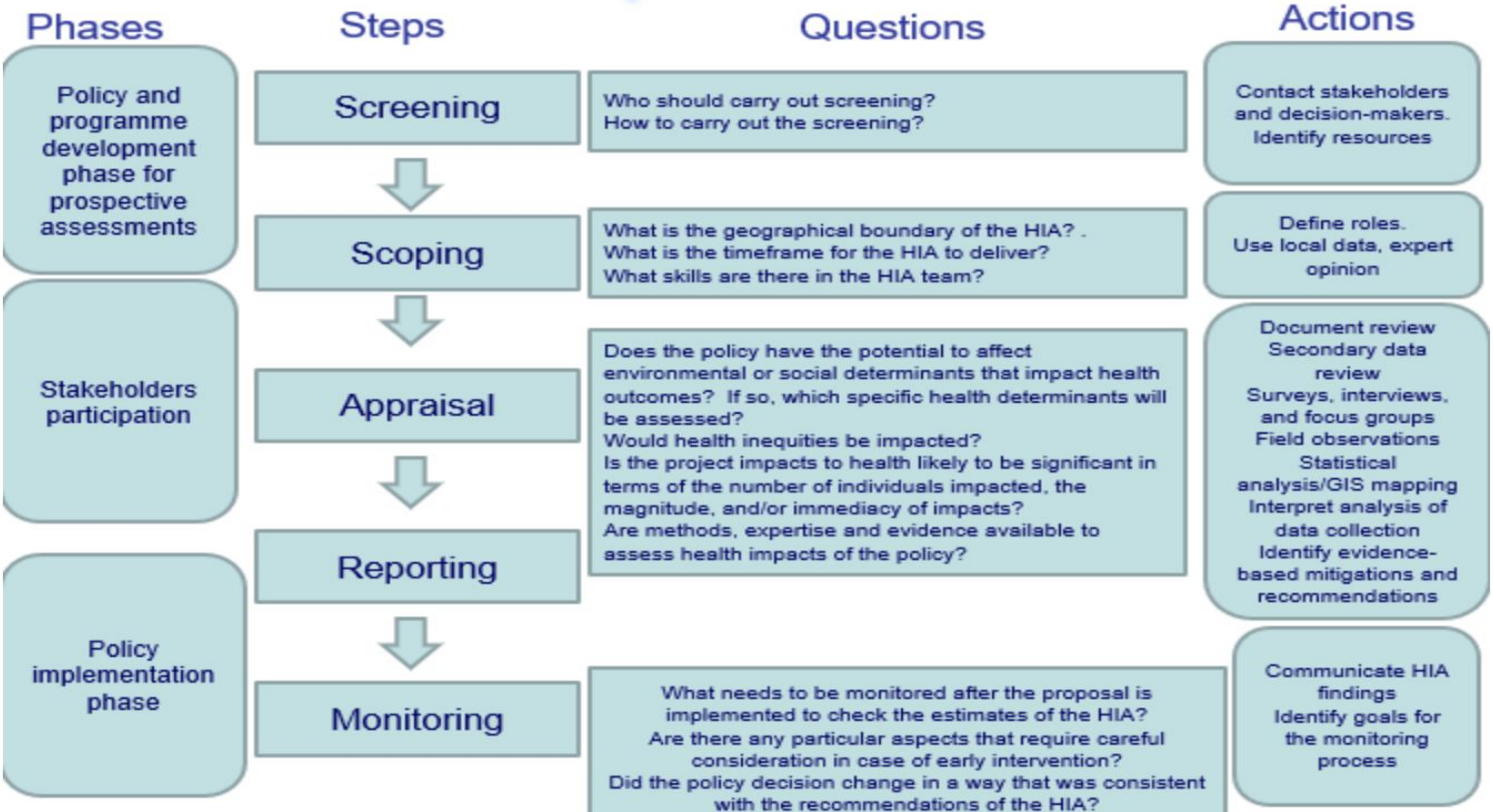
https://nap.nationalacademies.org/catalog/13229/improving-health-in-the-united-states-the-role-of-health

