




Life and breath

How air pollution affects health in Minnesota

MINNESOTA
DEPARTMENT OF HEALTH
POLLUTION CONTROL AGENCY

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Executive summary

It is critical that all Minnesotans have a chance to lead healthy and fulfilling lives. Achieving this requires equitable access to opportunities and conditions where everyone can thrive. One important condition is living in an environment with clean air. The goal of this report from the Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Health (MDH) is to provide a better understanding of the health impacts from air pollution and the scale of the problem statewide. This report will serve as a guide, informing decisions and actions to reduce air pollution across the state and address health inequities that affect quality of life for all Minnesotans.

What's at stake?

Good health and well-being are created by many things. While air quality in Minnesota currently meets federal standards, even low and moderate levels of air pollution can contribute to serious illnesses and early death. Understanding how air pollution affects health across the state helps show what's at stake and points to actions to improve the health of all residents. This report estimates the health impacts using the most current outdoor air quality data available (from 2013), matched with available hospital and emergency department admission data, and addresses how broad reductions in air pollution could improve health. Air pollution data used in this project include fine particle pollution (a complex mixture of extremely small solid and liquid particles) and ozone (a colorless gas composed of three atoms of oxygen), two common air pollutants in Minnesota. These pollutants are generated from various sources, such as vehicle emissions, and can travel long distances. The relationship between air pollution and health is complex and involves multiple factors that can vary across the state. Overall, the analyses presented in this report estimate that in 2013 across Minnesota:

- About 5 to 10% of all residents who died, and 1 to 5% of all residents who visited the hospital or emergency room for heart and lung problems, did so partly because of fine particles in the air or ground-level ozone.
- This is roughly 2,000 to 4,000 deaths, 500 additional hospital stays, and 800 emergency room visits.

Who is impacted by air pollution and where?

All Minnesotans are affected by pollution from the air we breathe, but vulnerable populations, such as seniors, people with pre-existing heart or lung conditions, and children with uncontrolled asthma are affected more than others. The report findings include:

- There are small differences in annual average air pollution levels across Minnesota counties. However, higher levels of ozone pollution are found in the southern region of the state, while fine particle levels are highest in metro and parts of southeast Minnesota.
- Air pollution affecting health is not just a big city or metro issue. Across the state, counties with larger populations of people without health insurance or living in poverty experience the highest rates of health-related impacts from air pollution.

> Communities and regions with the highest burden include senior populations in the metro, central, and southeast parts of Minnesota.

Health benefits of improving air quality

Improving air quality can provide significant public health benefits. Over the last decade, air pollution across Minnesota has improved. However, it is critical that we adopt programs and policies to further reduce air pollution and increase health resilience, as air quality threats from wildfires and climate change are forecast to get worse in Minnesota. In addition to reducing air pollution, critical steps include addressing health inequities by removing barriers to care, doing more to prevent heart and lung diseases, and ensuring that all Minnesotans have what they need to thrive. There is growing evidence, including outcomes from the 2015 Life and Breath report for the Twin Cities metro area, that there are disparate health impacts of air pollution on communities with higher populations of people of color, so improving air quality is important for reducing health inequities.

This report, as a follow-up to the Life and Breath Twin Cities metro area report, found that if we reduce 2013 fine particles and ground-level ozone levels by 10%—roughly equal to the air quality improvements seen in the past decade—the following adverse health events could be prevented:

- 200 to 500 early deaths
- 70 hospitalizations
- 150 emergency department visits

The results of this report, along with other MPCA and MDH analyses and meaningful stakeholder engagement, will help us direct pollution reduction resources where they can help address environmental justice and health equity goals. Some progress has begun with the introduction of Environmental Assistance Grants, such as a settlement from the Volkswagen lawsuit at MPCA, and the Eliminating Health Disparities Initiative at MDH.

More about the study

This report is the result of long-term collaboration between the MPCA and MDH as part of the interagency Joint Environmental Risks Initiative. This analysis used mathematical modeling that takes data from epidemiological studies paired with air and health data to estimate the toll of air pollution. This report used mathematical modeling software, Environmental Benefits Mapping and Analysis Program-Community Edition (BenMAP-CE), which estimates the proportion of hospital admissions, emergency department visits, and deaths due to ambient air pollution. BenMAP-CE was developed by the U.S. Environmental Protection Agency (EPA), and uses established estimates of the relationship between air pollution and health from pivotal peer-reviewed scientific studies.

Like all scientific estimates, the estimates in this report come with some uncertainty and should not be taken as exact measures of impacts. However, they are useful for demonstrating the general size and scope of the problem and to confirm that air pollution poses a serious health threat. Because this report provides a general population-level snapshot of the impacts of air pollution across Minnesota in 2013, it does not address an individual person's exposures and health impacts, or how impacts related to higher or lower exposures within counties can change over time.

Introduction

Minnesota policy-makers and communities have expressed concern over the role air quality plays in health and health disparities. In 2015, the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Health (MDH) analyzed health impacts from air pollution in the Twin Cities Metro area and released our first report: Life and Breath: How air pollution affects public health in the Twin Cities. At that time, air quality in Minnesota met federal health-based standards (and it continues to meet standards); however, findings showed significant impacts of air quality on heart and lung health, and even premature death. Estimated air quality differences across the Twin Cities were small, but the disparate burden of health impacts pointed to vulnerabilities among lower income areas and communities of color. This updated Life and Breath report expands the analyses to Greater Minnesota, estimating the health impacts of fine particles and ozone pollution for each county in Minnesota.

The goal of this report is to inform decisions that can meaningfully reduce air pollution, its impacts on disease and death, and the underlying health inequities and environmental injustices. MPCA and MDH work collaboratively with partners under the Joint Environmental Risks Initiative to collect and analyze data to inform pollution reduction initiatives and health promotion and disease prevention programs through education and outreach.

Reducing air pollution is important, but not the whole picture. Public health resilience also depends on advancing health equity. Seniors, people with pre-existing heart or lung conditions, and children with uncontrolled asthma experience more severe health impacts when there are subtle changes in air quality. Likewise, structural inequities, including lack of access to quality health care, economic and social opportunities, cumulative impacts from other exposures, and social stressors, all take a toll on health resilience and quality of life.

This report estimates the impact of annual average fine particle pollution (also known as particulate matter less than 2.5 micrometers in diameter, or $PM_{2.5}$) and ground-level ozone on a range of health outcomes, including respiratory and cardiovascular hospital admissions, emergency department visits, and deaths. In addition, the report estimates how many health impacts could be avoided from a 10% decrease in ambient air pollution. Moving forward, the information provided in this report will be used to raise awareness about air pollution and health, inform pollution reduction and health promotion programs, and support work with partners to advance environmental justice and health equity.

Sources of air pollution

When air quality is bad in Minnesota, it is generally because of higher than usual concentrations of fine particles or ozone. These pollutants are caused by a number of sources, such as vehicles, tractors, construction equipment, power plants and other facilities burning fossil fuels, as well as residential wood burning for heat and recreation. Wildfires and other short-term events also impact air quality, but may not be captured accurately in modeled air data for this analysis.

Fine particles are made up of a complex mixture of extremely small solid and liquid particles.

- Particles are a combination of organic chemicals, acids, metals, and soil or dust.
- Burning coal, gasoline, diesel, wood, and other fuels releases fine particles directly in the environment. They can also be created indirectly through chemical reactions among other air pollutants.

Ozone is a colorless gas composed of three atoms of oxygen.

- In the upper atmosphere it helps protect the earth from the sun's ultraviolet radiation. At ground level, however, ozone can be a harmful pollutant, also known as smog.
- Ground-level ozone is created in the air through a chemical reaction of nitrogen oxides (NO_X) and volatile organic compounds (VOCs) mixing in the presence of sunlight and high temperatures.

Learn more about air pollution:

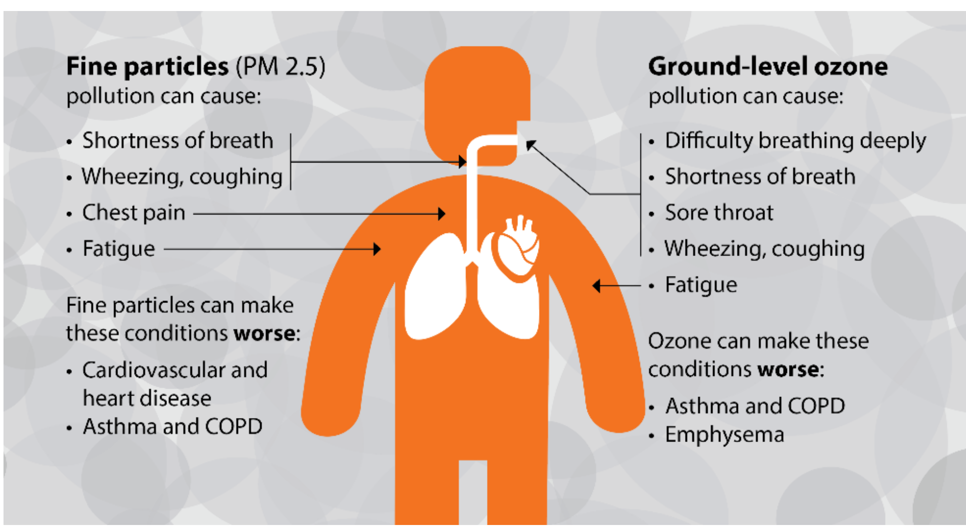
- Air pollutants and sources: https://www.pca.state.mn.us/air/air-pollutants-and-sources
- County air emissions and sources: https://www.pca.state.mn.us/air/statewide-and-county-air-emissions

Types and intensity of air pollution sources vary across the state, so pollution levels also differ substantially between pockets of urban areas close to major highways compared to rural, less densely populated regions. Fine particles can travel thousands of miles from the source, and some pollution in Minnesota comes from sources outside of Minnesota. Higher concentrations of ozone in Minnesota typically occur in the summer, when daylight hours are long and temperatures are high. Areas downwind of city centers can experience higher concentrations of ozone, which is often transported long distances. Between 2008—the year of air data for the original Life and Breath report across the Twin Cities metro area—and 2013, fine particle concentrations in Minnesota decreased by about 10% while ozone concentrations remained roughly the same.[i]

Many air pollutants can negatively impact health, and the MPCA works to regulate and reduce emissions. This report focuses on fine particles and ozone because they are the primary drivers of unhealthy air in Minnesota and well-known causes of adverse health events.[ii] [iii]

Air pollution and health

Minnesotans' health is shaped by many things. Access to quality health care, family health history, and community and environmental conditions are all important. Air pollution exposure, even at low and moderate levels, can contribute to serious illnesses and early death. When the air quality is unhealthy, people with heart and lung conditions may be more impacted and experience symptoms like chest pain, shortness of breath, wheezing, coughing, or fatigue. Other groups of people who may be more sensitive to air pollution include children, seniors, or people of all ages who do extended or heavy physical activity like playing sports or working outdoors.



Health effects of air pollution are well documented in the scientific literature. Impacts range from increased symptoms, medication use, and doctor visits, to hospital visits, and even death. Risks of certain health impacts are related to higher air pollution concentrations, and these impacts can be quantified. This report focuses on severe health events that have been strongly linked with fine particle and ozone pollution, including premature deaths, respiratory and cardiovascular hospitalizations, and emergency department visits.

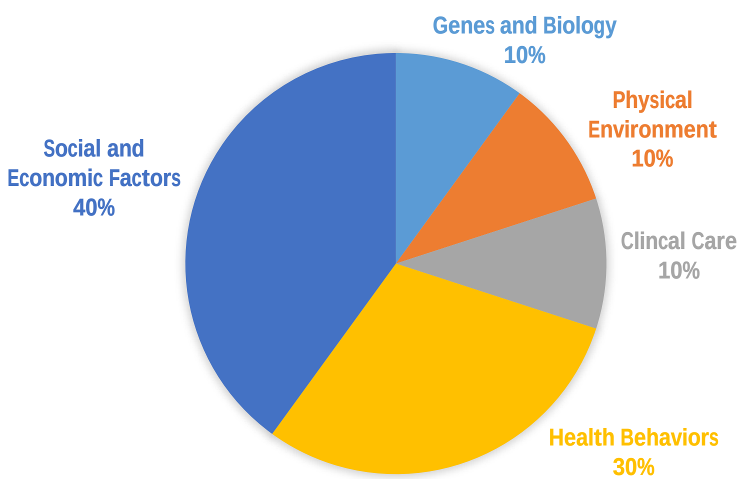
Achieving healthy air for all

All Minnesotans deserve to live in conditions that support a healthy and fulfilling life. Good health and a safe and clean environment are fundamental to this goal, but we are falling short for some Minnesota communities. Advancing health equity and environmental justice are MDH and MPCA agency priorities. These frameworks guided this analysis, and will inform how these results are integrated into the work and partnerships of both agencies.

