STATE OF GLOBAL AIR /2019

A SPECIAL REPORT ON GLOBAL EXPOSURE TO AIR POLLUTION AND ITS DISEASE BURDEN

HEI

IHME

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What is the State of Global Air?

The State of Global Air report brings into one place the latest information on air quality and health for countries around the globe. It is produced annually by the Health Effects Institute and the Institute for Health Metrics and Evaluation's Global Burden of Disease project as a source of objective, peer-reviewed air quality data and analysis.

Like previous reports, this year's publication presents information on outdoor and household air pollution and on the health impacts of exposure to air pollution. For the first time, the report also explores how air pollution affects life expectancy.

Who is it for?

The report is designed to give citizens, journalists, policy makers, and scientists access to reliable, meaningful information about air pollution exposure and its health effects. The report is free and available to the public.

How can I explore the data?

This report has a companion interactive website that provides tools to explore, compare, and download data and graphics with the latest air pollution levels and associated burden of disease. Anyone can use the website to access data for 195 individual countries or territories and their related regions, as well as track trends from 1990 to 2017. Find it at stateofglobalair.org/data.

Where will I find information on:

INTRODUCTION

Our health is strongly influenced by the air we breathe. Poor air quality causes people to die younger as a result of cardiovascular and respiratory diseases, and also exacerbates chronic diseases such as asthma, causing people to miss school or work and eroding quality of life.

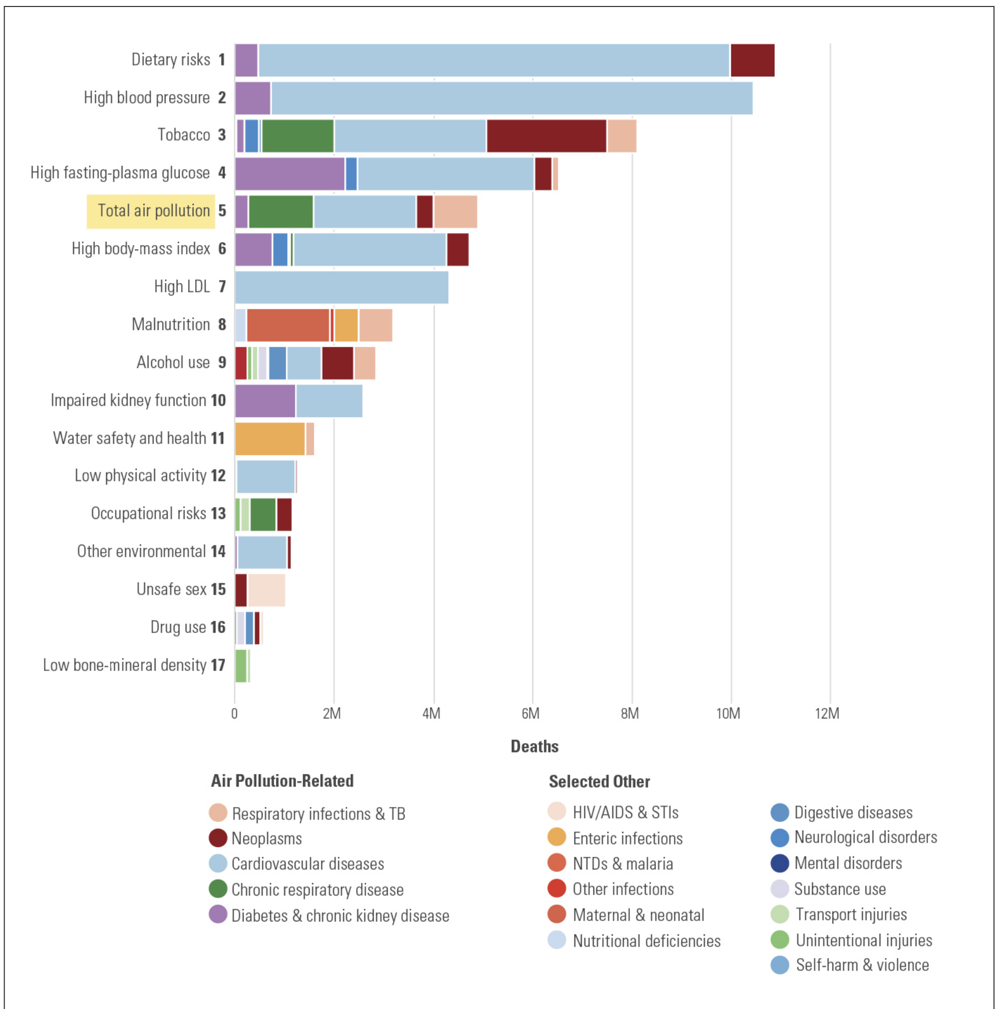
Air pollution affects the young and the old, the rich and the poor, and people in all areas of the globe. Research over the past several decades has revealed a multitude of ways in which poor air quality affects our health and quality of life, and scientists continue to learn more. Studies have also continued to illuminate the causes of air pollution, helping us understand why air quality is worse in some places and better in others.

Air pollution is the fifth leading risk factor for mortality worldwide. It is responsible for more deaths than many better-known risk factors such as malnutrition, alcohol use, and physical inactivity. Each year, more people die from air pollution–related disease than from road traffic injuries or malaria.

This publication, the third annual State of Global Air report, presents the latest information on worldwide air pollution exposures and health impacts. It draws from the most recent evidence produced as part of the Global Burden of Disease (GBD) project of the Institute for Health Metrics and Evaluation (IHME) (see textbox "Improving Global Burden of Disease Estimates with New and Better Data"). The State of Global Air report is produced by the Health Effects Institute (HEI).

Building on previous State of Global Air reports, this publication offers a global update on outdoor (ambient) air pollution and on household air pollution from use of solid fuels for cooking. To track outdoor air quality, the report focuses on the concentrations of two pollutants in particular: fine particle air pollution (particulate matter measuring less than 2.5 micrometers in aerodynamic diameter, or $PM_{2.5}$) and ozone found near ground level (tropospheric ozone). This assessment also tracks exposure to household air pollution from burning fuels such as coal, wood, or biomass for cooking. These forms of air pollution are considered key indicators of

Figure 1. Global ranking of risk factors by total number of deaths from all causes for all ages and both sexes in 2017.



Explore the rankings further at the IHME/GBD Compare site.

air quality, and each contributes to the collective impact of air pollution on human health.

Air pollution consistently ranks among the top risk factors for death and disability worldwide. Breathing polluted air has long been recognized as increasing a person's chances of developing heart disease, chronic respiratory diseases, lung infections, and cancer. In 2017, air pollution was the fifth highest mortality risk factor globally and was associated with about 4.9 million deaths and 147 million years of healthy life lost (Figure 1). This report summarizes the latest evidence on the health impacts of air pollution and discusses how these health impacts affect how long, and how well, people live.

WHAT'S NEW THIS YEAR?

- *Assessing impacts on life expectancy.* Life expectancy — a measure of how long a person can expect to live — has always been an important indicator of the health of a society. This year, the State of Global Air features an analysis of how much air pollution reduces life expectancy in countries around the world.
- *Accounting for risks from type 2 diabetes.* In light of recent evidence indicating that air pollution contributes to development of type 2 diabetes, this year's assessment includes estimates of the related health burden.

IMPROVING GLOBAL BURDEN OF DISEASE ESTIMATES WITH NEW AND BETTER DATA: ANNUAL UPDATES

Despite some differences, the estimates of air pollution health burden from multiple analyses consistently show that air pollution has a large impact on population health.

As the science continues to advance, the GBD project has incorporated new data and methodology into its air pollution and health assessments. This year's State of Global Air report presents updated information for all of the indicators addressed in previous reports.

While new methodology may result in differences between assessments from previous years, trends over time are recalculated with each update to ensure the findings are internally consistent within each report. These updates help ensure that each assessment provides the most accurate information available based on rigorous scientific methods:

- *Eliminating double counting.* This year's report analyzes the burden of disease from ambient air pollution independently from that of household air pollution. Past estimates had the potential for some double counting of the disease burden in populations exposed to both ambient and household air pollution.
- *New methods for analyzing health impacts from exposures.* The mathematical methods for analyzing how exposure to pollution relates to specific health risks (known as *exposure–response functions*) have been updated. The new methods reflect data from recent epidemiological studies on the impacts of ambient $PM_{2.5}$, household air pollution and secondhand smoke and from updated literature reviews on the impacts of active smoking.
- *New methods for assessing ozone.* The method for estimating ozone concentrations has been revised, incorporating for the first time an extensive database of ground-level ozone measurements. In addition, the ozone exposure metric was changed to an 8-hour daily maximum level to align with more recent epidemiological analyses.
- *Inclusion of more $PM_{2.5}$ measurements.* The database of ground measurements of $PM_{2.5}$ has been expanded from approximately 6,000 to 9,960 sites. Including more measurements in the models used to calibrate satellite-based estimates results in finer-grained estimates of $PM_{2.5}$ concentrations that vary more smoothly and realistically over space and time. In addition, estimates of $PM_{2.5}$ exposure now directly incorporate uncertainty distributions from the calibration model.

Of these changes, those related to eliminating double counting and the updating of exposure–response functions have the largest impact on the disease burden estimates. For more information about these changes, please refer to the Additional Resources.

Other groups have estimated the burden of air pollution on human health as concern over air pollution has grown. Most notably, the World Health Organization (WHO) has long made its own periodic estimates, with the most recent analysis (of 2016 data) released in early 2018. IHME, the primary source of information for this report, is the only organization that updates its estimates annually; its methods are increasingly being adopted by others, including the WHO. Given the complexity of the process for developing these estimates, some variation is not surprising. However, as the methods used by different organizations converge, this variability is expected to diminish.

EXPOSURE TO AIR POLLUTION

Two main pollutants are considered key indicators of ambient, or outdoor, air quality: fine particle pollution — airborne particulate matter measuring less than 2.5 micrometers in aerodynamic diameter, commonly referred to as $PM_{2.5}$ — and ground-level (tropospheric) ozone. Analyses show that much of the world's population lives in areas with unhealthy concentrations of these pollutants. The latest data reveal encouraging improvements in some areas and worsening conditions in others.

Household air pollution from the burning of solid fuels for cooking is an important source of exposure to particulate matter inside the home. This practice continues to be widespread in many regions of the world and can also be a substantial contributor to ambient pollution.

