AIR QUALITY AND HEALTH IN CITIES

A STATE OF GLOBAL AIR REPORT

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.

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WHAT IS THE STATE OF GLOBAL AIR?

The *State of Global Air* (SoGA) is a research and outreach initiative to provide reliable, meaningful information about air quality around the world. A collaboration of the Health Effects Institute and the Institute for Health Metrics and Evaluation's Global Burden of Disease project, the program gives citizens, journalists, policymakers, and scientists access to high-quality, objective information about air pollution exposure and its health impacts. All data and reports are free and available to the public.

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ABOUT THIS REPORT

This report provides an overview of air pollution levels and associated health impacts in cities around the world. Since urban areas are often hotspots for poor air quality, city-level data can help to inform targeted efforts to curb urban air pollution and improve public health. This report draws on data from the Global Burden of Disease project and from peer-reviewed analyses led by Susan Anenberg of the George Washington University.

WHO IS IT FOR?

The report and website are designed to give practitioners, citizens, journalists, policymakers, and scientists access to information about air pollution exposure and its health effects. These resources are free and available to the public.

HOW CAN I EXPLORE THE DATA?

This report has a companion interactive website with tools to explore, compare, and download data and graphics. Anyone can use the website to access data for more than 7,000 cities and track long-term trends for air pollutants and associated health impacts. Find it at *www.stateofglobalair.org*.

CONTENTS

INTRODUCTION

Air pollution affects us all. Air pollution is responsible for 1 in 9 deaths worldwide and accounts for *6.7 million deaths in 2019* alone. Of these, more than 4 million deaths were linked to exposure to outdoor fine particle pollution worldwide. Breathing polluted air increases a person's risk of heart disease, lung diseases and respiratory infections, type 2 diabetes, and more. Mothers' exposure to air pollution during pregnancy can lead to an increased risk of their infants being born too small or too early. Polluted air has also been linked to asthma and lower respiratory infections among children. Exposure to air pollution also shortens life expectancy. These health impacts lead to missed school and work, chronic illness, and death—harming families, communities, and economies.

Exposure to air pollution is linked to increased hospitalizations, disability, and early death from respiratory diseases, heart disease, stroke, lung cancer, and diabetes, as well as communicable diseases like pneumonia.

The public is increasingly concerned about air pollution. Levels of air pollutants continue to exceed the *Air Quality Guidelines* established by the World Health Organization (WHO). Almost everyone lives in areas where outdoor fine particle pollution concentration exceeds the WHO guideline for healthy air (5 μg/m^3). *More than half of the world's population live in areas that do not even meet WHO's least stringent interim target of 35 μg/m^3.* Some groups of people, including children, pregnant women, the elderly, and people with heart and lung diseases, are more affected by exposure to air pollution than others. Furthermore, poorer communities tend to be exposed to higher concentrations of air pollution, resulting in a greater risk of adverse health effects. As more data become available on both air quality and impacts on health, more people are advocating for improved air quality.

Cities are at the front line for air pollution impacts—and interventions. By 2050, almost 68% of the world's population will be living in cities and breathing urban air. The pace of urbanization is particularly fast in low- and middle-income countries, which brings both challenges from the rapid increase in emissions and opportunities for improving air pollution control through city planning. Cities can take action to control key sources of urban pollution such as traffic, industrial activities, waste burning, the burning of solid fuels like coal and wood in homes, and power plants. However, it is important to note that relocation of pollution sources from within the city to the outskirts is often not a viable solution for improving air quality.

Mayors from more than 45 cities around the world have signed the *C40 Clean Air Accelerator*, making a commitment to provide healthy air for everyone and implement substantive clean air policies by 2025. Addis Ababa (Ethiopia), one of the signatories, is expanding its air pollution monitoring network as well as data on emissions and will develop data-driven policies to address poor air quality. *MORE*.

Data are crucial to informing action at the city level. As cities look to take a leading role in improving air quality, it becomes increasingly important to have reliable city-level data on air quality and health impacts. However, the infrastructure for monitoring air quality at the ground level has not kept pace as cities have expanded. In fact, according to the *2022 WHO Air Quality Database*, 40% percent of countries have no ground-level particulate matter monitors. A *UNICEF report* shows that in Africa only 6% of children, compared to 72% of children across Europe and North America, live near a reliable air quality monitoring station. This leads to critical information gaps and missed opportunities to mitigate air as cities grow. Emerging technologies and satellite-based remote-sensing methods offer new ways for cities to supplement missing ground-based monitoring and to understand patterns of air pollution exposures around the world through space and time. Knowledge of trends in air quality levels can help to inform decision makers as to where policy actions have the most potential to reduce population exposure and provide benefits in improved health. For example, Quezon City (Philippines) has established its own air quality monitoring network including reference-grade and other sensors and is developing an Air Quality Management Plan in 2022-2023.

Cities are at the front line for air pollution impacts and interventions. Thoughtful interventions and investments to improve air quality can bring significant health and economic dividends.

How can this report help? Increasing public awareness of air pollution and its impacts is an essential step in reducing air pollution and improving public health. City residents and leaders need the highest quality scientific information about air pollution trends, sources, and impacts to implement data-driven clean air actions to build a cleaner, healthier future. This report and its companion website provide current, comparable, and comprehensive information on pollutant levels and health impacts in cities throughout the world.

What's in This Report?

This report summarizes data on air pollution exposures and associated health impacts in more than 7,000 cities from 2010 to 2019. In line with the United Nations definition of a city, only cities with a minimum population of 50,000 in 2019 were included in this analysis. Cities are grouped into 21 regions as defined by the Global Burden of Disease project (Figure 1).

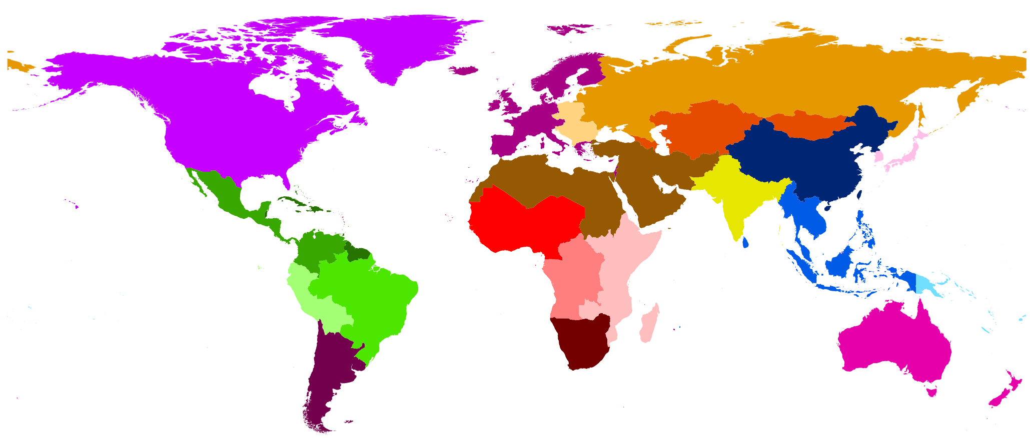
It is important to note that urbanization patterns and populations are not distributed evenly around the world. More than half of the cities in this report are located in just six regions including East Asia (*n* = 1,571), South Asia (*n* = 1,503), North Africa and Middle East (*n* = 628), Western Europe (*n* = 587), and Southeast Asia (*n* = 516) (Figure 1). Full data on 7,239 cities can be found at *www.stateofglobalair.com*, including data on air quality trends from 2000 to 2019. This is the only available source for the most up-to-date estimates of long-term air pollution levels and trends in cities around the world.

