The burden of air pollution in Bogotá, Colombia 2021

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Key Findings

- **What were the $PM_{2.5}$ concentrations in 2021?**
  The measured 2021 annual mean $PM_{2.5}$ concentration in Bogotá was 13.7 µg/m^3, more than twice the Air Quality Guideline recommended by the World Health Organization (WHO).
- **What were the health impacts?**
  It is estimated that long-term exposure to $PM_{2.5}$ in Bogotá contributed to 3,400 premature deaths during 2021.
  Had $PM_{2.5}$ concentrations met the WHO guideline, the number of premature deaths attributable to $PM_{2.5}$ pollution could have been reduced by 64%, saving an estimated 2,200 lives each year.
- **How do deaths from air pollution compare to fatalities from other causes?**
  There are an estimated 3,400 premature deaths attributable to $PM_{2.5}$ exposure in 2021. Per capita, this fatality rate is comparable to that from tobacco smoking and far greater than the fatality rates from intentional homicide or drug use in Colombia.
- **How can air quality in Bogotá be improved?**
  Colombia must commit to improving air quality. Combining strategies that target the largest emitters of fine particulate matter ($PM_{2.5}$), including reducing private vehicle use, industrial source controls, low and zero emission vehicle fleets, and road cleaning systems will help to achieve good air quality in the short and long term.

Contents

Introduction

> *"The global burden of disease associated with air pollution exposure exacts a massive toll on human health worldwide: exposure to air pollution is estimated to cause millions of deaths and lost years of healthy life annually. The burden of disease attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diet and tobacco smoking, and air pollution is now recognized as the single biggest environmental threat to human health."*

The World Health Organization (WHO, 2021)

Not only are the consequences of exposure to air pollution tragic for the individuals affected, but they also have wider implications for our society and the economy. It leads to shortened lives, increased medical costs, and reduced productivity through lost working days (HRAPIE, 2013).

Colombia is a rapidly urbanising country, and as the population of Bogotá grows, the number of people exposed to urban air pollution is increasing. Every year, exposure to air pollution causes millions of premature deaths and the loss of years of healthy life worldwide. Globally, the risk of death posed by air pollution is of similar magnitude to that from unhealthy diets and even smoking (WHO, 2021). Not only are the consequences tragic for the individuals affected, but they also have wider implications for our society and economy. Exposure to air pollution leads to shortened lives, increased medical costs, and reduced productivity through lost working days. Children exposed to air pollution prenatally and early are also more likely to experience adverse health outcomes as adults (WHO, 2018b).

This report uses ground level monitoring data to estimate the number of premature deaths that can be attributed to fine particulate matter air pollution ($PM_{2.5}$, see Box 1). Long-term exposure to $PM_{2.5}$ pollution is considered in Bogotá. Comparison is also made against four major city regions, New York, Delhi, Kuala Lumpur and Seoul.

The principal sources of atmospheric pollution within Bogotá are road transport, the resuspension of dust from unpaved roads, industry, and commercial activities such as restaurants and street vendors (Pachón et al., 2018). Roads in Bogotá are heavily congested; approximately 2.1 million vehicles were registered in Bogotá in 2015, and the number of vehicles is increasing rapidly (Mangones et al. 2020). Air pollutants are also transported into the city from outside, a source that is especially important during the seasons where biomass burning is common (Ballesteros-González et al., 2020; Mendez-Espinosa et al., 2019).

The air pollution problems facing society today are closely linked to the climate crisis through a common cause, the combustion of fossil fuels and unsustainable agricultural practices. The Intergovernmental Panel on Climate Change (IPCC) reported in 2022 that a substantial reduction in fossil fuel use is required to reduce emissions of greenhouse gases and air pollutants, and that because the cost of low-emission energy has dramatically reduced it can now be more costly to maintain emission-intensive infrastructure than to transition to renewable energy (IPCC, 2022).

Box 1: What is $PM_{2.5}$?

Particulate matter (PM) is pollution in the form of small liquid or solid particles suspended in the atmosphere. PM pollution is described according to the size of the particles, rather than the chemicals within them.

$PM_{2.5}$ refers to any particle that is less than 2.5 micrometres across; it is sometimes known as *'fine particulate matter'* or *'fine suspended particles'* (FSP). $PM_{2.5}$ particles are small enough to penetrate deep into the lungs to the gas-exchange region (Morakinyo et al., 2016).