FINE PARTICLE AIR POLLUTION

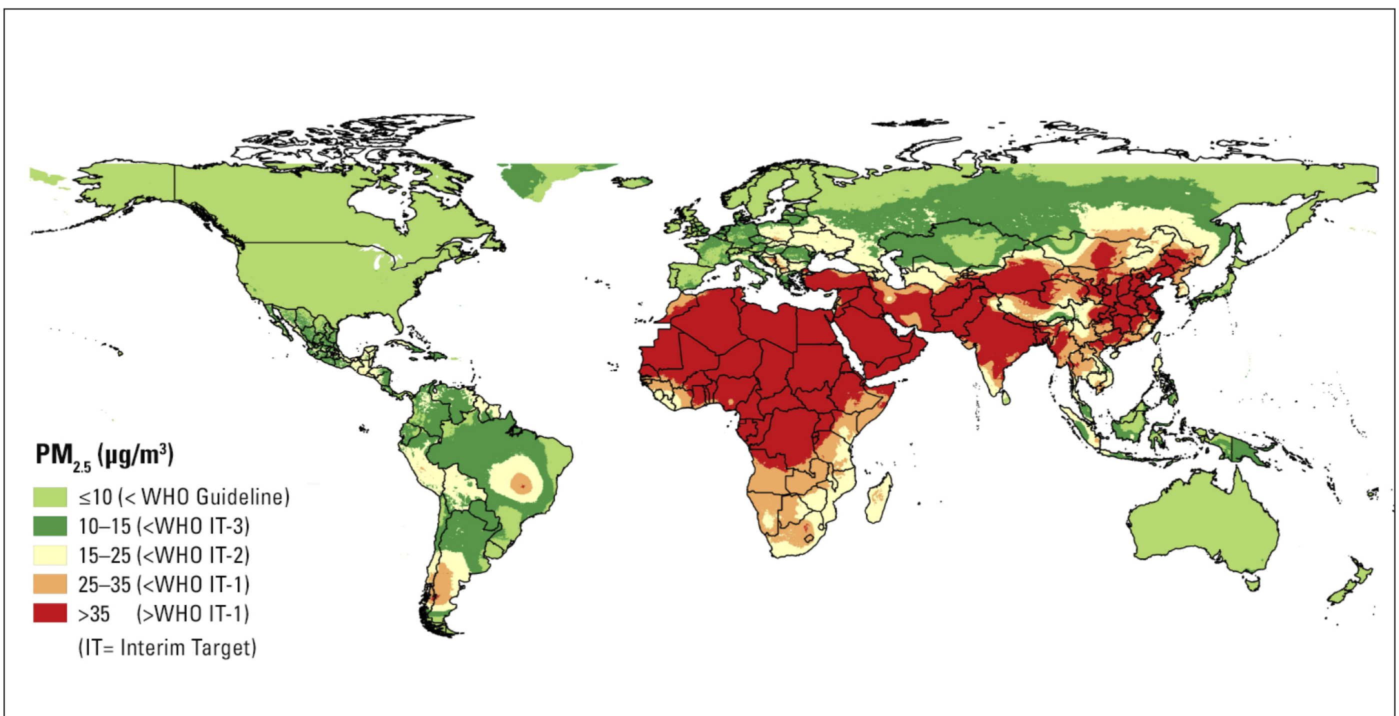
Fine particle air pollution comes from vehicle emissions, coal-burning power plants, industrial emissions, and many other human and natural sources. While exposures to larger airborne particles can also be harmful, studies have shown that exposure to high average concentrations of $PM_{2.5}$ over the course of several years is the most consistent and robust predictor of mortality from cardiovascular, respiratory, and other types of diseases (see textbox "How $PM_{2.5}$ Exposure Is Estimated").

More than 90% of people worldwide live in areas exceeding the WHO Guideline for healthy air. More than half live in areas that do not even meet WHO's least-stringent air quality target.

Around the world, ambient levels of $PM_{2.5}$ continue to exceed the Air Quality Guideline established by the WHO. The guideline for annual average $PM_{2.5}$ concentration is set at 10 µg/m^3 based on evidence of the health effects of long-term exposure to $PM_{2.5}$, but the WHO acknowledged it could not rule out health effects below that level. For regions of the world where air pollution is highest, the WHO suggested three interim air quality targets set at progressively lower concentrations: Interim Target 1 (IT-1, ≤35 µg/m^3), Interim Target 2 (IT-2, ≤25 µg/m^3), and Interim Target 3 (IT-3, ≤15 µg/m^3). Figure 2 shows where these guidelines were still exceeded in 2017.

In 2017, 92% of the world's population lived in areas that exceeded the WHO guideline for $PM_{2.5}$. Fifty-four percent lived in areas exceeding IT-1, 67% lived in areas exceeding IT-2, and 82% lived in areas exceeding IT-3.

Figure 2. Annual average $PM_{2.5}$ concentrations in 2017 relative to the WHO Air Quality Guideline.



HOW $PM_{2.5}$ EXPOSURE IS ESTIMATED

Particulate matter concentrations are measured in micrograms of particulate matter per cubic meter of air, or μg/m^3. Many of the world's more developed countries monitor $PM_{2.5}$ concentrations through extensive networks of monitoring stations concentrated around urban areas. These stations provide continuous hourly measurements of pollution levels, offering a rich source of data that has served as the foundation for most studies of the potential health effects of air pollution and for management of air quality.

While these data sources are valuable, on-the-ground air quality monitoring stations are few and far between in the rapidly growing urban areas of countries at low and middle levels of development, as well as in rural and suburban areas throughout the world. To fill the gaps and provide a consistent view of air pollution levels around the world, scientists combine available ground measurements with observations from satellites and information from global chemical transport models.

Using this combined approach, scientists systematically estimate annual average concentrations of $PM_{2.5}$ across the entire globe divided into blocks, or grid cells, each covering 0.1° × 0.1° of longitude and latitude (approximately 11 km × 11 km at the equator). To estimate the annual average $PM_{2.5}$ exposures for the population in a specific country, scientists combine the concentrations in each block 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*, because they give greater weight to the air pollution experienced where most people live.

PATTERNS AND TRENDS IN $PM_{2.5}$ EXPOSURE

The GBD project estimated population exposures to $PM_{2.5}$ across the world for the period 1990 to 2017. These assessments reveal a lot of regional variation in $PM_{2.5}$ exposure and point to valuable insights about the drivers behind high $PM_{2.5}$ exposure and the impact of efforts to improve air quality.

Exposures to $PM_{2.5}$ Vary Substantially Across Countries and Regions

Exposures to $PM_{2.5}$ show substantial variation both between and within regions of the world. In 2017, annual $PM_{2.5}$ exposures were highest in South Asia, where Nepal (100 μg/m^3), India (91 μg/m^3), Bangladesh (61 μg/m^3), and Pakistan (58 μg/m^3) had the highest exposures. Bhutan's exposure level (38 μg/m^3) was the lowest in the region but was still above WHO's first interim target (IT-1).

The region with the second-highest $PM_{2.5}$ exposures was western sub-Saharan Africa, where Niger (94 μg/m^3), Cameroon (73 μg/m^3), Nigeria (72 μg/m^3), Chad (66 μg/m^3), and Mauritania (47 μg/m^3) had the highest exposures. Countries in North Africa and the Middle East experienced similarly high levels, for example, Qatar (91 μg/m^3), Saudi Arabia (88 μg/m^3), Egypt (87 μg/m^3), Bahrain (71 μg/m^3), Iraq (62 μg/m^3), and Kuwait (61 μg/m^3). All other countries in this region had $PM_{2.5}$ exposures between 30 and 60 μg/m^3. In the region of East Asia, China had the highest $PM_{2.5}$ exposures (53 μg/m^3), while North Korea and Taiwan experienced concentrations of 32 and 23 μg/m^3, respectively.

The 10 countries with the lowest national $PM_{2.5}$ exposure levels were the Maldives, the United States, Norway, Estonia, Iceland, Canada, Sweden, New Zealand, Brunei, and Finland. Population-weighted $PM_{2.5}$ concentrations averaged 8 μg/m^3 or less in these countries.

The sources responsible for $PM_{2.5}$ pollution vary within and between countries and regions. Dust from the Sahara Desert contributes to the high particulate matter concentrations in North Africa and the Middle East, as well as to the high concentrations in some countries in western sub-Saharan Africa. A recent analysis by HEI found that major $PM_{2.5}$ sources in India include household burning of solid fuels; dust from construction, roads, and other activities; industrial and power plant burning of coal; brick production; transportation; and diesel-powered equipment. The relative importance of various sources of $PM_{2.5}$ in China was quite different, with a separate study identifying the major sources as industrial and power plant burning of coal and other fuels; transportation; household burning of biomass; open burning of agricultural fields; and household burning of coal for cooking and heating. Information on the HEI India and China studies can be found in Additional Resources.

The mix and magnitude of the contribution of different sources are changing as 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. Future editions of the State of Global Air will feature the data on source contributions at national and global levels.

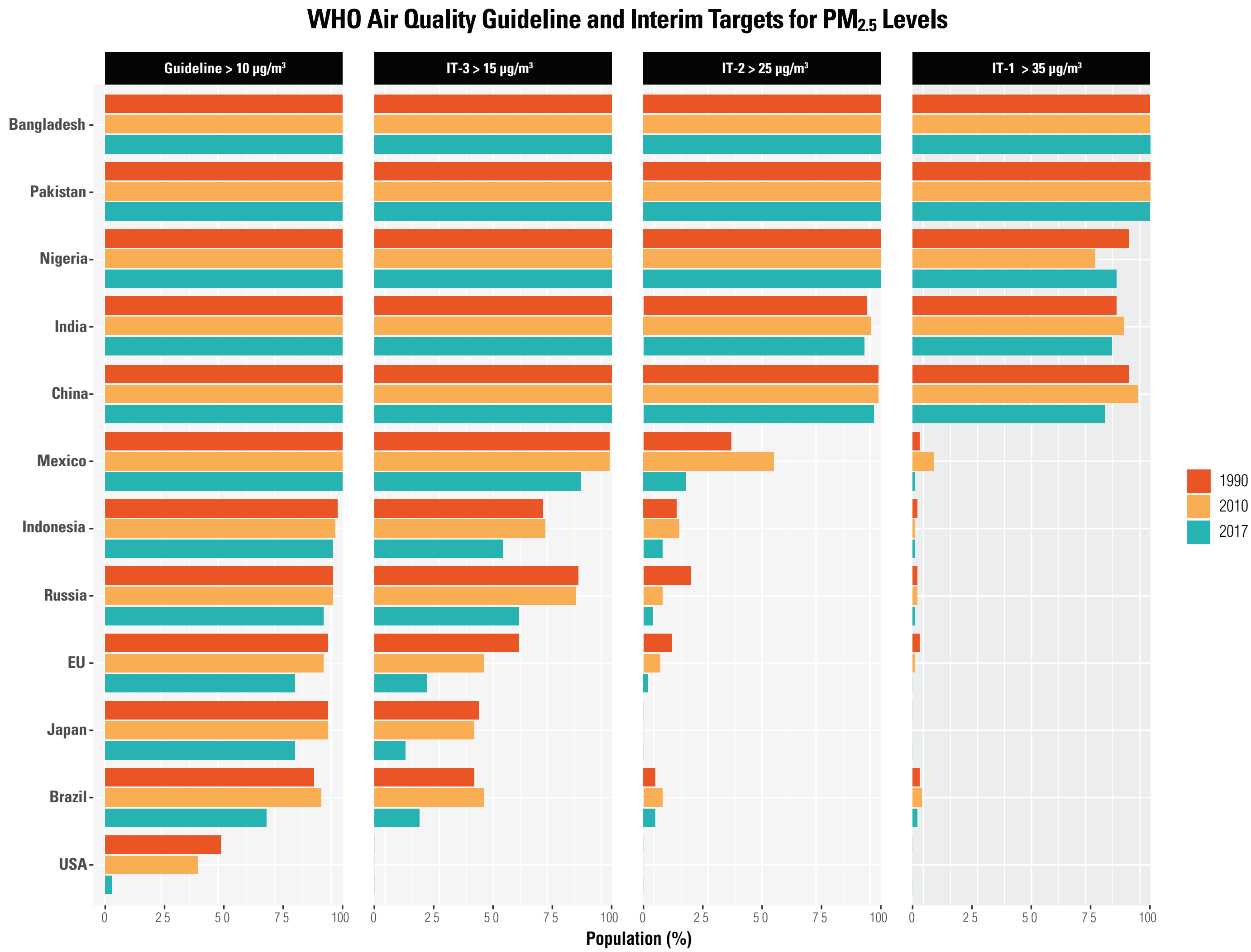
Exposures Are Stagnant in Some Places, Improving in Others

Globally, the percentage of the world's population living in areas that exceed the most-stringent WHO Air Quality Guideline (10 μg/m^3 $PM_{2.5}$) decreased slightly, from 96% in 1990 to 92% in 2017. At the same time, the percentage living in areas that fail to meet even the least-stringent target, IT-1 (35 μg/m^3 $PM_{2.5}$), remained steady at around 54%.

Changes in air quality have been experienced unevenly across different countries over the past several decades. Figure 3 shows the percentages of the populations living in areas exceeding the WHO guideline and each of the three interim targets for the 11 most populous countries and the European Union in 1990, 2010, and 2017.

