

# Air Pollution and the Health of New Yorkers:

The Impact of Fine Particles and Ozone



## Acknowledgements

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# Executive Summary

Air pollution is a leading environmental threat to the health of urban populations overall and specifically to New York City residents. Clean air laws and regulations have improved the air quality in New York and most other large cities, but several pollutants in the city's air are at levels that are harmful.

This report provides estimates of the toll of air pollution on the health of New Yorkers. It focuses on 2 common air pollutants—fine particulate matter (PM<sub>2.5</sub>) and ozone (O<sub>3</sub>). Emissions from fuel combustion directly and indirectly cause many cities to have high concentrations of these pollutants. Both have been extensively researched and are known to contribute to serious illnesses and death, especially from lung and heart diseases, at concentrations prevailing in New York City today.

Air pollution, like other significant risk factors for poor health such as smoking and obesity, is rarely indicated as the cause of an individual hospital admission or death in official records. Statistical methods, therefore, must be used to apply research findings about the relationship

between exposures and the risk of illnesses and death to actual population rates of morbidity and mortality to calculate estimates of the public health burden caused by air pollution. In this report, the New York City Department of Health and Mental Hygiene used methods developed by the U.S. Environmental Protection Agency to estimate the impact of air pollution on the numbers of deaths, hospital admissions and emergency department visits caused by exposure to PM<sub>2.5</sub> and ozone at current concentrations in New York City.

Health Department estimates show that each year, PM<sub>2.5</sub> pollution in New York City causes more than 3,000 deaths, 2,000 hospital admissions for lung and heart conditions, and approximately 6,000 emergency department visits for asthma in children and adults. A modest reduction of 10% in current PM<sub>2.5</sub> levels could prevent more than 300 premature deaths, 200 hospital admissions and 600 emergency department visits annually, while attaining the goal of “cleanest air of any big city” would result in even greater public health benefits (**Table 1**).

**Table 1. Health impacts from current PM<sub>2.5</sub> exposure and benefits of reducing exposure in New York City.\***

Health Effect	Age Groups Affected (in years)	Annual Health Events Attributable to Current PM <sub>2.5</sub> Levels	Annual Health Events Avoided If PM <sub>2.5</sub> Levels Were Reduced by 10%	Annual Health Events Avoided If PM <sub>2.5</sub> Levels Were Reduced to Cleanest Air of Any Large City
Premature mortality	30 and above	3,200	350	760
Hospital admissions for respiratory conditions	20 and above	1,200	130	280
Hospital admissions for cardiovascular conditions	40 and above	920	100	220
Emergency department visits for asthma	Under 18	2,400	270	580
Emergency department visits for asthma	18 and above	3,600	390	850

PM<sub>2.5</sub>=particulate matter

\* Based on 2005-2007 data on air pollution, mortality and illnesses

Ozone causes an estimated 400 deaths from all causes, more than 800 hospital admissions and more than 4,000 emergency department visits among children and adults. Reducing ozone levels by 10% could prevent more than 80 premature deaths, 180 hospital admissions and 950 emergency department visits annually (**Table 2**).

Other Health Department estimates show that the public health impacts of air pollution in New York City fall especially heavily on seniors, children with asthma and people living in low-income neighborhoods. Even modest reductions in the levels of these pollutants could prevent hundreds

of deaths, hospital admissions and emergency department visits (**Tables 1 and 2**).

This study shows that despite improvements in air quality, air pollution is one of the most significant environmental threats to New Yorkers, contributing to approximately 6% of deaths annually. To reduce this toll, action is needed to address important local pollution sources; [PlaNYC](#), the city's sustainability plan, has already launched, completed and planned several emission-reducing initiatives that will result in cleaner air and fewer serious illnesses and premature deaths in all parts of the city.

**Table 2. Health impacts from current O<sub>3</sub> exposure and benefits of reducing exposure in New York City.\***

Health Effect	Age Groups Affected (in years)	Annual Health Events Attributable to Current O <sub>3</sub> Levels	Annual Health Events Avoided If O <sub>3</sub> Levels Were Reduced by 10%
Premature mortality	All ages	400	80
Hospital admissions for asthma	Under18	420	90
Hospital admissions for asthma	18 and above	450	90
Emergency department visits for asthma	Under18	1,800	370
Emergency department visits for asthma	18 and older	2,900	600

O<sub>3</sub>=ozone

\* Based on 2005-2007 data on air pollution, mortality and illnesses

# Introduction and Background

Air pollution is one of the most serious environmental threats to urban populations (Cohen 2005). Exposures vary among and within urban areas, but all people living in cities are exposed, and many are harmed, by current levels of pollutants in many large cities. Infants, young children, seniors and people who have lung and heart conditions are especially affected, but even young, healthy adults are not immune to harm from poor air quality. Exposures to common urban air pollutants have been linked to a wide range of adverse health outcomes, including respiratory and cardiovascular diseases, asthma exacerbation, reduced lung function and premature death (U.S. Environmental Protection Agency 2006, 2009).