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

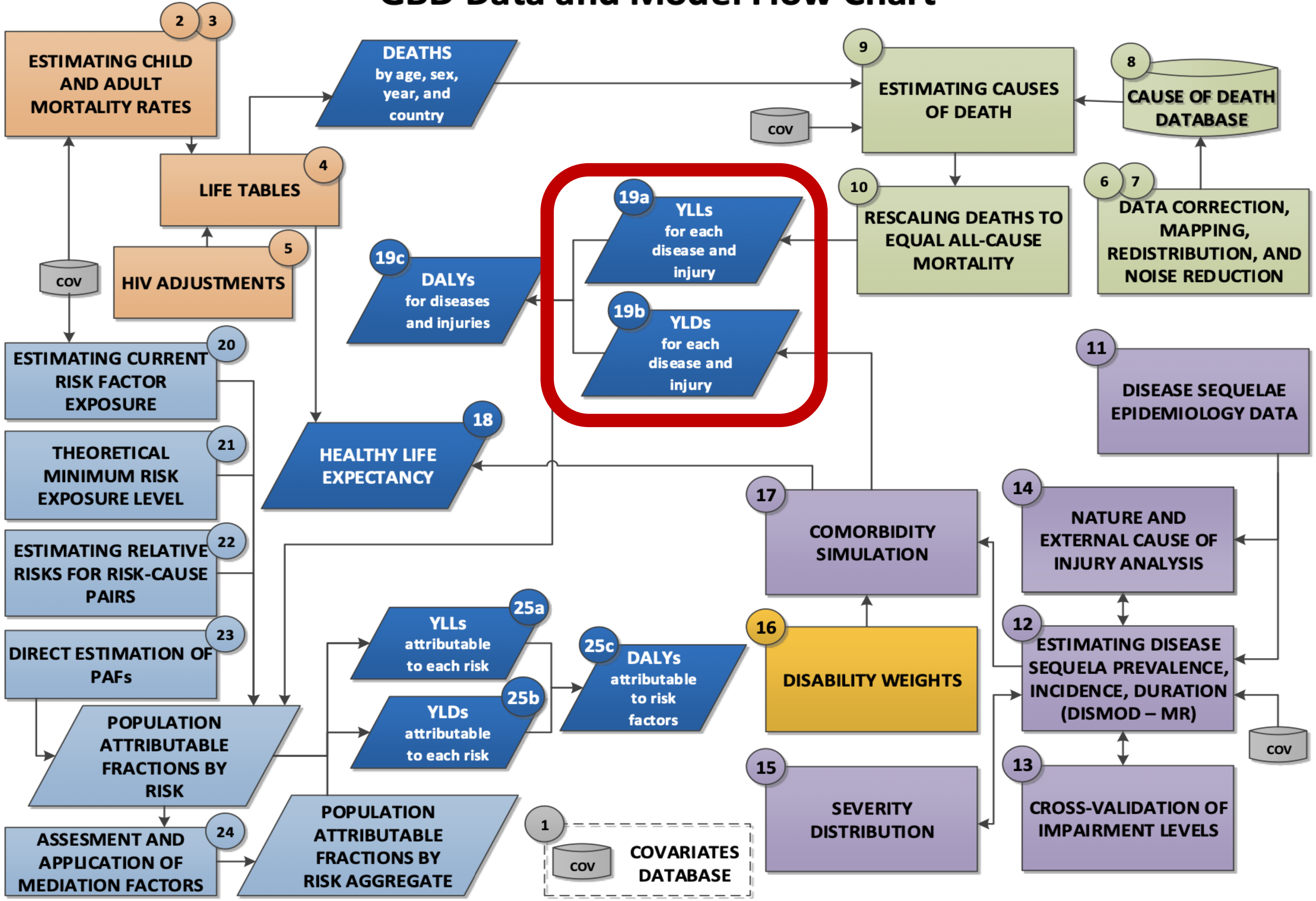


Burden Estimation: A Component of HIA

- 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

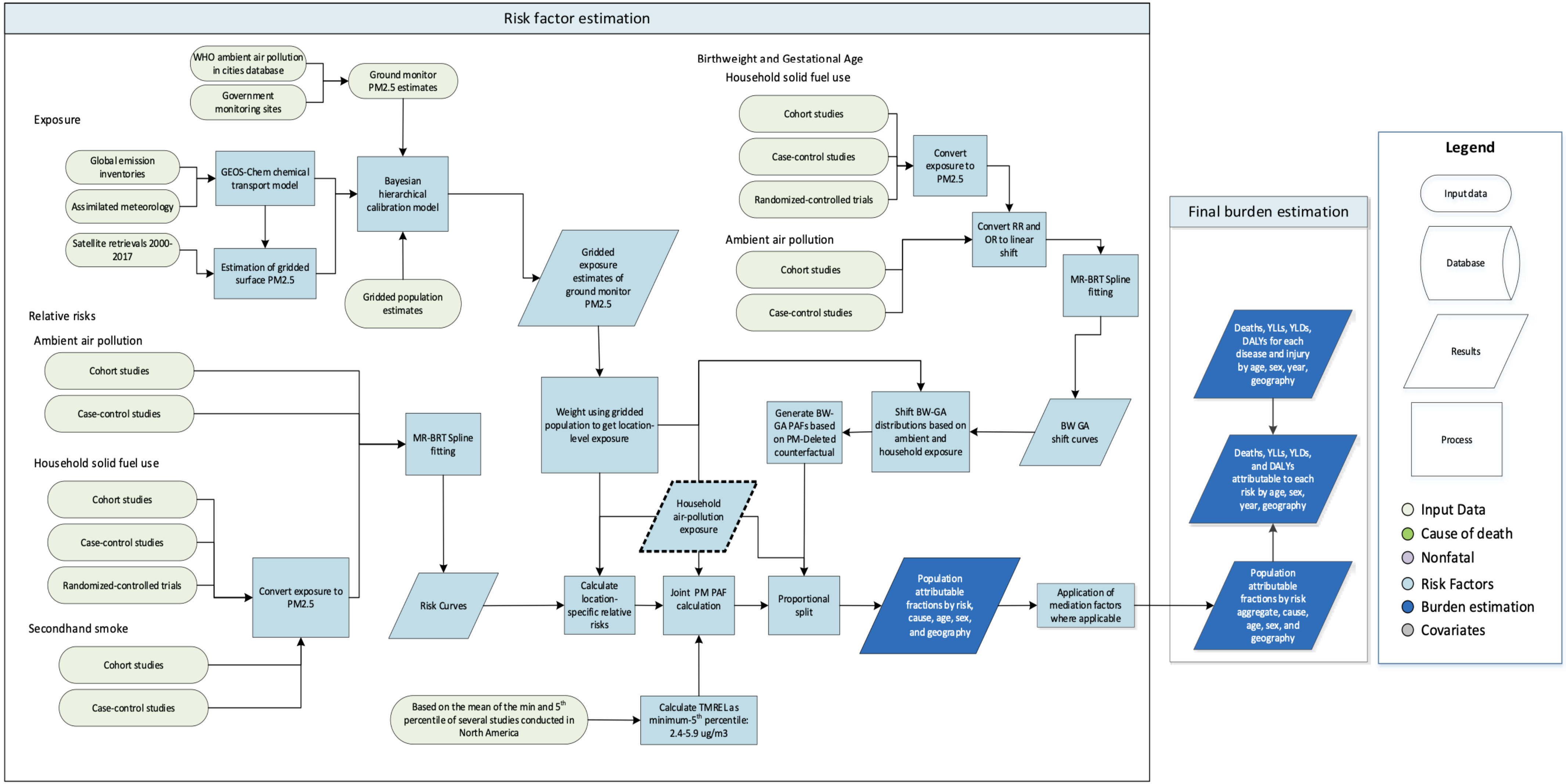
GBD Data and Model Flow Chart