Air pollution is a complex mixture of particles and gases emerging from a wide variety of manmade and natural sources. This report considers two main air pollutants found in cities:

- **Ambient (outdoor) fine particle air pollution ($PM_{2.5}$)** is made up of airborne particles measuring 2.5 μm or less in aerodynamic diameter. Anthropogenic (human) sources of $PM_{2.5}$ include household burning, energy production and use, industrial activities, vehicles, and other sources. Exposure to $PM_{2.5}$ can result in cardiovascular (heart), respiratory (lung), and other types of diseases. *MORE*.
- **Nitrogen dioxide (NO_2)** is a gaseous pollutant and a key marker of traffic-related air pollution. NO_2 is particularly abundant in cities and urban areas. NO_2 and other nitrogen oxides can also react with other chemicals in the air to form particulate matter and ozone. Combustion of fossil fuels in vehicles, energy production, and industries is the leading source of NO_2. In cities, vehicles are often a major source of NO_2 and people living close to roads and highways experience higher NO_2 exposures. Exposure to NO_2 can aggravate asthma symptoms and has been linked to the development of asthma in children and adults. There is also considerable evidence supporting the link between long-term exposure to NO_2 and deaths.

This is the first report from the State of Global Air to assess NO_2 exposures globally.

The focus of this report is on long-term exposures to each of these air pollutants — exposures that occur over years and that have been shown by studies to be the strongest determinants of the heavy burden from chronic diseases, which can take several years to develop and persist for a long time. Deaths from six diseases were included to estimate the burden on health associated with $PM_{2.5}$: ischemic heart disease, stroke, lower respiratory infections, lung cancer, type 2 diabetes, and chronic obstructive pulmonary disease (COPD).



High-Income
- Southern Latin America (*N* = 80)
- Western Europe (*N* = 587)
- High-income North America (*N* = 376)
- Australasia (*N* = 35)
- High-income Asia Pacific (*N* = 142)

Latin America/Caribbean
- Caribbean (*N* = 60)
- Central Latin America (*N* = 303)
- Tropical Latin America (*N* = 356)
- Andean Latin America (*N* = 55)

Sub-Saharan Africa
- Southern Sub-Saharan Africa (*N* = 88)
- Western Sub-Saharan Africa (*N* = 233)
- Central Sub-Saharan Africa (*N* = 44)
- Eastern Sub-Saharan Africa (*N* = 175)

North Africa/Middle East
- North Africa and Middle East (*N* = 628)

East Asia/Pacific
- East Asia (*N* = 1,571)
- Southeast Asia (*N* = 516)
- Oceania (*N* = 3)

Eastern Europe/Central Asia
- Central Asia (*N* = 69)
- Eastern Europe (*N* = 282)
- Central Europe (*N* = 133)

South Asia
- South Asia (*N* = 1,503)

FIGURE 1 The 21 regions, as defined by the Global Burden of Disease project, along with the number of cities analyzed in each region.

AMBIENT FINE PARTICLE AIR POLLUTION

Ambient fine particle air pollution, also known as $PM_{2.5}$, is the most consistent and robust predictor of deaths from cardiovascular, respiratory, and other diseases in studies of long-term exposure to air pollution. Learn more about $PM_{2.5}$ and its global health impacts in our *State of Global Air 2020 report*. Long-term exposure to $PM_{2.5}$ was measured as annual average $PM_{2.5}$ concentration in μg/m^3.

Want to know the $PM_{2.5}$ exposure and related disease burden in your city? Explore our *interactive tool*.

PATTERNS IN URBAN $PM_{2.5}$ EXPOSURE

Fine particle pollution does not affect cities around the world evenly. In 2019, $PM_{2.5}$ exposures across 7,239 cities ranged between 0.1 μg/m^3 in Trabzon, Turkey, and 133 μg/m^3 in Jhusi, India, with a global average of 34.6 μg/m^3. On average, South Asia, West Sub-Saharan Africa, and East Asia cities reported $PM_{2.5}$ exposure higher than the least stringent WHO interim target (35 μg/m^3) (Figure 2). We also zoomed in on the five most populous cities in each of the 21 regions (ending with 103 cities as only three cities in Oceania reported a population larger than 50,000 in 2019). Of these cities, the most heavily polluted cities are located in South Asia, East Asia, Southeast Asia, West Sub-Saharan Africa, and Andean and Central Latin America (Figure 3). In the 20 cities with highest $PM_{2.5}$ exposures among these 103 cities, residents in cities from India, Nigeria, Peru, and Bangladesh are exposed to $PM_{2.5}$ levels that are several-fold higher than the global averages (Table 1). Only four of these cities (i.e., Suva, Fuji; Honiara, Solomon Islands; Montevideo, Uruguay; and Havana, Cuba) met the WHO annual $PM_{2.5}$ Air Quality Guideline of 5 μg/m^3 in 2019.

Stagnant progress as residents in many cities still breathe dangerously polluted air.

TABLE 1 Among the most populous cities in each region (*N* = 103), top 20 with the highest population-weighted annual average $PM_{2.5}$ exposures in 2019

Rank	City, Country	Population-weighted $PM_{2.5}$ (μg/m^3)
1	Delhi, India	110
2	Kolkata, India	84.0
3	Kano, Nigeria	83.6
4	Lima, Peru	73.2
5	Dhaka, Bangladesh	71.4
6	Jakarta, Indonesia	67.3
7	Lagos, Nigeria	66.9
8	Karachi, Pakistan	63.6
9	Beijing, China	55.0
10	Accra, Ghana	51.9
11	Chengdu, China	49.9
12	Singapore, Singapore	49.4
13	Abidjan, Côte d'Ivoire	47.4
14	Mumbai, India	45.1
15	Bamako, Mali	44.2
16	Shanghai, China	40.1
17	Dushanbe, Tajikistan	39.7
18	Tashkent, Uzbekistan	38.0
19	Kinshasa, Democratic Republic of the Congo	35.8
20	Cairo, Egypt	34.2