Health equity

Health equity is the state of being where everyone has what they need to be healthy. In Minnesota, on average, residents rank among the healthiest in the nation—but those averages do not tell the whole story. Minnesota has some of the largest health disparities in the country. The common belief used to be that good health was due to quality medical care and personal choices alone, but we know now that social and economic structural factors, such as education, income, racial discrimination, transportation, community social status, and housing, are major contributors to overall health (Figure 1).[iv]

Figure 1. Social determinants of health



To ensure health equity for all Minnesota communities, we must work toward comprehensive public health solutions that acknowledge and address the range of factors that support health. In relation to air pollution, the conditions that can make individuals and communities more vulnerable to negative impacts must be considered. These includes age, neighborhood resources, pre-existing illness or disability, and structural social and economic inequities. This report quantifies geographic differences across counties with higher or lower proportions of populations of color and indigenous people, residents living in poverty, sensitive age groups, and health insurance coverage. Exploring disparities in this way provides a starting place for better understanding the range of factors that may drive inequitable health impacts of air pollution and how to act to achieve change.

Learn more about health equity at MDH: http://www.health.state.mn.us/divs/che.

Environmental justice

The MPCA is committed to making sure that pollution does not have a disproportionate impact on any group of people — the principle of environmental justice. This means that all people — regardless of their race, color, national origin or income — benefit from equal levels of environmental protection and have opportunities to participate in decisions that may affect their environment or their health.

When it comes to air pollution, the commitment to environmental justice necessitates thinking about where roads and industries are located, and which communities are most impacted by those air pollution sources. This report explores county-level air quality and health disparities, but other work is being done to look at many communities in greater detail.

Learn more about environmental justice at MPCA: https://www.pca.state.mn.us/EJ.

Strategies to improve air and health

It is critical that sustainable programs and policies are adopted to reduce air pollution and increase health resilience, as air quality threats from wildfires and climate change are forecast to get worse in Minnesota.[v] MPCA is working with partners to:

- Reduce pollution in population centers
- Focus on areas of concern for environmental justice
- Offset excessive vehicle emissions through a settlement with Volkswagen
- Improve understanding of air quality at the community scale
- Increase awareness about air quality forecasts, alerts, and tools for communities and health care providers

A focus on advancing health equity and addressing differences in outcomes by poverty, age, race, and location, in conjunction with reductions in air pollutants, is key to reducing health impacts of poor air quality. MDH strives to:

- Work toward health systems and environmental regulations and interventions that promote a healthy environment and quality of life for all
- Expand linkages between communities and clinical care and prevention resources
- Advance health-based guidance for key air pollutants
- Track connections between environmental exposures, inequities and health outcomes
- Identify current vulnerable populations and determine sub-groups of greatest susceptibility for future risks

Methods

Data and analysis for this report are similar to the 2015 Life and Breath report, which focused on the 165 zip codes comprising the seven-county Twin Cities metro area. Here, pollution attributable health impacts are estimated for Minnesota's 87 counties and eight state regions, known as the State Community Health Services Advisory Committee regions.

Health impacts were estimated using mathematical modeling from the EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE), a tool for estimating health impacts associated with changes in air pollution over a defined geographical region. BenMAP-CE is a publicly available model that is free to download and has been applied extensively in health effects studies both in the U.S. and globally.[vi] For each county, average annual fine particle pollution and summertime ozone concentrations were matched with hospitalizations, emergency room visits and deaths to generate overall estimates of the proportions of health impacts that can be attributed to air pollution.

For the purposes of this report, a brief description of the data and analyses is provided. Detailed descriptions of analytic methods can be found in the 2015 Life and Breath report.

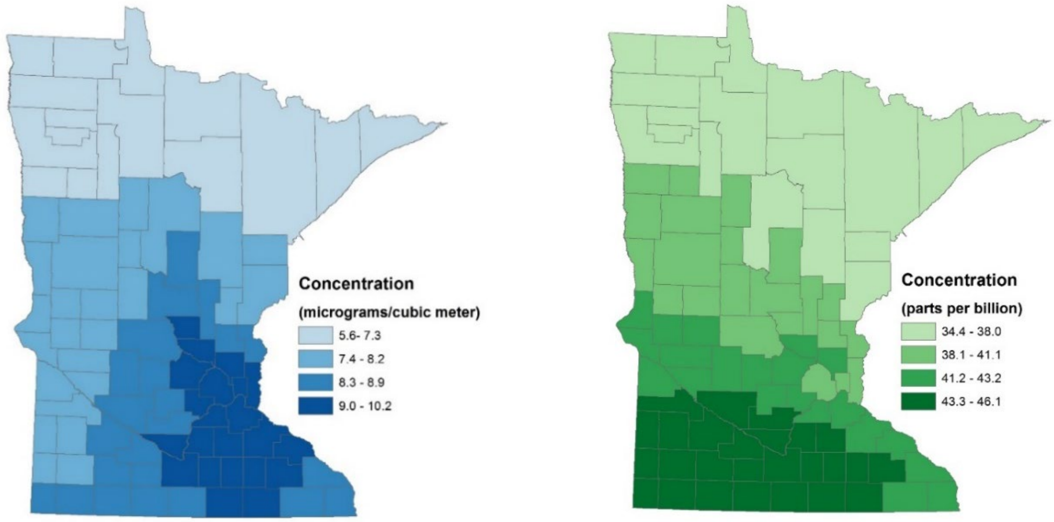
Air quality data

This report estimated air pollution concentrations using a "downscaler" model, which combines data from air monitors with modeled data for areas of the state where no monitors exist. The data used in this analysis are 2013 – the most recent year of modelled data available – annual average of fine particles, or $PM_{2.5}$, (daily 24-hour average) and the warm season (May-September) average ozone (8-hour maximum). Overall, 2013 was a representative year for recent air quality in Minnesota. Both annual fine particles and seasonal ozone average concentrations were similar to concentrations in the years just before and just after.

> Average fine particle concentrations were almost twice as high in counties surrounding the Twin Cities compared to northern counties (Figure 2).
>
> Average ozone concentrations were one-and-a-half times as high in some southern counties compared to some northern counties.

The 2013 air data are comprised of average daily census tract concentrations. Air pollution concentrations were aggregated over time to provide annual average values, and then across space to provide county and regional-level annual and seasonal average values. Using these averages helps approximate chronic exposures, but also smooths out local variations over time and space. For estimates of health impacts attributable to fine particles and ozone pollution, natural background levels (the amount of the pollutants in the air not produced by humans) of these pollutants were subtracted. Subtracting natural background concentrations (0.84 micrograms per cubic meter for fine particles and 27.7 parts per billion for ozone) gives us a sense of the total health burden of air pollution that could theoretically be influenced by Minnesota's actions and policies. However, to understand the context of total air pollution across the state, Figure 2 includes the background levels below.

Figure 2. Annual average fine particles (left) and summertime ozone (right), by county (2013)*



*Concentrations include natural background

Health data

While air quality can affect health and well-being in many direct and indirect ways, this report focuses on certain severe health events that have been directly linked with air pollution, including hospitalizations and emergency department (ED) visits for respiratory and cardiovascular conditions and premature deaths (i.e., deaths that were statistically unlikely to have happened when they did, if not for exposure to polluted air). We focus on these health outcomes because they have been strongly linked with ozone and fine particle pollution in the EPA's Integrated Science Assessments, which draw on multiple lines of evidence, including toxicology, epidemiology and controlled human exposure. [ii] [iii] These critical outcomes do not tell the whole story of air and health, however, because they do not account for the more common (but harder to measure) situations where poor air quality may trigger lung and heart disease symptoms, missed days of work or school, or limit activities and diminish overall quality of life.

Hospitalization and ED visit data were obtained from the Minnesota Hospital Association. The data set covers nearly all of Minnesota's hospitals, but does not include federal and sovereign facilities, such as Veteran's Administration and Indian Health Services locations. The inability to access these data may mean certain populations were under-represented in some estimates. Death data were obtained through the MDH Office of Vital Records for primary cause of death. Appendix A describes details related to hospitalization and ED visit diagnosis codes for asthma, chronic obstructive pulmonary disease (COPD), all respiratory conditions, and all cardiovascular conditions.

> In general, hospital visit and death rates vary widely across the state, compared to small differences in annual air pollution concentrations.

This report provides county and regional rates of hospital visits and deaths in the Results section alongside air pollution attributable rates and fractions (i.e., percent of total events). Respiratory and cardiovascular hospitalizations and ED visits, all-cause deaths, and cardiopulmonary deaths for each county were averaged over five years centered on 2013 (i.e., 2011 to 2015) to protect privacy and ensure stable rates for each county. Rates for each county were based on total population data from matching years of the U.S. Census Bureau's American Community Survey five-year estimates (2011-2015). For counties that had five or fewer hospital visits, this report used an empirical method to aggregate neighboring county data to further ensure stable rates. Details on this aggregation method using the Geographic Aggregation Tool[vii] are provided in Appendix B. Health data were analyzed in Statistical Analysis System 9.4.[viii]

Estimating health impacts of air pollution

Pivotal peer-reviewed epidemiology studies of the relationship between fine particles and ground-level ozone with hospitalizations, ED visits and deaths provide the basis for estimates of the attributable impacts of air pollution. The most appropriate studies were identified to derive air pollution effect estimates (also known as concentration-response functions). The effect estimate is the unique number characterizing the relationship between the level of exposure to fine particle or ozone pollution and likelihood of a specific health event in a specific population. The chosen studies and corresponding estimates are found in Appendix C. These effect estimates were used in BenMAP-CE modelling to estimate the proportion of population health events that were attributable, or due in part, to air pollution concentrations.

In the case of all-cause premature deaths, two statewide estimates of the number of deaths attributable to fine particle pollution are reported in this report. These estimates are based on two highly respected long-term cohort studies: Harvard 6-Cities (H6C) study and American Cancer Society (ACS) study.[ix][x] While there are strengths and weaknesses to both studies, EPA and other researchers have extensively employed the effect estimates from each study, and this report aims to be consistent with this body of work. The H6C study is a set of six economically diverse cities, while the ACS study includes a much larger population from a broader geographic area of mostly white communities. The effect estimate derived in the H6C study is roughly twice as high as the effect estimate from the ACS study; that is, using the H6C would produce an estimate of about twice as many premature deaths attributable to fine particle pollution than using the ACS study effect estimate. For the earlier Life and Breath metro area report, the H6C study better reflected the population of the Twin Cities area. However, for the state as a whole, both studies were valid for this report. The broad range in results helps emphasize that the aim is not to provide precise estimates of health impacts from air pollution in Minnesota, but rather to convey the general magnitude of the problem.

Reducing air pollution by 10 percent

Quantifying potential impacts of reducing air pollution can help decision-makers set targets and distribute resources. This report used a statewide 10% reduction scenario to estimate health impacts that could be avoided with improved air quality. A 10% reduction scenario is an achievable air quality improvement goal recommended by Clean Air Minnesota, a consortium of leaders of Minnesota's business, government, and nonprofit sectors. To quantify potential benefits, 2013 average air pollution levels were decreased by 10% using mathematical models across the state, and then compared to the estimated number of air pollution attributable health impacts between the 2013 air quality levels and the 10% reduction levels.