IHME



GBD Methods for Ambient Air Pollution

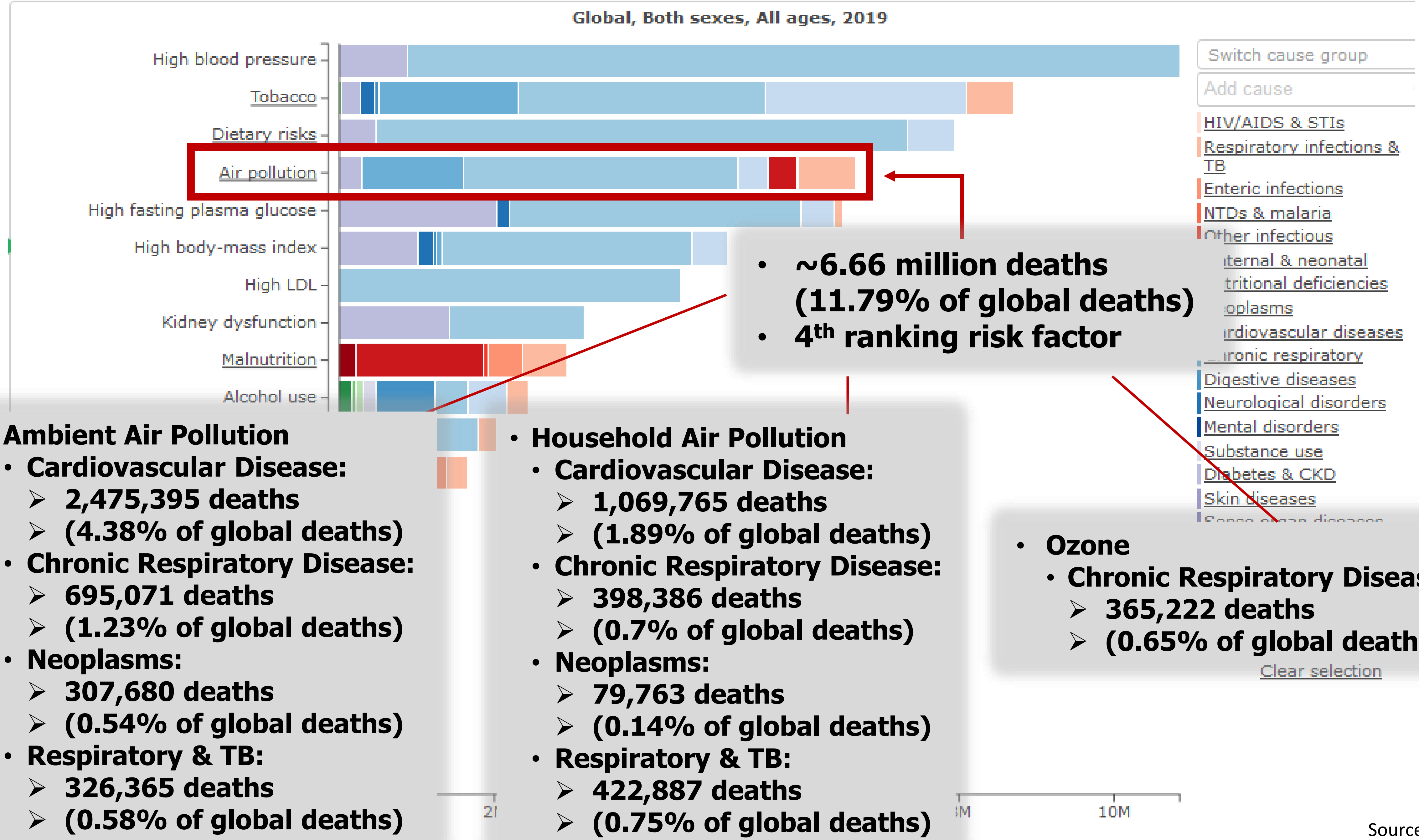
Flowchart



The TMREL for Ambient Air Pollution

Theoretical minimum-risk exposure level

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).