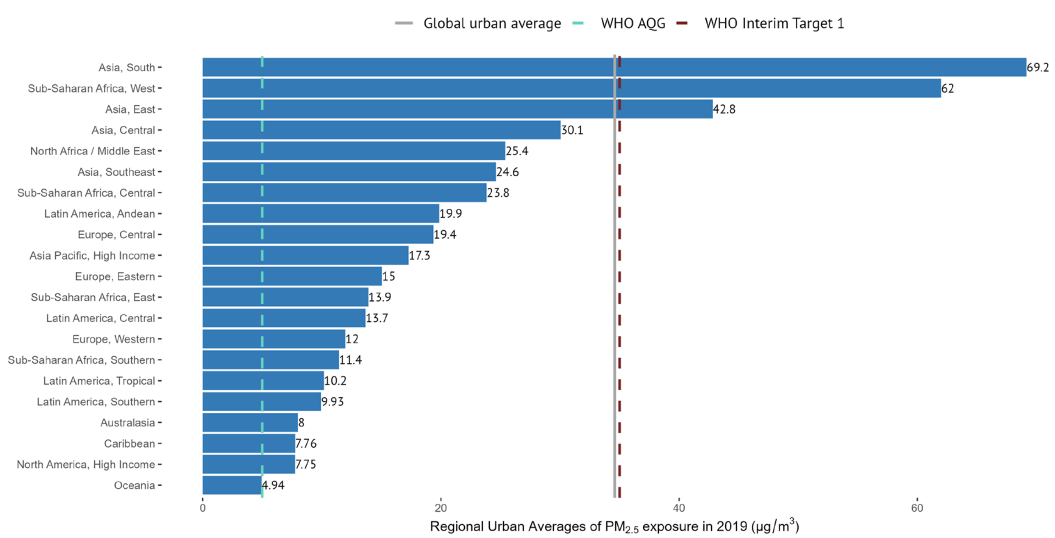


FIGURE 2 Regional urban averages of population-weighted annual average $PM_{2.5}$ concentrations in 2019.

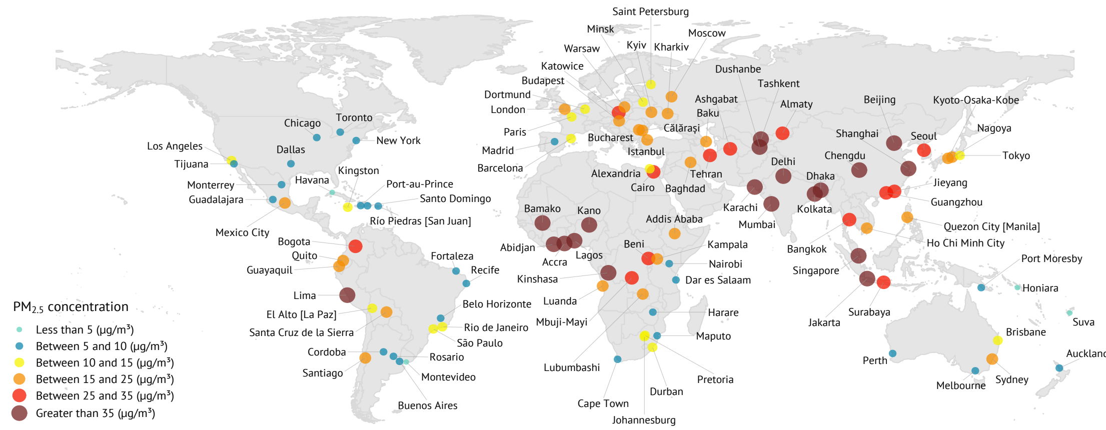


FIGURE 3 Population-weighted annual average $PM_{2.5}$ concentrations in the five most populous cities in each region in 2019 (*N* = 103)*.

*Only 3 cities in Oceania reported population over 50,000 and were included in this report, resulting in 103 cities when using a subset of the 5 most populous cities in each region. *Explore the data for all 7,000 cities on the State of Global Air website.*

TRENDS IN URBAN $PM_{2.5}$ EXPOSURE

Overall, $PM_{2.5}$ exposures have decreased in some cities between 2010 and 2019 but more progress is necessary to protect the health of residents. In 2019, 41% of all analyzed cities still experience $PM_{2.5}$ levels that exceed even the least stringent WHO $PM_{2.5}$ interim target of 35 µg/m³, compared with 43% in 2010 (Figure 4). Although 200 fewer cities were exceeding the least stringent WHO interim target of 35 µg/m³ by the end of that decade, the proportion of cities experiencing this dangerous level of pollution remained very high.

> Exposures are particularly high in cities in Asia, West Sub-Saharan Africa, and Andean and Central Latin America.

India and Indonesia have seen the most severe increase in $PM_{2.5}$ pollution, whereas China has seen the greatest improvements. Of 7,239 cities, India is home to 18 of the 20 cities with the most severe increase in $PM_{2.5}$ pollution from 2010 to 2019. The other two cities are in Indonesia. All these cities saw an increase of more than 30 µg/m³ during that decade. Of the 50 cities with the most severe increase in $PM_{2.5}$, 41 are in India and 9 are in Indonesia. On the other hand, of the 20 cities with the greatest decrease in $PM_{2.5}$ pollution from 2010 to 2019, all are located in China. Air quality has improved in many cities due to the country's considerable efforts to reduce air pollution since 2013 (see *What are Cities Doing to Address Air Pollution?*).

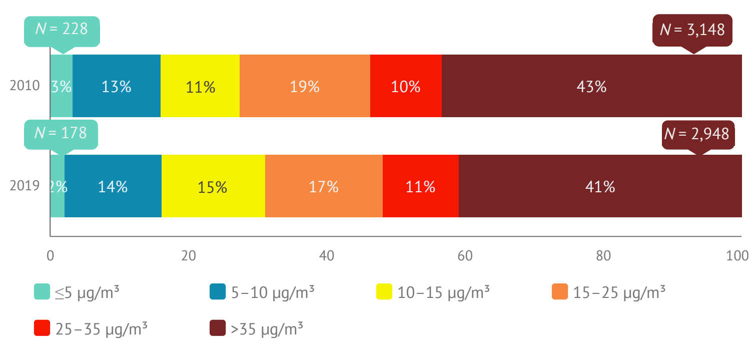


FIGURE 4 Percentage of cities by population-weighted annual average $PM_{2.5}$ concentration in 2010 and 2019 (*N* = 7,239).

Many cities around the world lack local data on air quality. Based on the 2022 WHO Air Quality Database, of the 20 cities with the steepest increases in $PM_{2.5}$ exposures in our data, only two (Satna and Varanasi in India) have an official monitoring station at ground level. This fact points to the need for improved local air quality monitoring infrastructure worldwide. Although data such as those presented here — based on ground monitors, satellite data, and models — can provide valuable insights, local air quality monitoring is important for validating and improving such estimates, tracking impacts of local interventions, and increasing local awareness and engagement.

SOURCES OF $PM_{2.5}$ IN CITIES

The sources of air pollution vary across regions, countries, and even within cities. Common sources in cities around the world include fossil fuel–based energy generation, industrial activities, and transportation. Other common sources of $PM_{2.5}$ pollution in cities in low- and middle-income countries include burning coal and wood for cooking and heating in households, waste burning, and dust from construction sites.