The left-most column in the figure shows that decreases in only half of the most populous countries have driven the slight global decrease in percentage of people living in areas exceeding the WHO guideline. The most striking decrease occurred in the United States, where the proportion of people living in areas exceeding the WHO

Figure 3. Percentage of population living in areas with $PM_{2.5}$ concentrations exceeding the WHO Air Quality Guideline and interim targets in the 11 most populous countries and the European Union in 1990, 2010, and 2017.



guideline plummeted from 50% in 1990 to about 40% in 2010 and to just 3% in 2017. In Brazil, after increasing slightly in 2010, the percentage of the population living in areas above the WHO guideline declined by nearly 23% to 68% in 2017. The EU and Japan both experienced 14% declines, mostly since 2010, but both still had about 80% of their populations living in areas above the WHO guideline in 2017. In the remaining countries the percentages of population living in areas above the guideline ranged from 92% in Russia to 100% in China, India, Nigeria, Pakistan and Bangladesh.

The remaining three columns of Figure 3 show that progress since 1990 toward meeting the three interim targets has also been mainly evident in the same set of countries — Brazil, Japan, the EU, Russia, Indonesia, and Mexico. These are also countries where the percentages of population exceeding the least-stringent targets (IT-1 and IT-2) were comparatively low in 1990.

However, in the remaining countries, most of which are in Asia, air quality has remained stubbornly poor. In Bangladesh and Pakistan, their entire populations have remained exposed to $PM_{2.5}$ levels above all three interim targets (that is, above 35 µg/m³) since 1990. India, Nigeria, and China experienced decreases in the percentages of their population exposed above IT-1. China had the lowest percentage of its population exposed above IT-1 at 81% (see textbox "In China, Aggressive Pollution Controls Yield Results").

Least-Developed Countries Suffer the Worst Air Quality

The GBD project categorizes each country's level of development using a sociodemographic index (SDI), which reflects a combination of income levels, educational attainment, and fertility rates. Figure 4 shows a strong inverse relationship between a country's level of social and economic development and the $PM_{2.5}$ exposures experienced by its population; that is, less-developed countries suffer $PM_{2.5}$ exposures that are four to five times those of more-developed countries. The pattern for ozone (discussed in the next section) tells a different story.

IN CHINA, AGGRESSIVE POLLUTION CONTROLS YIELD RESULTS

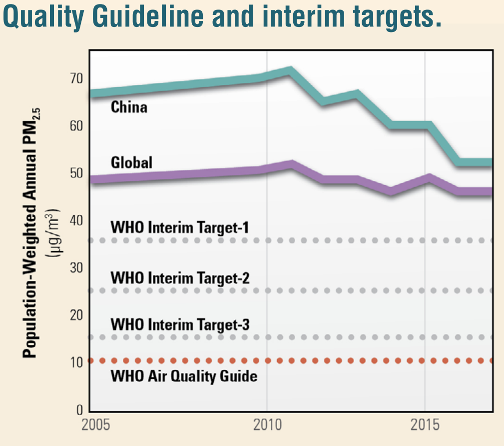
In China, $PM_{2.5}$ pollution has dropped markedly in recent years. However, concentrations continue to exceed the WHO's least-stringent target.

In recent years, China has begun to move aggressively to reduce air pollution. A key milestone in this effort was the first Action Plan for Air Pollution Prevention and Control, issued by the State Council of China in 2013. The Action Plan set key air quality targets and included specific actions to reduce the reliance on coal, cut industrial emissions, control the number of vehicles in some cities, and increase lower-emission energy sources. When this plan expired in 2017, China issued a new 3-year plan (2018 to 2020), which targets more cities.

GBD data suggest that China has seen a steady decline in $PM_{2.5}$ exposures. A separate analysis of air quality and related health impacts in 74 Chinese cities recently found that annual average $PM_{2.5}$ concentrations fell by one-third from 2013–2017, a significant achievement. The study also showed a 54% reduction in sulfur dioxide concentrations and a 28% drop in carbon monoxide.

However, challenges remain. As shown in the figure, the population-weighted annual concentration of $PM_{2.5}$ in China still exceeds the WHO guideline and even WHO's least-stringent target (IT-1, 35 μg/m^3 $PM_{2.5}$). In 2017, the GBD estimated that approximately 852,000 deaths were attributable to $PM_{2.5}$ exposures in China. Ozone exposures have also remained largely untouched by the actions taken in China to date, and the GBD project attributed an additional 178,000 chronic respiratory disease–related deaths in China in 2017 to ozone.

Trends in population-weighted annual average $PM_{2.5}$ concentrations in China and globally compared with the WHO Air Quality Guideline and interim targets.



Explore the data on the State of Global Air interactive site.

While China's air pollution is still worse than that experienced on average across the globe, the remarkable improvements seen in recent years bring significant benefits to China's population and underscore the potential for air quality management efforts to rapidly and substantially improve air quality both in China and around the world.

OZONE

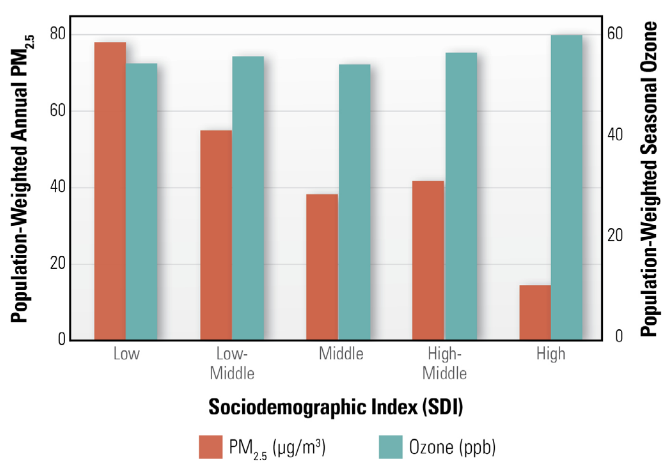
Ozone pollution is a continuing challenge in more-developed countries and is increasing in less-developed areas, posing new air quality concerns.

Ozone is a gas with both natural and human sources. When it is high up in the atmosphere (in the stratosphere), ozone plays a protective role, shielding Earth from harmful rays and ultraviolet radiation. When it is near ground level (in the troposphere), it acts as a greenhouse gas and a pollutant, with harmful effects on human health. Most ground-level ozone pollution is produced by human activities (for example, industrial processes and transportation) that emit chemical precursors (principally, volatile organic compounds and nitrogen oxides) to the atmosphere, where they react in the presence of sunlight to form ozone. Exposure to ground-level ozone increases a person's likelihood of dying from respiratory disease, specifically chronic obstructive pulmonary disease.

PATTERNS AND TRENDS IN OZONE EXPOSURE

Figure 5 shows population-weighted seasonal 8-hour ozone concentrations in each location (see textbox "How Ozone Exposure Is Estimated"). In general, ozone concentrations vary less around the world compared with $PM_{2.5}$. Population-weighted concentrations range from a low of about 20 to 30 parts per billion (ppb), mostly in small island nations, to a high in the 60s to low 70s in Asia and the Middle East, led by Kuwait at 72 ppb. Among the world's 11 most populous countries, population-weighted seasonal ozone concentrations range from about 45 ppb in Brazil to 68 ppb in China.

Figure 4. Trends in pollution concentrations by socio-demographic index for population-weighted annual average $PM_{2.5}$ and population-weighted seasonal average ozone.

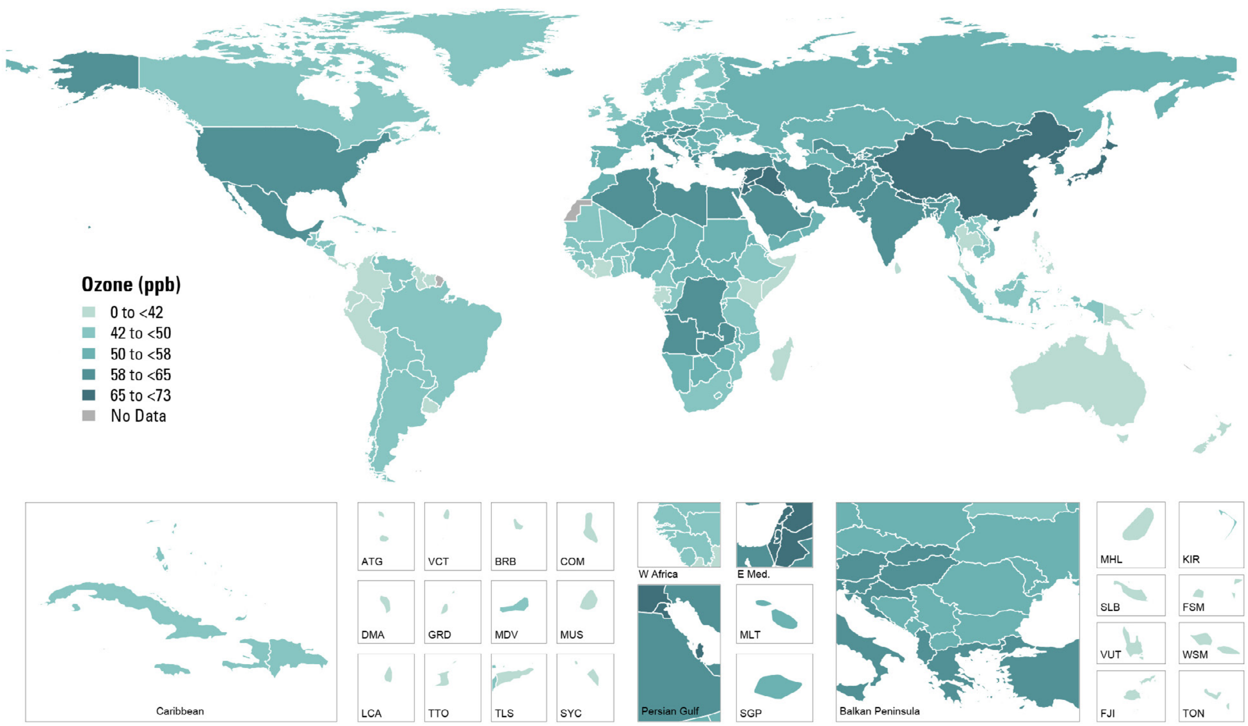


Explore the $PM_{2.5}$ data and the ozone data on the State of Global Air interactive site.

The pattern of ozone exposures by level of sociodemographic development differs markedly from the patterns seen with $PM_{2.5}$ (see Figure 4) and household air pollution (discussed later). The more developed regions, like North America, also continue to experience high ozone exposures in the world, despite extensive and successful air quality control for ozone-related emissions in many of these countries. In countries at middle levels of development with rapidly growing economies, such as China, population-weighted ozone concentrations have been increasing slowly but steadily. These trends reflect a combination of factors, including increased emissions of ozone precursors (such as nitrogen oxides, methane, and nonmethane volatile organic compounds, among other chemicals) with industrialization and economic development, coupled with warmer temperatures, especially at mid-latitudes.

Although some progress has been made, curbing increases in this complex pollutant will continue to pose an important challenge in more-developed countries and will become a pressing issue in less-developed countries as their economies grow.

Figure 5. Population-weighted seasonal average (8-hour max) ozone concentrations in countries around the world in 2017.



Explore the data on the State of Global Air interactive site. For country abbreviations, see ISO3 website.

HOW OZONE EXPOSURE IS ESTIMATED

Ozone concentrations are measured in parts per billion (ppb). When assessing exposure to ozone, scientists focus on measurements taken in the warm season in each region, when ozone concentrations tend to peak in the mid-latitudes (where most epidemiological studies have been conducted), rather than on annual averages. Like $PM_{2.5}$, ozone concentrations are measured in more-developed countries using extensive monitoring networks, but many parts of the world do not have such networks. Consequently, the GBD project has historically relied solely on chemical transport models to estimate ozone concentrations around the world in a consistent way.