The World Health Organisation (WHO) publishes guidelines for air quality which are designed to protect public health. The WHO Air Quality Guidelines are determined through detailed reviews of the latest scientific research and apply to different air pollutant concentrations over differing averaging periods. In many countries, including Colombia, there are also national air pollution standards. However, in Colombia, the national standards are substantially weaker than the WHO's Air Quality Guidelines (Table 1). The WHO guideline and the current national standards for annual mean concentrations of $PM_{2.5}$ are shown in Table 1.

Table 1: The World Health Organization Air Quality Guidelines and MADS air quality standards for 24-hour and annual average concentrations of $PM_{2.5}$.

	Annual mean $PM_{2.5}$ concentration ($\mu g/m^3$)
National Standard	25
WHO Guideline	5

Source: WHO (2021), MADS (2017)

Methods

The number of premature deaths that can be attributed to long-term $PM_{2.5}$ exposure are estimated using ground-level air quality measurements for 2021. The measured annual average concentrations of $PM_{2.5}$ are combined with population for Bogotá and country-wide public health data for Colombia. Scientific risk models are then applied to these data in order to quantitatively estimate the health costs of exposure to $PM_{2.5}$ air pollution in each location. In addition to the actually measured $PM_{2.5}$ exposure, a further scenario in which the WHO Guideline was attained is examined by the analysis in order to estimate the potential health benefit from improving air quality in Bogotá (Table 2).

This report only assesses premature mortality. Only those causes of mortality where robustly quantifiable relationships with air pollution have been established in the literature and where epidemiological data are available for Colombia in the Global Burden of Disease (GBD, 2019) catalogue are included (Table 3). Many more health impacts can be attributed to $PM_{2.5}$ exposure, including non-lethal health outcomes such as low birth weight (Dadvand et al., 2013), preterm birth (Trasande et al., 2016), increase in asthma symptoms (HRAPIE, 2013), increase in hospital admissions and emergency room visits due to asthma (Zheng et al., 2015), and mental health issues (Braithwaite et al., 2019).

Table 2: Scenarios

Scenario	**Guideline / Standard**	**Description**
A	2021 Actual	Assessment of premature deaths attributable to $PM_{2.5}$ exposure **for measured annual mean $PM_{2.5}$ concentrations during 2021**
B	WHO Guideline	Assessment of premature deaths attributable to annual mean $PM_{2.5}$ exposure **had the WHO Guideline been achieved.**

Ground-level Air Quality Measurements

The analysis uses measured annual and monthly mean $PM_{2.5}$ observations in Bogotá aggregated from 17 monitors distributed across the city by IQAir and published in their *2021 World Air Quality Report* (IQAir, 2021). The data include those from governmental and regulatory monitoring stations, as well as non-regulatory stations operated by individuals, educational institutions, and non-profit organisations.

Monitors operated by non-governmental organisations and individuals underwent quality checks by IQAir before being included in the *2021 World Air Quality Report* (IQAir, 2021). Photo submissions are used to verify that the sensor is in a suitable, sheltered outdoor location. IQAir continuously checks that the carbon-dioxide (CO_2) concentration, humidity and temperature readings reflect outdoor conditions during operation. The data are also screened for outlying data points when compared with neighbouring monitoring stations during IQAir's quality assurance checks (IQAir, private communication).

IQAir uses the median of each individual station within Bogotá to determine an annual mean $PM_{2.5}$ concentration for the city. This provides an approximation of the city-wide annual average $PM_{2.5}$ concentration. The distribution of monitors within the city is not considered and it must be noted that, if the monitors are preferentially located in heavily or lightly polluted areas, the $PM_{2.5}$ concentration calculated may over- or under-estimate the true city-wide average. It has previously been established that governmental monitors in Bogotá are most commonly located away from major pollution sources (Farrow, 2021). Non-governmental monitors are usually located where people live. We therefore assume that data from them are a better approximation of the population's average exposure.

Real-world air pollution datasets are rarely complete. Outages during maintenance and technical faults result in missing data. Data for Bogotá are available for 363 days in 2021 and for 98.7% of all hours of the year.

Health Impact Assessment

Premature deaths resulting from exposure to $PM_{2.5}$ are assessed for the two pollution scenarios listed in Table 2. The following causes of mortality are included: premature mortality from all causes, and a breakdown by a selection of specific causes, namely stroke and other cerebrovascular diseases (CeVD), diabetes, ischaemic heart disease (IHD), lung cancer (LC), lower respiratory infections (LRI) and chronic obstructive pulmonary disease (COPD).