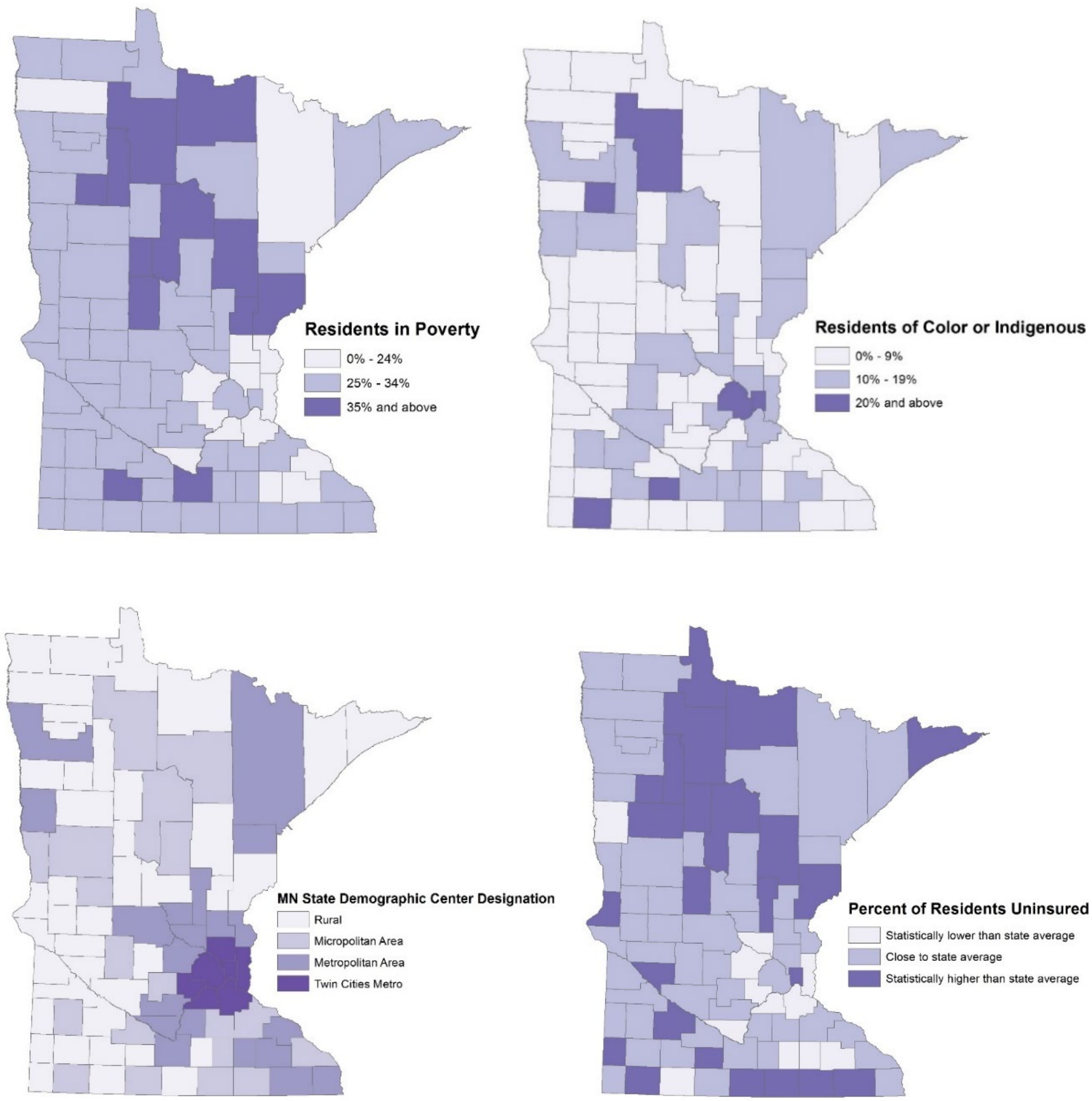
Identifying health inequities

Quantifying differences in health outcomes across known social determinants of health is one way to identify health inequities. In this report we used four factors; poverty status, racial and ethnic composition, health insurance coverage, and urban-rural location to examine whether areas with different social economic population characteristics experience differential impacts of air pollution. This approach follows the large and growing environmental health disparities literature that demonstrates and seeks to understand how these social and economic factors, and the structural inequities they represent, work to diminish health resilience and drive disparate impacts.

To quantify inequities in premature mortality by the four aforementioned factors (poverty, race, health insurance and location), this report used the total number of deaths with population-weighted average air pollution concentrations (i.e., an average value based on the weighted population of each group of counties) to calculate attributable health impacts. Weighting average air pollution estimates to correspond to population density allows for more reliable estimates of population-level impacts. We focused on mortality inequities because they are the most severe and numerous impact in this analysis. Additionally, this report looks separately at mortality and hospital visit impacts by age.

- Counties were categorized according to each of these four factors (Figure 3). Poverty and race/ethnicity data were drawn from the U.S. Census Bureau's 2011-2015 American Community Survey. Racial and ethnic composition for each county was measured as the percent Indigenous, Black, or People of Color (IBPOC) residents. Highest rates of IBPOC residents were in the Twin Cities and in some Greater Minnesota counties. In general, differences in the size and composition of IBPOC population across counties makes it hard to characterize differences in exposure and health risks across groups.
- Poverty rates were measured as the percent of residents living below twice (200%) the Federal Poverty Line. While rates of poverty were somewhat higher in Greater Minnesota counties, compared to counties in the Twin Cities metropolitan region, county-level rates mask within-county inequality and areas of concentrated poverty.
- Urban and rural categories were drawn from the Minnesota State Demographic Center.[xi] Greater Minnesota counties defined as "metropolitian" or "micropolitan" include one or more bordering counties that are integrated based on commuting patterns with an urban core, capturing communities that cross county borders on a regular basis (Figure 3).
- Insurance coverage rates for each county were drawn from the U.S. Census Bureau's Small Area Health Insurance Estimates (SAHIE) program. The SAHIE program models health insurance coverage estimates using data from several sources including the American Community Survey. The report calculates how coverage rates in each county compared to the state as a whole, and defined three categories based on whether county rates showed statistically significant differences from the statewide rate (Figure 3). These categories correspond to statistically lower (4.3 - 5.7%), statistically equivalent (5.8 - 7.8%), and statistically higher (7.9 - 12.3%) un-insurance rates. Counties with higher percentages of residents without insurance coverage were spread across the state. While insurance coverage is one way to measure healthcare access, it likely does not capture many aspects of accessibility and quality of care, which may also vary across counties and regions.

Figure 3. Demographic categorizations of Minnesota counties: Poverty rates, racial/ethnic composition, urban and rural classifications and residents without insurance coverage



Although concentrations of air pollution varied up to two-fold across Minnesota counties, there were not large differences in concentrations between demographic categories of counties' poverty, racial/ethnic composition, urbanicity, or level of uninsured population. For example, counties with more than 35% of the population living in poverty tended to have slightly lower average concentrations of both fine particles and ozone (Table 1), and make up the more rural geographic areas of the state (Figure 3). Counties with higher percent IBPOC residents had slightly higher average levels of fine particle pollution, but similar average levels of ozone pollution (Table 1). These differences are small, but small changes in air pollution exposure can be important for health, especially among sensitive populations. Importantly, average air pollution concentrations by county can hide finer-scale variability that arise based on how pollution sources are distributed across an area, especially in more urbanized regions.

Table 1. Population-weighted average air quality by poverty and racial/ethnic composition

County Group	Average $PM_{2.5}$ concentration (micrograms per cubic meter)	Average ozone concentration (parts per billion)
All counties	9.3	41.1
Counties with:		
0-25% residents in poverty	9.3	41.2
25-35%	9.4	41.2
35% or more	8.0	39.6
Counties with:		
0-10% Indigenous, Black, People of Color residents	8.6	41.3
10-20%	9.1	41.1
20% or more	10.1	40.9
Counties that are:		
Rural	7.9	40.5
Micropolitan	8.5	41.6
Metropolitan	8.6	40.5
Twin Cities metro area	10.0	41.3
Counties with:		
Lower than state average uninsured population	9.5	41.5
Close to state average uninsured population	8.8	40.5
Higher than state average uninsured population	9.8	40.8

Results

Statewide air pollution attributable health impacts

The results presented here are not counts of specific individuals, but rather estimates of health impacts attributable to air pollution for whole populations. We used mathematical models with inputs from large scale epidemiology studies (Appendix C) and thus these data are not to be taken as exact numbers of heart and lung hospitalizations, ED visits or deaths caused by air pollution alone. The estimates are meant to provide a better understanding about health impacts due to air pollution exposure and are not based on tracking individual level exposures and health outcomes. Some of the health outcomes presented can result in short-term impacts (e.g., an increase in ED visits due to more asthma attacks on poor air quality days), and others (e.g., cardiovascular hospitalizations) may present after longer periods of exposure to air pollution.

In 2013, fine particle pollution contributed to an estimated 2,000 to 4,000 deaths, 300 respiratory hospitalizations, 140 cardiovascular hospitalizations, and 525 asthma-related ED visits across the state of Minnesota (Table 2). This report uses two epidemiology studies' data for modeling early death related to fine particles concentrations with different age strata (25 and older, and 30 and older) to estimate a range of premature deaths likely attributable to air pollution. In this analysis, the largest impact from fine particle pollution is early death, with up to 10% of deaths statewide due in part to fine particle pollution in 2013.[xii]

The report estimates that a 10% reduction in fine particles levels from 2013 annual average concentrations could have avoided between 200 and 500 early deaths, 35 respiratory hospitalizations, 15 cardiovascular hospitalizations and close to 60 asthma ED visits.

Table 2. Estimated Minnesota health events attributable to fine particle pollution in 2013

Health effect	Age group*	Attributable number of events (95% CI)**	Percent of total events (95% CI)**	Attributable rate of events per 100,000 people (95% CI)**	Avoided events from 10% reduction in $PM_{2.5}$*** (95% CI)**
All-cause deaths: Estimate 1****	25 and older	4,098 (2,098 - 5,983)	10.2% (5.2% - 14.9%)	112.8 (57.8 - 164.7)	474 (237 - 709)
All-cause deaths: Estimate 2****	30 and older	1,866 (1,270 - 2,449)	4.7% (3.2% - 6.2%)	57.1 (38.9 - 75.0)	210 (142 - 278)
Asthma hospitalizations	Under 18	15 (0 - 75)	1.7% (0% - 8.8%)	1.2 (0 - 5.9)	1.6 (0 - 8.6)
Asthma and COPD hospitalizations	18 to 64	61 (21- 100)	1.8% (0.6% - 3.0%)	1.8 (0.6 - 2.9)	6.7 (2.3 - 11.1)
All respiratory hospitalizations	65 and older	249 (144 - 352)	1.7% (1.0% - 2.5%)	33.0 (19.1 - 46.8)	27.6 (15.9 - 39.2)
Asthma emergency department visits	All ages	525 (146 - 896)	2.4% (0.7% - 4.1%)	9.7 (2.7 - 16.5)	58.3 (16.1 - 100.2)
Cardiovascular hospitalizations	65 and older	140 (53 - 226)	0.6% (0.2% - 0.9%)	18.6 (7.1 - 30.0)	15.4 (5.9 - 24.9)

*Each age group is unique to represent the specific epidemiological study and the effect estimate

**95% confidence intervals are the range within which one can be 95% confident that the true value lies.

*** 2013 annual average $PM_{2.5}$ levels minus natural background levels.

**** As described above in the Methods section, two major studies of the relationship between fine particle pollution and early deaths—the Harvard 6-Cities study and the American Cancer Society study—were used in the analysis (see page 9 above).

Attributable rate (AR) is the estimated rate of health impacts due to air pollution in a specific population. This is a good measure of a population's overall vulnerability to air pollution, whether due to differences in exposure level or differences in underlying structural inequities. A population-based rate helps to make clear comparisons between counties or groups of differing sizes.

Percent of total events due to air pollution – also referred to as the Attributable Fraction – is the proportion of total health events caused by air pollution. This measure can help to tease out the specific contribution of air pollution to health outcomes compared to health effects from other structural inequities.

In 2013, summertime ground-level ozone pollution contributed to an estimated 57 cardiopulmonary deaths, 55 asthma hospitalizations, and close to 300 asthma-related ED visits (Table 3). By reducing ground-level ozone by 10% from 2013 levels, 18 deaths, 17 asthma-related hospitalizations, and close to 95 asthma ED visits could have been prevented.