This year, the GBD project updated and improved its methods for estimating ozone concentrations in two ways. First, the assessment now focuses on the seasonal 8-hour daily maximum concentrations instead of the 1-hour daily maximum concentrations used historically, because the 8-hour daily maximum is the metric used to characterize exposure in the most recent epidemiological studies of ozone's health effects (see Additional Resources). *Season* is defined by the 6-month period with highest mean ozone concentrations.

Second, this year's estimates have been strengthened by combining a blend of multiple chemical transport models with ozone measurements from a comprehensive database of measurements created as part of the Tropospheric Ozone Assessment Report (see Additional Resources). This approach has enabled correction for differences relative to observed values and the estimation of uncertainty in the model predictions.

GBD researchers combined the data from these updated models with population data to estimate "population-weighted seasonal average 8-hour maximum ozone concentrations" following the same process used for $PM_{2.5}$.

HOUSEHOLD AIR POLLUTION

In many places, people burn solid fuels (such as coal, wood, charcoal, dung, and other forms of biomass, like crop waste) to cook food and to heat and light their homes. This practice generates high concentrations of pollutants in and around the home.

The GBD project defines exposure to household air pollution as the proportion of each country's population living in households where cooking is done with solid fuels (see textbox "How Household Air Pollution Exposure Is Estimated"). Since households in colder regions also use solid fuels for heating, this approach likely underestimates household air pollution exposures in those areas.

PATTERNS AND TRENDS IN HOUSEHOLD AIR POLLUTION EXPOSURE

Globally, the number of people cooking with solid fuels has declined. However, disparities persist, and populations in less-developed countries continue to suffer the highest exposure to household air pollution.

In 2017, 3.6 billion people (47% of the global population) were exposed to household air pollution from the use of solid fuels for cooking. These exposures were most common in sub-Saharan Africa, South Asia, and East Asia (Figure 6).

Figure 7 shows the 13 countries with populations over 50 million in which more than 10% of the population was exposed to household air pollution. Because these countries have such large populations, the number of people exposed can be substantial even if the proportion exposed is low. An estimated 846 million people in India (60% of the population) and 452 million people in China (32% of the population) were exposed to household air pollution in 2017.

Many efforts are under way to shift households to cleaner energy sources. This shift would improve both indoor and outdoor air quality because burning of solid fuels in and around the home also contributes to ambient air pollution. While the contribution of household air pollution to ambient air pollution varies by location and has not been calculated for most countries, one recent global estimate suggested that residential energy use, broadly defined, contributed approximately 21% of global ambient $PM_{2.5}$ concentrations. Another study estimated that residential energy use contributed approximately 31% of global outdoor air pollution–related mortality. (Note that differences exist in the fuel types and energy uses included in those estimates.) HEI's Global Burden of Disease from Major Air Pollution Sources (GBD MAPS) project found that in India, household burning of biomass was responsible for about 24% of the total population-weighted $PM_{2.5}$ concentrations in 2015 and that in China

Nearly half of the world's population — a total of 3.6 billion people — were exposed to household air pollution in 2017.

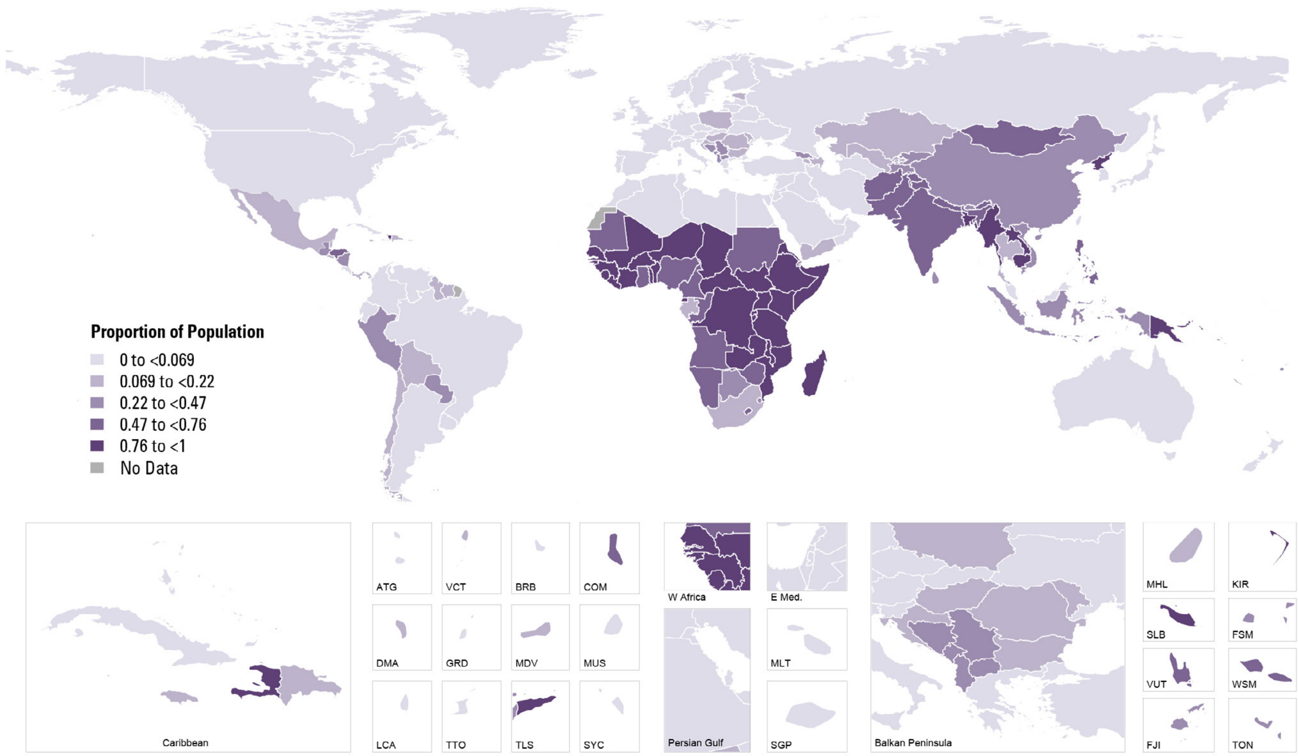
HOW HOUSEHOLD AIR POLLUTION EXPOSURE IS ESTIMATED

Estimation of exposure to household air pollution for the IHME GBD project begins by determining the proportion of households using solid fuels for cooking. Data on fuel use are extracted from numerous surveys, databases, and individual studies (including 680 studies from 150 countries from 1980 to 2017). These data are used together with demographic data to estimate the proportions of the population (grouped by age and sex) exposed to emissions from household use of solid fuel for each country in the GBD.

Next, in order to apply the integrated exposure–response functions to estimate disease burden, the use of solid fuels is translated into indoor $PM_{2.5}$ concentrations and then into exposures for men, women, and children. This translation process relies on a mathematical model describing the relation between indoor concentrations of household-air-pollution–related $PM_{2.5}$ (from about 90 studies) and several factors including the sociodemographic makeup of the household, where in the home the measurements were taken, the duration of the measurement, and whether the measurements represented personal exposure or just general room concentrations. These indoor concentrations are then translated to personal exposures by applying the ratio of personal exposures to indoor concentrations based on a subset of seven studies from six countries that included paired personal and indoor measurements. These ratios are modeled separately for men, women, and children based on differences in the time spent in household activities that would involve exposure to household air pollution.

Unlike those of previous years, this assessment estimates exposure to $PM_{2.5}$ due to cooking with solid fuels over and above exposure to ambient $PM_{2.5}$. This step is accomplished by subtracting the estimated ambient $PM_{2.5}$ exposures from the household air pollution exposure estimates in each study in the database. In this way, the analysis provides independent estimates of exposures to household and to ambient $PM_{2.5}$. See Additional Resources for more detail.

Figure 6. Proportion of population exposed to household air pollution from burning of solid fuels for cooking in countries around the world in 2017.



Explore the data on the State of Global Air interactive site. For country abbreviations, see ISO3 website.

Figure 7. Numbers of people and percentage of population exposed to household air pollution in 13 countries with populations over 50 million in which more than 10% of the population uses solid fuels for cooking.

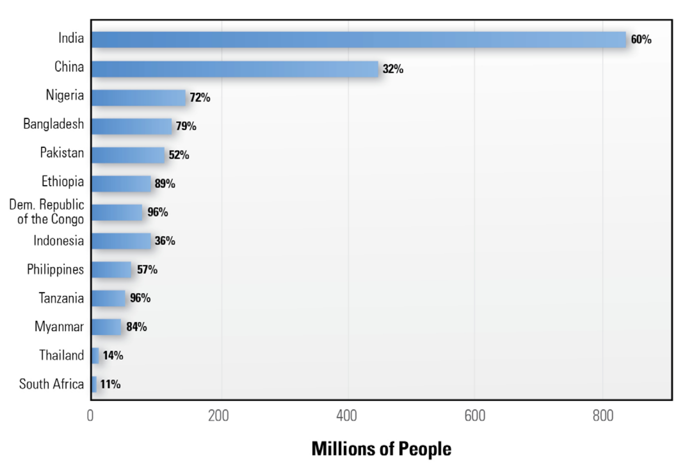
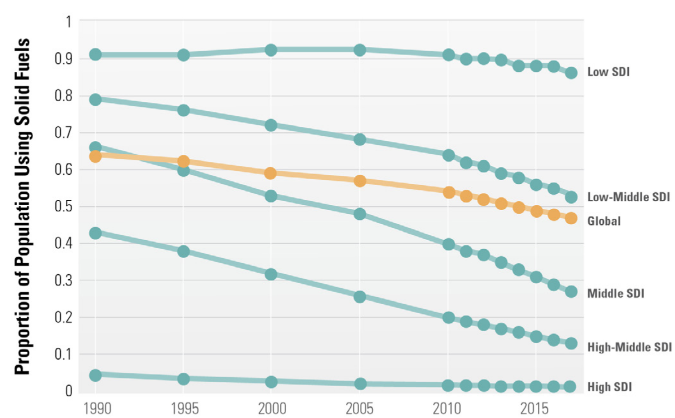


Figure 8. Trends in the proportion of population using solid fuels for cooking grouped by sociodemographic index (SDI).



Explore the data on the State of Global Air interactive site.

household burning of biomass and coal was responsible for about 19% of $PM_{2.5}$ in 2013 (see Additional Resources).

Globally, the proportion of households relying on solid fuels for cooking dropped from about 57% in 2005 to 47% in 2017 (Figure 8). This trend has been driven largely by changes in countries at the mid-levels of sociodemographic development (including low-middle, middle, and high-middle levels) (see textbox "Driving a Shift Toward Cleaner Household Fuels"). In China, the proportion of households cooking with solid fuels fell from 61% in 2005 to 32% (452 million) in 2017, largely due to aggressive efforts to reduce household burning of coal for cooking and heating. Similarly, India reduced its proportion of households cooking with solid fuels from 76% in 2005 to 60% (846 million) in 2017 due in part to a major government program to shift households from solid fuels to liquefied petroleum gas.

However, the rates of solid fuel use remain high in places at the lowest level of sociodemographic development, particularly in eastern, central, and western sub-Saharan Africa. Among countries at this level of development, the proportion of households using solid cooking fuels in 2017 ranged from 22% (6.6 million) in Yemen to 65% (19 million) in Nepal to more than 99% (9.8 million) in South Sudan. Although rates are coming down in many countries of the world, the numbers of people potentially exposed may remain the same or even increase as populations continue to grow.