Air pollution in cities comes from both local and regional sources, and the relative importance of these sources can vary from city to city. What the dominant sources of $PM_{2.5}$ are in a given location often depends on the local environment, household practices, and agricultural and industrial activities that occur in the vicinity. Furthermore, the mix and magnitude of the contribution of various sources are changing in response to polices. Some countries restrict activities or emissions to reduce air pollution while others continue or increase their reliance on coal and other major contributors to air pollution. Figure 5 provides examples of major contributors to $PM_{2.5}$ pollution in selected cities. The wide variation between cities underscores the need to account for local context when designing interventions to improve air quality and consider relative contributions to $PM_{2.5}$ from local and regional sources. In most instances, collaborations are needed for tackling regional sources.

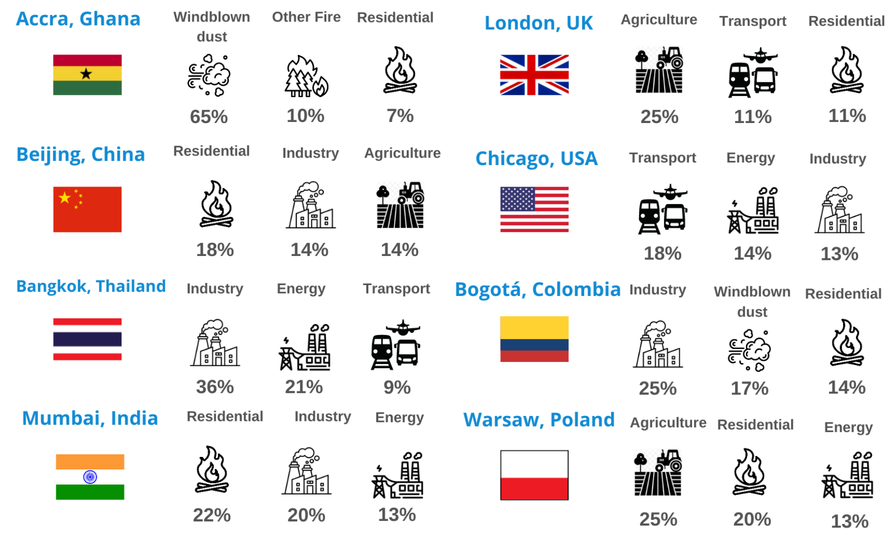


FIGURE 5 Top three contributors (by percentage) to $PM_{2.5}$ levels in selected cities in 2019 (based on data from McDuffie et al. 2021).

In 2019, the global median of $PM_{2.5}$ attributable death rates in cities was 58 deaths per 100,000 people, ranging between zero and 186 deaths per 100,000 people. Fifty cities (e.g., Coatzacoalcos, Mexico and Montego Bay, Jamaica) reported death rates at zero while Plovdiv, Bulgaria reported the highest death rate related to $PM_{2.5}$. More than 1.69 million deaths linked to $PM_{2.5}$ occurred in the 7,239 cities included in the analysis. They account for nearly 41% of global $PM_{2.5}$-attributable deaths for the year 2019, as reported by the GBD 2019 Study. Cities in East Asia (106 deaths/100,000 people), South Asia (86 deaths/100,000 people), Central Asia (78 deaths/100,000 people), Eastern Europe (78 deaths/100,000 people), and Central Europe (77 deaths/100,000 people) saw higher health impacts, which are reflected by higher regional urban median death rates attributable to $PM_{2.5}$ than the global urban median (Figure 6).

DISEASE BURDEN OF $PM_{2.5}$ IN CITIES

Long-term exposure to $PM_{2.5}$ pollution is associated with illness and early death from a variety of diseases including ischemic heart disease, lung cancer, COPD, lower respiratory infections (such as pneumonia), stroke, type 2 diabetes, and adverse birth outcomes. Ambient $PM_{2.5}$ is the largest driver of air pollution's burden of disease worldwide. The patterns of death rates linked to $PM_{2.5}$ discussed here reveal that the disease burden of pollution is far higher in some cities than others. However, the death rates discussed here are not age standardized, therefore differences in death rates across cities are not only linked to $PM_{2.5}$ exposure levels but may also reflect differences in age distributions between cities.

Cities in East, South, and Central Asia and those in Central and Eastern Europe see a disproportionately high disease burden from $PM_{2.5}$ exposures.

Of all cities analyzed, the 20 cities with the highest $PM_{2.5}$-linked death rates in 2019, 15 are in China, 3 are in Ukraine, and 2 are in Bulgaria.

When zooming in to the most populous cities in each region (i.e., a subset of 103 cities across 21 regions), we find that cities in East Asia (Beijing, Chengdu, Shanghai, Guangzhou, and Jieyang in China), South Asia (Delhi, Kolkata, and Mumbai in India; Dhaka, Bangladesh; and Karachi, Pakistan), Southeast Asia (Jakarta and Surabaya, Indonesia), Central Asia (Tashkent, Uzbekistan; Almaty, Kazakhstan; Ashgabat, Turkmenistan; Dushanbe, Tajikistan; Baku, Azerbaijan), Eastern Europe (Kyiv and Kharkiv, Ukraine; Minsk, Belarus; Moscow, Russia), Central Europe (Bucharest and Călărași, Romania; Katowice and Warsaw, Poland; Budapest, Hungary), and North Africa and the Middle East (Cairo, Egypt) saw death rates higher than the global urban median (58 deaths/100,000 people). (See this *interactive map*). Death rates of the 20 populous cities with highest $PM_{2.5}$-related death rates ranged from 77 deaths/100,000 people to 124 deaths/100,000 people (Table 2). Four large cities—Beijing (124 deaths/100,000 people) and Chengdu (118 deaths/100,000 people) in China and Kyiv (114 deaths/100,000 people) and Kharkiv (114 deaths/100,000 people) in Ukraine—experienced more than twice the rate of $PM_{2.5}$ linked deaths compared with the global urban median.

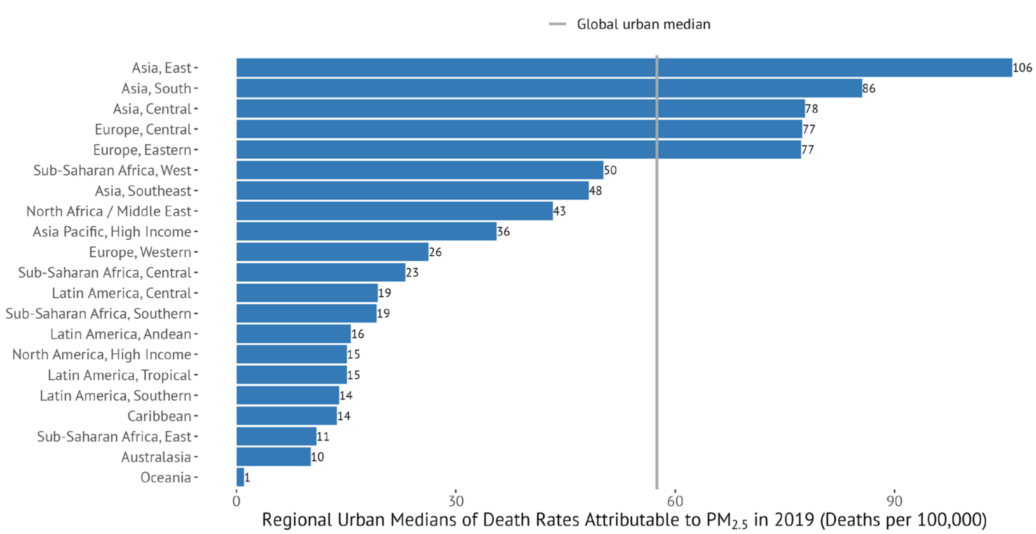


FIGURE 6 Regional urban medians of $PM_{2.5}$ attributable death rates in 2019.