Table 3. Estimated Minnesota health events attributable to ozone in 2013

Health effect	Age group	Attributable number of events (95% CI)*	Percent of total events (95% CI)*	Attributable rate of events per 100,000 people (95% CI)*	Avoided events from 10% reduction in ozone** (95% CI)*
Cardiopulmonary deaths	All ages	56.7 (21.3 - 91.8)	1.1% (0.4% - 1.7%)	1.0 (0.4 - 1.7)	17.7 (6.6 - 28.6)
Asthma hospitalizations	All ages	54.7 (33.8 – 75.0)	4.8% (3.0% - 6.6%)	1.0 (0.6 - 1.4)	17.2 (10.6 - 23.7)
Asthma emergency department visits	All ages	299 (0 - 648)	3.2% (0.0% - 6.9%)	5.5 (0 - 12.0)	93.7 (0 - 206)

*95% confidence intervals. These intervals are within which the true value is expected 95 out of 100 times.
** 2013 May-September seasonal average ozone levels minus natural background levels.

Statewide air pollution, mortality, and health equity impacts

As a first step toward understanding unequal impacts of air pollution across the state, this section looks at differences in early death rates by county for a number of known social determinants of health and risk factors, including poverty rates, racial and ethnic composition, health insurance coverage rates, and urban-rural categories. These analyses of mortality impacts show that health consequences from air pollution are highest in areas with the most vulnerable populations.

Mortality and poverty rates

The report estimates that areas with higher rates of poverty had higher attributable early death rates related to both fine particle and ozone pollution (Table 4). This pattern of higher vulnerability to air pollution in higher poverty areas reflects how the underlying burden of lower socioeconomic status may drive the increase in risk of early death. Moreover this applies to other demographic characteristics associated with lower socioeconomic status: people of color, people with lower access to health care and people living in rural areas tend to be more vulnerable to health impacts, including premature death from air pollution.

Table 4. Air pollution attributable death by county poverty rate

County group	$PM_{2.5}$ (all-cause, ages 25+)*			Ozone (cardiopulmonary causes, all ages)		
	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events
Statewide population	1,103.0	112.8	10.2%	98.4	1.05	1.1%
0-25%	918.3	94.4	10.3%	79.6	0.82	1.0%
25-35%	1,181.5	122.2	10.3%	106.5	1.16	1.1%
35% or more	1,421.9	125.6	8.8%	130.5	1.22	0.9%

* Effect estimate for all-cause mortality from Lepuele et al. Harvard Six Cities study.

Mortality and racial/ethnic composition

Areas with higher IBPOC populations experience slightly higher average annual fine particle pollution, which may contribute to their higher percentage of total deaths attributable to fine particles pollution (11.3%). Counties falling into the highest IBPOC group include the Twin Cities and four additional counties—two in the northwest and two in the southwest. The death rate attributable to air pollution in these counties is higher than the statewide rate, but lower than the group of counties with the lowest percentage of IBPOC populations (Table 5). The fact that this analysis estimates the highest air pollution attributable rates for the lowest IBPOC counties should not be seen as evidence that IBPOC communities are less vulnerable to the health impacts of air pollution. On the contrary, this report looks at areas of the state, not at individuals or communities, and there are an array of factors, in addition to the population's racial and ethnic composition, characterizing these different areas. The higher pollution attributable death rates in the lower IBPOC counties is likely due to the higher underlying death rates in more rural counties, which tend to have older populations than more urban areas of Minnesota, but also have less racial diversity. Moreover, the granular neighborhood level information related to the health impacts of air pollution on race and mortality can be lost when summarizing county level outcomes.

Table 5. Air pollution attributable death by county populations of IBPOC

County group	$PM_{2.5}$ (all-cause, ages 25+)*			Ozone (cardiopulmonary causes, all ages)		
	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events
Statewide population	1,103.0	112.8	10.2%	98.4	1.05	1.1%
Percent Indigenous, Black, or People of Color						
0-10 percent	1,297.6	122.1	9.4%	127.5	1.38	1.1%
10-20 percent	1,050.1	104.5	9.9%	92.9	0.97	1.0%
20 percent or more	1,027.6	116.5	11.3%	84.3	0.90	1.1%

* Effect estimate for all-cause mortality from Lepuele et al. Harvard Six Cities study.

Mortality and health insurance coverage rates

This analysis estimates that areas with higher rates of uninsured residents, compared to the statewide average, had higher attributable early death rates related to both fine particle and ozone pollution (Table 6). Similar to results for county poverty rates, this pattern reflects how the underlying burden from inadequate health coverage may drive the increase in risk of early death.

Table 6. Air pollution attributable death by county level of uninsured populations

County group	$PM_{2.5}$ (all-cause, ages 25+)*			Ozone (cardiopulmonary causes, all ages)		
	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events
Statewide population	**1,103.0**	**112.8**	**10.2%**	**98.4**	**1.05**	**1.1%**
Under 5.8% uninsured	859.4	91.6	10.7%	73.7	0.86	1.2%
5.8-7.7% uninsured	1,151.1	116.3	10.1%	104.0	1.07	1.0%
Over 7.7% uninsured	1,300.0	132.1	10.2%	116.8	1.23	1.1%

* Effect estimate for all-cause mortality from Lepuele et al. Harvard Six Cities study.

Mortality across urban/rural counties

The report estimates that rural and micropolitan areas had higher attributable early death rates related to both fine particle and ozone pollution (Table 7), further pointing to the overlap between underlying death rates, poverty, and health insurance coverage in rural areas of the state. As described in the discussion of attributable rates according to racial/ethnic population, the underlying factor driving higher vulnerability in more rural areas is that rural populations in Minnesota are generally older.

Table 7. Air pollution attributable death by Office of Rural Health Designation

County group	$PM_{2.5}$ (all-cause, ages 25+)*			Ozone (cardiopulmonary causes, all ages)		
	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events	Rate per 100,000 people	Attributable Rate per 100,000 people	Percent of total events
Statewide population	**1,103.0**	**112.8**	**10.2%**	**98.4**	**1.05**	**1.1%**
Rural	1,524.6	134.1	8.8%	158.5	1.66	1.0%
Micropolitan area	1,428.7	134.8	9.4%	139.8	1.57	1.1%
Metropolitan area	1,155.7	109.7	9.5%	103.2	1.01	1.0%
Twin Cities metro	924.6	104.7	11.3%	75.7	0.83	1.1%

* Effect estimate for all-cause mortality from Lepuele et al. Harvard Six Cities study.

Statewide air pollution impacts by age

Populations 65 years and older had the highest attributable early death rate (422 per 100,000 people) and hospitalization rate (33 per 100,000 people), while children less than 18 years of age had the highest rates of attributable asthma ED visits: 18 per 100,000 people and 11 per 100,000 for children under 18, for fine particles and ozone exposure respectively (Table 8 and Figure 4). Overall, adults 65 and older is the age group in this analysis with the highest rates of hospitalizations due to asthma, COPD or other respiratory illness due to the effects of air pollution (Table 8 and Figure 5).

Table 8. Statewide selected health impacts by age group

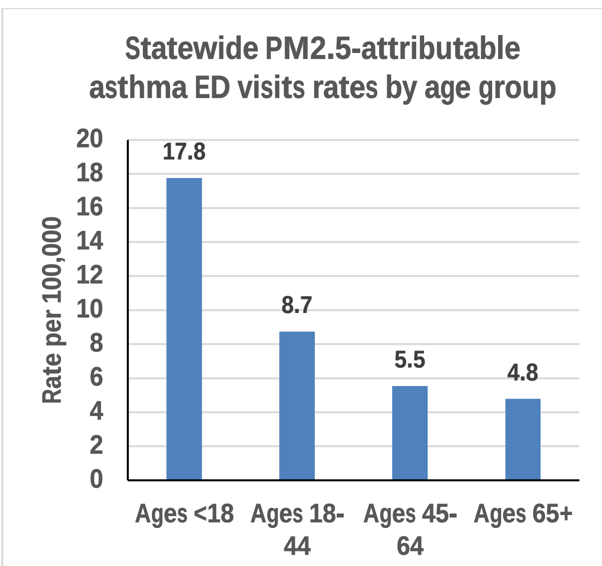
Age group	Fine particles			Ozone		
	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events	Rate per 100,000 people	Attributable rate per 100,000 people	Percent of total events
Death						
	All cause (ages 25+)*			Cardiopulmonary causes (all ages)		
Under 18				1.7	0.02	1.1%
25-44 or 18-44	99.5	10.1	10.1%	4.7	0.1	1.1%
45-64	463.7	46.8	10.1%	47.3	0.5	1.1%
65 and older	4226.9	422.8	10.0%	601.6	6.5	1.1%

Respiratory hospitalizations						
	Asthma and chronic obstructive pulmonary disease (COPD)			Asthma		
Under 18	80.0	1.1	1.4%	31.5	1.6	5.0%
18-44	34.4	0.6	1.8%	10.7	0.5	4.9%
45-64	182.3	3.2	1.8%	20.1	1.0	4.9%
65 and older	703.3	33.0	4.7%	30.3	1.5	4.9%
Asthma Emergency Department Visits						
Under 18	748.1	17.8	2.4%	325.1	10.7	3.3%
18-44	377.5	8.7	2.3%	166.4	5.4	3.2%
45-64	240.2	5.5	2.3%	97.9	3.2	3.2%
65 and older	211.3	4.8	2.3%	83.7	2.7	3.2%

* Effect estimate for all-cause mortality from Lepuele et al. Harvard Six Cities study.

The number of asthma ED visits are influenced by both fine particles and ozone; however, this analysis shows that a greater number of events are attributable to fine particles. While all age groups are impacted, the most sensitive group in this analysis is the pediatric population under 18 (Figure 4). The number of deaths attributable to fine particles is much larger than deaths attributable to ozone, a far more prominent difference than those seen for asthma ED visits (Figure 5). For both pollutants, the 65 and older populations are most vulnerable than other age groups to pollution attributable deaths (Figure 5).

Figure 4. Asthma ED attributable rates for fine particles (left) and ozone (right) by age group in 2013 (per 100,000 people)



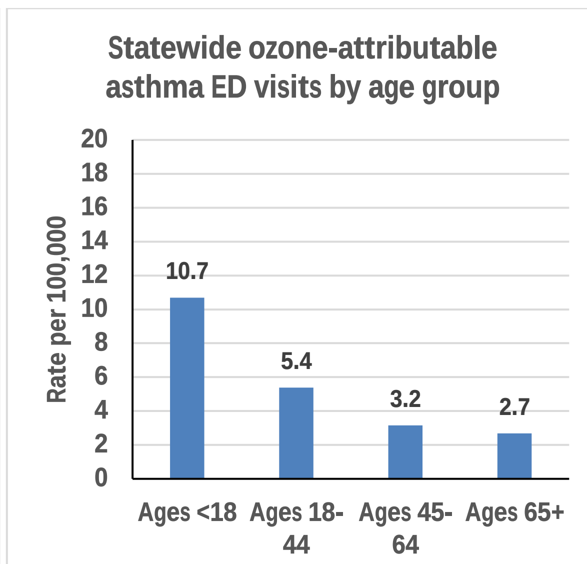
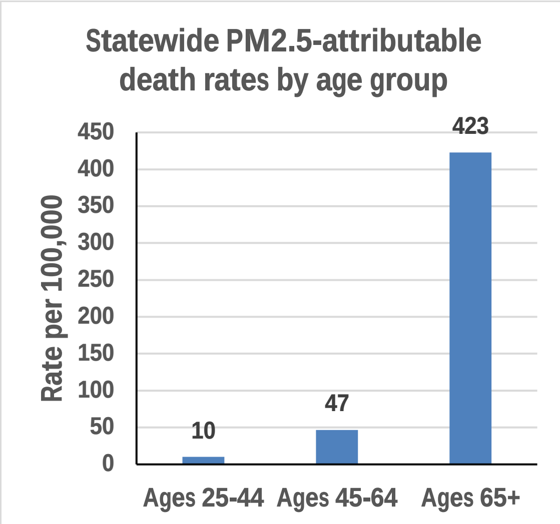
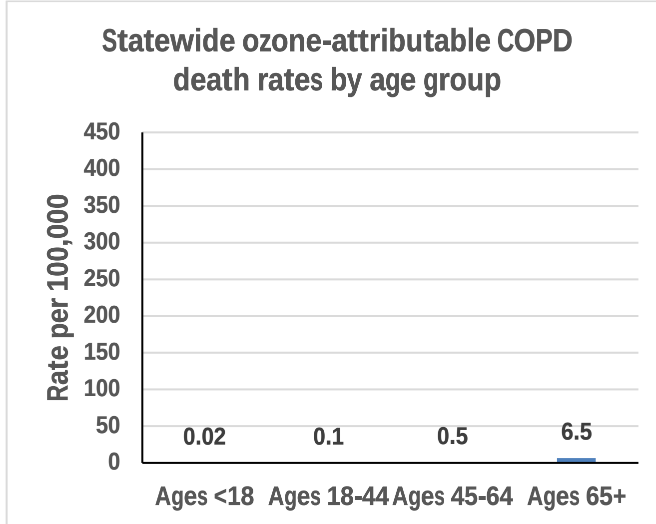