DRIVING A SHIFT TOWARD CLEANER HOUSEHOLD FUELS

Declines in the proportion of households burning solid fuels for cooking have been driven by multiple factors. Economic development and urbanization tend to increase people's access to cleaner fuels. In addition, governments in some countries have implemented large-scale programs to proactively replace solid fuel with cleaner energy sources for household cooking.

- In China, the government banned the use of coal for household cooking and heating in municipalities around Beijing in favor of a switch to natural gas. The effort stemmed from the emissions benchmarks established in China's Air Pollution Prevention and Control Action Plan, issued in 2013. Although households represent a relatively small proportion of China's overall coal use, in-home coal stoves lack the filtering systems used by coal-fired power plants, making homes an important contributor to coal-related emissions.
- In India, a sweeping government effort seeks to shift more households to liquefied petroleum gas (LPG) instead of biomass fuels. While many families can afford subsidized LPG fuel, the fee for installing a household LPG hookup can be prohibitive. The government initiative, known as Pradhan Mantri Ujjwala Yojana (PMUY), provided LPG connections to 35 million poor families free of charge between 2016 and early 2018 and aims to provide 80 million connections by 2020. A unique facet of the program is its focus on women as the drivers of change. Recognizing the role of women in household cooking, as well as the disproportionate burden of household air pollution on India's women and children, the program requires that each LPG connection be registered in the name of a woman.
- In Ghana, the government has worked to promote adoption of LPG for three decades. While the proportion of people cooking with solid fuels has declined since 1990, when 95% of the population relied on such fuels, it still remains high (73% in 2017). As part of its Sustainable Energy for All Action Plan, Ghana's government aims to provide 50% of the country's population with LPG access by 2020. In a related effort, the government launched the Rural LPG promotion program in 2013 to focus on increasing LPG use in rural areas where solid fuels are the most common source of energy.

As these programs are rolled out, researchers are working to track their impacts on air quality and population health.

THE BURDEN OF DISEASE FROM AIR POLLUTION

To quantify how exposure to air pollution impacts population health, the GBD project assesses the *burden of disease* in terms of increased mortality and disability borne by a population as a whole (see "How Burden of Disease Is Estimated" textbox).

The first step in estimating the burden of disease is determining when scientific evidence is strong enough to identify which health problems are caused by air pollution. Many studies conducted over several decades have documented a wide range of ways air pollution affects our health. Some of these effects are short-term, for example, when high-pollution days trigger asthma symptoms or cause a spike in hospitalizations related to respiratory or cardiovascular diseases. Others result from exposure to air pollution over a long period of time. These effects of long-term exposure include an increased likelihood of suffering chronic illness and experiencing early death from respiratory diseases, heart disease, and lung cancer. The WHO, U.S. Environmental Protection Agency, International Agency for Research on Cancer, and other organizations have systematically reviewed the scientific evidence to understand which health problems can be attributed to air pollution.

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

Building on a fundamental understanding of how air pollution affects health, researchers quantify the burden of disease from air pollution by calculating how air pollution exposures translate into numbers of deaths and years lived with disease or disability (i.e., *disability-adjusted life-years*, or DALYs). Such calculations help inform air quality interventions and provide important insights into the impacts of specific pollutants, the risks faced by particular groups of people, and the trends in air pollution's impact over time.

Using this approach, the GBD project estimated air pollution's health toll in countries across the globe in 2017 (Figure 9). Air pollution (ambient $PM_{2.5}$, household, and ozone) is estimated to have contributed to about 4.9 million deaths (8.7% of all deaths globally) and 147 million years of healthy life lost (5.9% of all DALYs globally) in 2017. The 10 countries with the highest mortality burden attributable to air pollution in 2017 were China (1.2 million), India (1.2 million), Pakistan (128,000), Indonesia (124,000), Bangladesh (123,000), Nigeria (114,000), the United States (108,000), Russia (99,000), Brazil (66,000), and the Philippines (64,000).

Air pollution contributed to almost 5 million deaths globally — nearly 1 in every 10 — in 2017.

HOW BURDEN OF DISEASE IS ESTIMATED

The GBD project describes *burden of disease* attributable to air pollution in terms of two factors: (1) the number of air pollution–attributable deaths in a given year, and (2) the number of healthy years of life lost from air pollution–attributable death or disability, represented by *disability-adjusted life-years* (DALYs).

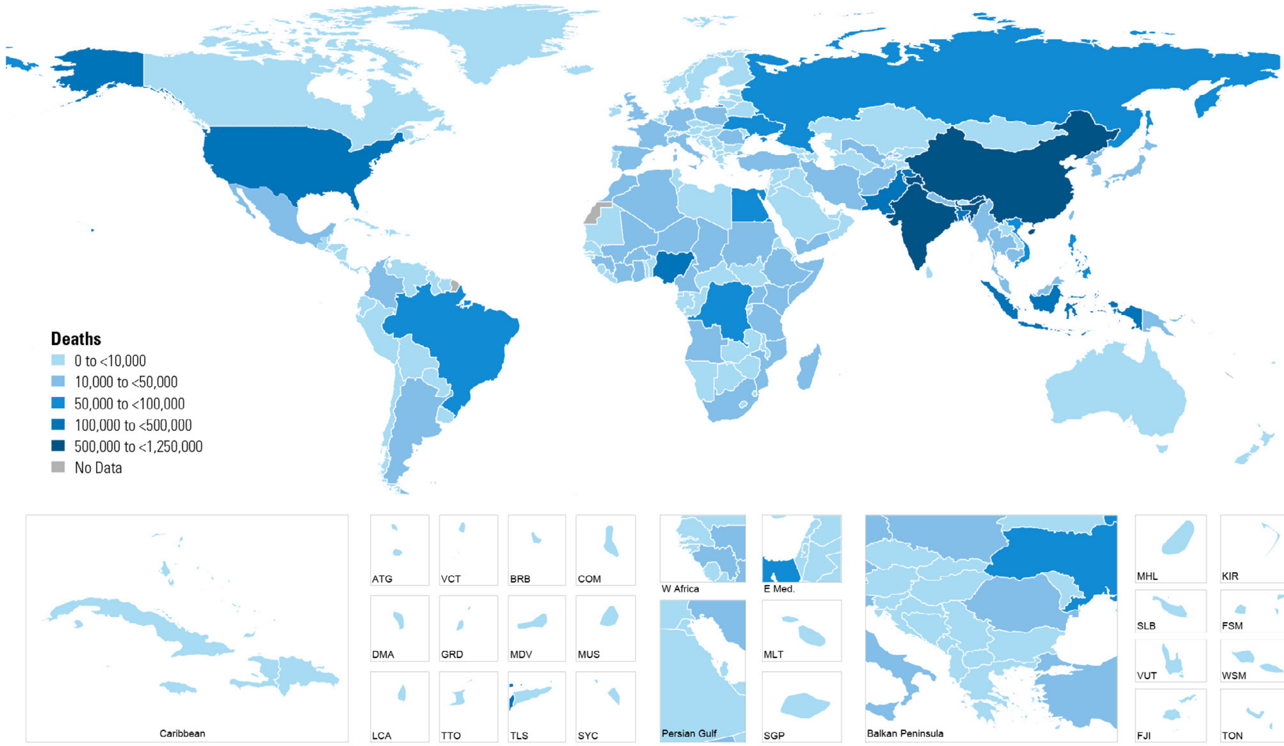
The number of deaths attributable to air pollution in a given year reflects those deaths that likely occurred earlier than would be expected in the absence of air pollution. DALYs are the sum of the years of life lost from those early deaths plus the years lived with a disability, such as paralysis from a stroke related to air pollution exposure, for a population, thus reflecting both the overall numbers of cases and the age at which death or disability occurs.

For both factors, GBD estimates disease burden based on (1) estimates of exposure to $PM_{2.5}$, ozone, and household air pollution relative to the exposure level at which the minimum risk has been observed for each pollutant; (2) mathematical functions, derived from epidemiological studies, that relate different levels of pollution exposure to cause-specific health impacts while accounting for age and sex differences; and (3) estimates of the underlying rates of death for each of the diseases that have been linked to air pollution.

Burden is also measured in terms of *age-standardized* death rates and DALY rates (i.e., the number of deaths or DALYs per 100,000 people). Simple rates of death or other outcomes expressed for a standard number of people allow comparisons between countries with very different size populations. Age-standardized rates are important because they allow the rates in two countries to be compared as if the countries had the same population age profile. Otherwise, a country with a much older population would appear to have higher rates of cardiovascular disease, for example, than a country with younger population, even if exposure levels were the same (see Additional Resources).

Air pollution ranks fifth among global risk factors for mortality (see Figure 1), exceeded only by behavioral and metabolic factors: poor diet, high blood pressure, tobacco exposure, and high blood sugar. It is the leading environmental risk factor, far surpassing other environmental risks that have often been the focus of public health measures in the past, such as unsafe water and lack of sanitation.

Figure 9. Numbers of deaths attributable to air pollution in countries around the world in 2017.



Explore the data on the State of Global Air interactive site. For country abbreviations, see ISO3 website.

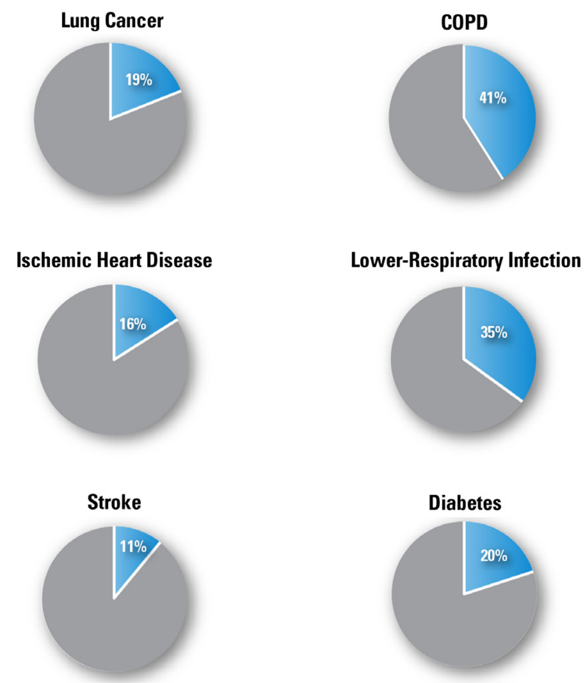
Most of the disease burden attributable to air pollution (82%) stems from chronic noncommunicable diseases. As shown in Figure 10, air pollution accounts for 41% of global deaths from chronic obstructive pulmonary disease (COPD), 20% of deaths from type 2 diabetes, 19% of deaths from lung cancer, 16% of deaths from ischemic heart disease, and 11% of deaths from stroke. Air pollution also contributes to communicable disease (e.g., 35% of deaths from lower-respiratory infection). These contributions vary among countries with different relative levels of ambient and household air pollution. The following sections describe how air pollution, as well as each of its main components — $PM_{2.5}$, ozone, and household air pollution — contributes to the burden of disease and loss of life expectancy.

BURDEN OF DISEASE FROM AMBIENT FINE PARTICLE AIR POLLUTION

$PM_{2.5}$ pollution contributed to nearly 3 million early deaths in 2017. More than half of this disease burden fell on people living in China and India.

Scientific evidence supports a causal relationship between exposure to ambient $PM_{2.5}$ and ischemic heart disease, cerebrovascular disease (ischemic stroke and hemorrhagic stroke), lung cancer, COPD, and lower-respiratory infections (in particular, pneumonia). In the past, these were the only diseases included in the GBD analysis of $PM_{2.5}$-attributable deaths and DALYs. This year, based on mounting evidence that $PM_{2.5}$ exposure contributes to diabetes incidence and deaths, type 2 diabetes was included in the GBD air pollution assessment for the first time (see textbox "New Findings on Diabetes").

Figure 10. Percentages of global deaths from specific diseases attributable to air pollution in 2017.



(COPD = chronic obstructive pulmonary disease.) Explore the data further at the IHME/GBD Compare site.