[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.



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

- **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)**

Source: GBD

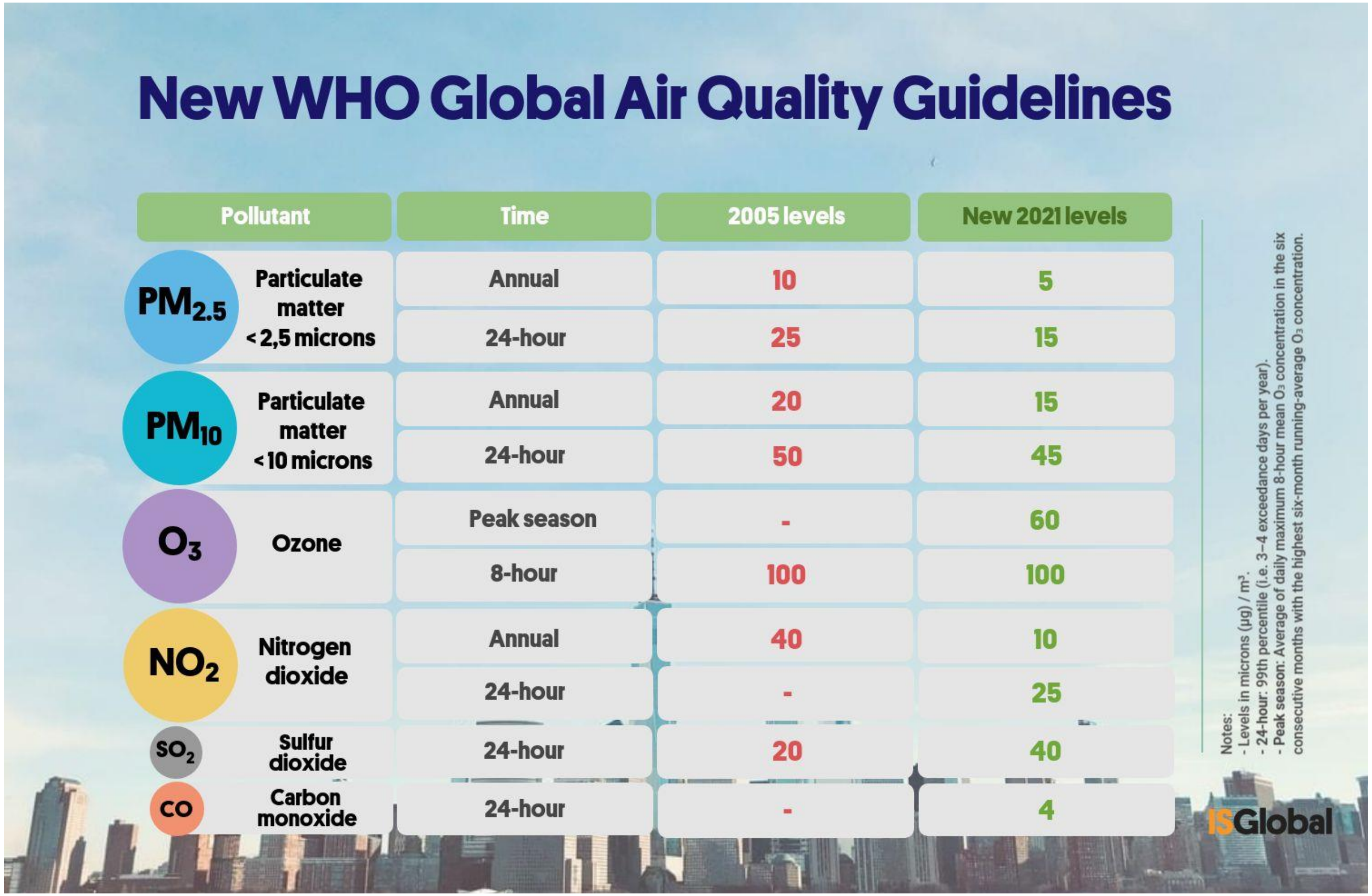
What do we need for burden estimation?