Prior to the advent of clean air laws in developed countries, the lethal effects of air contaminants from fuel combustion were dramatically evident during several severe air pollution episodes. In 1952, shortly after the 5-day London “Great Smog” episode, for example, it became clear to officials and the public that thousands had died and many tens of thousands were sickened by soot and sulfur dioxide (Davis 2002, Bell 2001). The episode was caused by burning coal, petroleum-based fuels and gas with no control on emissions, in combination with stagnant weather conditions. The extremely high levels of pollution caused large and marked increases in the number of daily deaths and illnesses from lung and heart disease, evident despite the lack of sophisticated statistical analyses.

Other severe air pollution episodes, such as in 1948 in Donora, Pennsylvania, (Helfand, 2001) in the 1950s and in the 1960s in New York City (McCarroll, 1966) and elsewhere, raised awareness that unregulated burning of fossil fuels in and near cities was harmful to public health. Eventually, state, local and, finally, federal laws and regulations such as [The Clean Air Act](#) began to turn the tide in controlling emissions.

Because of improvements in air quality, such deadly air pollution episodes are rare in U.S. cities. Modern research methods have shown, however, that deaths and serious illnesses from common air pollutants still occur at levels well below regulatory standards, and at current levels in New York and most large cities. Local actions to further reduce air pollution will mean changes in policies and behaviors, and will require significant investments in new vehicles and other equipment. Local officials and the public, therefore, must understand the magnitude and distribution of mortality and disease caused by air pollution in order to weigh the benefits against the cost of improving air quality.

This report provides estimates of the toll that air pollution takes on the health of New Yorkers, focusing on 2 common air pollutants—fine particulate matter (PM<sub>2.5</sub>) and ozone (O<sub>3</sub>). Both pollutants are among the most studied of environmental hazards, are found in New York City’s air at concentrations above clean air standards, and are known to adversely affect health at levels in our air today (Silverman 2010, Ito 2010). The report contains estimates of the number of emergency department visits, hospitalizations and deaths attributable to these pollutants overall and for various population groups, and the number of adverse health events that could be prevented by improvements in air quality.

The estimates in this report are based on methods used by the U.S. Environmental Protection Agency to quantify the harm from air pollution and the benefits of clean air regulations. Similar methods are used to estimate the health impacts of smoking, obesity, heat waves and other important public health risks ([U.S. Environmental Protection Agency, 2010, Centers for Disease Control and Prevention, Danaei 2009](#)).

## Sources and Health Effects of Fine Particulates and Ozone

Fine Particles (PM<sub>2.5</sub>) are small, airborne particles with a diameter of 2.5 micrometers or less. Major sources of PM<sub>2.5</sub> include on-road vehicles (trucks, buses and cars); fossil fuel combustion for generating electric power and heating residential and commercial buildings; off-road vehicles (such as construction equipment); and commercial cooking ([U.S. Environmental Protection Agency, National Emissions Inventory](#)). Fine particles can also become airborne from mechanical processes such as construction or demolition, industrial metal fabrication, or when traffic or wind stirs up road dust.

Fine particles in New York City's air come from sources both within and outside of the city; the outside sources account for more of the city's air pollution, but local sources account for differences in PM<sub>2.5</sub> concentration between locations within the city. The Health Department, in the ongoing New York City Community Air Survey ([NYCCAS](#)), is studying the impact of local sources (such as traffic and burning residual oil) on neighborhood air quality.