Incidence rates for deaths by these causes for Colombia, and – for comparison – for New York State, India, Malaysia and South Korea are taken from the Global Burden of Disease catalogue (GBD, 2019).

Risk functions are used to estimate the incidence of premature mortality attributable to $PM_{2.5}$ pollution at a given concentration. Table 4 shows the relative risk for a 10 $\mu g/m^3$ increase in annual mean $PM_{2.5}$ concentration. Risk ratios and incidence rates are combined with the population number of each location as recorded by National Administrative Department of Statistics (DANE, 2018) to convert death rates to absolute death numbers per province (see Table 5).

Population data for each of the four reference cities is adopted from IQAir (2021).

The actual incidence N of each cause of mortality is estimated for each province using the location's population P and national (or state, for New York) incidence rate n_a.

$$N = P \times n_a$$

The relative risk RR of each cause of mortality for a given increase in annual mean $PM_{2.5}$ concentration is estimated using the risk ratio r_0 (relative risk at 10 µg/m^3 increase) and pollutant concentration, c.

$$RR = r_0^{(c/c_0)},$$

with c_0=10 µg/m^3. The incidence of each cause of mortality for a hypothetical scenario with completely clean air is estimated by,

$$N_0 = \frac{N}{RR}$$

The incidence attributable to the measured annual mean $PM_{2.5}$ concentration can therefore be calculated by subtracting the actual incidence and that which is estimated to occur in the clean air scenario. To estimate the incidence for Scenario B where WHO Guideline $PM_{2.5}$ concentrations are achieved, c_S, the incidence in clean air, N_s, is related to the relative risk by

$$N_s = N_0 \times \left(r_0^{(c_S/c_0)} - 1\right).$$

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Uncertainty

The premature mortality figures presented here represent useful estimates of the real-world effect of air pollution based on currently available scientific knowledge and data. Like all research, the data and method used contain uncertainty. This uncertainty relates to the precision and representativeness of pollution measurement data, demographic and epidemiological data. Scientific understanding of the relation between exposure to air pollution and the associated risks for health is an active area of research. The estimates account only for long-term exposure to $PM_{2.5}$, and not for other air pollutants which are also known to have negative health impacts.

Pollutants such as nitrogen dioxide (NO_2), ozone (O_3) and sulphur-dioxide (SO_2) typically have poorer data availability than $PM_{2.5}$. Furthermore, health impacts from reactive species such as NO_2 are not included in our results because these pollutants tend to have high spatial variability and thus the data from point measurements are less representative for the whole city.

The uncertainty associated with the risk ratios and background incidence rates are presented in Tables 3 and 4.

Table 3. Relative uncertainties in the background incidence rates **(1/100,000/year)** used in the health impact assessment.

Location	Risk factor	Incidence per 100,000 (95%-confidence interval)					
		central	low	high	downward uncertainty	upward uncertainty	Name of *cause* in GBD (2019)
Colombia	**all causes**	**516**	**414**	**641**	**-20%**	**24%**	***All causes***
	CeVD	35	27	45	-23%	26%	*Stroke*
	Diabetes	15	12	19	-21%	26%	*Diabetes mellitus*
	IHD	87	68	109	-22%	24%	*Ischemic heart disease*
	LC	13	10	17	-22%	27%	*Tracheal, bronchus, and lung cancer*
	LRI	17	13	21	-23%	27%	*Lower respiratory infections*
	COPD	34	25	43	-26%	27%	*Chronic obstructive pulmonary disease*
New York City	**all causes**	**844**	**731**	**963**	**-13%**	**14%**	***All causes***
Delhi		**675**	**606**	**750**	**-10%**	**11%**	
Seoul		**597**	**576**	**618**	**-3%**	**4%**	
Kuala Lumpur		**562**	**463**	**679**	**-18%**	**21%**	

Table 4. Risk ratios (RRs) and their relative uncertainty used for the health impact assessment, for a 10 µg/m3 change in annual average pollutant concentration.