- 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*

What counterfactuals?
WHO Air Quality Guidelines—2021



New WHO Global Air Quality Guidelines

Pollutant		Time	2005 levels	New 2021 levels
$PM_{2.5}$	Particulate matter < 2,5 microns	Annual	10	5
		24-hour	25	15
PM_{10}	Particulate matter < 10 microns	Annual	20	15
		24-hour	50	45
O_3	Ozone	Peak season	-	60
		8-hour	100	100
NO_2	Nitrogen dioxide	Annual	40	10
		24-hour	-	25
SO_2	Sulfur dioxide	24-hour	20	40
CO	Carbon monoxide	24-hour	-	4

Notes:
- Levels in microns (µg) / m³.
- 24-hour: 99th percentile (i.e. 3–4 exceedance days per year).
- Peak season: Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration.

ISGlobal

Environmental Public Health Tracking

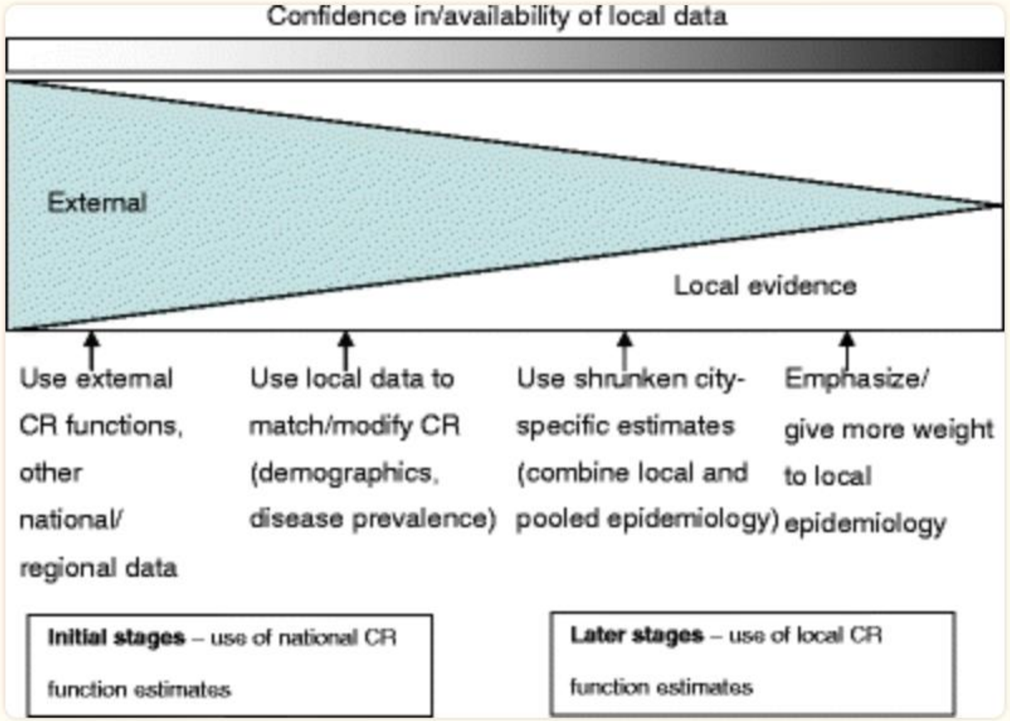


Fig. 1

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.

