ICIMOD CAPHER-India HEI

Early-Career Training on Air Pollution and Health, August 12-14, 2024 | ICIMOD, Kathmandu, Nepal

Introduction to Health Impact Assessment of air pollution

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IMPERIAL

This presentation

- Policy questions that health risk assessment (HRA) of AP answers;
- Measures of risk in population (RR, PAF, number of attributed cases, YLL, DALY);
- Main elements of risk assessment
- Uncertainties and limitations of HRA
- Examples of HRA use in policy making

Estimation of health effects of exposure to air pollution in a population: Modes of Health Risk Assessment (HRA)

Burden

- What is the size of the problem currently?
- How much inflated are current mortality rates?
- How much potential life years are we losing?

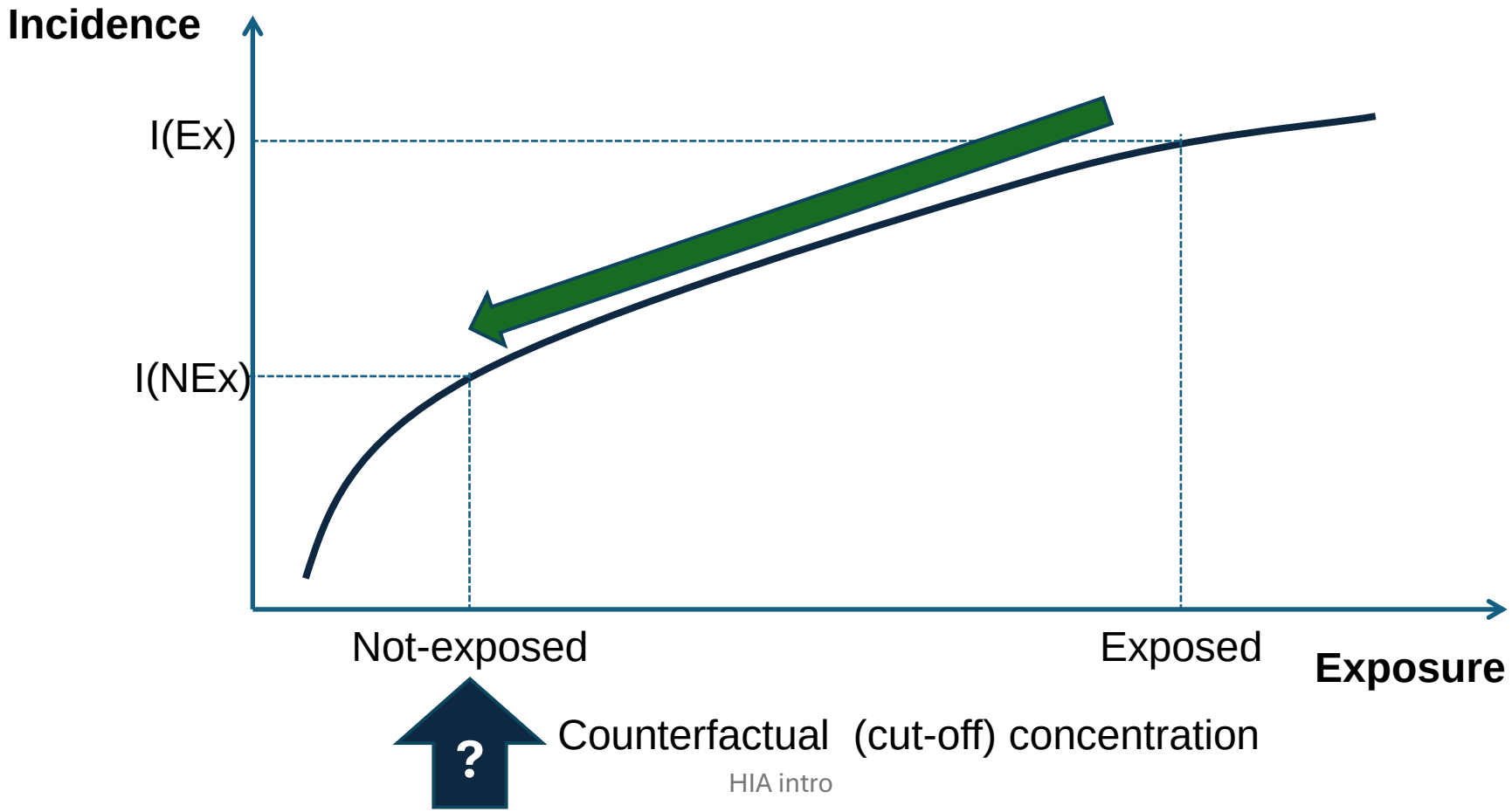
Impact

- If we apply policy X, what will be the (expected) burden change?
- What will be the pattern of mortality rate change?
- What will be the pattern of changes in total life years?

Model of risk reduction

I(Ex) / I(NEx) = RR (relative risk in Exposed vs. Not-exposed)

Incidence = number of cases / number of people at risk



Measures of risk: Attributable risk

Population Attributable Risk (PAR): difference between the incidence of a disease in population with “real world” exposure and (often hypothetical) population not exposed; incidence attributable to the exposure.

$$PAR = I_{exposed} - I_{not\ exposed}$$

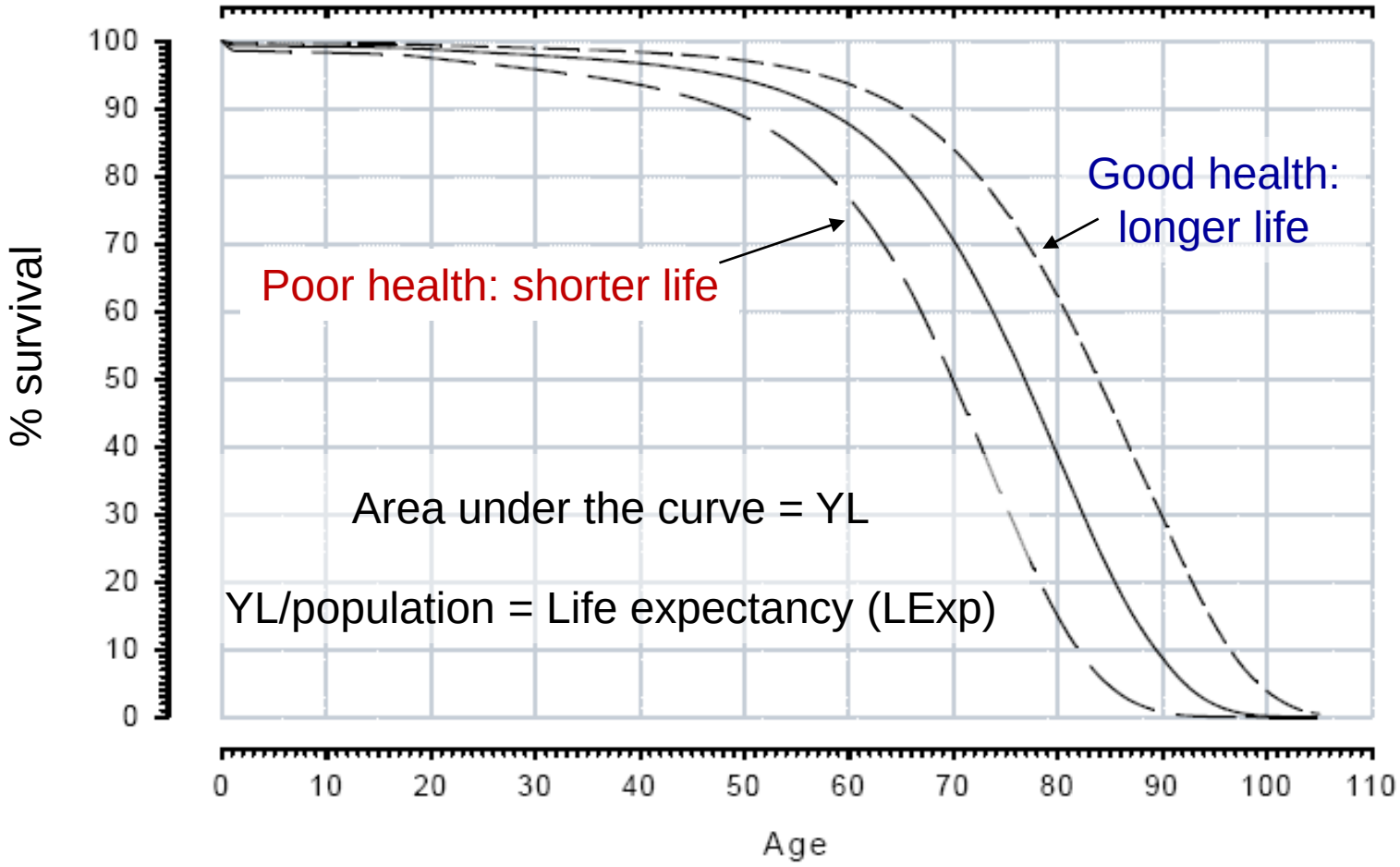
Population Attributable Fraction (PAF): fraction of the cases attributable to the exposure

$$PAF = (I_{exposed} - I_{not\ exposed}) / I_{exposed} = \frac{RR - 1}{RR}$$

$$PAR = PAF * I_{exposed}$$

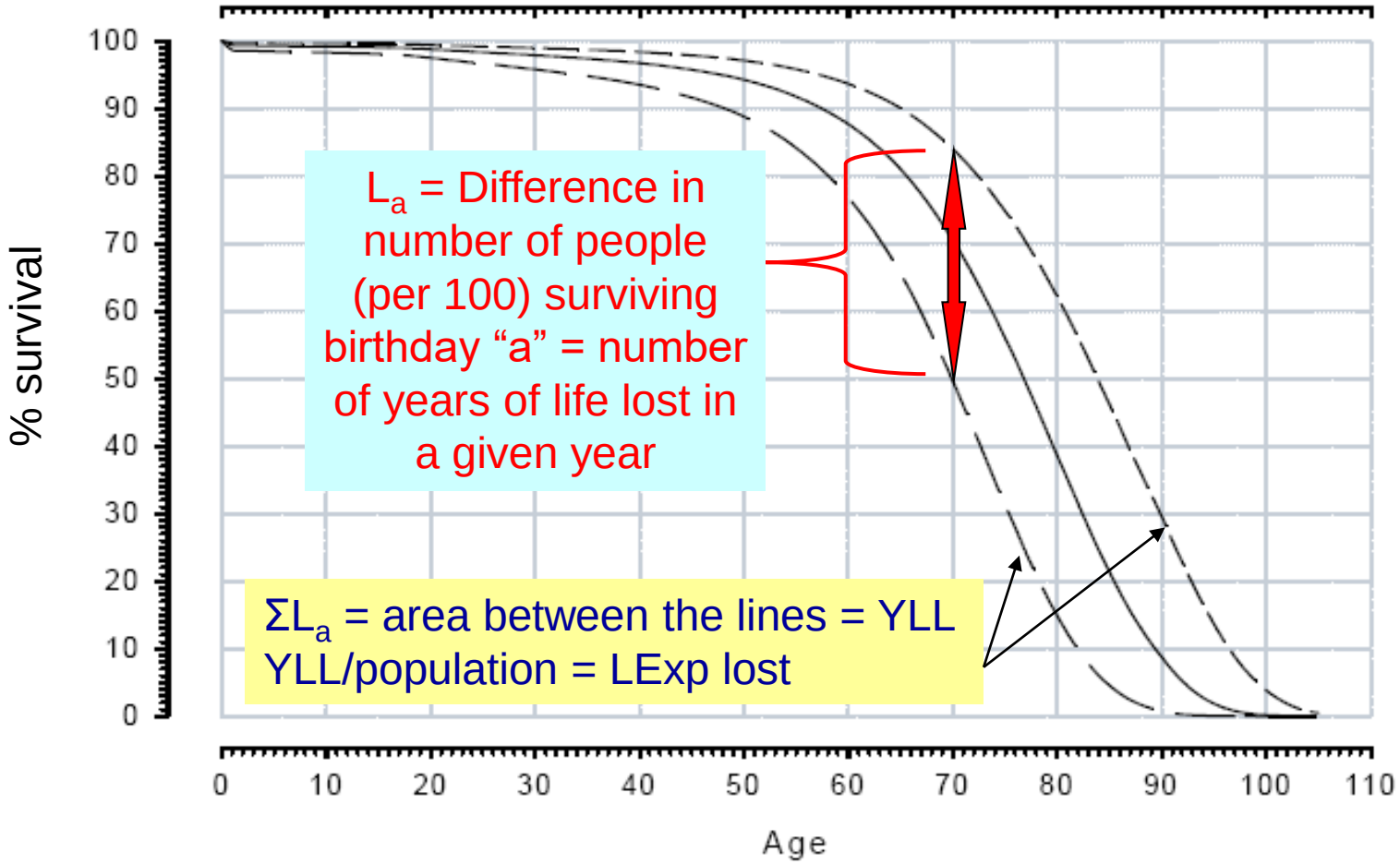
Number of attributable cases = PAR * *NEx* *NEx*: number of people in exposed population