In addition, growing scientific evidence suggests that air pollution may contribute to the development of asthma in children, low birth weight and pre-term birth, and neurological or cognitive disorders such as Alzheimers disease. While the evidence for these effects of air pollution on health has not been judged conclusive enough to justify their inclusion in GBD health burden estimates to date, researchers will continue to monitor the evidence to inform future GBD analyses.

In 2017, long-term exposure to ambient $PM_{2.5}$ contributed to 2.9 million deaths and to a loss of 83 million DALYs, making $PM_{2.5}$ exposure responsible for 5.2% of all global deaths and 3.3% of all global DALYs. Global patterns of deaths attributable to ambient $PM_{2.5}$ generally mirror the global patterns of population-weighted $PM_{2.5}$ concentrations around the world. The highest burden was concentrated in the world's two most populous countries: China (with 852,000 deaths and 19.8 million DALYS) and India (with 673,000 deaths and 21.3 million DALYs), which together accounted for 52% of the total global $PM_{2.5}$-attributable deaths and 50% of the DALYs.

The health burden from ambient $PM_{2.5}$ has risen in recent decades. Since 1990, there has been a 68% increase in the number of deaths attributable to $PM_{2.5}$, with the largest jump occurring between 1990 and 2010 and a more gradual increase since then. This trajectory in part reflects increases in $PM_{2.5}$ exposures, but other factors are at play, as well. Population growth and the underlying age and health of the population, including the mortality rates from the diseases to which $PM_{2.5}$ exposure contributes, also have important influences on trends. Even when $PM_{2.5}$ exposures decline, as they did, on average, in the United States, Russia, and Japan between 1990 and 2017, the reductions were largely offset by the growth and aging of the populations in those countries. Japan experienced a net increase in mortality attributed to air pollution.

BURDEN OF DISEASE FROM OZONE

Ozone pollution accounted for nearly half a million early deaths worldwide in 2017. That number represents a 20% increase since 1990, with most of the growth seen in the past decade.

Short-term exposure to ozone is linked to asthma exacerbation and other respiratory problems. Long-term exposure is associated with COPD. In 2017, ozone exposure accounted for about 472,000 deaths from COPD (15% of all COPD deaths globally), most of which occurred in China (38%) and India (31%) — highly populated countries with growing ozone concentrations. Global patterns of ozone-attributable deaths generally mirror the global patterns of population-weighted seasonal ozone concentrations around the world (Figure 5).

Growth in ozone-attributable mortality has been accelerating in recent years. Ozone-attributable deaths grew by 4% from 1990 to 2010, while the increase from 2010 to 2017 was about 15%.

BURDEN OF DISEASE FROM HOUSEHOLD AIR POLLUTION

Household air pollution remains a leading cause of death and disability worldwide, with a particularly heavy toll in less-developed countries.

Over the last few decades, epidemiological studies examining potential links between residential solid fuel use and health outcomes have been conducted around the world. Reviews of these studies by organizations such as IHME, WHO, and the International Agency for Research on Cancer among others have concluded the evidence

NEW FINDINGS ON DIABETES

In 2017, exposure to $PM_{2.5}$ was the third leading risk factor for type 2 diabetes deaths and DALYs, after high blood sugar and high body mass index.

Diabetes is a disorder affecting how the body processes food, which leads to a buildup of glucose, or sugar, in the blood. It can cause serious problems including heart disease, blindness, kidney failure, and lower-extremity amputations.

Type 2 diabetes represents a substantial, growing, and costly health burden. In 2017, the disease accounted for more than 1 million deaths and 57 million DALYs globally — burdens that have increased by 175% and 141%, respectively, since 1990. While rates of diabetes have risen across all countries, the largest burdens are found in China and India, reflecting in part their large populations. The economic costs of diabetes are substantial — estimated as 1.8% of worldwide gross domestic product in 2015 (see Additional Resources) — and pose a growing challenge to health care systems in countries at all levels of development.

Type 2 diabetes typically emerges later in life as a result of multiple factors. Long-recognized risk factors include high blood sugar, high body mass index, poor diet, and smoking. More recently, epidemiological studies in Asia, Europe, and North America, supported by toxicology research, have provided strong evidence that exposure to ambient and household $PM_{2.5}$ also contributes to type 2 diabetes incidence and mortality. In the 2017 GBD analysis, exposure to $PM_{2.5}$ was found to be the third leading risk factor globally for type 2 diabetes deaths and DALYs, after high blood sugar and excessive body weight.

Exposure to $PM_{2.5}$ pollution contributed to 276,000 deaths and 15.2 million DALYs from type 2 diabetes in 2017 worldwide. This burden was highest in India, where $PM_{2.5}$ exposure accounted for 55,000 deaths and 2.7 million DALYs. Reducing the burden of disease from type 2 diabetes and other diseases will require multipronged public health strategies aimed at reducing exposure to multiple risk factors including air pollution.

points to a causal relationship between exposures to household air pollution and cardiovascular disease (ischemic heart disease and stroke), COPD, acute lower-respiratory infections, lung cancer, and cataracts. The International Agency for Research on Cancer has classified indoor burning of coal as a known human carcinogen and indoor burning of biomass as a probable human carcinogen.

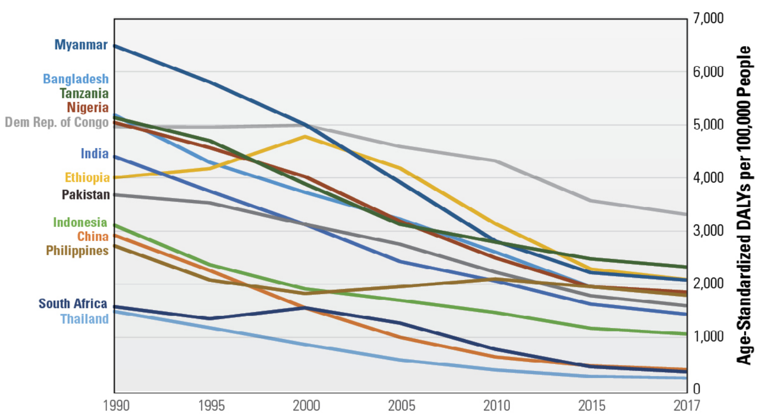
The GBD project estimates the disease burden attributable to household air pollution from ischemic heart disease, stroke, COPD, lower-respiratory infections, and type 2 diabetes using the same exposure–response relationships used to assess the burden from exposure to ambient $PM_{2.5}$ air pollution. Based on current understanding of its health impacts, household air pollution ranks among the most important global risk factors for early death and disease. In 2017, household air pollution contributed to 1.6 million deaths (2.9% of all deaths) and 59 million DALYs (2.4% of all DALYs).

The regional patterns of deaths attributable to household air pollution reflect both population sizes and the proportion of each population using solid fuels (Figure 6). The largest numbers of deaths were in India (482,000) where 60% of the population cooks with solid fuels, followed by China (271,000) where 32% of the population does. Together, these two large countries accounted for about 46% of deaths and about 37% of DALYs attributable to household air pollution. Countries in sub-Saharan Africa, primarily those in eastern, central, and western sub-Saharan Africa, where 80 to 92% of the population relies on solid fuels, collectively accounted for another 24% of deaths and 34% of DALYs attributable to household air pollution. Afghanistan, Pakistan, Indonesia, and Myanmar also bore large mortality burdens from exposure to household air pollution.

There is some good news in the battle against household air pollution–related disease. In the 13 most populous countries in which at least 10% of the population relies on solid fuel, age-standardized DALY rates declined steadily between 1990 and 2017 (Figure 11). These trends reflect a reduction in the proportion of the population cooking with solid fuels combined with public health improvements that have reduced mortality from diseases related to household air pollution, such as vaccine availability and wider access to treatments for acute lower-respiratory infections and noncommunicable diseases.

However, there is still much room for improvement, and wide disparities persist. For example, in Tanzania, household air pollution contributed to 2,310 DALYs per 100,000 people in 2017, while in Thailand it contributed to 192 DALYs per 100,000 people. In high-income countries of North America and the Asia-Pacific region, household air pollution–related DALY rates were less than 5 per 100,000 people.

Figure 11. Trends in the DALY rates (DALYs/100,000 population) attributable to household air pollution in countries with populations over 50 million in which more than 10% of the population uses solid fuels for cooking.



Explore the data on the State of Global Air interactive site.

PATTERNS AND TRENDS IN THE HEALTH IMPACTS OF AIR POLLUTION

The health burden of air pollution is affected by many factors. Trends in exposures to various forms of pollution have a large influence, but so do factors like age and health status, which can affect susceptibility to and the likelihood of dying from air pollution–related diseases. Understanding these trends is crucial to informing steps to improve air quality and public health.

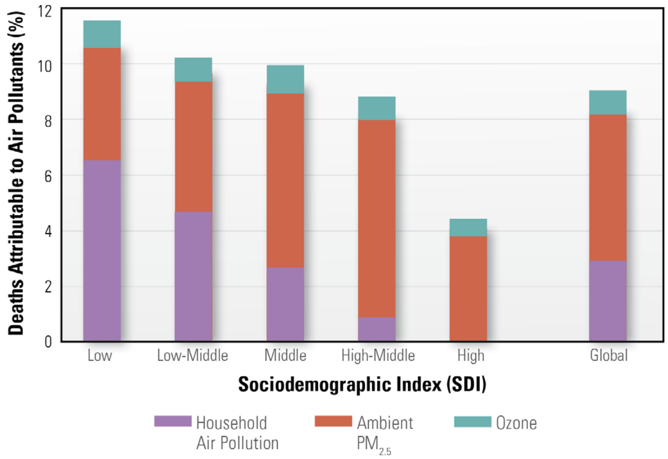
Less-Developed Countries Suffer Greater Health Impacts from Air Pollution

Less-developed countries face a double burden from household and ambient air pollution.

Strong relationships exist between a country's level of development (measured in the GBD project according to the sociodemographic index) and the health burden from air pollution. These relationships are captured in Figure 12, which shows the percentage of deaths attributable to household air pollution, $PM_{2.5}$, and ozone exposure for countries at low, low-middle, middle, high-middle, and high levels of development. In the least-developed countries, air pollution accounts for a higher proportion of deaths overall, with household air pollution responsible for the largest portion of these deaths. These countries may face a double burden from high exposure to both household and ambient air pollution.

For countries in the middle, high-middle, and high levels of development, the percentage of deaths attributable to all forms of air pollution and particularly to household air pollution declines relative to those at the lowest level of development. The impact of household air pollution is negligible in the most-developed countries. In addition to reflecting differences in overall exposure to air pollution, the differences in the numbers of deaths for countries at various levels of development also reflect factors tied to the underlying health of a population, the fraction of total deaths accounted for by air pollution–linked diseases, and the population's age structure. Understanding the relative importance of these

Figure 12. Comparison of percentages of deaths attributable to household air pollution, ambient $PM_{2.5}$, and ozone by sociodemographic index.



Explore the data further at the IHME/GBD Compare site.

underlying factors is important in addressing air pollution–related death and disease.