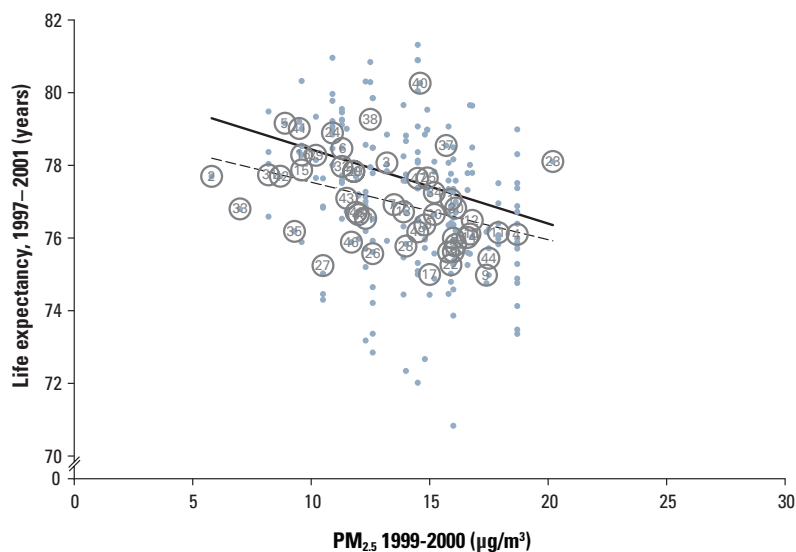
PM<sub>2.5</sub> is small enough to be inhaled deep into the lungs and affects both respiratory and cardiovascular system functions. Changes observed in people exposed to PM<sub>2.5</sub> include increased airway inflammation and sensitivity, decreased lung function, changes in heart rhythm and blood flow, increased blood pressure, increases in the tendency to form blood clots, and biological markers of inflammation (U.S. Environmental Protection Agency 2009). These health effects cause increases in symptoms, emergency department visits, hospital admissions and deaths from heart and lung diseases (Bell 2009, Krewski 2009, Silverman 2010).

Studies show that, even at current levels, short-term exposures to combustion-related pollutants exacerbate respiratory and cardiovascular

conditions, and increase mortality risk. Higher, long-term average concentrations increase the cumulative risk of chronic diseases and death. One recent study (Pope 2009) showed that in cities with higher average PM<sub>2.5</sub>, the population's life expectancy was reduced by an average of more than half of a year for every 10 µg/m<sup>3</sup> increase in concentration (**Figure 1**). Data from the study also showed that reductions in PM<sub>2.5</sub> concentrations during the 1980s and 1990s accounted for approximately 15% of the overall increase in life expectancy during that period.

O<sub>3</sub> is not emitted directly from fuel combustion; it is produced by chemical reactions involving nitrogen oxides (NO<sub>x</sub>)—a mixture including nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>)—volatile organic compounds and sunlight. O<sub>3</sub> concentrations typically peak in the afternoon and are highest in the summer, when daylight hours are long and temperatures are high. Although NO<sub>x</sub>

**Figure 1. Lower life expectancy is associated with living in cities with higher PM<sub>2.5</sub> levels.\* §**



PM<sub>2.5</sub>=particulate matter

\* Dots represent population-weighted mean life expectancies at the county level and circles labeled with numbers represent population-weighted mean life expectancies at the metropolitan-area level. Solid lines represent regression lines with the use of county-level observations, and broken lines represent regression lines with the use of county-level and metropolitan area-level observations.

§ Reprinted from Fine-Particulate Air Pollution and Life Expectancy in the United States, *N Engl J Med*. 2009;360:376-386. C. Arden Pope II, Majid Ezzati and Douglas W. Dockery with Permission from the New England Journal of Medicine.