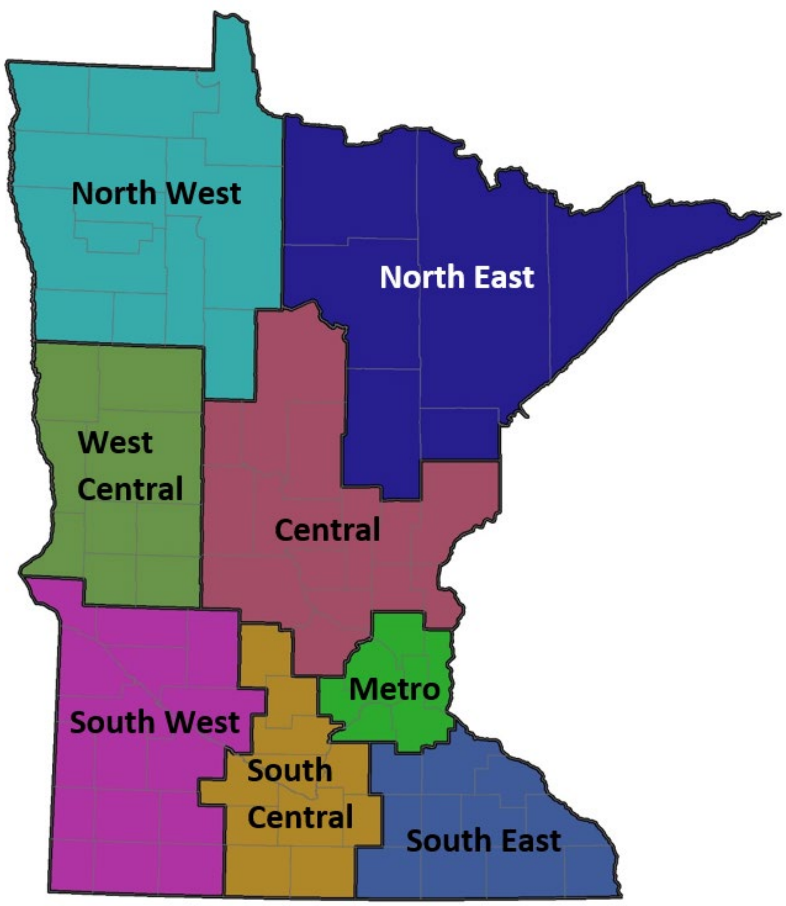
Figure 5. Attributable early death rates for fine particles (left) and ozone (right) by age group in 2013 (per 100,000 people)





Regional and county-level impacts of air pollution

Figure 6. State Community Health Service Advisory Committee (SCHSAC) regions



In addition to state-level analyses, regional and county-specific analysis showed that air quality—along with attributable rates of hospitalizations, ED visits, and deaths—varied by region and county.

Regional health effects from fine particles ($PM_{2.5}$)

- The highest attributable death rates from fine particles and ozone pollution were concentrated in the southern regions of the state.
- Fine particle-related respiratory and cardiovascular hospitalizations among seniors were most severe in the metro, central and southeastern regions.
- Impacts for childhood asthma hospitalizations and asthma ED visits are greatest in the metro region, followed by the central, southeast and northeast regions (Table 9).
- Regional ozone impacts were most severe for asthma ED visits, and were up to two times greater in the metro and southeast Minnesota regions compared to other regions (Table 10).
- In general, the southern regions were most impacted by cardiopulmonary deaths from ozone.

Table 9. Fine particles attributable rates by region in 2013 (per 100,000 people)

SCHSAC region	Attributable rates of all-cause deaths (Over age 25)*	Attributable rates of asthma & COPD hospitalizations (Age 18-64)	Attributable rates of respiratory hospitalizations (Over age 65)	Attributable rates of cardiovascular hospitalizations (Over age 65)	Attributable rates of asthma hospitalizations (Under age 18)	Attributable rates of asthma ED visits (All ages)
Metro	105	1.9	41	23	1.6	12
Central	109	1.9	28	17	0.7	7.1
Southeast	125	1.5	37	19	0.9	8.2
Northeast	122	1.9	24	12	0.7	7.8
South Central	134	1.6	24	16	0.6	6.6
Southwest	143	1.5	13	7.9	0.3	5.1
West Central	130	1.7	24	13	0.5	5.4
Northwest	118	1.8	16	10	0.4	6.2

* Effect estimate for all-cause early death from Lepuele et al. Harvard Six Cities study.

Table 10. Ozone attributable rates by region in 2013 (per 100,000 people)

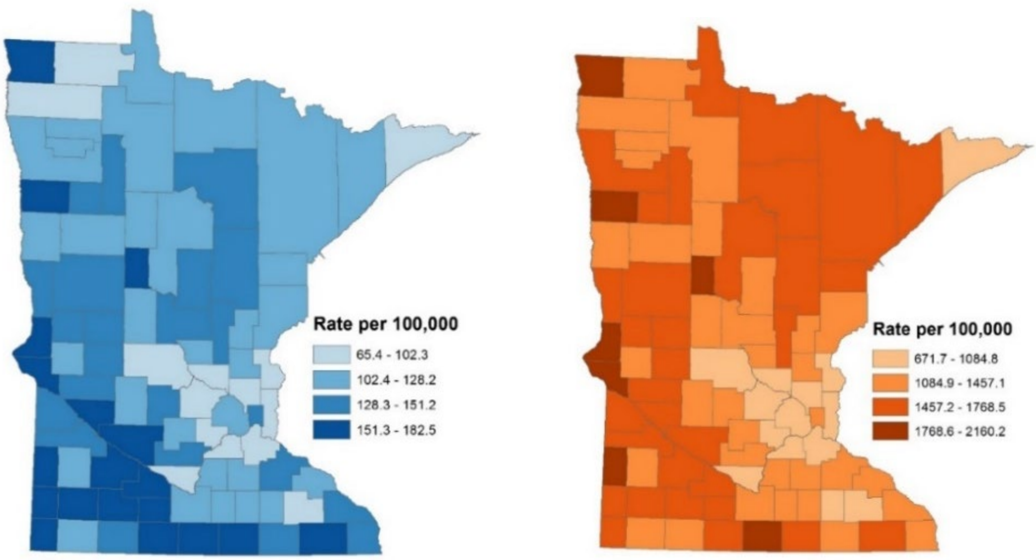
SCHSAC region	Attributable rates of cardiopulmonary deaths per 100,000 people (All ages)	Attributable rates of asthma hospitalizations per 100,000 people (All ages)	Attributable rates of asthma ED visits per 100,000 people (All ages)
Metro	0.8	1.3	6.5
Southeast	1.5	1.0	5.6
Central	1.0	0.8	4.2
South Central	1.6	0.7	4.8
Southwest	2.0	0.3	4.2
West Central	1.6	0.8	3.9
Northeast	0.9	0.4	3.2
Northwest	1.1	0.4	3.6

County health effects from fine particles ($PM_{2.5}$)

All-cause deaths

An estimated 57 to 113 deaths per 100,000 people from all causes across the state of Minnesota occurred in 2013 due in part to fine particles pollution (Table 2). Southwest and south central areas have the highest attributable rates across the state and reflect the underlying death rate (Table 9). However, the greatest impact in terms of absolute deaths was in the metro region, where half of all Minnesota deaths attributable to fine particles occurred. This is the result of the higher population density in the metro region.

Figure 7. Fine particles attributable (left) and underlying (right) death rates* in Minnesota by county

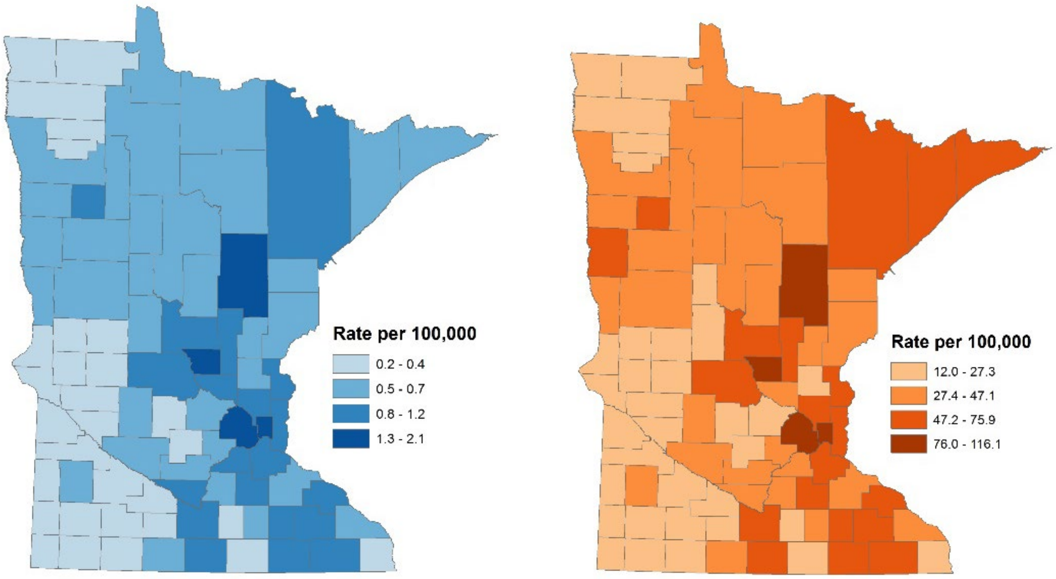


* Effect estimate for all-cause early death from Lepuele et al. Harvard Six Cities study.

Asthma hospitalizations for children

An estimated 1.2 asthma hospitalizations per 100,000 children less than 18 years old were attributable to fine particles pollution across the state in 2013 (Table 2). Childhood asthma hospitalization rates across Minnesota ranged from 0.2 to 2.1 per 100,000 children by county. Counties with the highest attributable rates are in the metro region, and parts of central, northeast and southeast Minnesota. Hennepin and Ramsey counties experience the most childhood asthma hospitalizations attributable to air pollution, which corresponds with the same patterns for underlying overall population rates (Figure 8).

Figure 8. Fine particles attributable (left) and underlying (right) child asthma hospitalizations rates (under 18 years) in Minnesota by county.



Respiratory hospitalizations in adults

The communities and regions with the highest burden include senior populations in the metro, central, and southeast parts of Minnesota (Figure 10). Across the state, estimated asthma and COPD hospitalization rates of 1.8 per 100,000 among adults between the age 18 and 64 were attributable to fine particles pollution, based on 2013 annual air concentrations (Table 2). Asthma and COPD adult hospitalizations were most severe in parts of the metro and northern regions (Figure 9). An estimated 33 respiratory hospitalizations per 100,000 adults 65 and older were attributable to fine particles pollution in 2013. Adults 65 and older were the most vulnerable age group for respiratory hospitalizations, which largely reflects the respective underlying hospitalization rates as seen by county and region in the state.