Survival curves – effects of health levels in a population



YL = years of life

Survival curves – effects of health levels in a population



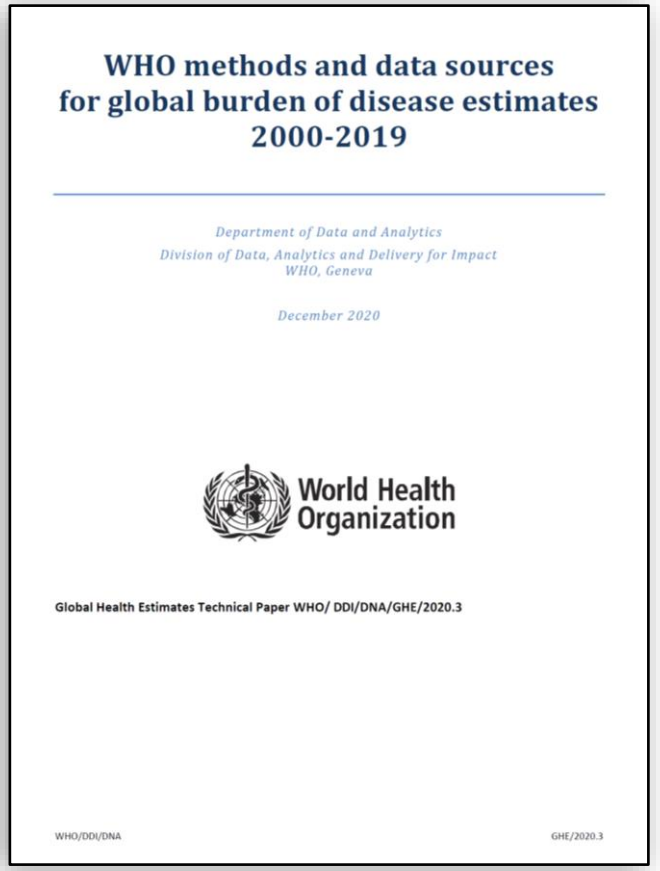
YLL= years of life lost

LExp = life expectancy

Burden of disease: gap between a population´s health status and that of a normative reference population

Integrated indicator of burden of disease: Disability-Adjusted Life Year (DALY)

- DALY is based on **years of life lost** from premature death and **years of life lived in disability** (less than full health);
- DALY – single measure to quantify the burden of disease, injuries and risk factors;
- Introduced by Murray & Lopez in World Development Report 1993 prepared by WHO & HSPH for the World Bank;
- Several modifications of the methodology since 1993;
- DALYs for all WHO MS produced periodically by WHO based on databases and information provided by the MS.



WHO methods and data sources for global burden of disease estimates 2000 – 2019; WHO/DDI/DNA/GHE/2020.3
https://www.who.int/data/global-health-estimates

Disability weights (examples for selected diseases)

For GBD2019 and WHO GHE 2019: based on large population surveys and available for 234 health states.

Health state	Disability weight
Cancer	
Cancer: diagnosis and primary therapy	0.288
Cancer: metastatic	0.451
Cardiovascular diseases	
Acute myocardial infarction: days 1-2	0.432
Acute myocardial infarction: days 3-28	0.074
Stroke: long-term consequences, moderate	0.070
Stroke: long-term consequences, moderate plus cognition problems	0.316
Stroke: long-term consequences, severe	0.552
Stroke: long-term consequences, severe plus cognition problems	0.588
Chronic respiratory diseases	
Asthma: controlled	0.015
Asthma: partially controlled	0.036
Asthma: uncontrolled	0.133
COPD and other chronic respiratory problems, mild	0.019
COPD and other chronic respiratory problems, moderate	0.225
COPD and other chronic respiratory problems, severe	0.408

WHO 2020

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HRA: Selection of pollutant – outcome pair: criteria to consider

- Strength of evidence on causality of the association
- Public health interpretation of the health outcome (direct vs. indirect measures of health)

- Availability of studies providing concentration-response functions (CRFs)
- Availability of data on exposure
- Availability of data on the health outcome frequency in the assessed population

Causality determinations on the long- and short-term effects of air pollutants for different disease categories

Category	$PM_{2.5}$ (EPA 2019)		NO_2 (EPA 2016)		Ozone (EPA 2020)	
	Long-term	Short-term	Long-term	Short-term	Long-term	Short-ter
Reproductive and Developmental effects	*Suggestive*	*Suggestive*	*Suggestive*	*Suggestive*	*Suggestive*	
Respiratory effects	***Likely***	***Likely***	***Likely***	***Causal***	***Likely***	***Causal***
Cardiovascular diseases	***Causal***	***Causal***	*Suggestive*	*Suggestive*	*Suggestive*	*Suggestive*
Metabolic effects	*Suggestive*	*Suggestive*	*Suggestive*	*Suggestive*	*Suggestive*	***Likely***
Neurological effects	***Likely***	*Suggestive*			*Suggestive*	*Suggestive*
Cancer (lung cancer)	***Likely (a)***		*Suggestive*		*Inadequate*	
Mortality	***Causal***	***Causal***	*Suggestive*	*Suggestive*	*Suggestive*	*Inadequate*

(a) IARC 2013: $PM_{2.5}$ and PM_{10} exposure is carcinogenic to humans (Group 1)

Input information needed for HRA

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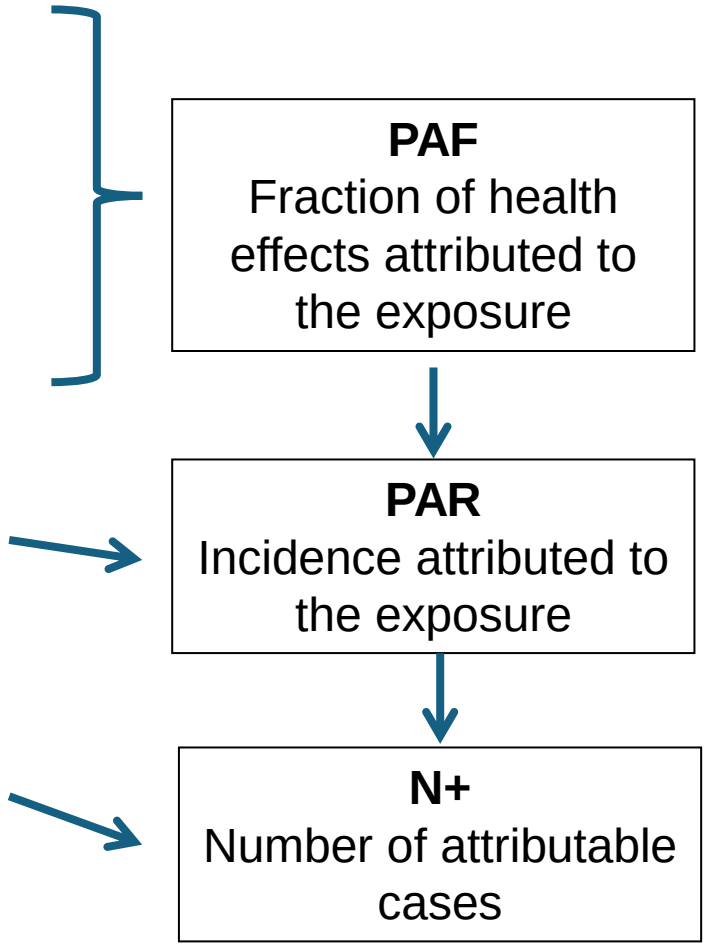
- **Size of target population (N)**



Selection of exposure data for HRA

Pollutants:

- Particulate Matter ≤ 2.5μm (PM2.5) (not available, can be estimated from PM10 data using PM2.5/PM10 ratio from local observations or literature)
- Particulate Matter ≤ 10μm (PM10);
- Ozone (O3);
- Nitrogen Dioxide (NO2);
- Black Carbon (BC);

Selection of monitoring stations providing data:

- Data from continuous monitoring (with at least 18 h of measurements per day) for more than 75% of the days in a year
- Located in residential area of the city and far from industrial emission sources;
- Data from „traffic“ stations (located within 50 m from roads with intensive traffic) should not be used unless they are also located in densely populated area and could be considered characteristic for residents' exposure.
- If data available from more than 1 station in a population – take all data.