Older People Face the Highest Risks

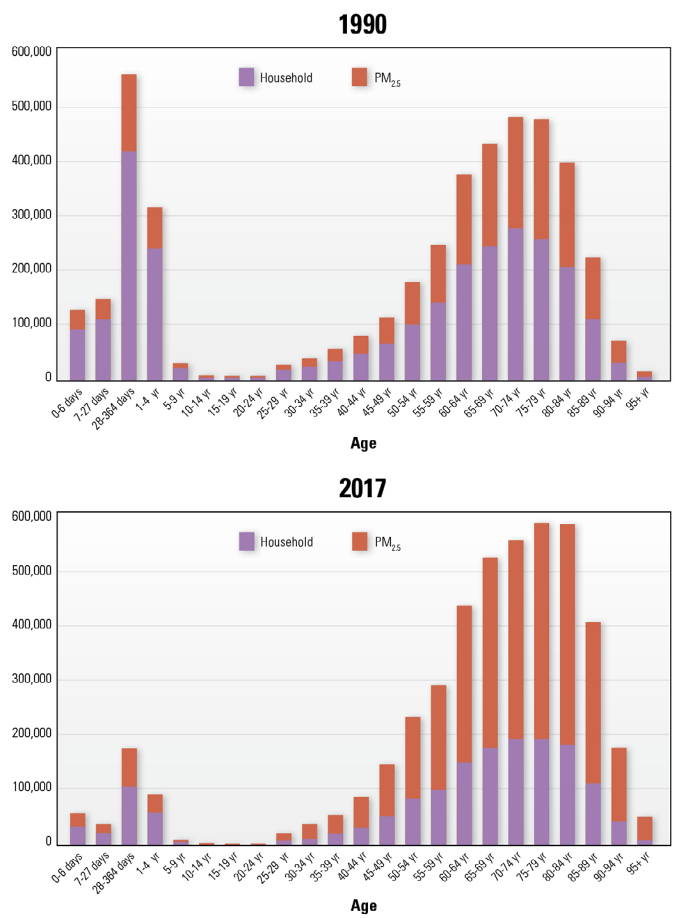
Since 1990, the health burden of air pollution exposure has shifted further to older populations.

Air pollution takes its greatest toll on people age 50 and older (Figure 13), who suffer the highest burden from noncommunicable air pollution–related diseases such as heart disease, stroke, lung cancer, diabetes, and COPD. In 2017, 88% of deaths (34% of DALYs) attributable to ambient $PM_{2.5}$ occurred in those aged 50 and older, and 55% (16% of DALYs) occurred in those age 70 and older, while just 5% (15% of DALYs) occurred in children less than 5 years old. The pattern is somewhat different for household air pollution, which imposes a relatively higher burden on the youngest age groups compared with $PM_{2.5}$ exposure. In 2017, 14% of deaths (34% of DALYs) attributable to household air pollution occurred in children less than 5 years old, largely because of the higher rates of lower-respiratory disease in this age group, particularly in places where cooking with solid fuels is prevalent. The higher percentages of DALYs experienced by children relative to older populations reflects the larger numbers of years of healthy life lost, a key element of that measure of burden.

The pattern of air pollution's impacts in different age groups has shifted markedly since 1990 (Figure 13). In 1990, those under 5 years old faced a much greater burden than in 2017, suffering 32% of all deaths (59% of DALYs) attributable to household air pollution and 17% of all deaths (40% of DALYs) attributable to ambient $PM_{2.5}$. The impacts of exposure to ambient $PM_{2.5}$ relative to exposure to household air pollution in 1990 were also smaller than in 2017 for all age groups. These shifts reflect a transition from historical patterns in which the overall burden of disease was dominated by communicable diseases in children to patterns in which the burden is dominated by noncommunicable diseases in older people. Thanks to worldwide improvements in the prevention and treatment of communicable diseases such as malaria and pneumonia and to reductions in the number of people burning solid fuels, populations are living longer. However, aging populations are comparatively more susceptible to the noncommunicable diseases to which air pollution is a contributor.

Older people already experience the greatest loss of healthy life-years due to noncommunicable, pollution-linked diseases. As countries — particularly those at lower and middle levels of development — continue to experience high levels of air pollution and growing and aging populations, this burden will increase. While improvements in treatment for those already suffering from heart disease and other noncommunicable diseases will play a key role, aggressive strategies are needed to prevent new cases of noncommunicable diseases by tackling their major risk factors including high blood pressure and smoking, as well as air pollution.

Figure 13. Proportion of the burden of disease (deaths) attributable to ambient and household air pollution by age group in 1990 and 2017, showing shifts in burden from younger to older age groups and from household air pollution to ambient pollution.



Explore the data further at the IHME/GBD Compare site.

AIR POLLUTION'S IMPACT ON LIFE EXPECTANCY

Life expectancy — the number of years a person is expected to live — is a common yardstick for assessing the health of a population. Globally, life expectancy at birth has increased by more than two decades on average since 1950, a remarkable improvement. However, wide disparities in life expectancy remain across different countries and regions. For example, a boy born in the Central African Republic today can expect to live about 50 years on average (roughly the same as the global average life expectancy for boys born in 1950), while a girl born in Singapore can expect to live around 87 years. Differences in rates of childhood death are a main driver of variation in life expectancy over time and across locations, though many other factors play a role (see "How Life Expectancy Is Estimated" textbox.)

Air pollution collectively reduced life expectancy by 1 year and 8 months on average worldwide, a global impact rivaling that of smoking. This means a child born today will die 20 months sooner, on average, than would be expected in the absence of air pollution.

To understand how various factors influence our health, researchers assess how they lengthen or shorten the average person's life expectancy in a population. Comparing the impacts of different risk factors on life expectancy is useful for understanding their relative importance for public health and of the potential benefits of interventions to address them.

According to an analysis of GBD data from 2016, air pollution exposures collectively reduce life expectancy by 20 months on average worldwide. When considered separately, exposure to ambient $PM_{2.5}$ is responsible for just over 1 year, household air pollution is responsible for almost 9 months, and ozone is responsible for less than 1 month of life span lost.

The impacts of air pollution exposure on life expectancy are substantial. Figure 14 compares the reductions in life expectancy for total air pollution, ambient $PM_{2.5}$, household air pollution, and ozone to the impacts of other major risk factors and causes of death. Air pollution reduces average life expectancy by almost as much as active tobacco smoking.

High exposures to ambient $PM_{2.5}$ are a major contributor to loss of life expectancy around the world (Figure 15): the higher the $PM_{2.5}$ exposures, the greater the loss. For example, exposures to ambient $PM_{2.5}$ have reduced life expectancy by an estimated average of 1 years and 7 months in South Asia and 1 year and 3

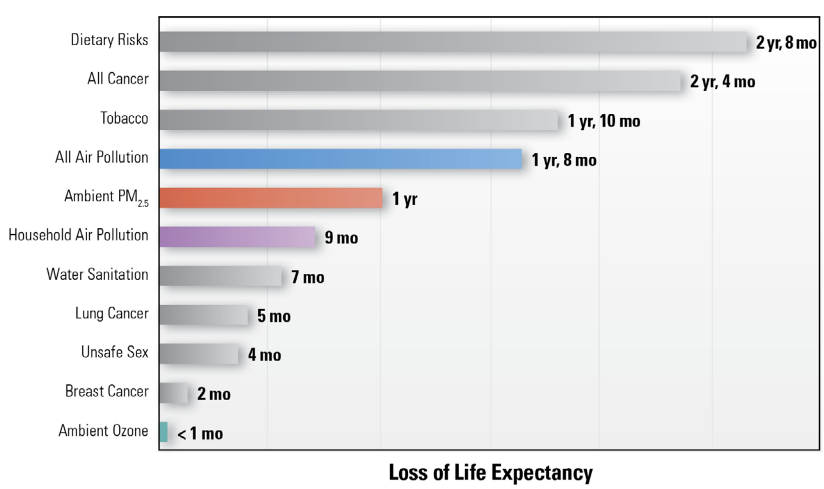
HOW LIFE EXPECTANCY IS ESTIMATED

This report presents life expectancy at birth. It is a statistical estimate of the expected lifespan of an individual based on a person's year of birth, sex, and location, and assumes that current mortality rates remain the same indefinitely into the future.

To assess the impact of a particular factor on life expectancy, researchers quantify the average person's likelihood of dying from diseases related to that factor at different ages and calculate a "risk-deleted" life expectancy — that is, the length of life that would be expected if the factor were absent. The difference between life expectancy and "risk-deleted" life expectancy quantifies the average reduction in life expectancy attributable to that factor.

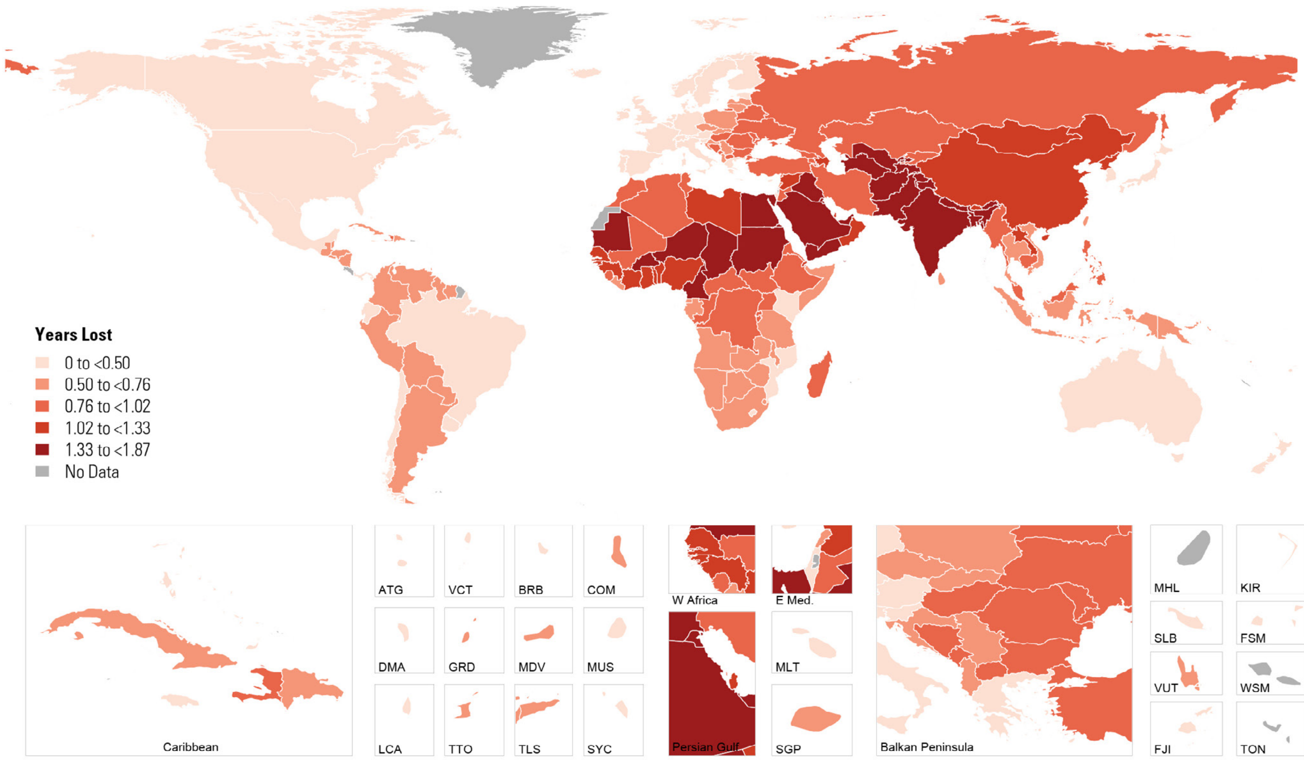
This is the first year that life expectancy has been included in the State of Global Air. The findings reported here are based on the work of University of Texas Assistant Professor Joshua Apte, who estimated air pollution's impacts on life expectancy at birth using GBD data and methods from 2016. (See Additional Resources for more information.) GBD 2016 included some overlap between $PM_{2.5}$ and household air pollution, which is why the life expectancy loss from total air pollution is less than that of the sum of the losses attributable to individual pollutants.

Figure 14. Contribution of major risk factors to loss of life expectancy.



Explore the data on the State of Global Air website Life Expectancy page.

Figure 15. Global map of life expectancy loss attributable to existing levels of $PM_{2.5}$ exposure in 2016.



Explore the data on the State of Global Air website Life Expectancy page.

months in North Africa and the Middle East. The impact on life expectancy in more-developed countries is far lower, about 4½ months on average in the high-income regions of North America and Asia Pacific.