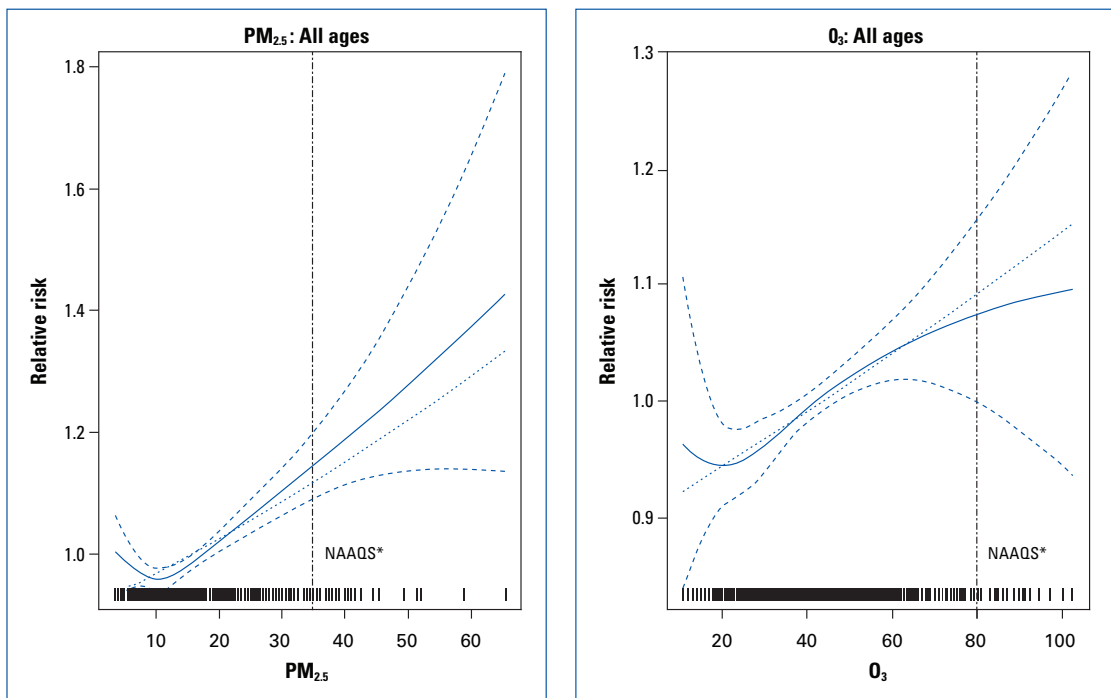
emissions from vehicles contribute to higher ozone in urban areas, in city locations where fresh  $\text{NO}_x$  emissions are concentrated,  $\text{NO}$  reacts with, and removes, ozone from the atmosphere in a reaction known as ozone “scavenging.” As a result, concentrations in urban areas with an abundance of  $\text{NO}_x$  from traffic sources tend to have somewhat lower concentrations of ozone than more suburban locations downwind from the city center.

$\text{O}_3$  reacts with and damages organic matter such as plant foliage, the human airway and other lung tissues. Exposure to  $\text{O}_3$  causes irritation and inflammation of the lungs, and leads to coughing, wheezing, worsening of asthma and lowered resistance to lung infections. Physical activity

during peak ozone periods increases exposure and the likelihood of symptoms. Long-term exposure to higher  $\text{O}_3$  levels can permanently reduce lung function. (Calderón-Garcidueñas 2003, Rojas-Martinez 2007) These health effects of  $\text{O}_3$  contribute to increased emergency department visits, hospital admissions and deaths on days with higher ozone concentrations (Silverman 2010, Ito 2007, Huang 2005), and to increased mortality associated with chronic ozone exposure (Jerrett 2009).

Studies have shown that for both  $\text{PM}_{2.5}$  and  $\text{O}_3$  exposure, health effects occur at concentrations well below the current [National Ambient Air Quality Standards](#); this effect was clear in a study of asthma hospitalizations in New York City

**Figure 2. The risk of hospitalization for asthma increases with increases in daily levels of  $\text{PM}_{2.5}$  and  $\text{O}_3$  in New York City.**



$\text{PM}_{2.5}$ =particulate matter

$\text{O}_3$ =ozone

\* NAAQS- National Ambient Air Quality Standard

The figure shows at levels below and above the National Ambient Air Quality Standard (NAAQS) an increasing risk of hospitalization for asthma with increasing  $\text{PM}_{2.5}$  and  $\text{O}_3$  levels. The solid lines are smoothed fit data, with long broken lines indicating 95% confidence bands. The short broken lines are linear fitted lines. The vertical dotted lines are the current NAAQS for  $\text{PM}_{2.5}$  and the 1997 NAAQS for  $\text{O}_3$  (current 2007  $\text{O}_3$  NAAQS is 75ppb). The density of lines at the bottom of the figure indicates the number of days measured at a given concentration sample size.

Reprinted from Permission from Elsevier: Silverman RA, Ito K. Age-Related Associations of Fine Particles and Ozone with Sever Acute Asthma in New York City. *J Allergy Clin Immunol.* 2010; 125(2):367-373



**(Figure 2)** (Silverman 2010). Elderly people, children and infants, and people with lung or heart disease are most affected by exposure to both pollutants. There is evidence that medications used to manage lung or heart disease may reduce the severity of health effects caused by air pollution (Liu 2009, Qian 2009). As a result, populations and neighborhoods with higher rates of chronic disease and less access to quality health care may be more affected by air pollution-related health problems.