Location of air quality monitors - examples

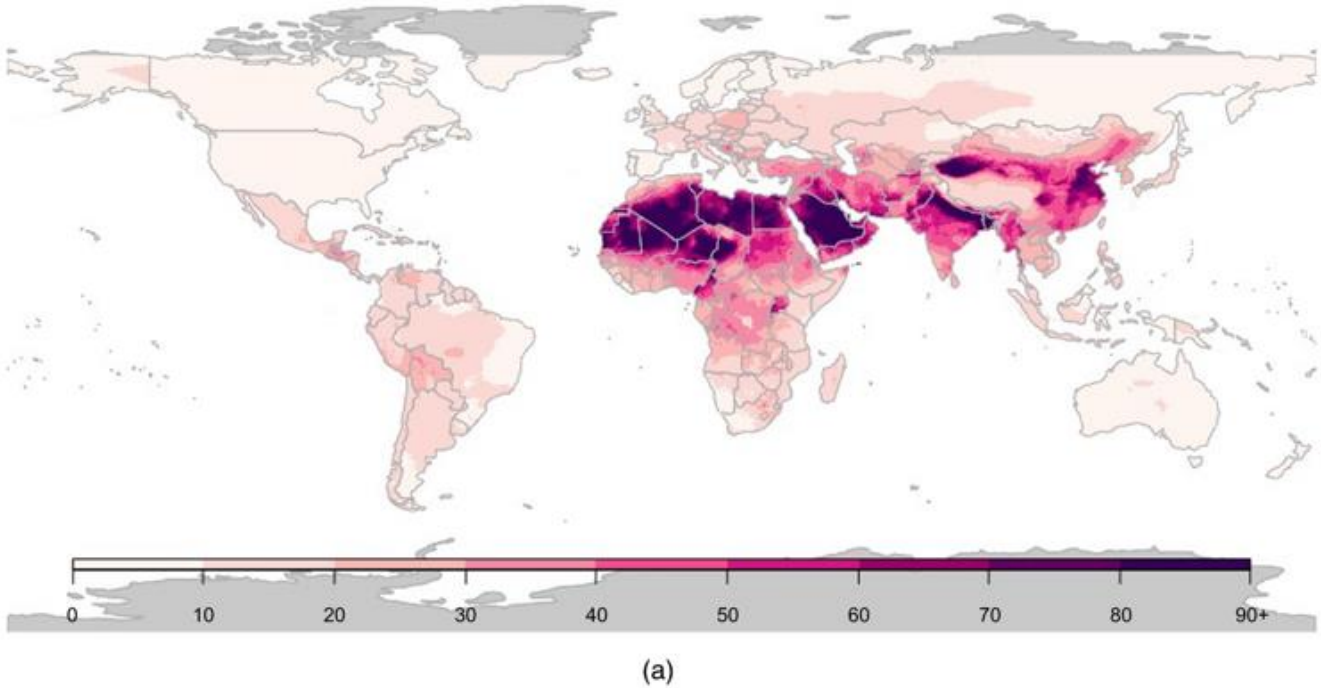
Surrounding of the monitoring station

In front of the wall

Behind the wall

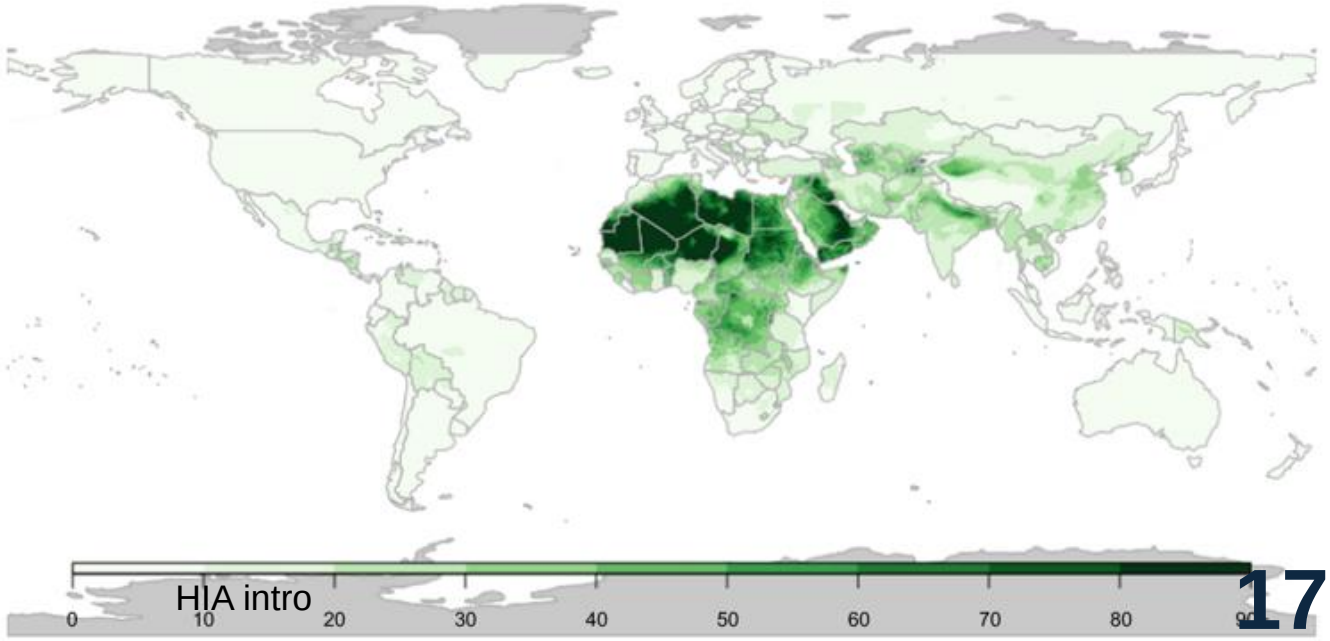
DIMAQ model estimates for PM2.5

Annual mean, 2014



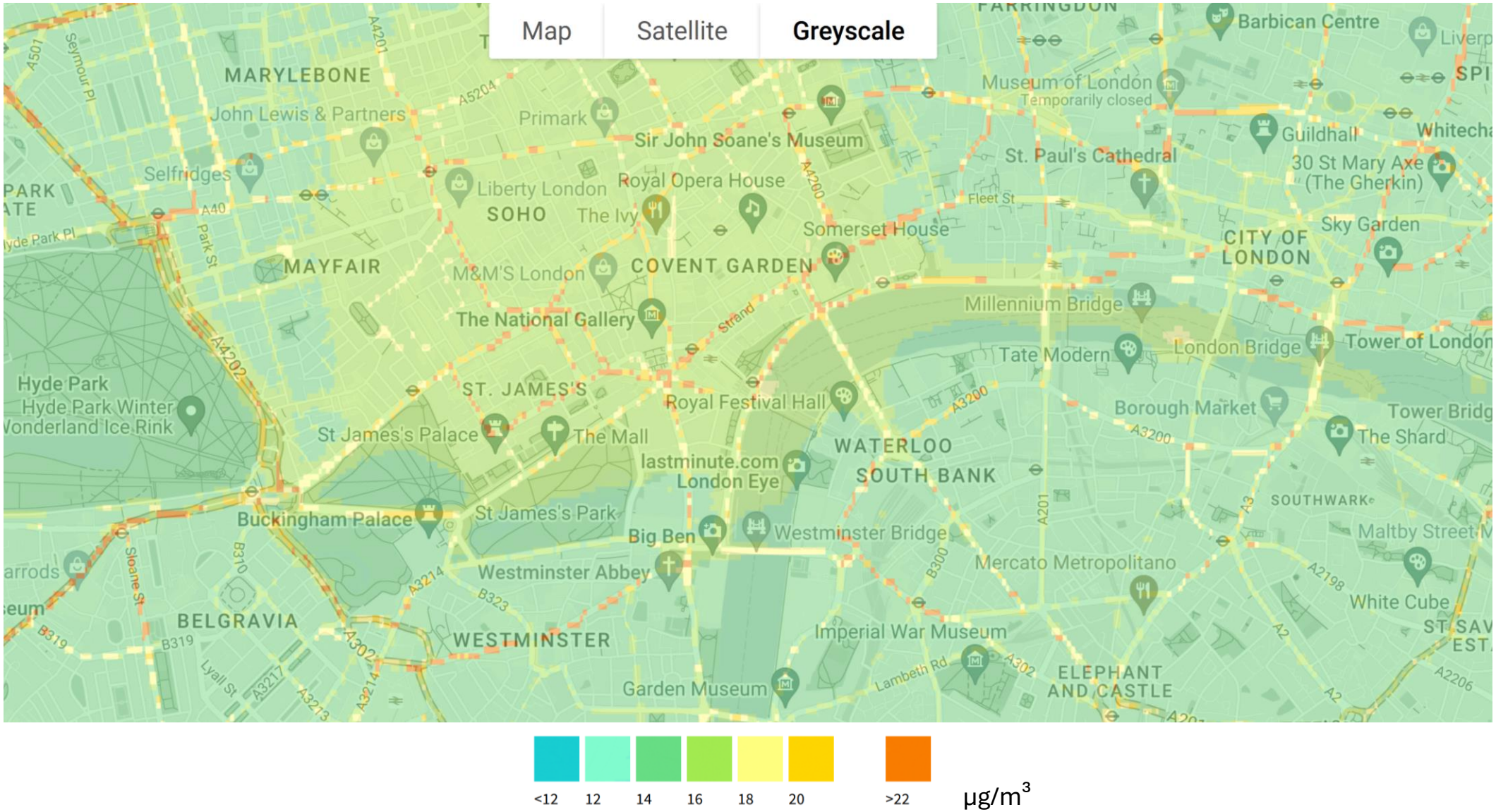
(a)

Uncertainty in annual mean, 2014



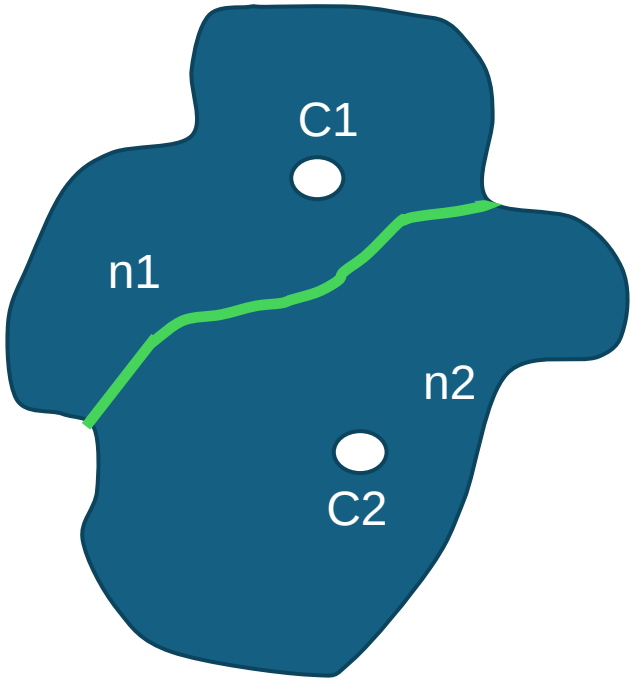
Shaddick et al, J Roy Stat Soc C 2018

Annual mean PM2.5 air pollution in London, based on measurements made in 2016



http://www.londonair.org.uk/london/asp/annualmaps.asp

Population-weighted mean concentration



C1 - concentration in location 1 (31 µg/m³)
C2 – concentration in location 2 (22 µg/m³)

n1 – population in district 1 (120 000)
n2 – population in district 2 (60 000)

N=n1+n2 – total population of the city (180 000)

C – population-weighted city mean concentration:

C = (C1*n1 + C2*n2)/N $C = \sum_{i=0}^{m} C_i * n_i / N$

C = (31*120000 + 22*60000)/180000 = 28 µg/m³

(mean of C1 and C2 = 26.5 µg/m³)

AIR QUALITY

Population-Weighted Concentration

HEALTH IMPACT

Burden On Your Health

https://www.stateofglobalair.org/data-cities/#/air/plot

State of Global Air 2022

Select Pollutant

Ambient particulate matter pollution

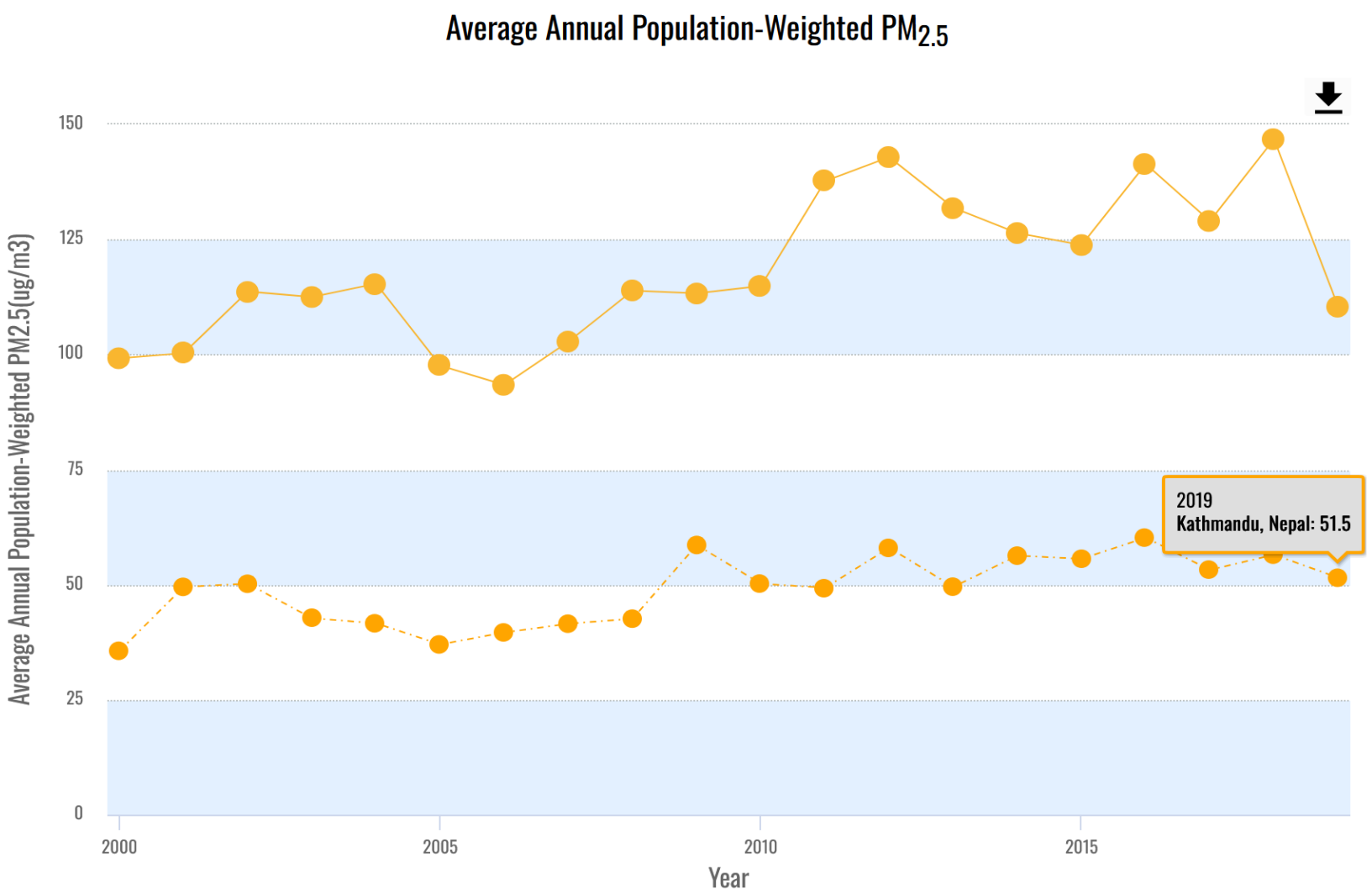
Choose a city, country

Delhi [New Delhi], India

- [ ] Show Global Averages
- [ ] Show Country Averages
- [ ] Show Regional Averages
- [ ] Show WHO AQ Guideline
- [ ] Show WHO Interim Target 1
- [x] Choose A City For Comparison