TABLE 2 Among the most populous cities in each region (N = 103), top 20 with the highest $PM_{2.5}$-related disease burden in 2019

Rank	City, Country	$PM_{2.5}$- Attributable Death Rates (deaths/100,000)
1	Beijing, China	124
2	Chengdu, China	118
3	Kyiv, Ukraine	114
4	Kharkiv, Ukraine	114
5	Jakarta, Indonesia	106
6	Delhi, India	106
7	Shanghai, China	105
8	Kolkata, India	99
9	Bucharest, Romania	90
10	Călărași, Romania	90
11	Tashkent, Uzbekistan	90
12	Guangzhou, China	90
13	Almaty, Kazakhstan	86
14	Jieyang, China	86
15	Dhaka, Bangladesh	86
16	Katowice, Poland	85
17	Ashgabat, Turkmenistan	79
18	Budapest, Hungary	78
19	Warsaw, Poland	77
20	Minsk, Belarus	77

The burden on health of $PM_{2.5}$ has grown rapidly in cities in Southeast Asia. Of 7,239 cities analyzed, all the 20 cities with the largest increase in $PM_{2.5}$-attributable death rates from 2010 to 2019 are located in Southeast Asia, including 19 cities in Indonesia and one in Malaysia. All 20 cities reported increases of more than 10 µg/m^3 in $PM_{2.5}$ exposures in 2019 compared with 2010.

In addition to $PM_{2.5}$ exposure, factors such as population aging and change in baseline disease rates are also important factors that drive the changes in death rates related to $PM_{2.5}$. Even if exposures to air pollution are decreasing, the overall attributable burden of disease can increase if a population is growing faster than exposures are falling. Similarly, a population that is aging will likely face a higher burden of disease because older people are more susceptible to diseases linked with air pollution. When looking at the 20 cities with the greatest decrease in $PM_{2.5}$-attributable death rates from 2010 to 2019 (all in Russia), the main driver was the lower baseline disease rate in 2019 rather than the change in $PM_{2.5}$ concentrations.

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Obilić power plant in Pristina, Kosovo

What are Cities Doing to Address Air Pollution?

Five initiatives illustrate the value of designing air quality interventions in ways that are responsive to local context:

Bidya Banmali Pradhan (ICIMOD, Nepal)

Brick kilns are an important source of outdoor $PM_{2.5}$ and other pollutants across South Asia. In Nepal, a tragic earthquake in 2015 offered an unexpected opportunity. The earthquake damaged nearly half of the country's brick kilns. To help the brick industry "build back better," local entrepreneurs teamed up with experts to help build more efficient, less-polluting kilns using zig-zag technology. The approach, which reduces coal consumption, particulate matter, and dust exposure, is now being expanded across South Asia. For details, watch this short *video*.

A brick kiln in Nepal

Unsplash

In China, following the launch of the National Air Quality Action in 2013, Beijing along with Tianjin and the Hebei province implemented a series of city and regional action plans between 2013 and 2017. These plans promoted end-of-pipe controls and cleaner energy structures to reduce emissions from coal-fired power plants and industries, while also setting stringent vehicle emission and fuel quality standards to curb traffic-related pollution. To monitor progress, Beijing expanded its air monitoring system from 35 monitoring stations in 2013 to more than 1,000 in 2019. These monitoring stations documented a 36% drop in the city's annual average $PM_{2.5}$ level in just five years. Meanwhile, the Beijing-Tianjin-Hebei region saw a 25% reduction in their annual average $PM_{2.5}$ level. *MORE*.

Beijing, China

Unsplash

In 2018, Ghana's Environmental Protection Agency launched a detailed air quality management plan for the capital city, Accra, where windblown dust and activities such as traffic and e-waste burning contribute to poor air quality. The plan emphasizes expanded air quality monitoring capacity along with new emissions standards and a public campaign to improve public awareness of air quality challenges and solutions. Accra was also the first African city to join the BreatheLife campaign led by the WHO, the United Nations Environment Programme, and the Climate & Clean Air Coalition. *MORE.*

Accra, Ghana

AirQo

AirQo was launched in 2015 at Makerere University with the goal of addressing the data gap on air quality in Uganda and across Sub-Saharan Africa. The team uses a combination of ground monitoring data and machine learning techniques to build air pollution datasets. They have also installed a network of low-cost monitors across Uganda with plans to expand to 10 other cities across 5 countries in Africa. Since the launch, the team has continuously expanded access to air quality data in Uganda through a web-based data platform and a mobile app that allow users to access real-time data as well as historical information on air quality. They collaborate with local and international researchers as well as decision-makers to inform interventions on air pollution. *MORE*.

AirQo collaboration with NEMA in Uganda

Pixabay

Based on data from the *Plan de descontaminación del Aire para Bogotá (PDDAB)*, Bogotá has reported a 20% reduction in the levels of particulate matter (PDDAB, 2020). The air quality protection policy in the city has expanded and been enforced, making air quality a responsibility of all city residents. Through the Air Quality Plan, 45 projects have been established aiming to reduce air pollutant levels, including a public information system, citizen science initiatives, and periodic air quality reports and real-time reporting of air quality data. The plan utilizes data reported by the Air Quality Monitoring Network, the Atmospheric Modelling System, and the annual emissions inventories of criteria air pollutants.

City view of Bogotá, Colombia

AMBIENT NITROGEN DIOXIDE POLLUTION

NO_2 is a common gaseous air pollutant in urban areas. It belongs to a group of highly reactive gases known as nitrogen oxides (NO_x) and is often used as an indicator for this group and for the broader traffic related air pollution mixture. Due to their highly reactive nature, nitrogen oxides also contribute to the formation of other pollutants, including ozone and particulate matter. NO_2 is mainly generated through the burning of fuel in vehicles, power plants, and industrial facilities. As city residents tend to live closer to busy roads with dense traffic, they are often exposed to higher NO_2 pollution than residents of rural areas. NO_2 also has a shorter lifetime compared with $PM_{2.5}$ and other air pollutants. As a result, NO_2 levels show very high variability in space and time — levels can vary significantly even across a few kilometers within the city. In comparison, $PM_{2.5}$ levels tend to show less spatial variation at the fine scale. As such, strategies for air quality management at the local (i.e., city) and regional scales can vary for different pollutants, and cities often have a better ability to control sources of NO_2, especially traffic.