### Studies of Air Pollution and Population Health

Illnesses caused by air pollution, such as asthma attacks, heart attacks and stroke, have multiple causes; as a result, most health events triggered by air pollution cannot be identified directly. Research, however, has shown that there is an increase in these events on days with higher air pollution concentrations and in cities where pollution concentrations are higher on average. There are 2 types of studies (see below) that researchers use to quantify the relationship between the concentrations of pollutants measured in the air and the risk of adverse health effects in the population. The report uses the results from both types of studies to estimate air pollution health impacts in New York City.

One type of study assesses the acute effects of short-term exposures to a specific air pollutant. These studies use statistical methods for analyzing time-series data to assess whether the health events under study, such as daily emergency

department visits for asthma, are more frequent on or shortly after days when air pollution concentrations are higher. These models also control for other factors that vary with time and can influence health events, such as the season, weather and day of the week. The daily risk of a particular health event is related to the daily concentration of a pollutant as a so-called concentration-response function. In **Figure 2**, for example, researchers analyzed daily hospitalizations for asthma using time series models. The estimates showed that, for a daily (8-hour maximum) ozone concentration increase of 22 parts per billion during the warm season (April through August), asthma hospital admissions among children 6 to 18 years of age increased an average of 20% (Silverman 2010). Due to random variation in daily counts of any health event, estimating an acute effect concentration-response function reliably requires analyzing a large amount of data (usually over several years).

Another type of study assesses the health effects of chronic (long-term) exposure to air pollution. This type of study may involve following a study population over time and comparing the risk of health events among individuals living in multiple cities with different average levels of air pollution. In chronic effect studies, the statistical analyses may be used to also adjust for individual factors such as smoking and weight. The amount of increase in risk is related to a given change in average air pollution concentration to estimate a chronic exposure concentration-response function.

# Methods

## Overall Approach

In this report, methods were adapted from those utilized by the U.S. Environmental Protection Agency and state air quality regulatory agencies to estimate changes in the number of illnesses and deaths that could occur in a population if air pollution concentrations were reduced by a specified amount (U.S. Environmental Protection Agency 2010, 2008) (**Figure 3**). This method:

- Uses air quality monitoring data to characterize current, or baseline, air pollution levels
- Specifies comparison air quality conditions, such as possible reductions in air pollution concentrations or levels that meet other air quality goals
- Computes the hypothetical change in air pollution concentrations as the difference between the current and the comparison levels within each neighborhood
- Uses the change in air pollution concentrations, concentration-response functions from the epidemiological literature, and local population

and baseline health event rates to calculate the health impact associated with the change in ambient air quality, by neighborhood.

- Combines these neighborhood health impacts to estimate citywide impacts

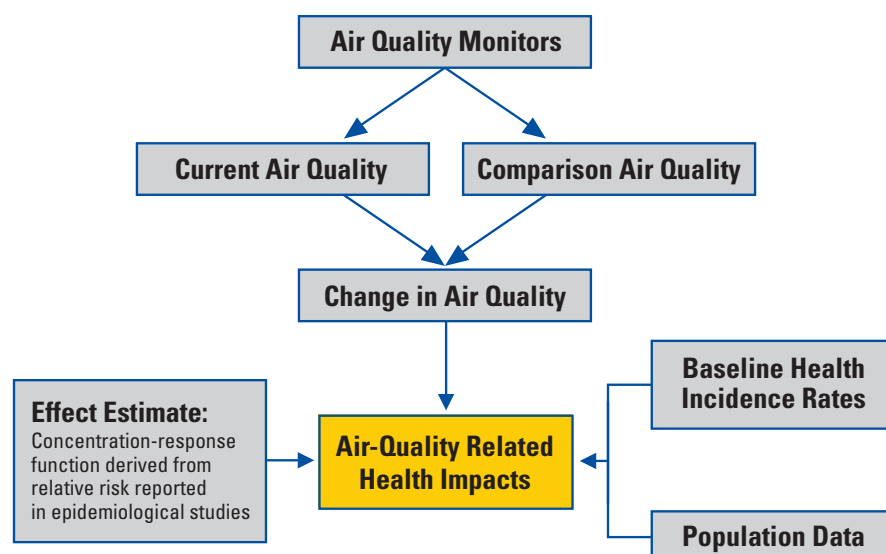
This health impact analysis was conducted using U.S. Environmental Protection Agency's [Benefits Mapping and Analysis Program](#) (BenMAP), a Geographic Information System-based program that allows analysts to systematically calculate health impacts across regions of interests.