Kathmandu, Nepal

PLOTS | TABLES



Input information needed for HRA

- **Current exposure level (or exposure distribution in the population) (C)**
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- **Concentration-response function (CRF, RR)**
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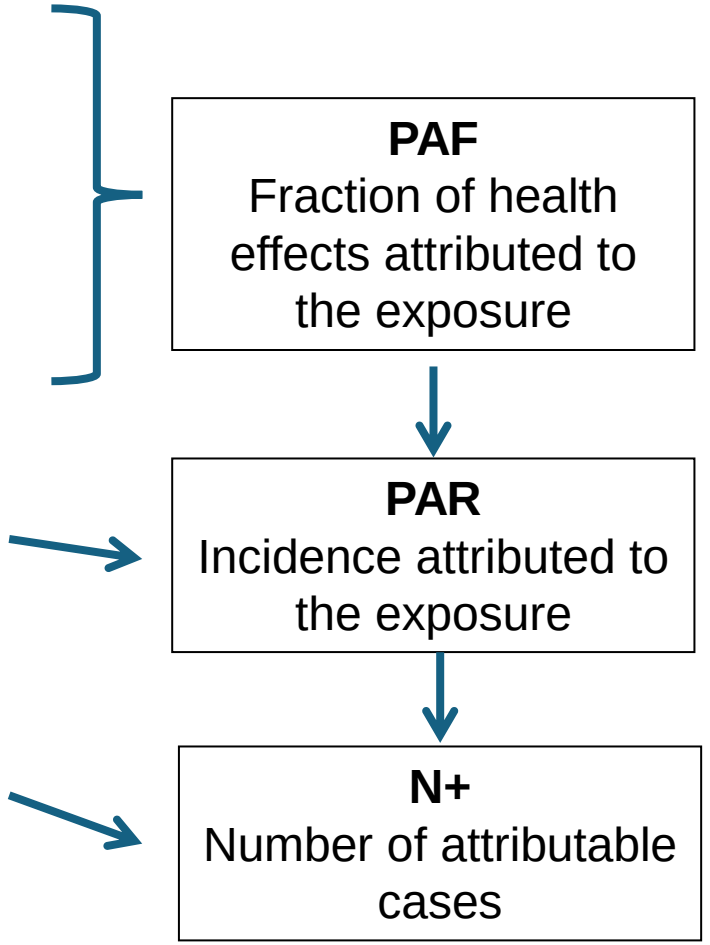

Reference exposure level (counterfactual)

Health burden analysis:

- The lowest exposure level observed
- GBD study: *Theoretical Minimum Risk Exposure Level (for PM2.5: 2.4 – 5.9 $\mu g/m^3$)*
- Exposure level with RR>1

Must be clearly defined and reported in each HRA!

Impact assessment:

- Exposure level expected (assumed) after planned intervention or policy scenario

Input information needed for HRA

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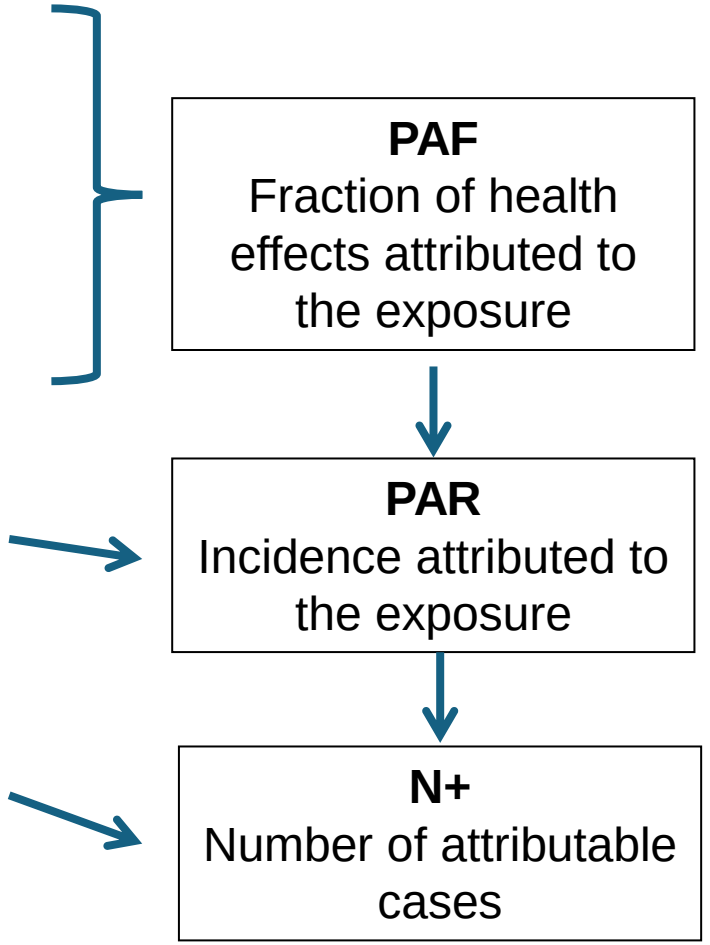
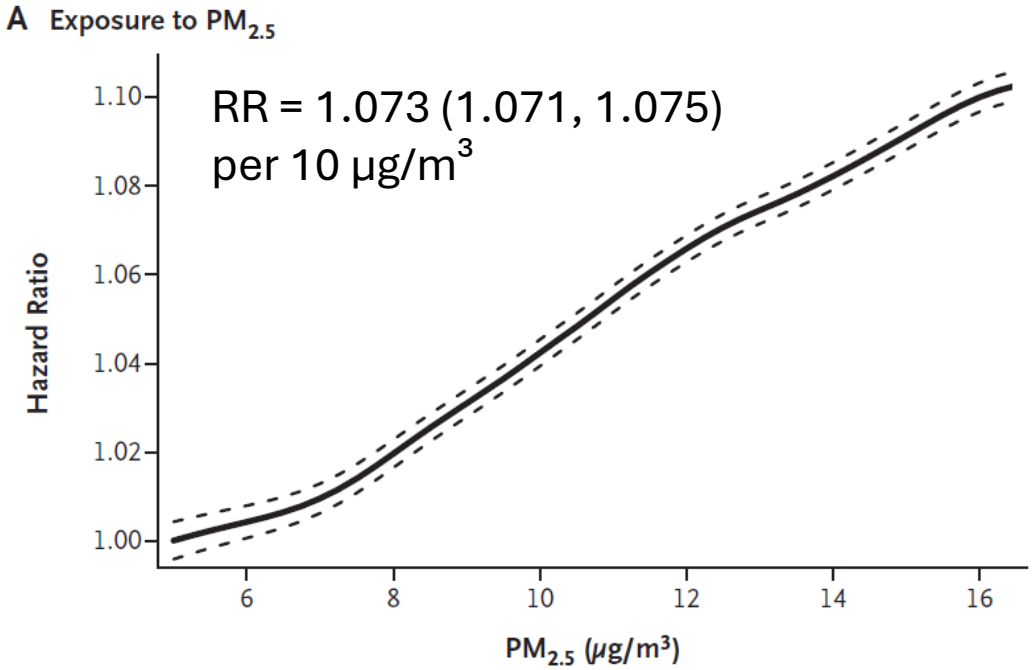
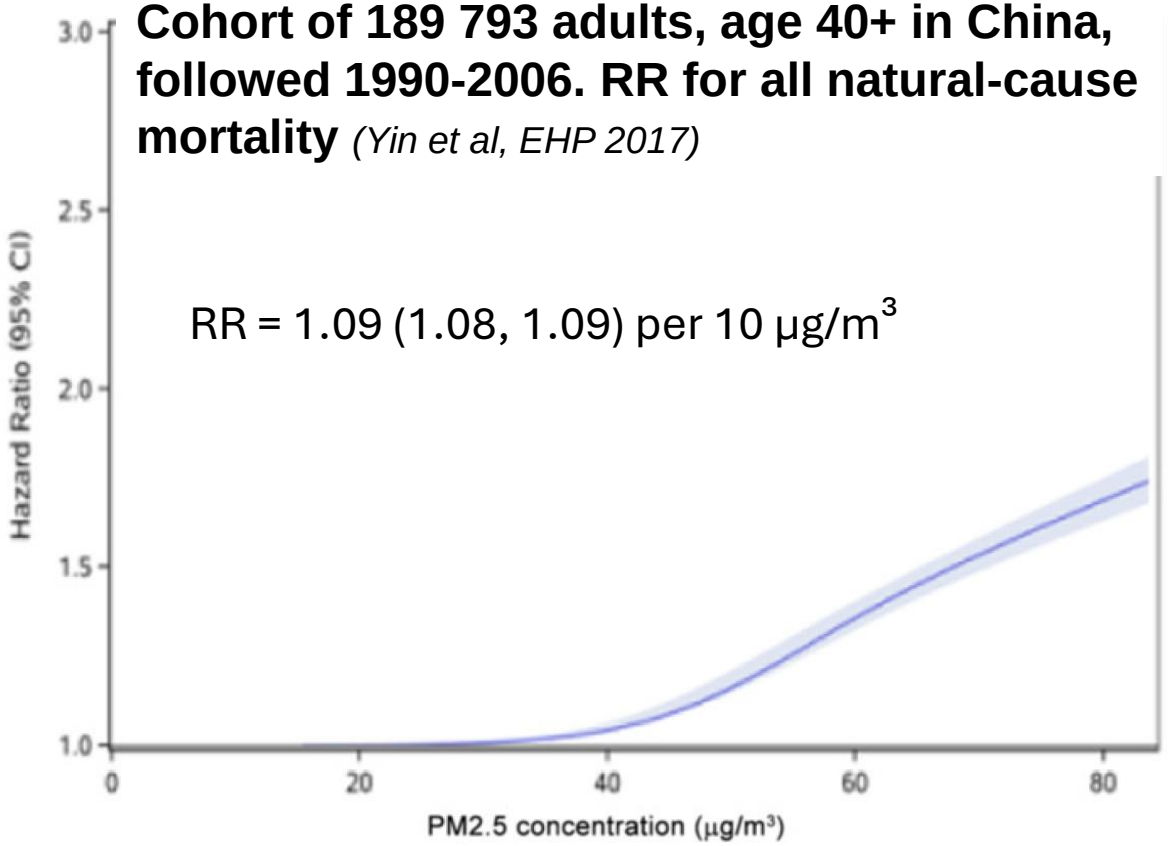


CRFs for all-cause mortality based on selected studies

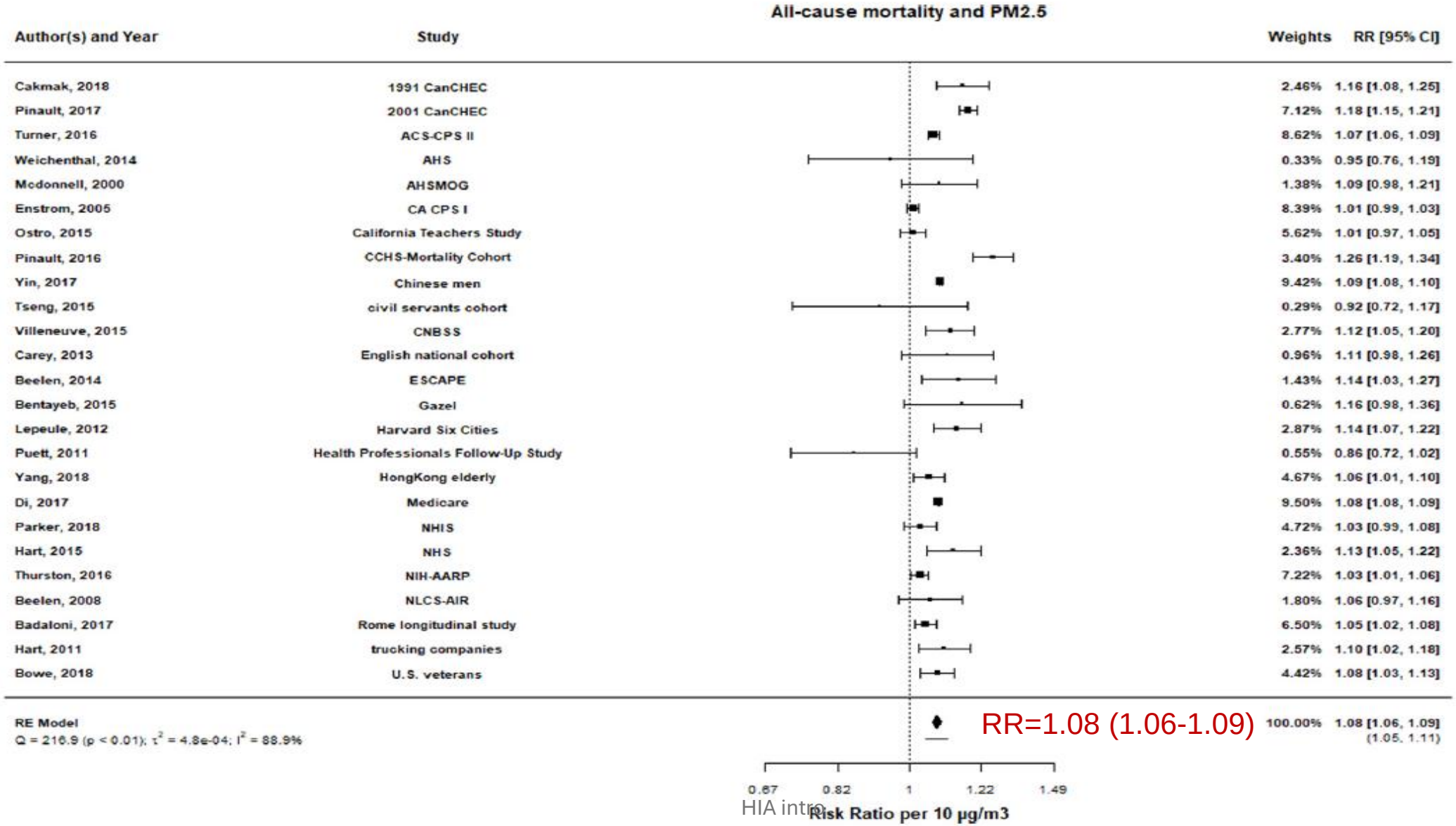
Cohort of 60 925 433 US adults, age 65+, followed 2000-2012; RR for all-cause mortality *(Di et al, NEJM 2017)*