SOGA Africa: Death Rates Linked to $PM_{2.5}$

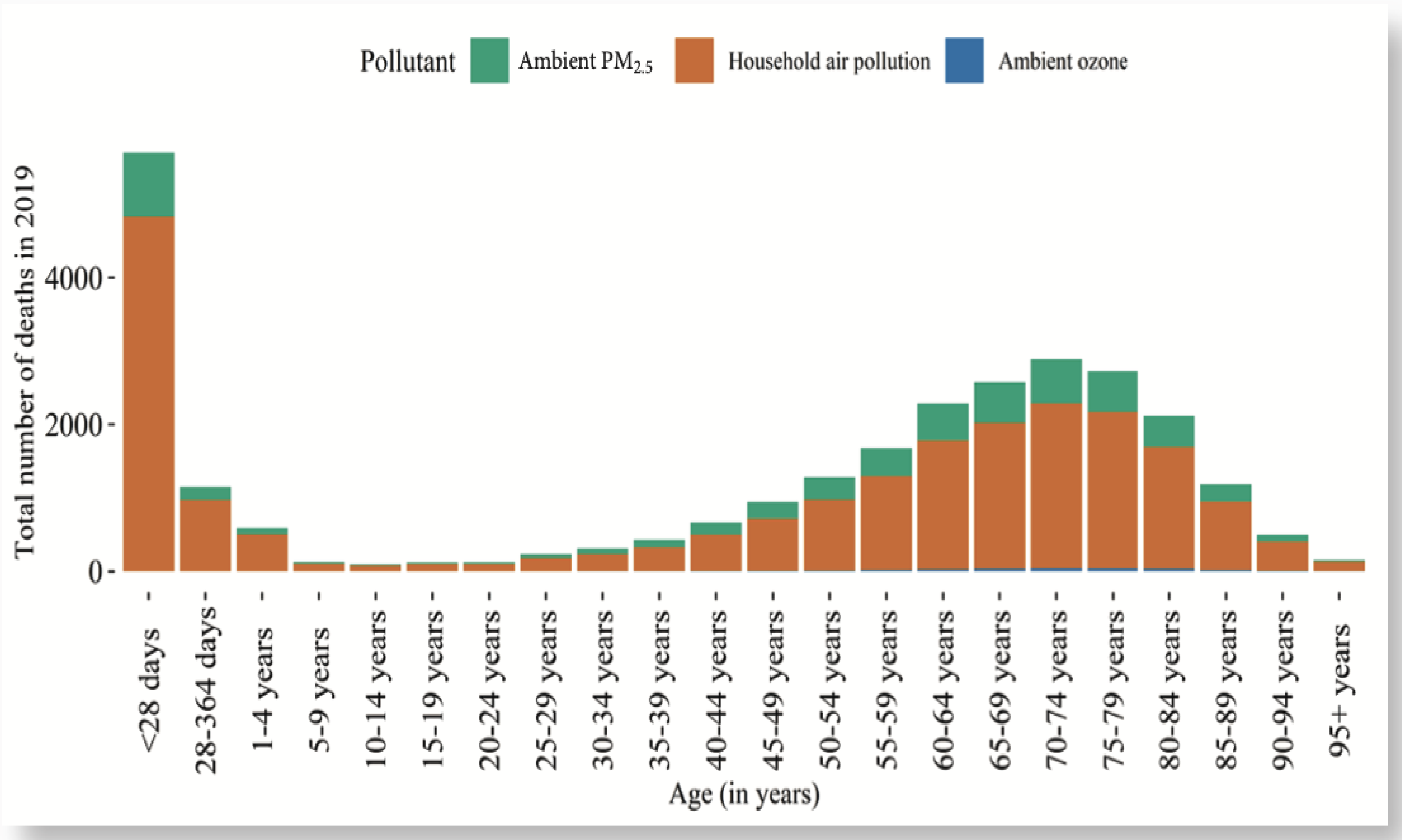
TABLE 2 Death rates linked to $PM_{2.5}$ across African regions in 2019

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

*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.



