Breathe Cities

Breathing Life into Cities

The Health and Economic Opportunities of Action for Clean Air

Annexes

Annex 1: Full list of cities analysed

The below table shows the list of cities analysed for this report, their $PM_{2.5}$ concentrations in 2015 (sources of information are available in annex 2), and the $PM_{2.5}$ concentrations we project are required for cities to follow the WHO Road Map and halve mortality due to air pollution. For more information on the city selection methodology, please refer to Annex 2.

Region	City	Country	Population in Millions (2015)[i]	2015 PM2.5	Required PM2.5 in 2040
Africa	Accra	Ghana	2.3	29.8	14.0
Africa	Cape Town	South Africa	4.1	6.6	3.3
Africa	Ekurhuleni	South Africa	3.5	52.8	23.7
Africa	Ibadan	Nigeria	3.2	82.5	34.8
Africa	Johannesburg	South Africa	5.0	54.9	24.6
Africa	Kano	Nigeria	3.6	106.3	42.6
Africa	Kumasi	Ghana	2.6	74.5	32.0
Africa	Lagos	Nigeria	12.2	42.3	19.4
Africa	Mombasa	Kenya	1.1	11.4	5.6
Africa	Nairobi	Kenya	3.9	20.6	9.9
Africa	Nakuru	Kenya	0.3	14.4	7.0
Africa	Sekondi Takoradi	Ghana	0.7	53.0	23.8
Asia	Bandung	Indonesia	2.5	85.9	36.0
Asia	Bangkok	Thailand	9.4	20.4	9.8
Asia	Beijing	China	18.4	77.8	33.2
Asia	Chiang Mai	Thailand	1.1	27.7	13.1
Asia	Chon Buri	Thailand	1.3	17.1	8.3
Asia	Chongqing	China	13.4	46.2	21.1
Asia	Chukyo M.M.A. (Nagoya)	Japan	9.4	15.3	7.4
Asia	Delhi	India	25.9	123.8	47.7
Asia	Jakarta	Indonesia	10.2	33.0	15.5
Asia	Kinki M.M.A. (Osaka)	Japan	19.3	14.5	7.0
Asia	Kolkata (Calcutta)	India	14.4	95.0	39.0
Asia	Mumbai (Bombay)	India	19.3	42.2	19.4
Asia	Shanghai	China	23.5	50.0	22.6
Asia	Surabaya	Indonesia	2.9	33.7	15.8
Asia	Tokyo	Japan	37.3	15.9	7.7
Europe	Antwerpen	Belgium	1.0	16.4	7.9
Europe	Barcelona	Spain	5.3	18.4	8.9
Europe	Birmingham (West Midlands)	United Kingdom	2.5	9.2	4.5
Europe	Brussels	Belgium	2.0	13.5	6.6
Europe	Kraków (Cracow)	Poland	0.8	28.1	13.3
Europe	Liège	Belgium	0.7	16.2	7.8

[i] Data taken from Urban Agglomerations from the UN World Urbanisation Prospects dataset, year 2015

Europe	Łódź	Poland	0.7	24.9	11.9
Europe	London	United Kingdom	8.7	10.4	5.1
Europe	Lyon	France	1.6	16.0	7.8
Europe	Madrid	Spain	6.2	11.0	5.4
Europe	Manchester	United Kingdom	2.6	11.7	5.7
Europe	Marseille-Aix-en-Provence	France	1.6	10.9	5.3
Europe	Milan	Italy	3.1	31.5	14.8
Europe	Napoli (Naples)	Italy	2.2	15.8	7.7
Europe	Paris	France	10.7	16.6	8.0
Europe	Plovdiv	Bulgaria	0.3	26.4	12.5
Europe	Rome	Italy	4.1	18.3	8.8
Europe	Sofia	Bulgaria	1.3	26.0	12.3
Europe	Valencia	Spain	0.8	11.8	5.8
Europe	Varna	Bulgaria	0.3	13.0	6.3
Europe	Warsaw	Poland	1.7	22.0	10.5
North America	Chicago	United States of America	8.8	10.0	4.9
North America	Guadalajara	Mexico	4.8	17.1	8.3
North America	Los Angeles-Long Beach-Santa Ana	United States of America	12.3	10.6	5.2
North America	Mexico City	Mexico	21.3	21.9	10.5
North America	Monterrey	Mexico	4.5	11.3	5.5
North America	New York-Newark	United States of America	18.6	8.0	3.9
South America	Belo Horizonte	Brazil	5.8	8.2	4.0
South America	Bogotá	Colombia	9.7	17.0	8.2
South America	Buenos Aires	Argentina	14.7	13.9	6.7
South America	Cali	Colombia	2.6	19.1	9.2
South America	Córdoba	Argentina	1.5	6.1	3.0
South America	Medellín	Colombia	3.7	20.5	9.8
South America	Rio de Janeiro	Brazil	12.9	16.0	7.7
South America	Rosario	Argentina	1.4	7.5	3.7
South America	São Paulo	Brazil	20.9	16.5	8.0

Annex 2: Methodology

Here we outline the approach we took in this report to estimating the $PM_{2.5}$ reduction required to meet the WHO target by 2040, the associated mortality reduction, the economic benefit calculated through the Value of Statistical Life (VSL) and years of life (including productive) lost.