Cohort of 189 793 adults, age 40+ in China, followed 1990-2006. RR for all natural-cause mortality *(Yin et al, EHP 2017)*

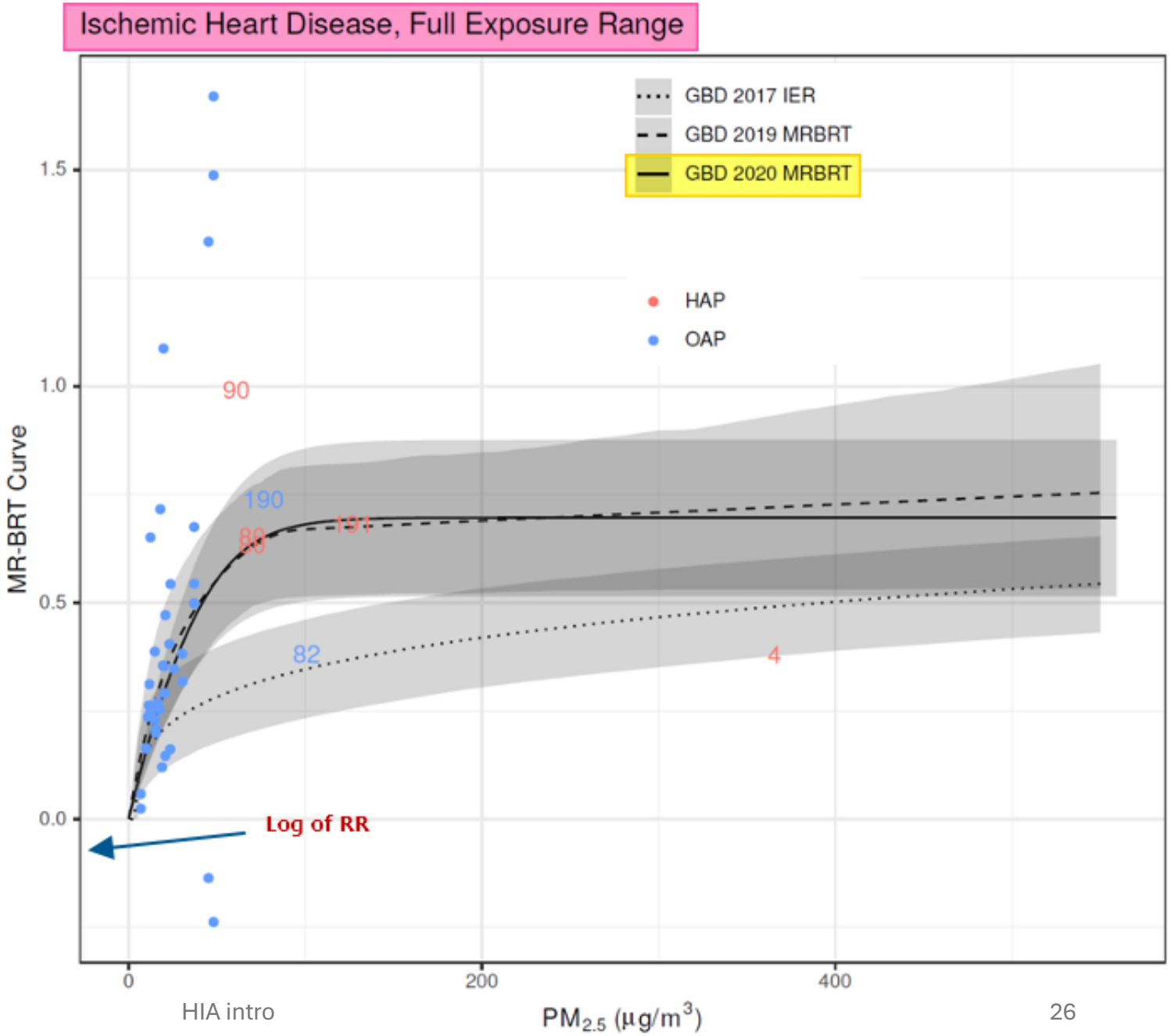


Long-term exposure to PM2.5 and natural-cause mortality – systematic review and meta-analysis supporting WHO 2021 update



Chen & Hoek, Env Internat 2020

Extrapolation of CRFs to high exposure ranges in GBD study



GBD collaboration, Lancet 2024 (suppl)

Selection of systematic reviews on the effects long term exposure to PM2.5 on morbidity in EMAPEC project (PROSPERO: CRD42023397145)

PM2.5, long term	SRs found	SRs included	SRs evaluated	Good Quality
Asthma in children	11	9	6	2
Asthma onset in adults	0			
ALRI in children	3	2	2	0
ALRI in adults	0			
COPD	7	2	2	1
IHD events	11	7	6	1
Stroke	12	8	6	2
Heart failure	2	1	1	0
Atrial fibrillation	5	4	4	1
Hypertension	12	8	7	2
Diabetes	9	8	3	2
Dementia	7	6	6	2
Parkinson disease	8	6	3	1
Autism Spectrum Disorder	8	7	4	4
Lung cancer	11	9	3	2

"Good quality" SR:

- all critical criteria met,
- not more than 4 other criteria missed

Forastiere et al., Env Epi 2024

Relative risk estimates for incidence of diseases from selected systematic reviews recommended for health risk assessment of $PM_{2.5}$ (WHO EMAPEC project)

Outcome (incidence)	ICD10 codes	Age (years)	List	RR (95%CI) per 10 µg/m³	Mean exposure range (µg/m³)	SR reference
Asthma in children	J45	0 - 18	A	1.34 (1.10; 1.63)	5 - 38	Khreis et al. (2017)
COPD	J41 – J44	30+	A	1.18 (1.13; 1.23)	5 - 26	Park et al. (2021)
IHD events	I21-I22	30+	A	1.13 (1.05; 1.22)†	5 - 65	Zhu et al. (2021)
Stroke	I60 – I64	30+	A	1.16 (1.12; 1.20)†	5 - 36	Yuan et al. (2019)
Hypertension	I10 - I11	30+	A	1.17 (1.05; 1.30)†	5 - 77	Qin et al. (2021)
Diabetes	E11 – E14	30+	B+	1.10 (1.03; 1.18)†	5 - 79	Yang BY et al. (2020)
Dementia	F00-F03, G30	60+	A	1.46 (1.12; 1.77)†	5 – 25§	Cheng et al. (2022)
Autism SD	F84.0, F84.1, F84.5, F84.8, F84.9	2 - 12	B+	1.66 (1.23; 2.25)†	5 – 30§	Lin LZ et al. (2022)
Lung cancer	C34	30+	A	1.16 (1.10; 1.23)	5 - 44	Yu et al. (2021)

† Relative risk estimates from revised meta-analysis

§ Restrict applicability of the CRFs of these conditions to exposure differences not larger than 10 µg/m³ within the indicated concentration ranges

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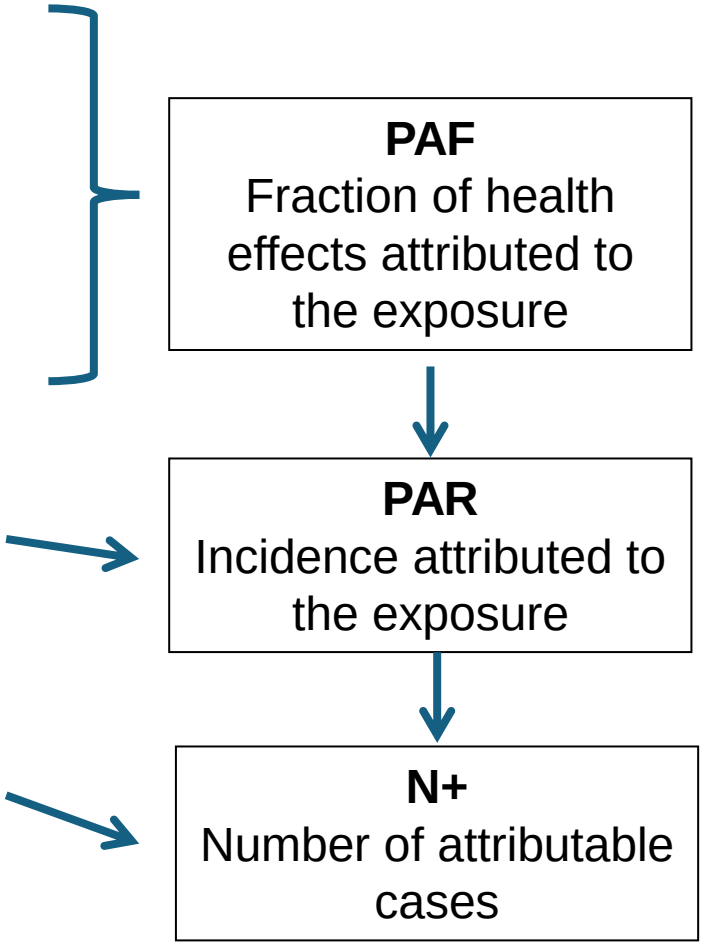

Example: City X

- Current annual mean PM2.5 exposure level in City X C= 51 µg/m^3
- The plan is to reduce it to C_0 = WHO IT1 = 35 µg/m^3 (i.e. by 16 µg/m^3)
- CRF for all-cause mortality based on Chen & Hoek 2020, RR= 1.08 per 10 µg/m^3, i.e. 1.131 per 16 µg/m^3

PAF = (1.131 – 1)/1.131 = 0.116 (11.6% of total mortality can be attributed to the exposure > 35 µg/m^3 in City X)

- What if C_0= 25 µg/m^3 (WHO IT2)? (RR per 26 µg/m^3=1.222)

PAF = (1.222 – 1)/1.222 = 0.182 (18.2% of total mortality can be attributed to the exposure > 25 µg/m^3 in City X)

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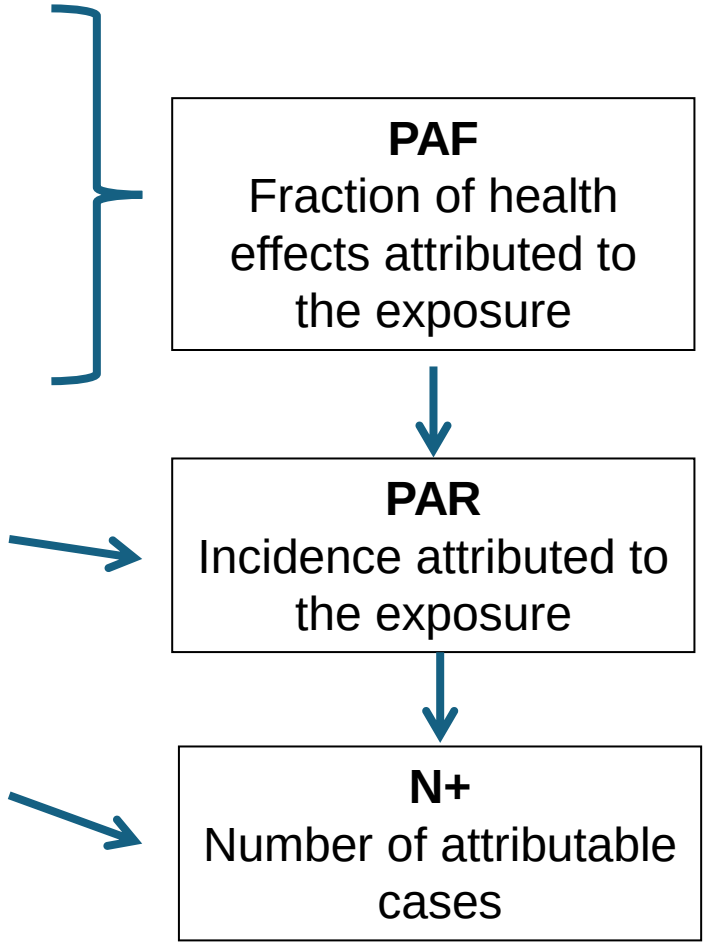


Data on the health outcome frequency in the HRA target population

- Optimal:
  - official health statistics for the target population (city, province, …)
  - For the most recent year (or mean of several years)
  - For the age group for which CRF applies (e.g. 30+)

- If the optimal data not available:
  - Take (incidence) data for the larger population, containing the target area
  - Make (information based) assumptions for estimating the data for the target group
  - Use the data (or estimates) for similar areas (countries?) not containing the target population from international sources

WHO MORTALITY DATABASE

Interactive platform visualizing mortality data

https://platform.who.int/mortality/themes/theme-details/MDB/all-causes

Portal home | Cause of death explorer | Country or area profile | Resources | About

All causes

Causes of death explorer

- All causes
- Communicable, maternal, perinatal and nutritional conditions
- Noncommunicable diseases
- Injuries
- Ill-defined diseases

Reset to default

Deaths by sex and age group for a selected country or area and year

Age groups*: All × Search...