Kenya

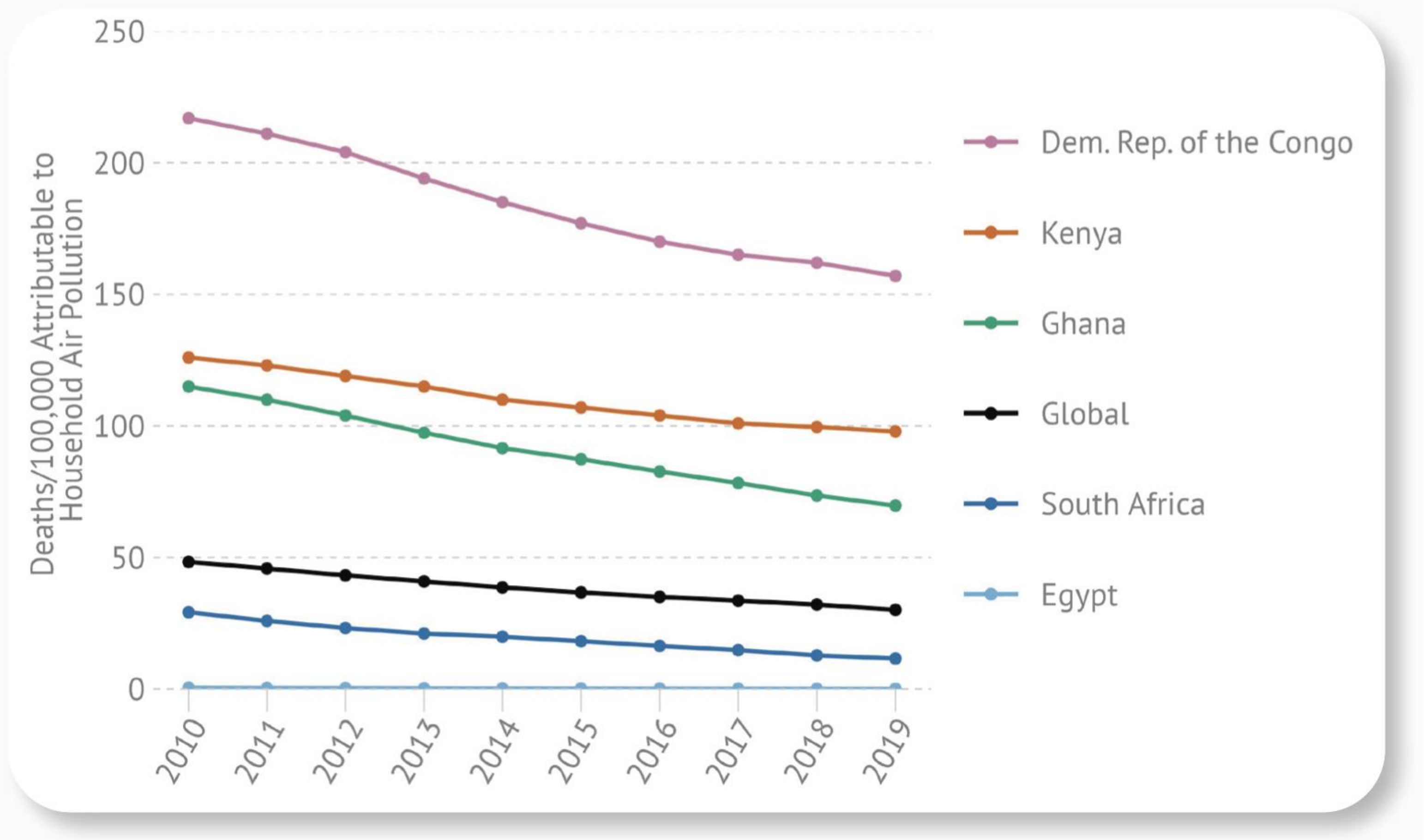
SOGA Africa: Cause-Specific Deaths Linked to $PM_{2.5}$

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

Percentage of Cause-Specific Deaths							
Country	**Diabetes**	**COPD**	**Stroke**	**Ischemic Heart Disease**	**Lung Cancer**	**Lower Respiratory Infections**	**Neonatal**
Egypt	**24** (18–30)	**43** (34–53)	**35** (30–39)	**31** (26–34)	**29** (22-36)	**29** (19–40)	**15** (10–20)
Ghana	**24** (18–31)	**48** (39–58)	**35** (32–39)	**31** (28–34)	**31** (24-39)	**36** (25–47)	**17** (11–22)
Democratic Republic of the Congo	**26** (18–37)	**64** (51–76)	**38** (34–42)	**35** (32–39)	**36** (26-44)	**50** (38–60)	**20** (13–26)
South Africa	**20** (14–26)	**25** (18–32)	**19** (16–23)	**19** (16–23)	**18** (13–24)	**17** (11–25)	**12** (9–15)
Kenya	**30** (17–30)	**46** (35–58)	**33** (29–36)	**30** (26–33)	**29** (22–37)	**39** (28–50)	**22** (20–24)

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

Original Research Article

ISEE ENVIRONMENTAL EPIDEMIOLOGY

OPEN

Fine particulate pollution concentration in Addis Ababa exceeds the WHO guideline value

Results of 3 years of continuous monitoring and health impact assessment

Abera K … shu[a],
Dawit Si …

Results: The daily mean (SD) $PM_{2.5}$ concentration was 42.4 µg/m³ (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/m³ WHO interim target annual level and 2,043 (17.7%) at the WHO 10 µg/m³ annual guideline.