Figure 9. Fine particles attributable (left) and underlying (right) asthma and COPD hospitalizations rates (ages 18-64) in Minnesota by county.

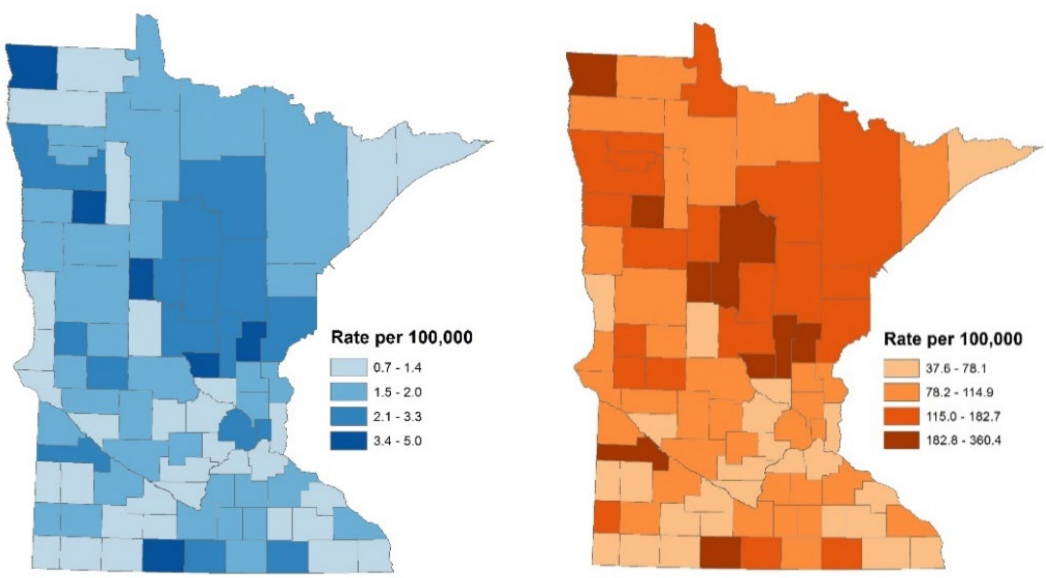
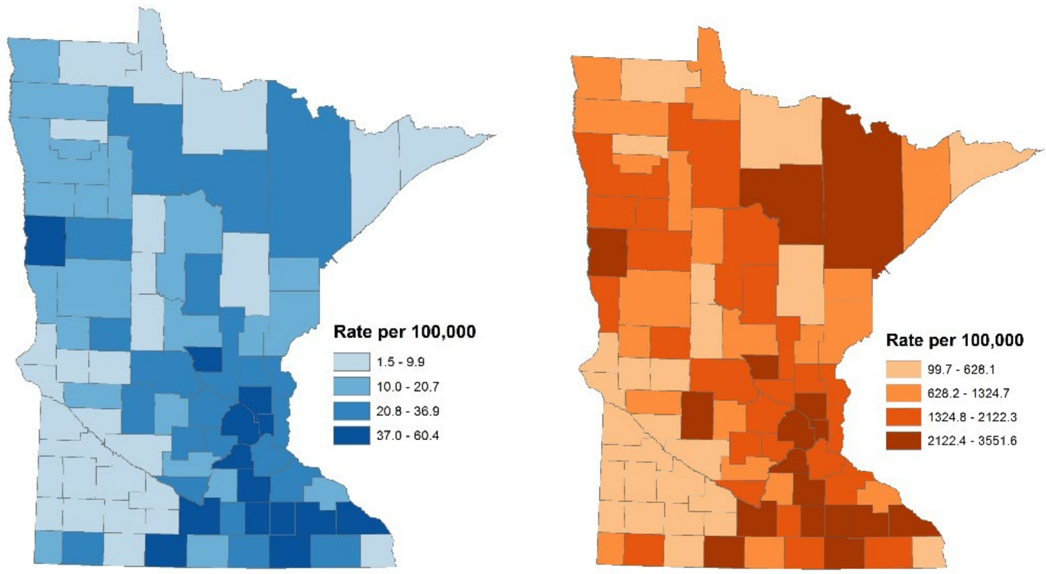


Figure 10. Fine particles attributable (left) and underlying (right) respiratory hospitalizations rates (age 65 and older) in Minnesota by county.

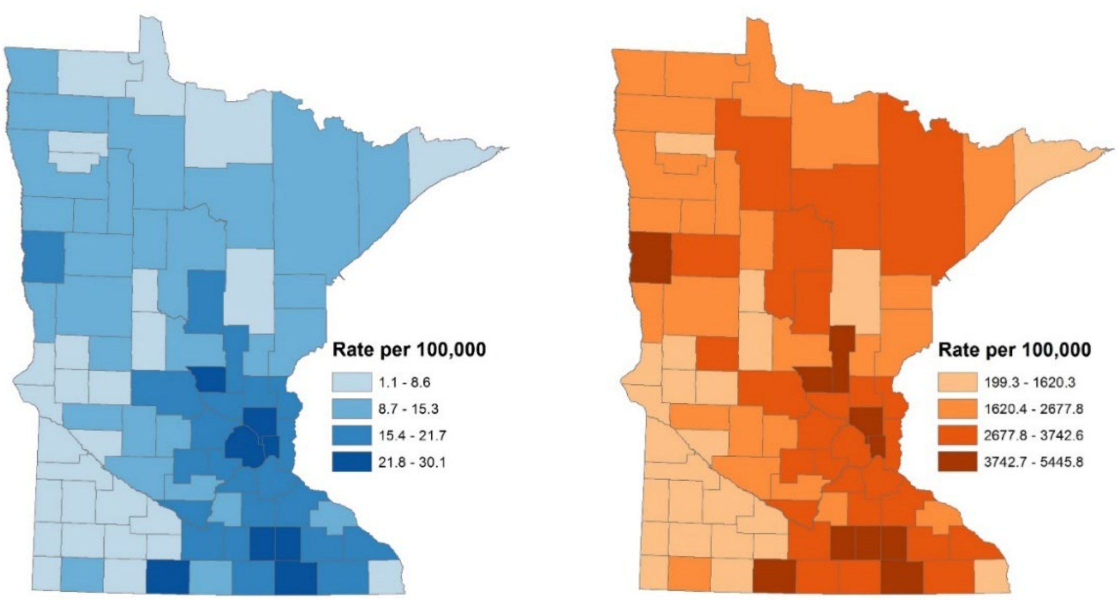


Cardiovascular hospitalizations

An estimated 18.6 cardiovascular hospitalizations per 100,000 adults age 65 and older were attributable to fine particles pollution across the state in 2013 (Table 2). Cardiovascular hospitalization rates across Minnesota range from 1.1 to 30.2 per 100,000 adults 65 and older by county. Counties with this highest attributable rates are in the metro region, and parts of central, northeast and southeast Minnesota (Figure 11).

For both respiratory and cardiovascular hospitalizations, seniors experienced the majority of all hospitalizations, meaning that small changes in air quality can have profound impacts on older populations in both rural and urban locations.

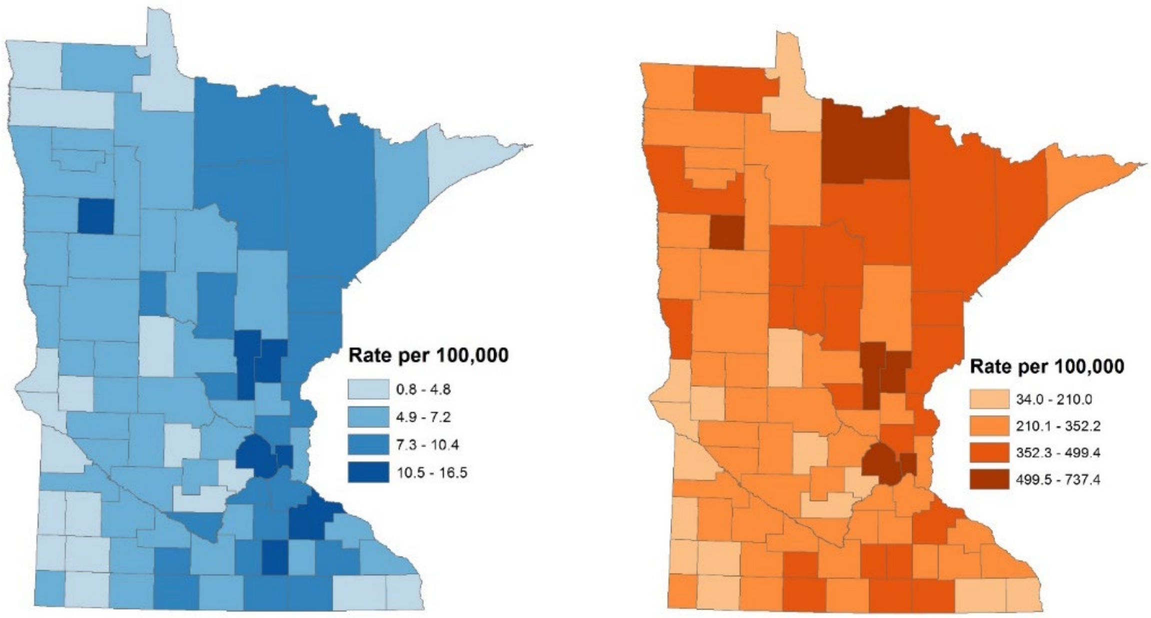
Figure 11. Fine particles attributable (left) and underlying (right) cardiovascular hospitalizations rates (age 65 and older) in Minnesota by county.



Asthma emergency department visits

An estimated 9.7 asthma ED visits per 100,000 people were attributable to fine particles pollution across the state in 2013 (Table 2). Air pollution attributable asthma ED rates across Minnesota ranged from 0.8 to 16.5 per 100,000 people by county. Counties with this highest attributable rates were in the metro region, and parts of central, northeast and southeast.

Figure 12. Fine particles attributable (left) and underlying (right) asthma emergency department visit rates (all ages) in Minnesota by county

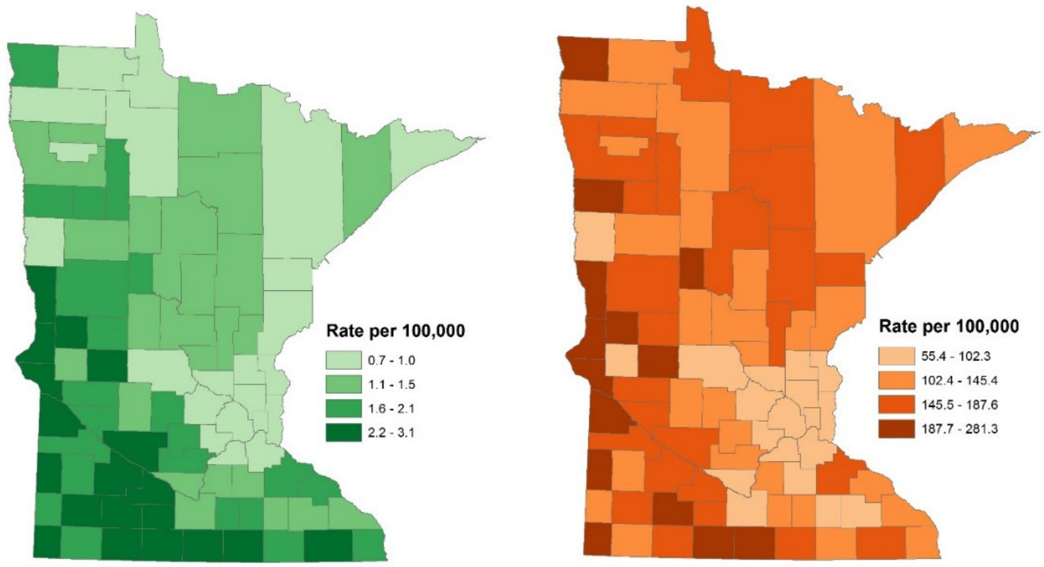


Regional health effects from ozone

Cardiopulmonary deaths

An estimated 57 cardiopulmonary deaths across Minnesota for people of all ages occurred in 2013 due to ozone (Table 3). Regional variation in attributable death rates ranged from 0.7 to 2.1 per 100,000 people. Southwest, southcentral and southeast areas of Minnesota had the highest attributable rates across the state; yet, the greatest impact estimating number of deaths shows the metro region with 17 deaths while the fewest occurred in the northwest region of the state (Figure 13).