Country or area*: Sri Lanka × Search...

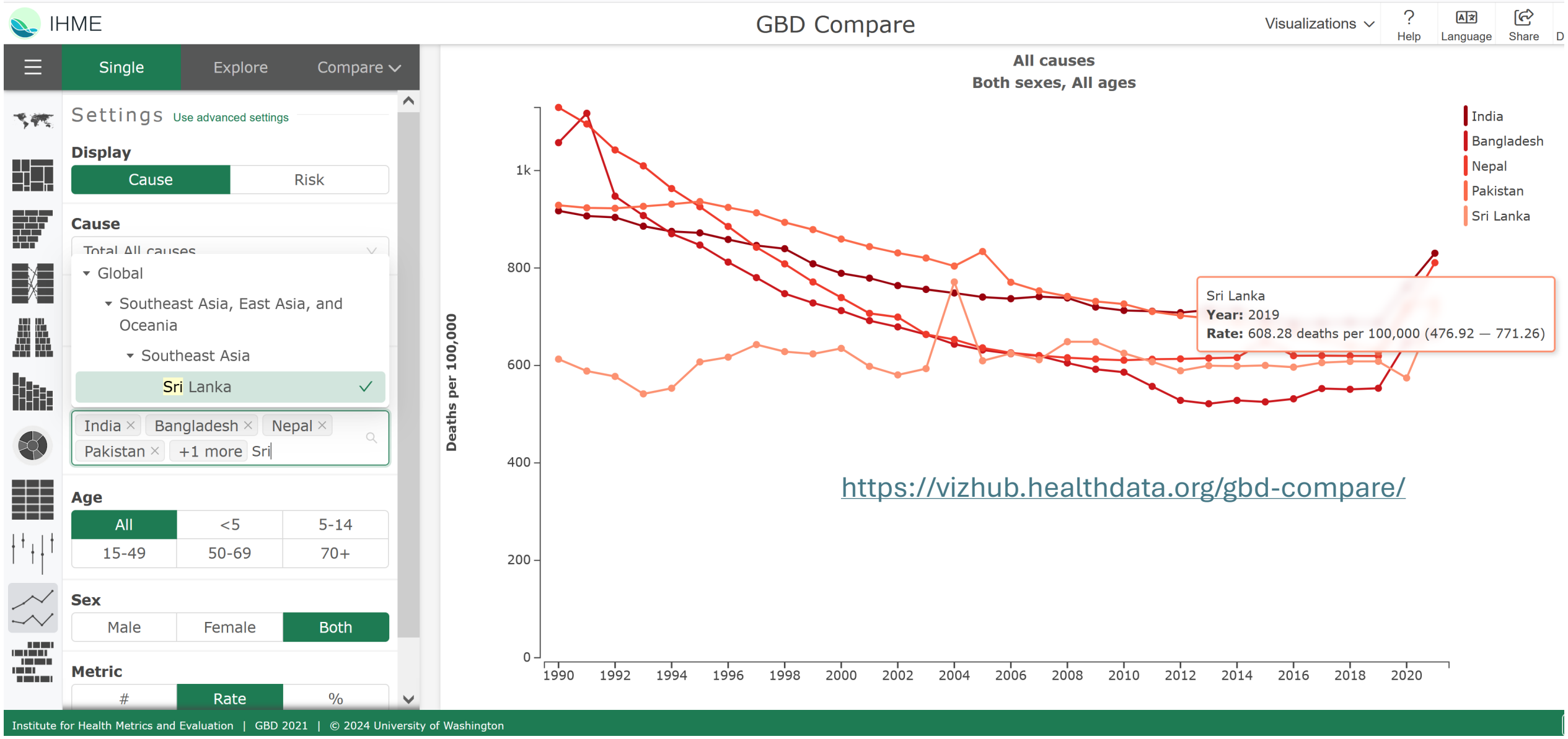
Sex*: All × Search...

Year: 2019

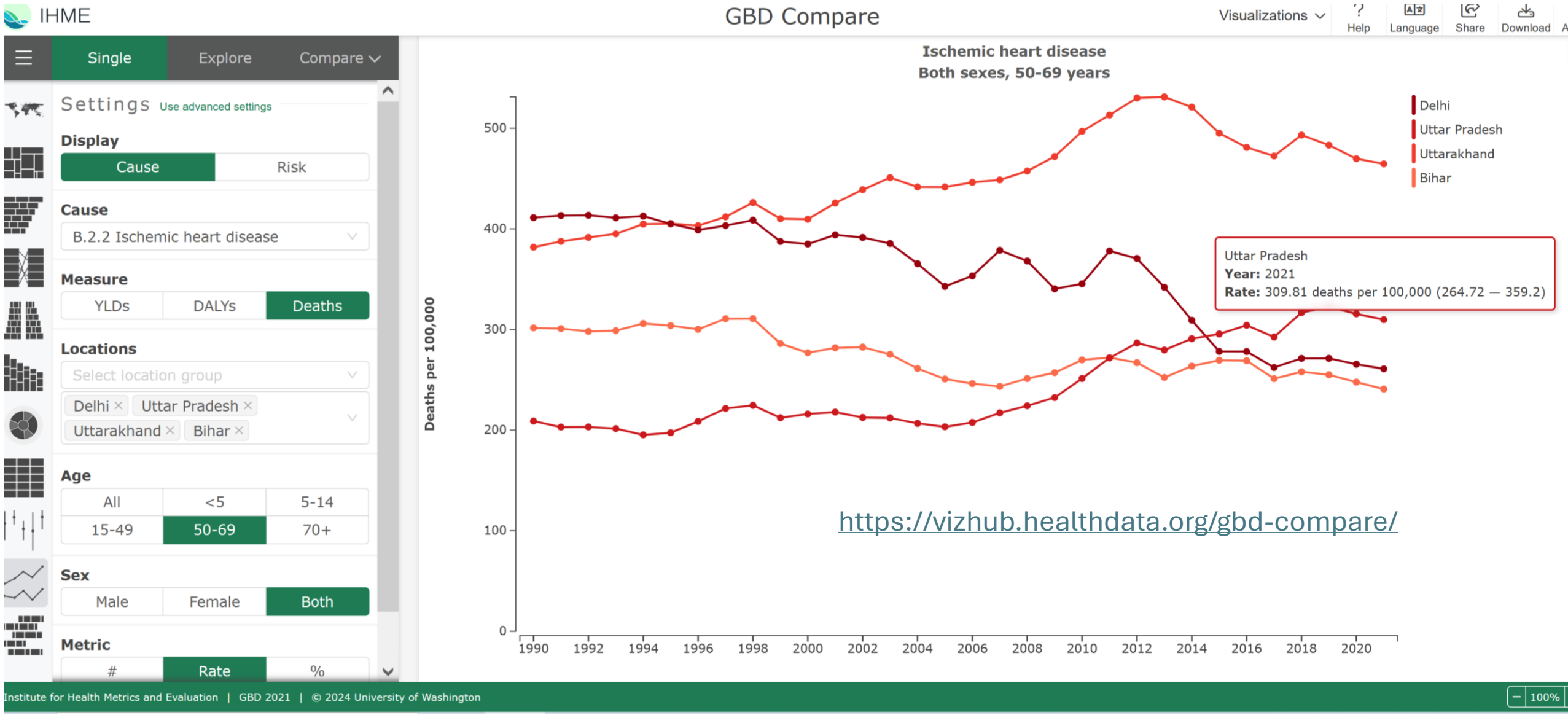
Related data

Age group		All
All	Number of deaths	146 397
	Death rate per 100 000 population	686.5

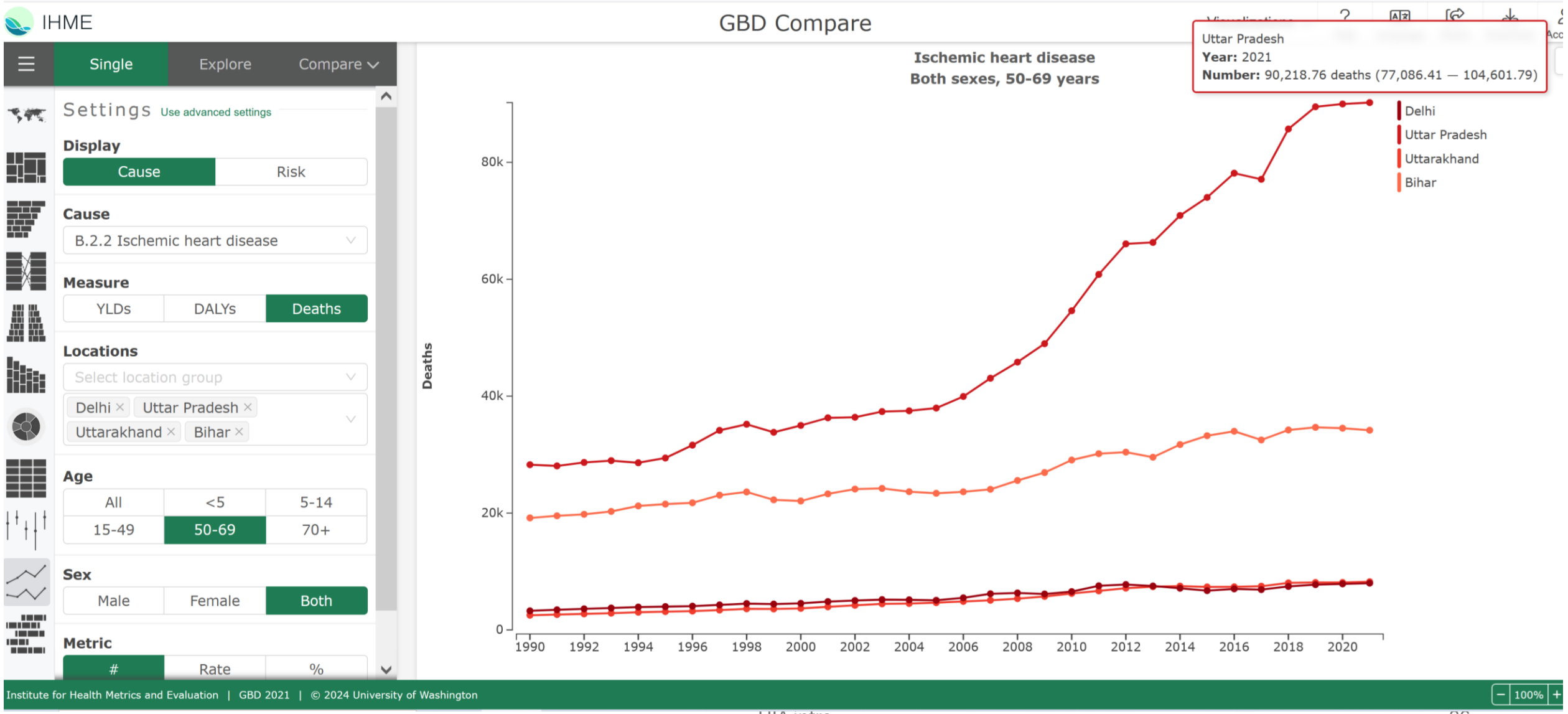
Mortality rates in South Asia countries – GBD project estimates



Mortality rates in India states – GBD project estimates



Number of IHD deaths, age 50-69 years, in India states – GBD project estimates



Example: City X, cont.

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  PAF = (1.131 – 1)/1.131 = 0.116 (11.6% of total mortality can be attributed to the exposure > 35 µg/m^3 in City X)

- All-cause mortality in age 30+ is I=1400 per 100 000 pop.