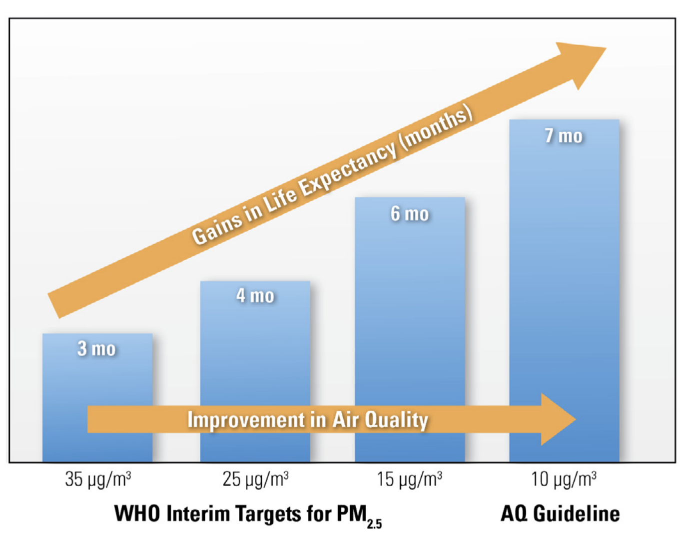
In regions where ambient air pollution is high and cooking with solid fuels is common, the reduction in life expectancy reflects the double burden from both ambient and household air pollution. In South Asia, for example, household air pollution contributes to an additional life expectancy loss of about 1 year and 3 months, bringing the total life expectancy loss from air pollution to 2 years and 6 months. In sub-Saharan Africa, where more than 80% of people cook with solid fuels, household air pollution dominates the impact on life expectancy, accounting for 1 year and 4 months of the nearly 2 years in life expectancy loss from air pollution overall. Since life expectancy in this region is already the lowest in the world (62.8 years on average), the proportional impact of air pollution is also higher.

LIVING LONGER BY CONTROLLING POLLUTION

Since exposure to air pollution shortens life expectancy, reducing air pollution could help people live longer. While it is hard to predict exactly how various levels of pollution reduction would translate into longer lifespans, researchers have estimated the gains that might be expected under hypothetical scenarios in which countries were assumed to experience different $PM_{2.5}$ exposures. These analyses assume that all other risk factors and conditions remained the same for the past several decades but that $PM_{2.5}$ had been kept below certain thresholds beginning with the WHO's three interim air quality targets — IT-1 (35 µg/m^3), IT-2 (25 µg/m^3), and IT-3 (15 µg/m^3) — and finally below its guideline for healthy air (10 µg/m^3).

Figure 16 shows the significant gains in life expectancy that might be expected had each of these successively greater reductions in $PM_{2.5}$ been met. The global life expectancy gains increase from about

Figure 16. Hypothetical global gains in life expectancy if air quality had met WHO interim targets or the Air Quality Guideline.

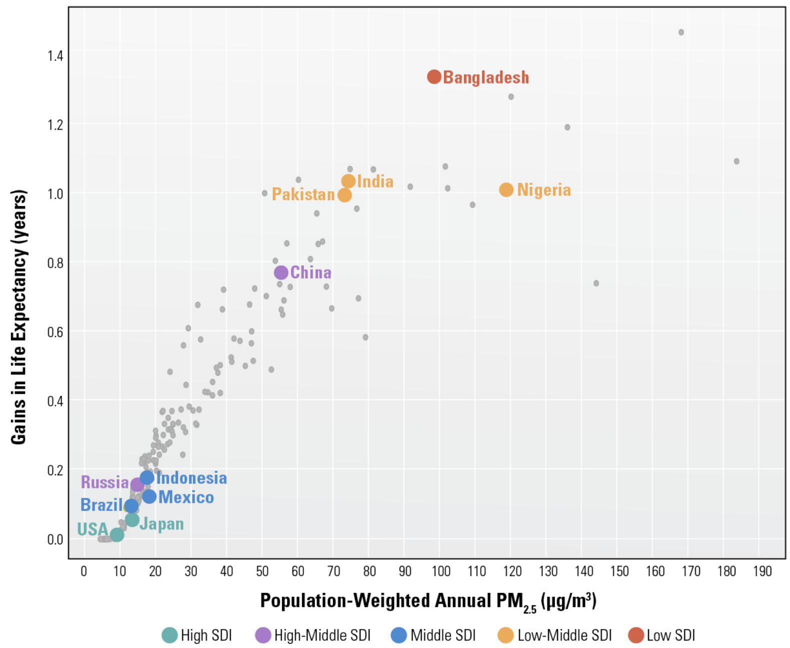


Explore the data on the State of Global Air website Life Expectancy page.

3 months on average at 35 μg/m³ to 7 months on average at 10 μg/m³.

The projected gains would not be experienced equally among all countries. Consistent with the way air pollution health burden is distributed, the gains from reducing air pollution would be most dramatic in countries that are often both the least developed and suffer the highest $PM_{2.5}$ exposures. Figure 17 displays the gains in life expectancy for countries around the world if they had met the WHO guideline of 10 μg/m³ of $PM_{2.5}$. The figure highlights the 11 most populous countries, which are color coded according to their level of development. All are arranged according to their actual $PM_{2.5}$ exposure levels in 2016. Bangladesh would have the highest expected gain of nearly 1.3 years, followed by India, Nigeria, and Pakistan with gains of about 1 year of life expectancy.

Figure 17. Hypothetical increases in life expectancy among the 11 most populous countries if $PM_{2.5}$ concentrations were limited to the WHO Air Quality Guideline, showing that those with the highest exposures and often lowest sociodemographic (SDI) levels have the most to gain (based on 2016 data).



Explore the data on the State of Global Air website Life Expectancy page.

CONCLUSIONS

The GBD project plays a key role in identifying factors that contribute to disease and early death — a crucial first step toward determining what can be done to improve public health. Air pollution — comprising ambient $PM_{2.5}$, ozone, and household air pollution from the burning of solid fuels — continues to be one of the most important risk factors contributing to death and disability worldwide. In 2017, air pollution ranked fifth among all mortality risk factors globally, accounting for nearly 5 million early deaths and 147 million years of healthy life lost. Ambient $PM_{2.5}$ accounted for 2.9 million deaths, while household air pollution accounted for 1.6 million deaths. Ozone accounted for about 472,000 early deaths in 2017.

Air pollution reduces life expectancy on average by 1 year and 8 months globally — a loss that ranks just below that related to smoking but above that related to unsafe drinking water and lung cancer. This loss of life expectancy is not borne equally across all regions and countries. The least-developed countries, where air pollution exposures are often the highest, face the largest declines in life expectancy related to air pollution. Because background life expectancies are often already lower in these countries, these declines represent a larger proportional impact on the overall lifespan compared with more developed countries, further widening the gaps between more- and less-developed regions in terms of air pollution's overall health burden.

The air quality data presented in the State of Global report and made available at www.stateofglobalair.org help explain why air pollution continues to pose a substantial threat to human health in so many countries around the world. In 2017, 92% of the world's population still lived in areas where $PM_{2.5}$ exceeds the WHO guideline for healthy air; 54% still lived in areas exceeding the WHO's least-stringent interim target, often by substantial margins. Household burning of solid fuels — coal, wood, charcoal, dung, and other forms of biomass — remains an important source of exposure to particulate matter, especially in low- and middle-income countries in South Asia and sub-Saharan Africa. Ozone concentrations are creeping upward globally, with particularly pronounced growth in rapidly developing countries like China.

Air pollution is among the highest 5 risk factors for population health globally, shortening life on average by 20 months around the globe. While progress is being made in reducing exposure and health burden in places like China, much still remains to be done.

Amid these concerning trends, there are some bright spots. In China, one of the world's most populous countries and one where air pollution exposures have historically been among the highest, major regulatory reforms appear to be driving substantial reductions in $PM_{2.5}$ exposure. In addition, the number of households cooking with solid fuels is declining in many parts of the world. Finally, recent decades have seen substantial reductions in childhood mortality and significant improvements in life expectancy overall, a testament to a number of public health successes.

However, much work remains to be done to further reduce air pollution and its heavy toll on population health. Even with improvements in air quality, the burden of disease attributable to air pollution continues to rise as populations grow, age, and become more susceptible to the noncommunicable diseases most closely related to air pollution. Facing these trends effectively requires not only making substantial gains in air quality but also reducing disparities in health in the least-developed countries that often carry the largest burdens.

The growing burden of disease from air pollution is among the major challenges facing national governments and public health officials, with far-reaching implications for national economies and human well-being. Better understanding the sources of air pollution and key contributors to its health burden is a critical next step for implementing effective air pollution control policies. In each country, it is important to parse the critical interplay among trends in air pollution levels, population structure, underlying disease, and economic factors that contribute to the estimates of health burden and loss of life expectancy. Knowledge of these trends is essential to understanding patterns in the burden of disease across countries and regions and vital to informing actions to reduce pollution in ways that have the greatest potential to benefit health.

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ADDITIONAL RESOURCES

GBD METHODS

These references provide background details on the latest GBD methods used to estimate $PM_{2.5}$, ozone, and household air pollution exposures and to estimate the premature deaths and disability-adjusted life-years (DALYs) reported in the State of Global Air this year:

Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. Lancet 389:1907–1918; *https://doi.org/10.1016/S0140-6736(17)30505-6*.

Gaudel A, Cooper OR, Ancellet G, Barret B, Boynard A, Burrows JP, et al. 2018. Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation. Elem Sci Anth 6(1):39; https://doi.org/10.1525/elementa.291.

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Shaddick G, Thomas M, Jobling A, Brauer M, Donkelaar A, Burnett R, et al. 2017. Data integration model for air quality: A hierarchical approach to the global estimation of exposures to ambient air pollution. J R Stat Soc Ser C Appl Stat 67:231–253; *https://doi.org/10.1111/rssc.12227*.

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Explore and download additional information and data on mortality and disease burden for air pollution, as well as other risk factors, at the IHME/GBD Compare site.

$PM_{2.5}$ AND OZONE HEALTH EFFECTS

For scientific evidence on the health effects associated with exposures to $PM_{2.5}$, ozone, and related air pollution, see the following publications:

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U. S. EPA (United States Environmental Protection Agency). 2009. Final Report: Integrated Science Assessment (ISA) for Particulate Matter (Final Report, Dec 2009). EPA/600/R-08/139F, 2009. Washington, DC:U.S. Environmental Protection Agency. Available: *http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=216546* [accessed 5 March 2019].

WHO (World Health Organization). 2015. Air Quality Guidelines: Global Update 2005. WHO Reg Off Eur. Available: *www.who.int/phe/health_topics/outdoorair/outdoorair_aqg/en/* [accessed 5 March 2019].

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Chafe ZA, Brauer M, Klimont Z, Dingenen RV, Mehta S, Rao S, et al. 2014. Household cooking with solid fuels contributes to ambient $PM_{2.5}$ air pollution and the burden of disease. Environ Health Perspect 122:1314–1320; https://doi.org/10.1289/ehp.1206340.

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Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525:367–371; http://doi.org/10.1038/nature15371.

HEI Household Air Pollution Working Group. 2018. *Summary for Policy Makers. Household Air Pollution and Noncommunicable Disease*. Boston, MA:Health Effects Institute.

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Weagle CL, Snider G, Li C, van Donkelaar A, Philip S, Bissonnette P, et al. 2018. Global sources of fine particulate matter: Interpretation of $PM_{2.5}$ chemical composition observed by SPARTAN using a global chemical transport model. Environ Sci Technol 52:11670–11681; https://doi.org/10.1021/acs.est.8b01658.

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CONTRIBUTORS AND FUNDING

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Glossary

For a glossary of terms, see the State of Global Air website.

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