Figure 13. Ozone attributable (left) and underlying (right) cardiopulmonary death rates (all ages) in Minnesota by county.



Asthma hospital and emergency department visits

Ozone impacts people of all ages, but in this analysis the most sensitive groups for hospitalizations were seniors, aged 65 and older, while those most affected by high rates of asthma related ED visits are children under 18 (Figure 14 and Figure 15). The highest rates for ozone-related health effects (including cardiopulmonary deaths, asthma hospitalizations, and asthma ED visits) are overall ED visits with the statewide attributable rate of 5.5 per 100,000 people. The estimated number of ED visits across the state in 2013 was close to 300, with 55 asthma related hospitalizations (Table 3). Regions of the state with the highest attributable rates for both hospitalizations and ED visits included the metro and southeast regions, but variability is low across the state (Table 9). The impacts were highest in the metro area, in part, due to population density, as with fine particle attributable impacts.

Figure 14. Ozone attributable (left) and underlying (right) hospitalizations for asthma rates (all ages) in Minnesota by county

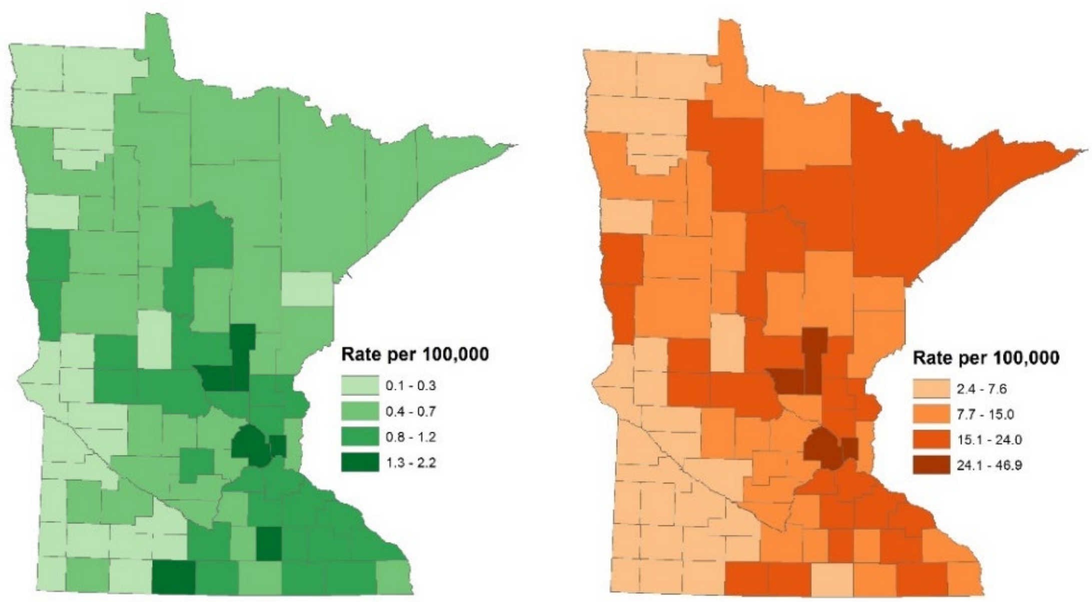
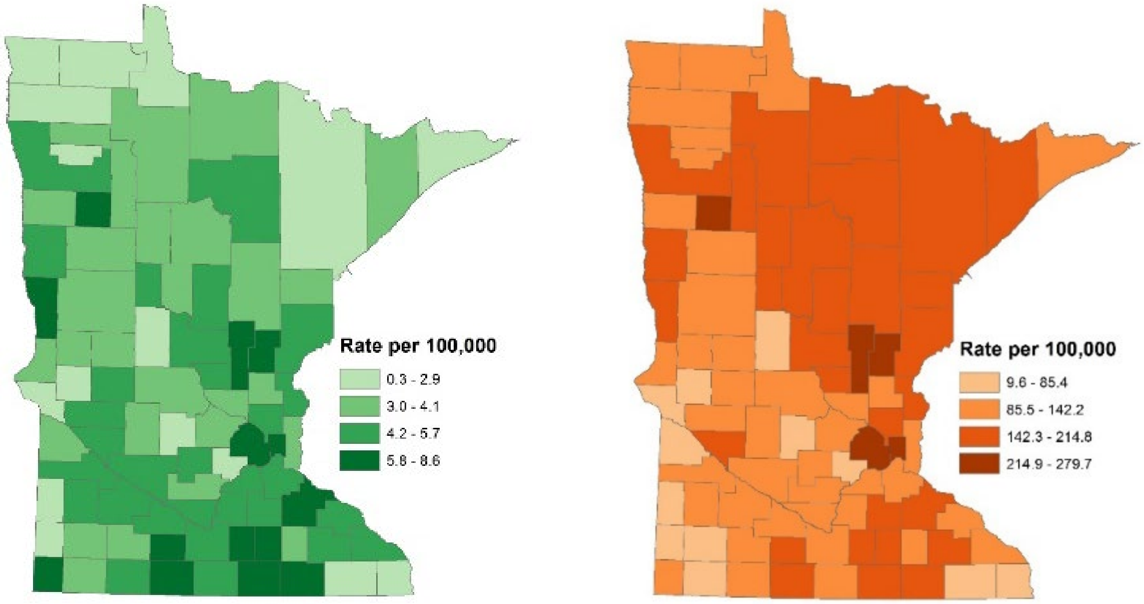


Figure 15. Ozone attributable (left) and underlying (right) asthma emergency department visit rates (all ages) in Minnesota by county



Discussion

Overall, this report estimates that in 2013 approximately 5 to 10% of all Minnesota residents who died, and 1 to 5% of all residents who were hospitalized or went to the emergency room for heart and lung problems, did so partly because of fine particles or ground-level ozone in the air. It is clear that all Minnesotans can be affected by air quality, but vulnerable populations are impacted more than others. At-risk populations include the elderly, children, people living in poverty, and people with little access to quality health care. While this report does not provide direct evidence that communities with higher proportions of Indigenous, Black or People of Color (IBPOC) have the highest rates of death and hospitalizations due to air pollution, there is a large body of literature (including the 2015 Life and Breath report for the Twin Cities metro area) that show IBPOC communities tend to suffer disproportionate health impacts from air pollution. The underlying structural causes of this widespread disparity may vary across communities, and geographic analyses (like those in this report) are helpful for opening discussions and further analyses with communities to uncover root causes. We know air pollution is not only a big city problem, and air pollutants are often not easily detectable, yet health impacts are experienced in all areas of Minnesota. Ironically, people who live in areas where the air is cleaner (some rural areas in Minnesota) can be more vulnerable to air pollution and the related health impacts. This, in part, is due to other underlying factors such as older and lower-income populations with fewer resources who may lack access to quality health care.

The health outcome estimated to be most frequently related to air pollution was premature death. Fine particles contribute to up to 10% of all deaths across Minnesota, and ozone pollution contributes to 1% of all cardiopulmonary deaths. Regionally, the southwest area of Minnesota has the highest death rates attributable to air pollution. One reason this area of the state is vulnerable to air pollution is that it also has the oldest overall population, compared to other areas of the state. Of all the regions in Minnesota, the southwest region had the highest percentage of its population aged 65 and older (nearly 19%, compared to a statewide average of under 14%). The metro region may have the most polluted air in

Minnesota, but it also has the youngest population (less than 12% of the population is 65 or older). This may explain in part why the metro region shows the lowest rate of premature deaths attributable to air pollution.

Additionally, this report indicated that higher poverty rural areas were more vulnerable to air pollution attributable deaths than lower poverty, urban areas. While areas with higher IBPOC populations were impacted with the greatest attributable *fraction*, which is the percentage of total deaths attributable to air pollution, the attributable *rates* were not highest in this group. This analysis was not able to incorporate the complex array of health-related factors going on in these areas. Areas with higher racial diversity tend to also be more urban areas where the population is generally younger and oftentimes has greater access to health care.

Cardiovascular health is affected by many modifiable factors including air pollution. Hospital admissions from fine particle pollution can be the result of compromised heart health. Older adults and children are often vulnerable and experience more cardiovascular harm from inhaled particles that can penetrate deep into the lungs and reach the bloodstream. This report estimated the impact on adults 65 and older across Minnesota and found the biggest impact was in the metro and southeastern regions.

Respiratory hospitalizations and emergency department visits can be caused by a variety of triggers, and both fine particles and ozone exposure can contribute to respiratory problems. The analyses in this report estimated several respiratory events including asthma, COPD, and all respiratory related hospital admissions for children, adults, and elderly populations across the state. We found that seniors (age 65 and older) were thirty times more likely to be hospitalized as a result of fine particles pollution than younger populations. However, children are not exempt from the health impacts of air pollution. Young people under 18 had rates that were approximately three times high for emergency room visits due to both fine particles and ozone pollution compared to adults. These impacts are felt throughout Minnesota, but the rates of hospitalizations and emergency department visits attributable to fine particles and ozone are highest in the metro and southeastern regions of the state.

Across the state, regions with larger populations of people without health insurance and living in poverty experience the most severe cardiovascular and respiratory impacts and even early death from air pollution. By providing estimates of health impacts attributable to air pollution for vulnerable populations, it is possible to direct public health actions including resources, programs and long-term prevention activities where most needed.

Overall, the estimates in this report come with some uncertainty and should not be taken as exact measures of impacts. However, they are useful for demonstrating the general size and scope of the problem and to confirm that air pollution poses a serious health threat. Because this report provides a general population-level snapshot of the impacts of air pollution across Minnesota in 2013, it does not address an individual person's exposures and health impacts. Likewise, it does not show how impacts related to higher or lower exposures within counties can change over time. However, the estimates in this report can be used as a compass that points to future action to provide the foundation for a healthy Minnesota by understanding how air pollution affects health across the state and what can be done to improve the health of all residents.

Limitations

The analyses in this report were conducted using the EPA's Environmental Benefits Mapping and Analysis Program Community Edition (BenMAP-CE). BenMAP-CE is a mathematical model that requires several data inputs including air quality data, hospital and death records and population data, all of which have limitations. The population data include demographic data for age, race, poverty, medical un-insurance rates, and rural versus urban location. These demographic data are defined by geographic boundaries. County and region-level percentages pose limitations, too, as they do not reflect finer-scaled demographic regions such as cities, zip codes or neighborhoods percentages.

The results in this report, including attributable rates and numbers of individuals impacted, were calculated estimates with confidence intervals that may contain true values. Effect estimates (or concentration-response values) are taken from scientific sources, and although they represent peer-reviewed contributions to air and health literature, they may not mirror the air quality composition and demographic characteristics of Minnesota. Fine particle pollution is composed of a broad range of toxins and varies by region, this has implications related to the specific exposure and health response.

Air quality data

Modeled air quality estimates were used in areas without monitored data. These models combine complex atmospheric model outputs with monitored values to estimate the concentration of air pollution in a region. Analyses employed annual average fine particles concentrations and warm-season average ground-level ozone concentrations. This method has several limitations including how it smooths air quality concentrations in time and space. Acute events and daily maximum values, including air quality events, are not explicitly represented in the annual averages used, yet poor air quality spikes often impact health outcomes such as an increase in emergency department visits for asthma. An extreme, but short-term spike in air pollution may produce an increased burden on health compared to the same exposure spread out as lower concentrations across several days. The statewide analyses included county and regional-level geographical units that aggregate air pollution concentrations and smooth out the finer scaled differences and local variation within the county and may not capture city, zip code, and census tract or neighborhood level variations in air pollution. For example, residents who live close to busy roads have greater exposure to air pollutants compared more remote areas, and such different areas can exist in the same county. This report assumes single values for fine particles and ozone for each of the 87 counties and 8 State Community Health Services Advisory Committee regions for the year.

The annual average exposure estimates of air quality do not take into account personal exposure. Many individuals move between counties and regions on a daily or weekly basis or throughout the year. Other residents live near higher-than-average air pollution concentration areas such as communities surrounding point sources from industry or high traffic roads. This report also does not consider the impacts of indoor air quality, which also can have meaningful health impacts.