  Population attributable risk PAR = I*PAF= 1400 * 0.116= 162.4 per 100 000 pop. (mortality attributable to the exposure > 35 µg/m^3)

- Total population: 1.4 million, 55% in age 30+, NEx=1 400 000*0.55= 770 000 in age 30+

  Number of attributable cases = NEx * PAR= (770 000/ 100 000) * 162.4 = 1250 deaths / year attributable to exposure > 35 µg/m^3

GBD estimates of ambient particulate matter attributable burden of disease in 2021 (both sexes)

Counterfactual PM2.5 C_0 = TRMEL 2.4-5.9 µg/m^3

Country	PM attributable:			
	Number of deaths	Mortality rate per 100 000	DALYs	DALYs per 100 000
Bangladesh	41900	25.4	1188000	722
India	837500	67.0	27410000	1940
Nepal	12700	40.7	363300	1170
Pakistan	103000	43.7	4399000	1870
Sri Lanka	11400	51.1	279300	1250

https://www.stateofglobalair.org/

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AirQ+

Glossary | Manuals | Disclaimer | Citation

Impact Evaluation | Detailed Results

Evaluation Name: City X

Health Endpoint

Health Endpoint: Mortality, all (natural) causes (adults age 30+ years)

Incidence (per 100 000 Population at risk per year): 1400

Pop. at risk (55%): # 770000

Calculation Parameters

Calculation Method: log-linear

Relative Risk: 1.08 Lower: 1.06 Upper: 1.09

Cut-off Value X0 (see formula) 35

Mean Concentration X: 51

Advanced

Calculate

Results (last calculation 2024-08-05 13:58:18)

	Central	Lower	Upper
Estimated Attributable Proportion	11.59%	8.9%	12.88%
Estimated number of Attributable Cases	1,249	960	1,388
Estimated number of Attributable Cases per 100,000 Population at Risk	162.20	124.62	180.32

AIR QUALITY

Population-Weighted Concentration

HEALTH IMPACT

Burden On Your Health

https://www.stateofglobalair.org/data-cities/#/health/plot

Select Pollutant

Ambient particulate matter pollution

Select Metric

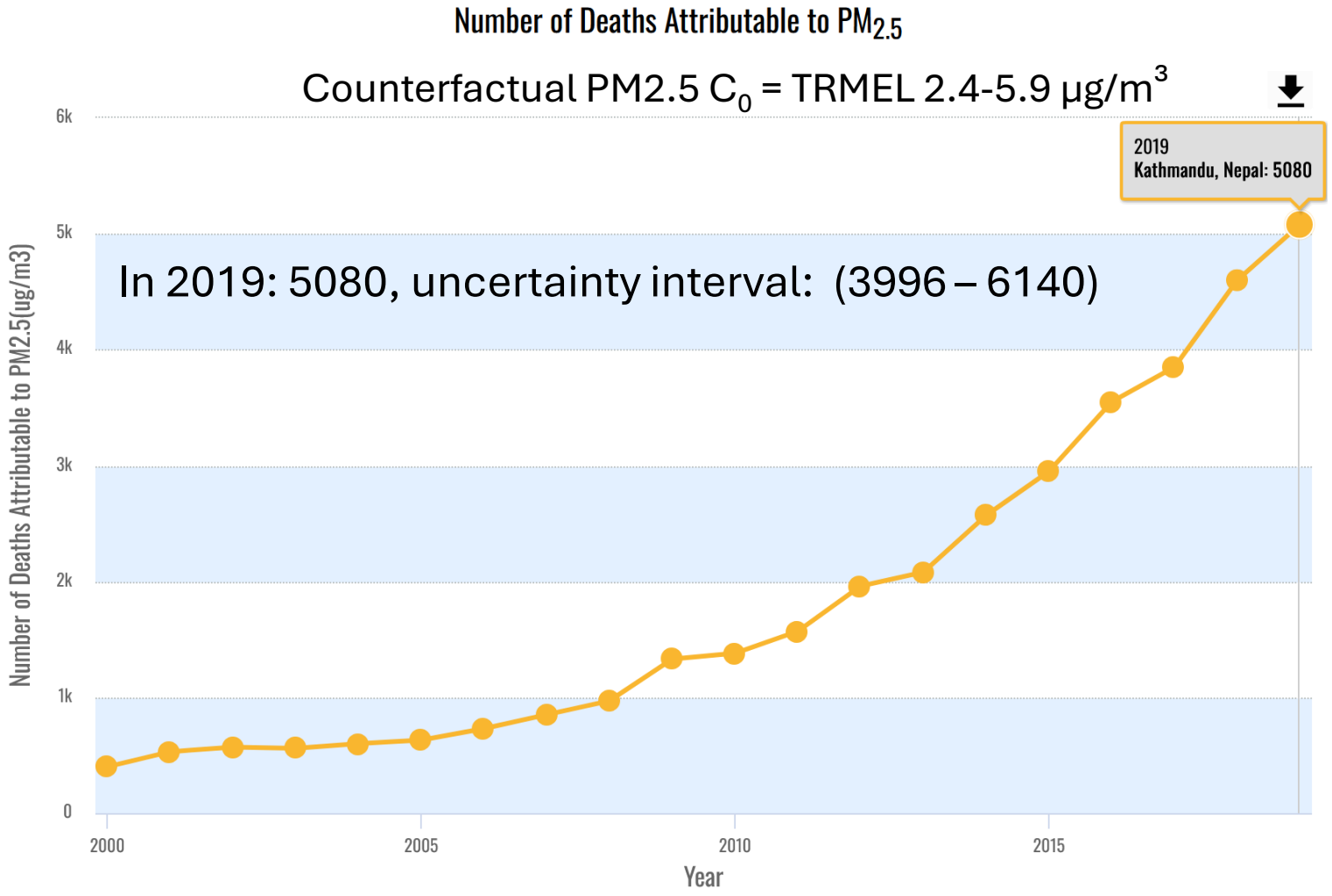
Number Rate

Choose a city, country

Kathmandu, Nepal

Choose A City For Comparison

PLOTS TABLES



Sources of uncertainty in HRA

- Concentration – response function:
  - Shape and range of applicability
  - Statistical uncertainty
- Level of exposure
  - Current (C)
  - Expected / counterfactual (C_0)
- Baseline incidence and population data

Good practice: analysis of sensitivity to various versions of input data and assumptions

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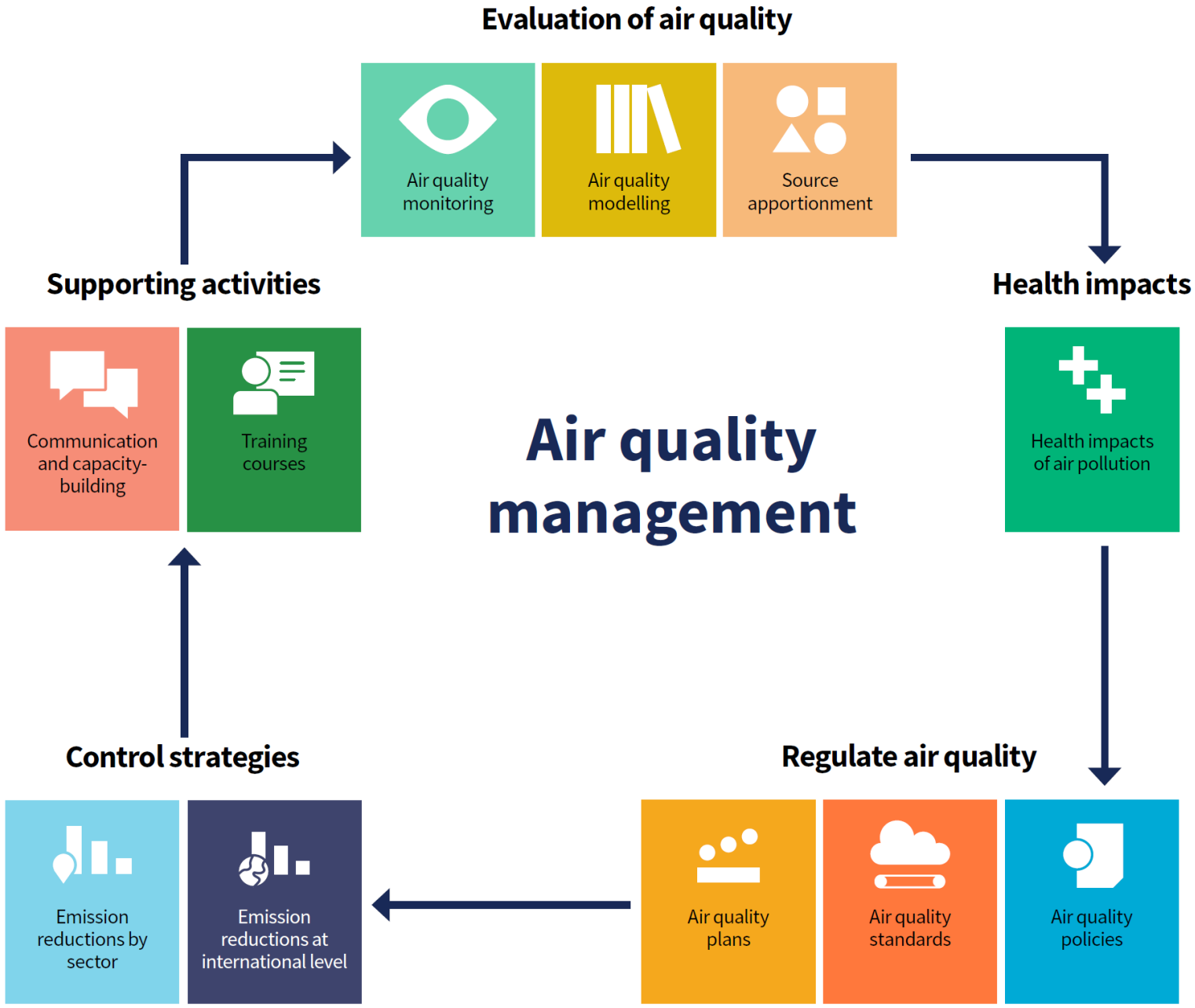
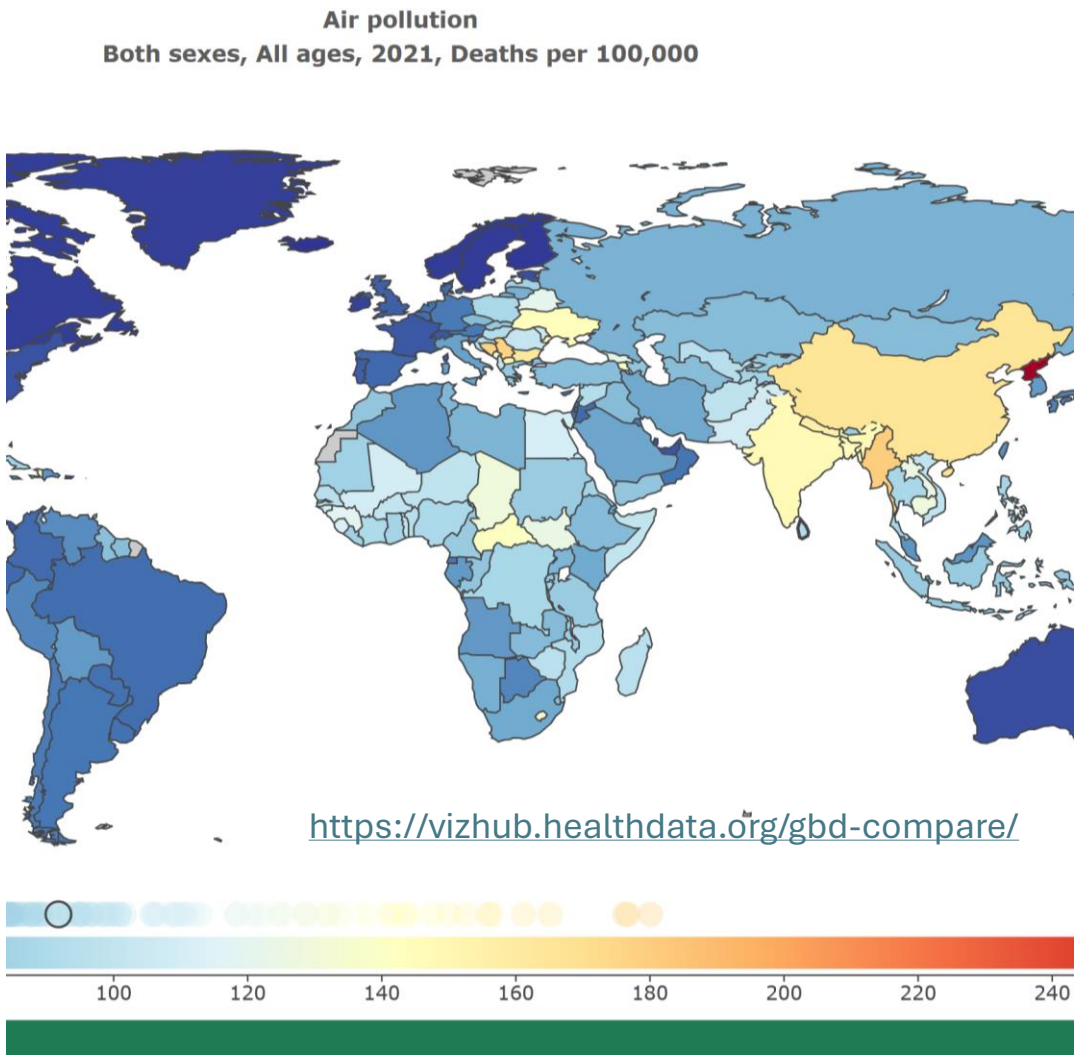
- Measures of risk in population (RR, PAF, number of attributed cases, YLL, DALY);
- Main elements of risk assessment
- Uncertainties and limitations of HRA
- Examples of HRA use in policy making