A large body of scientific literature has linked NO_2 pollution with health effects. Inhaling high levels of NO_2 in a short time can irritate the airways and aggravate existing respiratory diseases. For people with asthma, NO_2 exposure has been associated with more frequent and severe symptoms and a greater risk of hospitalization. Other studies suggest that exposure to NO_2 pollution can impair lung development, intensify allergies, make people more susceptible to respiratory infections, and increase the likelihood that a child will develop asthma. Although NO_2 may not be the main or only driver of these health impacts, it is considered to be a good proxy for exposure to traffic-related air pollution and is a pollutant that most strongly represents trends in traffic exposures. A recent comprehensive review from the Health Effects Institute (HEI) found a high level of confidence that strong connections exist between traffic-related air pollution and early death due to cardiovascular diseases. A strong link was also found between traffic-related air pollution and lung cancer mortality, asthma onset in children and adults, and acute lower respiratory infections in children.

NO_2 pollution is universally high in populous cities across regions and highlights different hotspots than hotspots of fine particle pollution.

Long-term exposure to NO_2 was originally estimated as annual average NO_2 concentration in parts per billion. For the comparison with WHO guideline values, exposure levels were converted to μg/m^3 under the assumption of a standard pressure of one atmosphere and 25° C.

PATTERNS IN URBAN NO_2 EXPOSURE

In 2019, the global average NO_2 exposure was 15.5 μg/m^3, but exposure levels varied considerably across cities (ranging between 0 and 68.9 μg/m^3). The highest exposure for NO_2 was seen in Beirut, Lebanon, and the lowest exposure was seen in São Tomé, São Tomé and Príncipe.

Geographic patterns of NO_2 pollution are strikingly different from the patterns seen for $PM_{2.5}$ pollution. $PM_{2.5}$ pollution tends to be highest in cities in low- and middle-income countries, whereas NO_2 levels are high in large cities across countries of all income levels (Figure 7). Almost all of the most populous cities across all 21 regions (81 out of 103 cities) reported NO_2 exposures higher than the global average of 15.5 μg/m^3; the only exceptions were cities in Oceania, Australia, and Central and East Sub-Saharan Africa (Figure 8). The populous cities that reported the highest NO_2 pollution were spread across different regions in the world (Table 3).

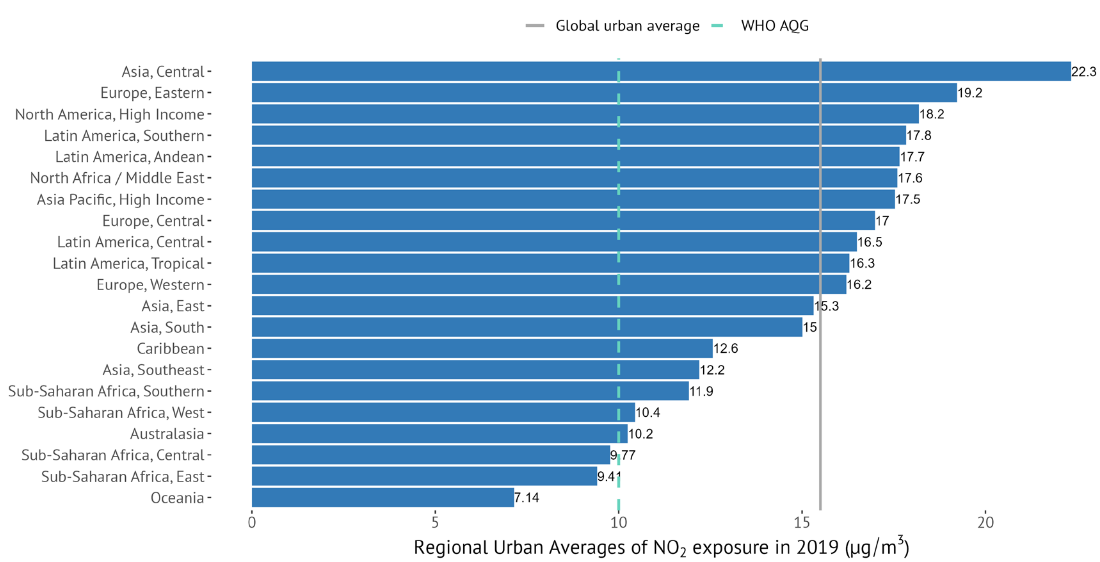

FIGURE 7 Regional urban averages of population-weighted annual average NO_2 concentrations in 2019.

TABLE 3 Among the most populous cities in each region (N = 103), top 20 cities with the highest population-weighted annual average NO_2 exposures in 2019

Rank	City, Country	Population-Weighted NO_2 (µg/m³)
1	Shanghai, China	41.6
2	Moscow, Russia	40.2
3	Tehran, Iran	39.8
4	Saint Petersburg, Russia	38.3
5	Beijing, China	37.7
6	Cairo, Egypt	37.5
7	Ashgabat, Turkmenistan	36.8
8	Minsk, Belarus	36.8
9	Istanbul, Turkey	35.3
10	Ho Chi Minh City, Vietnam	34.7
11	Dushanbe, Tajikistan	34.4
12	Seoul, Republic of Korea	33.4
13	Lima, Peru	31.6
14	Paris, France	31.6
15	Santiago, Chile	31.2
16	Tashkent, Uzbekistan	30.4
17	Baghdad, Iraq	28.8
18	Chengdu, China	28.4
19	Alexandria, Egypt	28.1
20	Bucharest, Romania	26.9

As a result of targeted actions to improve air quality, NO_2 exposures have been decreasing in many cities, particularly in high-income regions and in East Asia. However, NO_2 pollution is worsening in other regions.

Tracking NO_2 exposures also draws attention to urban air pollution concerns in regions that are not necessarily $PM_{2.5}$ hotspots. Many cities in high-income countries in North America (e.g., Winnipeg, Canada and Fargo, United States), Asia Pacific (e.g., Seoul, South Korea and Asahikawa, Japan), and Western Europe (e.g., Paris, France and Albacete, Spain), as well as in Eastern Europe (e.g., Moscow, Russia and Minsk, Belarus) experience high NO_2 exposures. Notably, NO_2 exposures in some cities in North Africa and Middle East (e.g., Beirut, Lebanon and Basra, Iraq), Latin America (e.g., Corumbá, Brazil and Arequipa, Peru), and Central Asia (e.g., Bishkek, Kyrgyzstan and Namangan, Uzbekistan) are high and continuing to increase.

TRENDS IN URBAN NO_2 EXPOSURE

Globally, NO_2 exposures are heading in an encouraging direction as 211 more cities met the WHO guideline in 2019 as compared with 2010. However, 86% of 7,239 cities still exceeded the WHO guideline for healthy air in terms of NO_2 (10 µg/m³) in 2019 (Figure 9). This percentage equates to about 2.6 billion people, almost 94% of all people living in cities included in this report. Four cities—Beirut, Lebanon; Shenyang, China; Shanghai, China; and Moscow, Russia, collectively home to over 53 million people—had NO_2 levels exceeding even the least stringent WHO interim target of 40 µg/m³. Of the cities that met WHO guidelines for NO_2, most are located along coastlines and have weather conditions that may help to disperse NO_2 pollution (e.g., Suva, Fiji; Karangasem, Indonesia; and Mtwapa, Kenya).