In our analysis we explored the opportunities and benefits for a variety of cities around the world, including those with a high potential to gain from clean air action based on their current population, and cities that are already taking action (as exemplified by the Breathe Cities initiative).

To reflect this variety of contexts, the cities and countries for the analysis were chosen according to the following methodology:

(1) the three largest cities in each country where a city is already part of the Breathe Cities initiative. This criteria was used to reflect existing efforts and potential for further clean air action.

(2) the largest city in each region (based on the Urban Agglomerations from the UN World Urbanisation Prospects dataset) outside of the Breathe Cities countries, followed by the two largest cities in the same country.

The number of cities selected in each region varied to complement the cities selected under the first criteria and ensure a good mix across the regions.

We then analysed these 63 cities' $PM_{2.5}$ concentration required to meet the WHO Road Map target of halving the population attributable fraction, the associated mortality reduction and the economic benefit.

Data for C40 cities analysed are from running a satellite/monitor hybrid dataset from Washington University's Atmospheric Composition Analysis Group, using dataset Global/Regional Estimates (V5.GL.05.02). For non-C40 Cities we reverted to the State of Global Air (SOGA) dataset. This dataset uses a very similar satellite/monitor method as the C40 data.[ii]

Uncertainties:

- Since the WHO have not confirmed an approach to apportioning the anthropogenic component of air pollution exposure for the purpose of the Road Map 2040 target, we based on our analysis on total exposure across all sources. Whilst we avoided cities with known high air pollution from natural sources (dust and soil NO_x)[iii], this may still overestimate anthropogenic source-linked health burden in some cases.
- Air quality exposure and concentration data is based on products whose error is known to vary across cities. This error may be greater in cities that have a low density of air pollution monitors on the ground and so must rely more on satellite observations and chemical transport modelling. However, using satellite/monitor datasets allows for standardised calculation of population-weighted $PM_{2.5}$ averages within entire city boundaries, and reduces the uncertainty compared to only using data from ground monitors.
- We used a single, all-cause mortality risk function from the WHO for this analysis, which allowed us to calculate a target $PM_{2.5}$ concentration from halving population-attributable fractions. This risk function was calculated from a meta-analysis of

[ii] Annual PM2.5 concentrations were estimated by integrating information from satellite-retrieved aerosol optical depth, chemical transport modelling, and ground monitor data. using data as described in van Donkelaar et al (2021). Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty Environmental Science & Technology, 2021, doi:10.1021/acs.est.1c05309.
[iii] Using data from Tessum et al, 2022. Sources of ambient PM2.5 exposure in 96 global cities. Atmospheric Environment. https://doi.org/10.1016/j.atmosenv.2022.119234

studies across the world, which included individual studies on both all-cause mortality and natural cause mortality. [1] However, there are relatively few studies in low- and middle-income countries, which tend to have higher air pollution concentrations. As such, there is greater uncertainty in the risk function at higher concentrations. This applies to many of the cities in this analysis.

- We assessed all-cause mortality linked to $PM_{2.5}$ exposure rather than modelling at the specific-disease level to align with the WHO's relative risk function. This will likely cause figures to be higher than in some other similar studies that use cause-specific mortality rates and relative risks.

(i) Calculation of $PM_{2.5}$ concentration required to meet the WHO target of halving the Population Attributable Fraction (PAF) by 2040

The Relative Risk (RR) for $PM_{2.5}$ was calculated by the WHO to be 1.08 exactly for a 10 unit change in $PM_{2.5}$. [2] The relationship between RR and $PM_{2.5}$ concentration is an exponential one. That is:

$$RR = e^{\beta p}, where\ p\ is\ the\ unit\ change\ in\ PM2.5$$

Therefore, to calculate the beta, we must:

$$\beta = \frac{ln(RR)}{p}$$

This provides a universal β value for this piece of work of approximately 0.008.

Annual population-weighted $PM_{2.5}$ concentration values were generally taken from the team at C40/Breathe Cities, which was derived from an air pollution monitor and satellite dataset. [3] Where a city chosen was not contained in this dataset, the value for $PM_{2.5}$ concentration was taken from the State of Global Air. [4] All values were taken for 2015, the baseline year for the WHO target.

For each city, we needed to work out the population-attributable fraction (PAF) for $PM_{2.5}$.

$$PAF = 1 - e^{-\beta p}, where\ p\ is\ the\ PM2.5\ concentration\ in\ 2015$$

This implicitly assumes a target base of 0 concentration of $PM_{2.5}$.