Air Quality management: a cyclical process

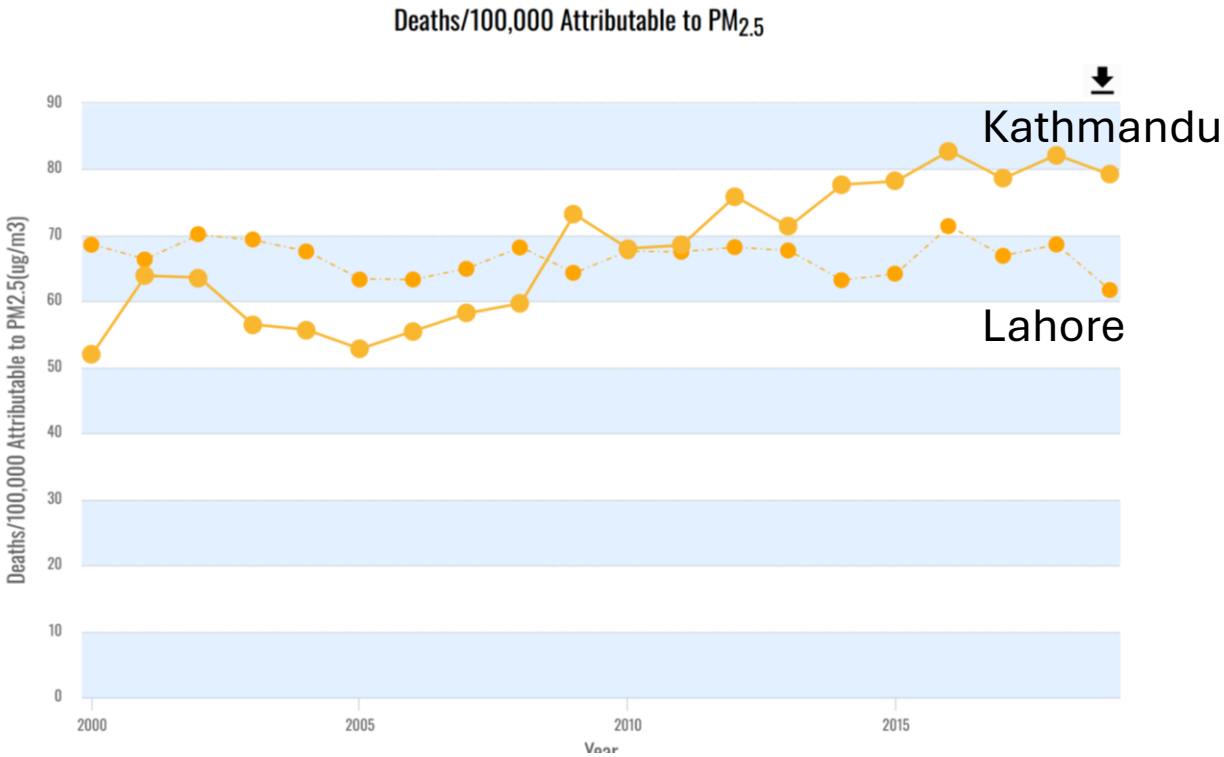
https://www.who.int/europe/publications/i/item/WHO-EURO-2023-6898-46664-67857



Use of GBD results to inform policy



https://vizhub.healthdata.org/gbd-compare/



https://www.stateofglobalair.org/data-cities/#/health/plot

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Air pollution exposure and health impacts in the Kathmandu valley

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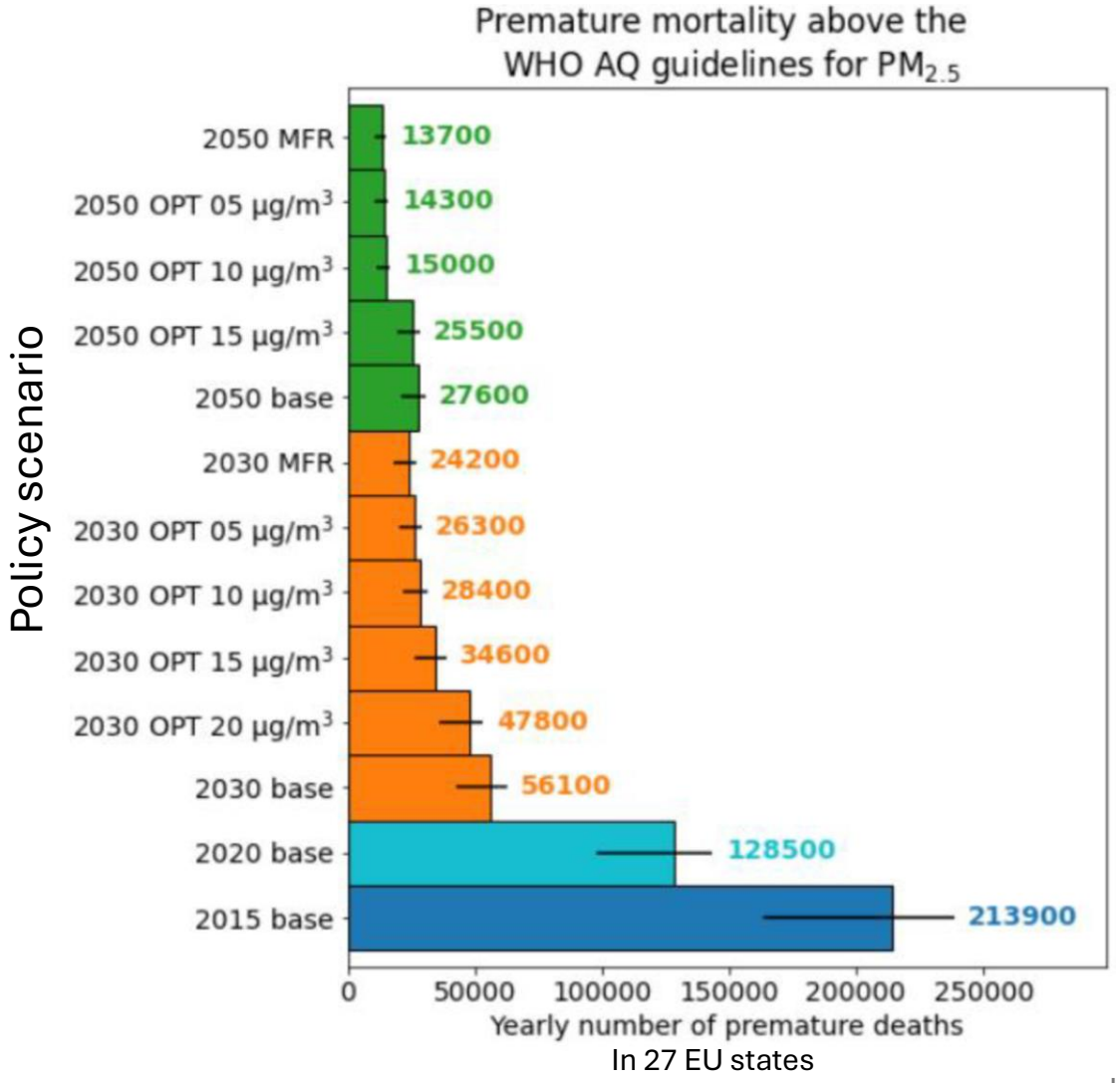
RR=1.06 (1.04, 1.08) from Hoek et al 2012)

Table 5B Mortality (Aged 30 and above) attributable and avoidable fractions and burdens from $PM_{2.5}$ ambient air pollution in Kathmandu valley using WHO HRAPIE estimate

		Attributable			*Avoidable*		
Period	*Measure*	*Central*	*Lower*	*Upper*	*Central*	*Lower*	*Upper*
Baseline (2017–2020)	Attributable fraction	0.2015	0.1364	0.2579	–	–	–
	Attributable cases	1979	1340	2533	–	–	–
	Attributable cases per 100, 000 population at risk	128.53	87.05	164.51	–	–	–
BAU (35% Reduction)	Attributable/Avoidable fraction	0.1269	0.0847	0.1646	0.0746	0.05175	0.09322
	Attributable/Avoidable cases	1679	1121	2179	300	220	355
	Attributable/Avoidable cases per 100, 000 population at risk	73.98	49.37	95.98	54.55	37.68	68.53
Progressive (60% Reduction)	Attributable/Avoidable fraction	0.0694	0.0458	0.0910	0.1320	0.0906	0.1669
	Attributable/Avoidable cases	919	606	1204	1061	734	1330
	Attributable/Avoidable cases per 100, 000 population at risk	40.47	26.72	53.03	88.06	60.33	111.48

Impact assessment for revision of EU AQ Directive (2022)



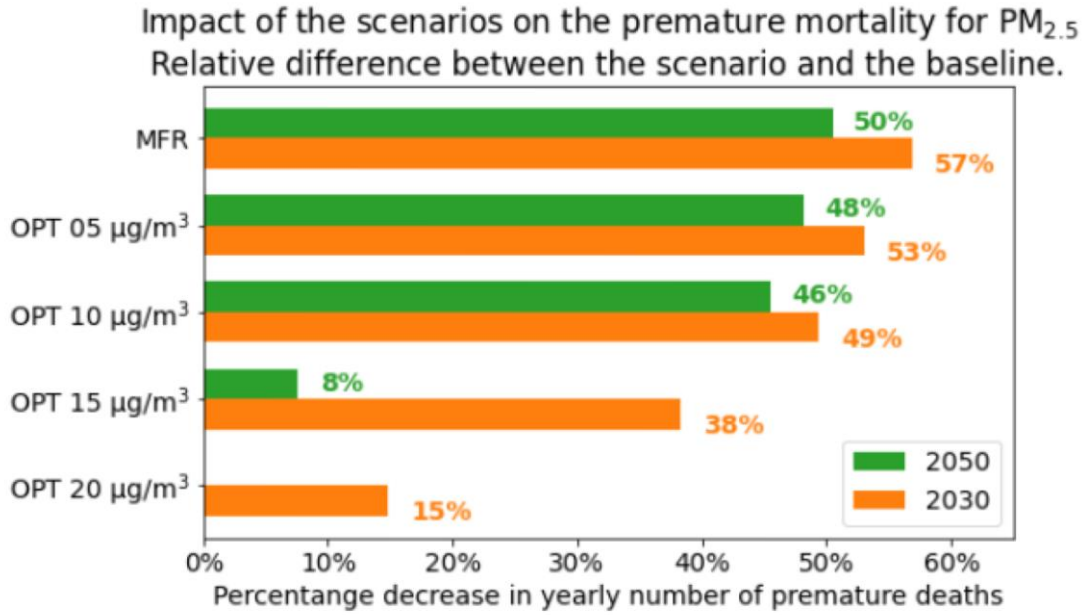
In 27 EU states

Study to support the impact assessment for a revision of the EU Ambient Air Quality Directives

Specific Contract under Framework Contract ENV/F1/ FRA/2019/0001

Final Report

https://op.europa.eu/en/publication-detail/-/publication/a05c2e91-54db-11ed-92ed-01aa75ed71a1/language-en



Summary

- **HRA provides:**
  - Quantitative estimates of the burden of air pollution on population health
  - Estimates of the impacts of selected policies affecting air pollution on health
  - Basis for economic assessment of air pollution health burden and its changes due to policies (not discussed here)
  - Essential arguments supporting clean air policy
- **HRA requires:**
  - Relevant data on population exposure and its expected changes due to policy under study
  - Reliable concentration-response functions (from epidemiology)
  - Data on relevant health indicators for the target population
  - Expertise in HRA implementation