	Value central	Value low	Value high	Source	Downward uncertainty	Upward uncertainty
premature death (all causes)	**1.062**	1.040	1.083	HRAPIE 2013	-35%	34%
premature death (CeVD)	**1.110**	1.050	1.170	Pope 2015	-55%	55%
premature death (diabetes)	**1.130**	1.020	1.260	Pope 2015	-85%	100%
premature death (IHD)	**1.140**	1.100	1.180	Pope 2015	-29%	29%
premature death (LC)	**1.142**	1.057	1.234	Krewski 2009	-60%	65%
premature death (LRI)	**1.120**	1.030	1.300	Mehta 2011	-75%	150%
premature death (COPD)	**1.128**	1.077	1.182	Krewski 2009	-40%	42%

Results

The measured 2021 annual mean $PM_{2.5}$ concentration for Bogotá was 13.7 µg/m^3. While this concentration is within Colombia's National Standard (25 µg/m^3), it is more than twice as high as the health based Air Quality Guideline recommended by the WHO (Table 1).

It is estimated that approximately 3,400 avoidable premature deaths can be attributed to long-term exposure to $PM_{2.5}$ in Bogotá during 2021. The risk of premature death from any cause for the population of Bogotá was estimated to be 9% higher than would be the case if the air were completely free from $PM_{2.5}$.

We estimate that 8% of all premature deaths that occured in 2021 can be attributed to exposure to $PM_{2.5}$ pollution. In particular, 13% of premature deaths from stroke and other cerebrovascular diseases, 15% of premature deaths from diabetes, 16% of premature deaths from both ischaemic heart disease, 17% of premature deaths from lung cancer, 14% of premature deaths from lower respiratory infections and 15% of premature deaths from COPD are attributable to $PM_{2.5}$ air pollution (Table 5).

The Colombian national target of 25 µg/m^3 is 5 times higher than the WHO's Air Quality Guideline for annual mean $PM_{2.5}$ concentration. Bogotá failed to meet the WHO guideline in 2021. Had the city complied with the WHO guideline, this would be expected to have reduced the number of premature deaths attributable to $PM_{2.5}$ pollution to about 1,200 per year, avoiding 64% of the premature deaths and thus saving 2,300 lives each year (Table 5).

Table 5: Results of the Health Impact and Cost Assessment for 2021

	Scenario A	Scenario B	Difference
	Actual	WHO AQG	
premature death (all causes)	**3,364**	**1,196**	**2,168**
premature death (CeVD)	389	136	254
premature death (diabetes)	187	65	123
premature death (IHD)	1,181	407	775
premature death (LC)	182	63	119
premature death (LRI)	196	68	128
premature death (COPD)	429	148	280

Table 6. Various causes of premature deaths in Colombia and Bogotá in deaths per 100,000 people per year.

		Exposed population (millions)	Deaths per year	Rate per 100,000 per year	Source
In Bogota	Scenario A – actual	8.2	3,364	**40.8**	This report
	Scenario B – WHO Guideline	8.2	1,196	**14.5**	
Road accidents in Colombia		48.7	8,987	**18.5**	WHO (2018a)
Tobacco smoking in Colombia		48.7	20,200	**41.5**	Tobacco Atlas (2022)
Drug use in Colombia		48.7	127	**0.3**	GBD (2019)
Intentional homicide in Colombia		48.7	12,309	**25.3**	World Bank (2022)

The mortality rate that can be attributed to long-term $PM_{2.5}$ exposure in Bogotá is 41 deaths per 100,000 people per year. Table 6 puts this into contexts with risk of death from road accidents, drug use or homicide in the Colombian population as a whole. The risk of death posed by $PM_{2.5}$ on someone living in Bogotá is roughly double the rate for road traffic fatalities in Colombia (19/100,000 per year) (WHO, 2018). The risk of death from $PM_{2.5}$ in Bogotá is greater than all of these risks). In fact, the risk of dying from $PM_{2.5}$ air pollution is similar to that posed by tobacco smoking in the Colombian population (see also Figure 1).