Backgr … ited in Ethiop … oral pat-terns ar …

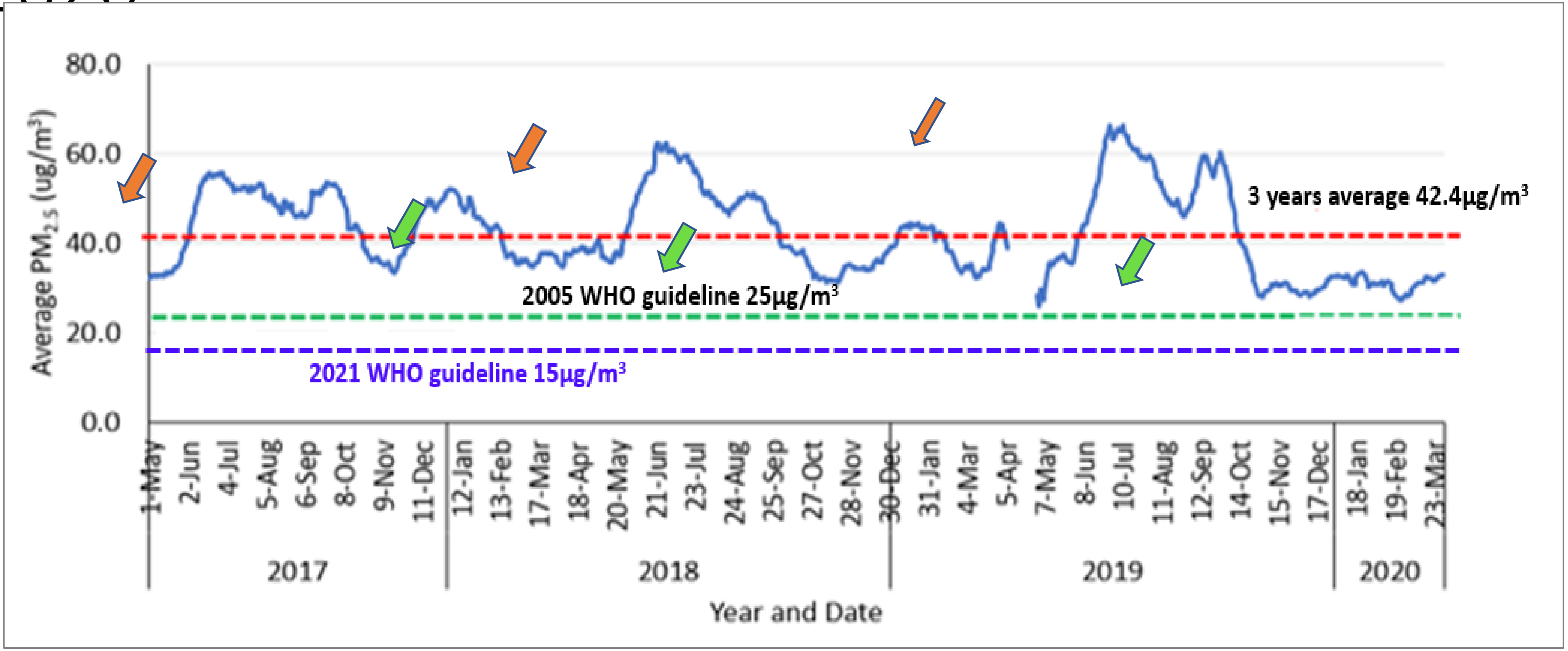
Methods: $PM_{2.5}$ concentrations were measured using a centrally-located Beta Attenuator Monitor (BAM-1022) for 3 years (1 April 2017 to 31 March 2020), with data downloaded biweekly. Deaths attributable to current $PM_{2.5}$ concentration levels were estimated using the AirQ+ tool. The daily average was estimated using hourly data.

Results: The daily mean (SD) $PM_{2.5}$ concentration was 42.4 µg/m³ (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/m³ WHO interim target annual level and 2,043 (17.7%) at the WHO 10 µg/m³ annual guideline.

Conclusion: $PM_{2.5}$ 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/m³. 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/m³ >>> 25 μg/m³ >>> 15 μg/m³ (WHO 2021)
3. 3-year average: 42.4 μg/m³ >>> 10 μg/m³ >>> 5 μg/m³ (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

BAM location	$PM_{2.5}$ µg/m³ (2017-2020)	Annual Attributable deaths with 95 CI, # (%)							
		WHO AI 1 (35 µg/m³)		WHO AI 2 (25 µg/m³)		WHOAI 3 (15 µg/m³)		**WHO annual Mean (10 µg/m³, 2005 guideline**	
		# (95%CI)	%	# (95%CI)	%	# (95%CI)	%	**# (95%CI)**	**%**
"TASH"	42.4	502 (330-661)	4.4	1147 (761-1495)	9.9	1753 (1176-2265)	15.2	**2043 (1377-2627)**	**17.7**
Internl School	34.7	0	0	654 (431, 859)	5.7	1290 (858-16770)	11.2	**1598 (1065-2063)**	**13.8**
US Embassy	24.2	0	0	0	0	613 (403-805)	5.3	**936 (620-1225)**	**8.1**
Remark: "0" shows the current level is below the WHO cut off with zero risk; AI - Annual Interim									

If the 42.4 µg/m³ is reduced to 10 µg/m³, 2043 premature deaths could be saved.

FIGURE 5 Contribution of key sources to $PM_{2.5}$ exposures in 2019.