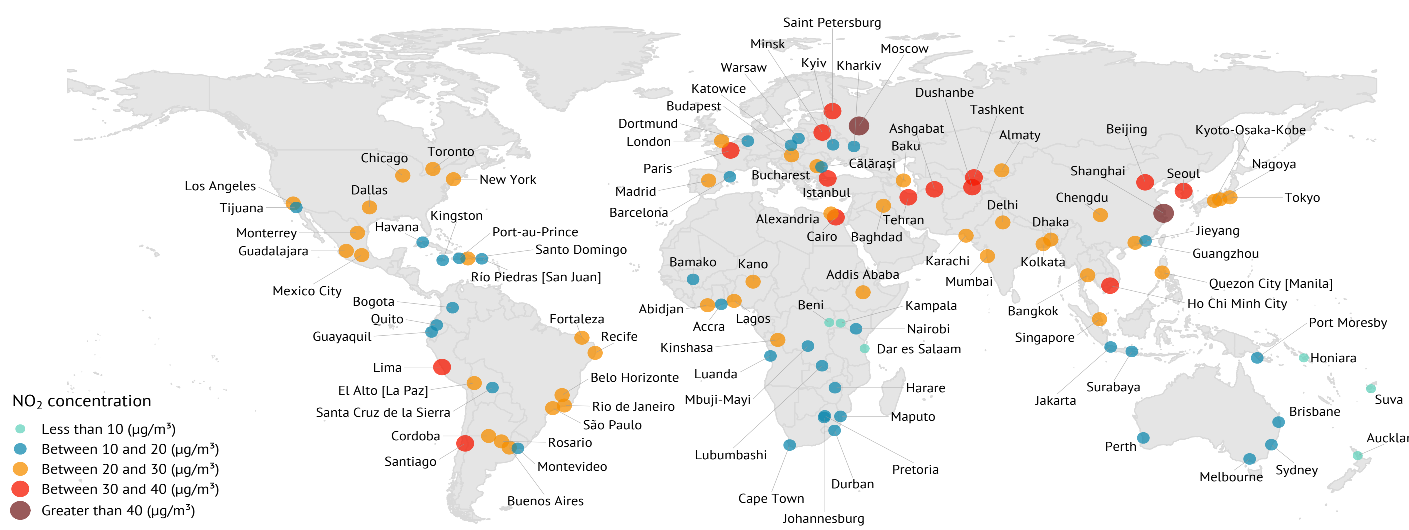

FIGURE 8 Population-weighted annual average NO_2 concentrations in the five most populous cities of each region in 2019.

NOTE: Current WHO guideline for the annual average concentration of NO_2 is 10 µg/m³. Global urban average concentration is 15.5 µg/m³.

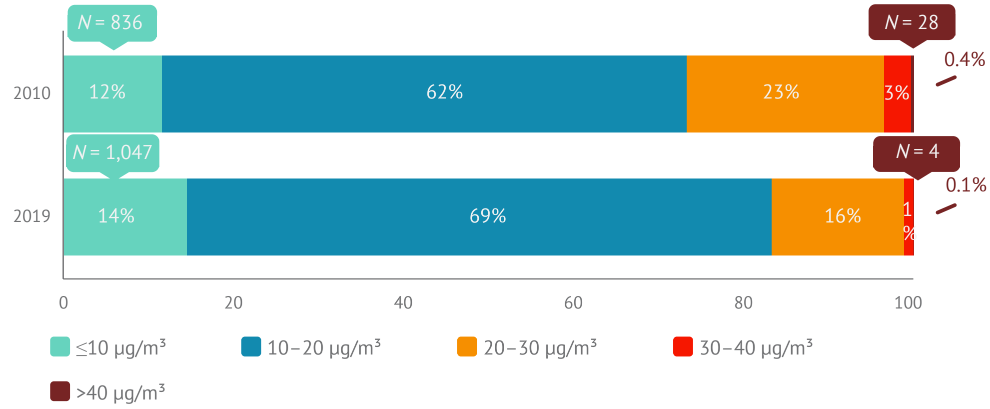

FIGURE 9 Percentage of cities by population-weighted annual average NO_2 concentration in 2010 and 2019 (*N* = 7,239).

Many cities, especially those in high-income countries, are reaping rewards for their efforts to improve air quality through traffic control interventions. For instance, London's Ultra Low Emission Zone initiative delivered a 36% reduction in NO_2 in the first six months after its launch in 2019.

Of the 20 cities with the largest decrease in NO_2 exposure between 2010 to 2019, 18 are located in China. The other two are in the United States (Los Angeles) and Japan (Tokyo). Cities seeing the largest increase in NO_2 exposures during this period include cities in low- and middle-income countries in North Africa and the Middle East, South Asia, Southeast Asia, and Latin America.

Ground-based monitoring stations for NO_2 are even more scarce than those for $PM_{2.5}$, especially in low- and middle-income countries. For example, the 2022 WHO Air Quality Database revealed that only 74 countries have official ground-based monitoring stations for NO_2 while 117 countries have monitoring stations for $PM_{2.5}$ and PM_{10}. Among the 20 cities experiencing the largest increase in NO_2 levels between 2010 and 2019, only 5 have an official air quality monitoring station, and only 3 of them measured NO_2.

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Mumbai, India

CONCLUSIONS

The United Nations estimates that two-thirds of the world's population will live in cities by 2050, with much of the growth in urban populations concentrated in Asia and Africa. Many large cities already experience far greater levels of air pollution than rural areas, and cities in Asia and Africa are already hotspots for $PM_{2.5}$ pollution. At the same time, NO_2 pollution — primarily from vehicle traffic — is high and growing in some cities and regions that are not $PM_{2.5}$ hotspots. Although the drivers and impacts of different types of air pollution vary from place to place, the dispiriting truth is that most people living in cities today are breathing unhealthy air. The toll of this reality is reflected in millions of deaths linked to air pollution each year, along with a heavy burden of chronic illness and disability among both children and adults.

In response, cities around the world are beginning to lead with action to curb air pollution. The good news is that a wide range of cost-effective solutions are already available to reduce pollution from many key pollution sources. These include promoting green and sustainable transportation, expanding access to clean energy for household use, shifting to clean and efficient energy production, including non-fossil fuel–based sources, and more. These solutions have the potential to both improve public health and slow climate change, and they are becoming increasingly affordable, accessible, and feasible in countries around the world. It is also crucial that planned interventions and policies include collaborative engagement across governments, researchers, civil society, and other interested parties.

City dwellers know that every city is unique. By leveraging evidence-based actions that are tailored to the local context, it is possible to create cleaner air for the world's growing urban populations.

How Can We Make Progress?

Leverage the expanding air quality monitoring toolbox: In many cities, the density of air monitors is inadequate to effectively track key pollutants that are relevant to public health. There still are vast areas, particularly in Asia and Africa, with no air quality monitoring networks. Although satellite-derived estimates can help fill in some of the data gaps, efforts to expand ground monitoring of air quality can improve the accuracy of these estimates and our understanding of local air quality trends. In addition to reference monitors, which can be expensive to install and operate, cities are now beginning to use low- and medium-cost sensors for collecting and reporting data on air quality. However, in addition to setting up monitors, it is important to invest in resources for calibration and maintenance to ensure the quality of data from these monitors.