The results of this report used single pollutant models in BenMAP-CE, whereas multiple pollutant models may be more realistic for estimating exposure-related health responses. The fine particles composition is also not accounted for and may impact disease and death based on specific particle types which vary across the state and nationally. Natural background concentrations are not included in the analyses, and the report may therefore underestimate the burden of disease. Other pollutants may have additional health effects in Minnesota, including gaseous nitrogen oxides (NO_x), which are not evaluated in this analysis. Elevated concentrations of NO_2 are sometimes observed in colder months and contribute to poor air quality during wintertime inversion events. Health hazards from NO_x are similar to those caused from ozone exposure.

Hospital and death data

While hospital and ED data cover most of Minnesota hospitals, they have important limitations: they do not include federal or sovereign hospitals, such as Veteran's Administration and Indian Health Services locations, nor do they include Minnesota residents who were discharged from Wisconsin hospitals. Some code classifications for disease-specific outcomes overlap for fine particles and ozone, such as asthma ED visits which is evaluated for both air pollutants.

Important outcomes such as lost work days, school absences, doctor office visits, and increases in medications used are not included in the impact evaluation. Hospital discharge data do not include important information, including patient race, environmental exposures, or structural barriers that affect health, and thus these experiences were not accounted for in this analysis.

Population data

Population estimates from the American Community Survey are published with a margin of error that indicates the likely ranges within which the true values fall. The demographic data, such as age and race, are estimates calculated from U.S. Census data.

A limitation of the metropolitan, micropolitan, and rural designations method is that county boundaries include or exclude areas that were considered rural due to low population density and remote locations. For example, this method categorized St. Louis County as metropolitan due to Duluth and the surrounding area, but we know that it is a large county with many rural areas.

Appendix A: Minnesota hospital discharge data

The Minnesota Hospital Discharge Dataset (MNHDD) contains patient claims data voluntarily submitted by members of the Minnesota Hospital Association (MHA), a trade association representing Minnesota hospitals. Minnesota Department of Health (MDH) purchases these data from MHA under a Memorandum of Understanding between MHA and MDH.

Hospitalization and ED data are extracted from MNHDD, maintained by the MHA. The Health Economics program at MDH, who contracts with MHA, maintains the data under strict privacy requirements. All hospital data comply by data suppression rules of counts less than or equal to 5 and less than 100,000 people.

MHA represents Minnesota's hospitals and health systems. Hospitals submit inpatient discharge data to MHA using a standardized billing form. Hospitalization data are considered 'inpatient' and include patients who were admitted to the hospital from the ED at that hospital or transferred from another hospital. ED data are considered 'outpatient' because a patient is treated and released, and do not include patients who were transferred for additional inpatient care.

Hospital records were selected using primary diagnosis field in both the 9th and 10th revision of the International Classification of Diseases-Clinical Modifications (ICD-CM). Hospital record keeping of ICD codes changed in October 2015 from ICD-9 to ICD-10.

Health outcomes	ICD 9	ICD 10
Cardiopulmonary deaths	N/A	I00-I79, J10-J18, J40-J47, J69
Asthma	496 (786.07 for Winquist et. al., ozone)	J45 (R062 for Winquist et. al., ozone)
Chronic lung disease	490-496	J40-J45,J471, J479, J67
All respiratory	460-519	J00-J99
Cardiovascular disease	410-414, 426-429, 430-438, 440-448	I20-I22, I24-I25,I44-I45, I47-I50, I60-I67, I69-I75, I77-I78,M30-M31, R001, G454

Appendix B: Geographic county aggregation

The Geographic Aggregation Tool (GAT) was developed by New York State Health Department for Health studies like this where small numbers of health events can limit interpretability or robustness of an analysis. The GAT employs user-defined criteria to identify counties that need to "borrow" information from neighboring counties to reach sufficient data density. In this analysis, counties identified for merging were those that would have otherwise been suppressed due to small numbers to protect privacy and ensure stable rates. Small numbers are defined as five or fewer health events and less than 100,000 total population, which is a standard MDH suppression limit. These suppressed counties were then matched with the fewest number of directly adjacent neighboring counties for merging. Total event counts and total populations of suppressed and merged counties were then combined to generate a new "regional" rate that was assigned to the suppressed county. Original rates were used for the merged counties.

Four of the hospitalization outcomes required the GAT tool to generate merged rates to protect privacy and ensure stable rates. The merged and original rates for impacted counties are documented below, where each row represents a new "region".

Suppressed counties and new merged rate per 100,000 population	Merged counties and original rate per 100,000 population
Hospitalizations-childhood asthma (ages <18) $PM_{2.5}$	
Cook, Lake, and St. Louis counties: 57.3	St. Louis County: 61.5
Houston and Winona counties: 22.1	Winona County: 30.0
Lake of the Woods and Beltrami: 35.9	Beltrami County: 35.0
Chippewa, La qui Parle, Swift, and Yellow Medicine counties: 14.0	
Clay, Norman and Wilkin counties: 44.2	Clay County: 49.0
Cottonwood, Jackson, and Redwood counties: 15.6	
Lincoln, Lyon, Murray, Nobles, Pipestone, and Rock counties: 12.03	Lyon County: 28.4
Clearwater and Mahnomen counties: 4.68	Mahnomen County: 70.4
Hospitalizations-all respiratory (ages 65 plus) $PM_{2.5}$	
Lincoln and Pipestone counties: 126.3	Pipestone County: 223.4
Rock and Nobles counties: 966.0	Nobles County: 1486.0
Hospitalizations-asthma and COPD (ages 18-64) $PM_{2.5}$	
Houston and Winona counties: 59.4	Winona County: 82.0
Big Stone and Traverse counties: 87.8	Traverse County: 88.0
Hospitalizations-asthma (all ages) Ozone	
Clearwater and Mahnomen counties: 12.63	Mahnomen County: 32.7
Murray, Nobles, and Rock counties: 3.017	Nobles County: 5.5
Itasca and Koochiching counties: 14.72	Itasca County: 18.9
Lake of the Woods and Beltrami: 14.58	Beltrami County: 15.8
Lincoln, Lyon and Pipestone counties: 4.40	Lyon County: 7.0
Kandiyohi and Renville counties: 7.63	Kandiyohi County: 10.4
Cook, Lake and St. Louis counties: 16.07	St. Louis County: 17.3
Winona and Houston counties: 9.99	Winona County: 13.6
Olmsted and Wabasha: 17.1	Olmsted County:19.6

Appendix C: Epidemiology studies and effects estimates

Fine particle matter health effects	Age group	Acute or chronic exposure/metric average	Effect estimate	Study location	Source of effect estimate
Death	25 plus	Chronic/Annual average	14% increase (for 10 µg/m^3)	Six Eastern/ Midwest cities	Lepeule at al., 2012
	30 plus	Chronic/Annual average	6% increase (for 10 µg/m^3)	116 US cities	Krewski et al., 2009
Hospital admissions for respiratory conditions	18-64	Acute/Daily 24-hour mean	2.2% increase (for 10 µg/m^3)	Los Angeles, CA	Moolgavkar, 2001[xiii]
	65 plus	Acute/Daily 24-hour mean	1.3-4.3% increase (for 10 µg/m^3)	119 US communities	Zanobetti et al., 2010[xiv]
Hospital admissions for cardiovascular conditions	65 plus	Acute/Daily 24-hour mean	0.68% increase (for 10 µg/m^3)	27 US communities	Peng et al., 2010[xv]
Hospital admissions for pediatric asthma	0-17	Acute/Daily 24-hour mean	2.0% increase (for 10 µg/m^3)	Washington DC	Babin et al., 2007[xvi]
Emergency department visits for asthma	All ages	Acute/Daily 24-hour mean	2.8% increase (for 10 µg/m^3)	St. Louis, MO	Winquist et al., 2012[xvii]

Ozone health effects	Age group	Acute or chronic exposure/metric average	Effect estimate	Study location	Source of effect estimate
Death	All ages	Acute, 24-hour daily mean	1.3% increase (for 10 ppb)	19 US cities	Huang et al., 2005[xviii]
Hospital admissions for asthma	All ages	Acute, daily 8-hour maximum	3.7% increase (for 10 ppb)	St. Louis, MO	Winquist et al., 2012
Emergency department visits for asthma	All ages	Acute, daily 8-hour maximum	2.4% increase (for 10 ppb)	St. Louis, MO	Winquist et al., 2012

Bibliography

[i]MPCA, “The air we breathe: The state of Minnesota’s air quality 2017”, available at: https://www.pca.state.mn.us/sites/default/files/lraq-1sy17.pdf.

[ii] U.S. Environmental Protection Agency. (2009). *Integrated Science Assessment for Particulate Matter (Final Report).*Washington, DC: U.S. Environmental Protection Agency.

[iii] U.S. Environmental Protection Agency. (2013). *Integrated Science Assessment for Ozone and Related Photochemical Oxidants.* Washington, DC: U.S. Environmental Protection Agency.

[iv] Advancing Public Health Equity in Minnesota: Report to the Legislature (2014). http://www.health.state.mn.us/divs/che/reports/ahe_leg_report_020114.pdf

[v] U.S. Global Change Research Program. (2018). Fourth National Climate Assessment: Midwest Region: Available: https://nca2014.globalchange.gov/report/regions/midwest

[vi] U.S. Environmental Protection Agency. (2014a). *Environmental Benefits Mapping and Analysis Program (BenMAP).*

[vii] Aggregation without aggravation: determining spatial contiguity and joining geographic areas using hashing. Babcock, GD. *Proceedings of the Northeast SAS Users Group Conference*, 2009, and in *Proceedings of the SAS Global Forum*, 2010.

[viii] SAS Institute Inc 2013. SAS/ACCESS® 9.4 Interface to ADABAS: Reference. Cary, NC: SAS Institute Inc.

[ix] Krewski, D., Jerrett, M., Burnett, R. T., Ma, R., Hughes, E., Shi, Y., et al. (2009). Extended Follow-up and spatial analysis of the American Cancer Society Study linking particulate air pollution and mortality. Boston: Health Effects Institute. Available: https://www.healtheffects.org/system/files/Krewski140.pdf

[x] LePeule, J. Laden, F., Dcoekery, D. & Schwartz,J. (2012) Chronic exposure to fine particles and mortality; an extended follow-up of the Harvard Six Cities Study from 1974-2009. Environ Health Perspect, 965-970.

[xi] Greater Minnesota, Refined and Revisited (2017). https://mn.gov/admin/assets/greater-mn-refined-and-revisited-msdc-jan2017_tcm36-273216.pdf

[xiii] Moolgavkar, S. H. (2000). Air pollution and hospital admissions for chronic obstructive pulmonary disease in three metropolitan areas in the United States. Inhalation Toxicology, 75-90.

[xiv] Zanobetti, A., Franklin, M., Koutrakis, P., & Schwartz, J. (2009). Fine particle air pollution and its components in association with cause-specific emergency admissions. Environmental Health, 8:58.

[xv] Peng, R. D., Bell, M. L., Geyh, A. S., McDermott, A., Zeger, S. L., Samet, J. M., et al. (2009). Emergency admissions for cardiovascular and respiratory diseases and the chemical composition of fine particle air pollution.Environmental Health Perspectives, 957-963.

[xvi] Babin, S. M., Burkom, H. S., Holtry, R. S., Tabernero, N. R., Stokes, L. D., Davies-Cole, J. O., et al. (2007). Pediatric patient asthma-related emergency department visits and admissions in Washington, DC, from 2001-2004, and associations with air quality, socio-economic status and age group. Environmental Health, 6:9.

[xvii] Winquist, A., Klein, M., Tolbert, P., Flanders, W., Hess, J., & Sarnat, S. (2012). Comparison of emergency department and hospital admissions data for air pollution time-series studies. Environmental Health, 11:70.

[xviii] Huang, Y., Dominici, F., & Bell, M. L. (2005). Bayesian hierarchical distributed lag models for summer ozone exposure and cardio-respiratory mortality. Environmetrics, 547-562.