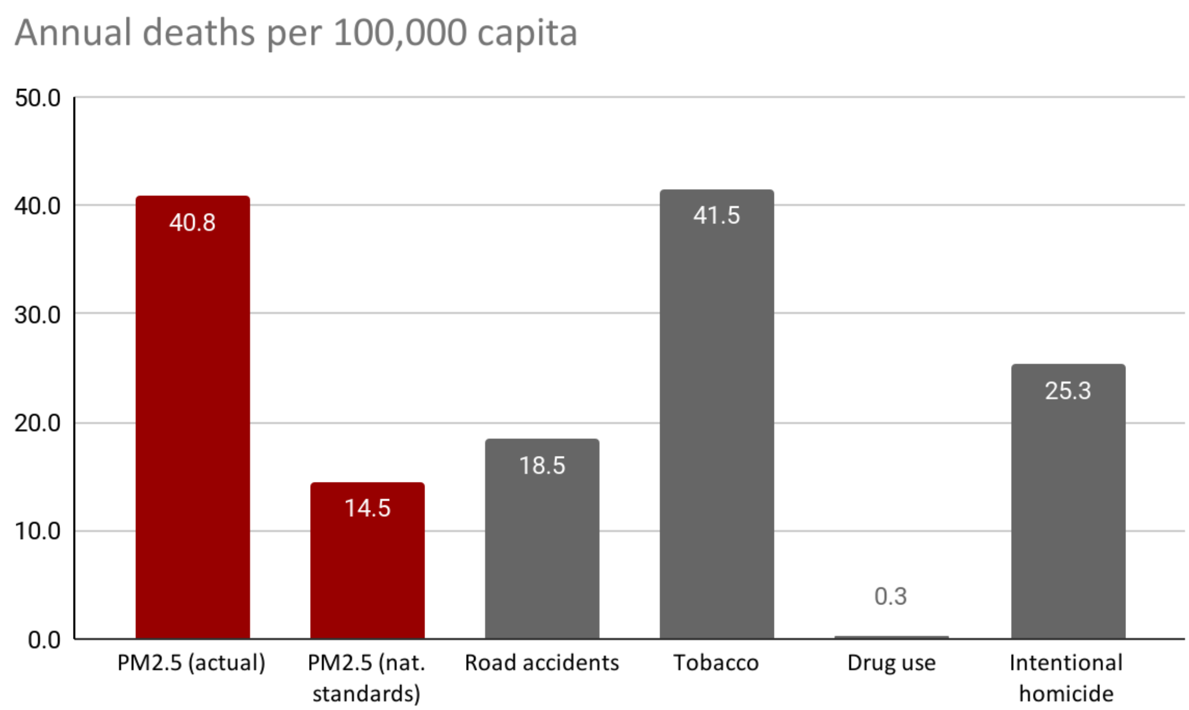

Figure 1: Comparison of deaths per 100,000 people that can be attributed to long-term exposure to $PM_{2.5}$ during 2021 for Scenarios A, and B (red) and other causes (grey).

A comparison of Bogotá with the four major city regions of New York, Delhi, Seoul and Kuala Lumpur reveals that the risk of premature deaths resulting from long-term $PM_{2.5}$ exposure is lower in Bogotá than in Delhi, Seoul and Kuala Lumpur (Table 7). In New York where $PM_{2.5}$ concentrations in 2021 were lower than those measured in Bogotá the risk is also lower.

Table 7. Comparison with World Cities

City	Population	$PM_{2.5}$ ($\mu g/m^3$)	Increased risk of premature death	Premature deaths due to $PM_{2.5}$
Bogotá	8,235,047	**13.7**	+9%	**3,364**
New York City	18,713,220	**10.0**	+6%	**9,217**
Delhi	29,617,000	**96.4**	+79%	**88,010**
Seoul	21,794,000	**19.7**	+13%	**14,533**
Kuala Lumpur	8,285,000	**18.6**	+12%	**4,928**

Conclusion

There has never been more evidence that air pollution affects health, and can do so even at low concentrations (WHO, 2021). The findings of this study demonstrate that action is urgently needed to address the problem of $PM_{2.5}$ pollution in Bogotá and Colombia to protect the health of the population.

This year, the IPCC found with high confidence that measures that reduce greenhouse gas and air pollutant emissions including demand reduction, and low emission transport modes have the potential to deliver both air quality improvements and health benefits whilst also contributing to the mitigation of climate change (IPCC, 2022).

The health burden from air pollution felt today in Bogotá deserves action to reduce pollutant concentrations. Bogotá has an extensive public transport network. Modernization of the public transport vehicle fleet and a transition to cleaner vehicles to reduce air pollutant emissions could significantly reduce air pollution emissions in places where people are exposed. Measures to phase out internal combustion engine vehicles, especially older vehicles that do not meet modern emission standards, will improve air quality throughout the capital and improve people's quality of life. Sustainable urban design can not only be effective in protecting populations against air pollution, but also climate change (IPCC, 2022).

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