Collect and digitize health records: Data on the burden of air pollution on health are vital for assessing the effectiveness of interventions, both in terms of public health benefits and economic impact. Analyses such as this one rely on information on disease rates and demographic characteristics. In the absence of city-level information, studies often use national disease rates. However, both population structures and disease patterns at the city level can be different from national averages. Looking ahead, it is important to collect city-level health data consistently and systematically and making them accessible to researchers. This can help researchers conduct more accurate and local analyses that inform communities and policymakers.

Start with our data: To help increase the adoption of these technologies and inform other strategies for reducing air pollution, cities need commitment, resources, and data. Our online *interactive app* includes trends of air pollution and related burdens on health for more than 7,000 cities worldwide. Using this tool, you can learn about air quality in your city, how it is changing, and burdens associated with air pollution.

Finally, available air quality data can already be used to inform decisions and policies aimed at improving air quality.

How Did We Estimate These Data?

How We Estimate Air Pollution Exposures

Particulate matter concentrations are measured in micrograms of particulate matter per cubic meter of air, or μg/m³. Ground monitoring of air quality remains limited in many regions of the world, particularly in low- and middle-income countries. To fill the data gaps and to provide a consistent view of air pollution levels in cities around the world, researchers combine data from different sources including ground monitoring and satellite data.

The scientific team systematically estimated annual average concentrations of $PM_{2.5}$ and NO_2 across the entire globe, which was divided into grid cells, each covering 0.0083° × 0.0083°of longitude and latitude (approximately 1 × 1 kilometers at the equator). They then used information from all grid cells within a city boundary to estimate the $PM_{2.5}$ concentration in a specific city.

To estimate the annual average $PM_{2.5}$ and NO_2 exposures (that is, the concentrations that a population in a specific city is more likely to be exposed to in one year), the team linked the concentrations in each grid cell with the number of people living within each block to produce a population-weighted annual average concentration. Population-weighted annual average concentrations are better estimates of population exposures than, for example, simple averages across monitors because they give greater weight to the pollutant concentrations experienced where most people live.

Because these population-weighted air pollutant concentrations represent annual averages across an entire city, they include, but do not represent, the considerably higher concentrations that may be observed day to day or in certain seasons, especially around major pollution sources. Satellite-derived data are more reliable in estimating long-term than short-term trends. Although short-term exposure spikes can affect health, it is long-term exposures that contribute most to the burden of disease and mortality from air pollution and therefore are the focus of this report.

Type of Data	NO_2	$PM_{2.5}$
Ground measurements	5,220 air quality monitors across 58 countries	3,787 air quality monitors across 63 countries
Satellite data	✓	✓
Global chemical transport models that use data on emissions, chemical reactions, and meteorological conditions to estimate the movement and concentration of pollutants	✓	✓
Other data	Land use characteristics such as vegetation and road networks	

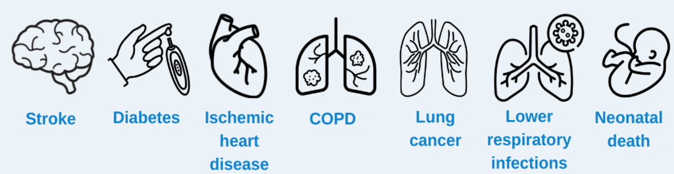
How Accurate Are These Estimates?

Extensive comparisons between these satellite-derived estimates and ground-level measurements demonstrate that they are reasonably accurate. They can be reliable indicators of $PM_{2.5}$ and NO_2 exposures where ground monitors do not exist or data are not publicly available.

However, it is important to note that the accuracy and certainty of the exposure estimates vary by region. Since ground measurements are incorporated in the model, estimates are less reliable for regions with fewer or no air monitoring stations (e.g., cities in Africa and Asia). In addition, estimates for coastal cities and cities with persistent snow or cloud cover also have higher uncertainty due to limited satellite coverage. Over time, more systematic and detailed data on emissions and traffic at the city level, as well as ground-level air quality data, can help improve the accuracy of the estimates.

How Burden of Disease Is Estimated

The scientific team calculated the disease burden associated with $PM_{2.5}$ exposures in cities using a rigorous method in line with the 2019 Global Burden of Disease study. Deaths from six diseases were included to estimate the burden on health associated with $PM_{2.5}$: ischemic heart disease, stroke, lower respiratory infections, lung cancer, type 2 diabetes, and chronic obstructive pulmonary disease (COPD). Of note, impacts on infant health were not estimated in this analysis.



To calculate $PM_{2.5}$ associated burden of disease in each city, the team combined the following:

- Mathematical functions, derived from epidemiological studies, that relate different levels of $PM_{2.5}$ to the increased risk of death from each cause, by age and sex, where applicable
- Estimates of population exposure to $PM_{2.5}$
- Country-specific data on underlying rates of disease and death for each pollution-linked disease (as city level data are not available for the majority of cities)
- Population size and demographic data

The results of these calculations are expressed for the population in every city in two ways:

Total number of deaths:

The number of deaths in a given year linked to $PM_{2.5}$ that likely occurred earlier than would be expected in the absence of air pollution.

Death rates:

The total number of deaths per 100,000 people. Note that these death rates were not age-standardized.

Continued

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Estimates of scientific uncertainty are provided for every value in the form of 95% uncertainty intervals (UIs), representing the range between the 2.5th and 97.5th percentiles of the distribution of estimated values.

How Can the Burden Estimates Be Improved?

The burden estimates can be improved further as more city-level data become available. For this analysis, national baseline disease rates were used as a proxy for cities of a specific country because city-level data is mostly not available. The country-level age distributions were also applied to cities directly. However, cities may have disease patterns and demographic profiles that are different from the national averages. Although comparisons have shown that estimates using country-level and city-level data are broadly in line with each other, using city-level disease rates and demographic data can certainly enhance the results. Moreover, fine particle pollution affects human health beyond deaths. Including data on other mortality and morbidity outcomes such as neonatal health outcomes and childhood asthma can lead to more representative estimates.

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Accra, Ghana

ABBREVIATIONS

AQG	air quality guidelines
COPD	chronic obstructive pulmonary disease
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
$PM_{2.5}$	particulate matter ≤2.5 μm in aerodynamic diameter
μg/m^3	micrograms per cubic meter
UI	uncertainty interval
WHO	World Health Organization

Pixabay

Bangkok, Thailand

KEY RESOURCES

METHODS

These references provide background details on the methods used to estimate $PM_{2.5}$ and NO_2 exposures and to estimate the burden reported here.

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The exposure estimates included in the analysis and State of Global Air incorporate city-level measurement data reported by countries to the World Health Organization and Open AQ, among many other sources. Explore, visualize, and download city-level data from the WHO Ambient Air Quality database and OpenAQ.

HEALTH EFFECTS OF AIR POLLUTION

For scientific evidence and perspectives on the health effects associated with exposures to $PM_{2.5}$ and NO_2, please see the following publications:

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Unsplash

Street view of Beijing, China