In order to reach the WHO target, cities would need to half this PAF value. In order to work out the $PM_{2.5}$ concentration target, we will need to back calculate the equation above but with a value of PAF half the size.

$$p = \frac{ln(1 - \frac{PAF}{2})}{-\beta}$$

(ii) Associated mortality reduction from meeting the WHO target of halving the Population Attributable Fraction (PAF) from $PM_{2.5}$ by 2040

This analysis makes further assumptions.

Firstly, we retrieved the 'all-cause' mortality rate from IHME GBD. This differs from other pieces of air pollution-related mortality analysis, where specific causes were focused on. Where possible, the applicable city/sub-regional data was chosen but otherwise country-level data was used, with the caveat that this introduces some uncertainty to the results because cities can have different mortality trends to the national average. However, reliable city-level data often does not exist, so using the GBD data allows for a standardised approach across all cities.

For 2015 mortality calculations, we used 2015 mortality rate data from the IHME GBD. For 2040, we used the latest mortality rate data from the IHME GBD (2021). Projections of future mortality rates are not provided by the GBD. However, demographic changes and changes in healthcare between 2021 and 2040 are likely to result in changes to mortality rates.

To calculate the actual absolute mortality values, it was necessary to approximate how many people in each age group live in each city. To calculate this, we used:

- UN World Urbanisation Prospects (WUP) data for cities over 300,000 people; and
- UN World Population Prospects (WPP) data for countries in five year age groups.

The UN WUP has approximations for 2015 which we used directly. For 2040, we projected linearly using data from 2030 to 2035 as a base.

Using the UN WPP, which is only available at country-level, we assumed that the age group proportions in the cities are roughly the same as at a country-level. For 2015, there was already data available for the year 2015. For 2040, we used the latest available data (for 2023) and assumed age group proportions will remain constant until 2040.

Then, simply using the newly calculated absolute population by age group and city, and the mortality rate by age group and city, we could calculate the absolute all-cause mortality.

$$Absolute\ all\ cause\ mortality\ =\ Population \times\ All\ cause\ mortality\ rate$$

Finally, the $PM_{2.5}$ mortality in each case, 2015, 2040 BAU and 2040 Target takes the applicable PAF of the all-cause mortality:

$$Absolute\ PM2.5\ mortality\ =\ PAF \times\ Absolute\ all\ cause\ mortality$$

(iii) Economic benefit calculated through the Value of Statistical Life (VSL)

To calculate economic benefit, we used the VSL data by year, city and country. This data is not disaggregated by age and puts a single value on life, irrelevant of age. It is retrieved from the team at C40/Breathe Cities and derived from the OECD national-level dataset 'Mortality, morbidity and welfare cost from exposure to environment-related risks'.[5] In 2015, exact data from that year is available. For 2040, the latest figure is used (2022).

To calculate the exact economic loss, through VSL, in each age group and city, the mortality is multiplied by the corresponding VSL figure:

$$Economic\ losses\ due\ to\ PM2.5 = VSL \times Absolute\ PM2.5\ mortality$$

(iii) Total years of life lost, including productive years

To calculate years of life lost (YLL), it is necessary to use Life Expectancy (LE) data to approximate how many years were lost in the case of each $PM_{2.5}$ related death. In order to do this, Life Expectancy data from C40/Breathe Cities by country was used. In 2015, exact data from that year is available. For 2040, the latest LE figure is used (2022). In order to calculate the Total YLL, the following calculation is performed for each age group.

$$Total\ YLL = LE \times Absolute\ PM2.5\ mortality$$

For example, where an individual dies due to $PM_{2.5}$ in 2040, the number of years they would have likely lived for is added to the YLL in 2040.

It is also of interest how much economic productivity has been lost therefore years of productive life lost (YPLL) was also calculated. This is very similar to the above, apart from that every year of life above 65 or below 18 was not included.

To do this, for age groups starting from less than 18 (i.e. 0-4, 5-9, 10-14, 15-19), we removed the number of years before 18 from the base year. Similarly, any year of LE spent after 65 was removed also: $YPLL = (LE - Years\ before\ 18 - Years\ after\ 65) \times Absolute\ PM2.5\ mortality$

References:

[1] Chen, J. and Hoek, G (2020) Long-term exposure to PM and all-cause and cause-specific mortality: A systematic review and meta-analysis. Available at: https://doi.org/10.1016/j.envint.2020.105974
[2] WHO (2021) WHO Global Air Quality Guidelines 2021. Available at: https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines
[3] Van Donkelaar et al (2021) Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. Environmental Science & Technology. Available at: https://doi.org/10.1021/acs.est.1c05309
[4] *Air Pollution and Health in Cities 2022.* State of Global Air.
[5] OECD (2024) Mortality, morbidity and welfare cost from exposure to environment-related risks; Value of a statistical life in US dollars purchasing power parity. Available at: https://stats.oecd.org/wbos/fileview2.aspx?IDFile=1356df09-6bd4-4b0b-9a95-d56e145769ad