## Data Sources

### Concentration-Response Functions

Recent epidemiological studies of the relationship of  $PM_{2.5}$  and  $O_3$  to mortality, hospital admissions and emergency department visits were reviewed. Although hundreds of studies have been published on the health effects of  $PM_{2.5}$  and  $O_3$ , studies used for the main analyses were those most relevant to the current New York City population.

**Figure 3. Flow chart illustrating the Air Pollution Health Impact Analysis Approach.**



The studies used in this report were taken from peer-reviewed scientific journals in the past decade and, to account for local study area demographics and pollutants, effect estimates from studies of New York City were used when possible. If local studies were not available, those used contained effect estimates from recent large, multi-city studies or those included in recent U.S. Environmental Protection Agency regulatory impact analyses (EPA 2008, EPA 2010). The studies chosen, and the corresponding concentration-response functions used for this report, are summarized below and in **Tables 3 and 4**. The abstracts are available in an [online appendix](#), which also provides health impact estimates from other studies not included in this report. The Discussion section in this report details variables and limitations in selecting suitable concentration-response functions.

### Particulate Matter Studies

One study (Krewski, 2009) followed 500,000 members of the American Cancer Society in 116 cities who participated in a cohort study from 1982 through 2000. The risk of death among the cohort was estimated in relation to the city's annual average  $PM_{2.5}$  concentrations; all-cause mortality rates in adults increased by 6% for every  $10 \mu\text{g}/\text{m}^3$  increase in annual  $PM_{2.5}$ .

Another study (Ito, 2007) studied daily hospital emergency department visits for asthma in people of all ages treated at public hospitals in New York City from 1999 through 2002. To allow for different effects of  $PM_{2.5}$  related to physical activity and particle composition in different seasons, separate analyses were completed for the warm and cold seasons. In the warm season, emergency department visits increased by 23%,

**Table 3.  $PM_{2.5}$  effect estimates used in this report.**

	Health Effect	Age Group (in years)	Acute or Chronic Exposure/Metric Average	Effect Estimate	Study Location	Source of Effect Estimate
$PM_{2.5}$	Premature mortality	30 and older	Chronic/Annual	6% increase in all-cause mortality associated with $10 \mu\text{g}/\text{m}^3$ increase in $PM_{2.5}$	United States (116 cities)	Krewski, 2009
	Emergency department visits for asthma	All ages	Acute/Daily 24-hour	Relative risk of 1.23 (summer) and 1.04 (winter) per $25.4 \mu\text{g}/\text{m}^3$ and $21.7 \mu\text{g}/\text{m}^3$ respective increase in $PM_{2.5}$	New York City	Ito, 2007
	Hospital admissions for all cardiovascular causes	40 and older	Acute/Daily 24-hour	0.8% (warm season) and 1.1% (cold season) increase in daily cardiovascular disease hospitalizations per $10 \mu\text{g}/\text{m}^3$ increase in $PM_{2.5}$	New York City	Ito, 2010
	Hospital admissions for all respiratory causes	20-64	Acute/Daily 24-hour	2.2% increase in daily chronic respiratory disease hospitalizations per $10 \mu\text{g}/\text{m}^3$ increase in $PM_{2.5}$	Los Angeles	Moolgavkar, 2000
		65 and older	Acute/Daily 24-hour	1.3%-4.3% increase in daily chronic respiratory disease admissions with $10 \mu\text{g}/\text{m}^3$ increase per $PM_{2.5}$ (depending on season)	26 U.S. communities	Zanobetti, 2009

$PM_{2.5}$ =particulate matter

on average, for each 25.4  $\mu\text{g}/\text{m}^3$  increase in daily  $\text{PM}_{2.5}$ ; in the cold season, the increase was 4% per 21.7  $\mu\text{g}/\text{m}^3$ . Similar methods were applied to emergency hospitalizations for cardiovascular health events (Ito, 2010) in New York City among adults aged 40 years of age and older, using hospital discharge data from the New York Statewide Planning and Research Cooperative System, which includes all New York City hospitals. The results showed, per 10  $\mu\text{g}/\text{m}^3$  increase in average daily  $\text{PM}_{2.5}$  concentrations, a 0.8% increase in cardiovascular hospitalizations in the warm season and a 1% increase in the cold season.

A study from Los Angeles County of adults 20 to 65 years of age (Moolgavkar, 2000) was used to analyze respiratory hospital admissions associated with  $\text{PM}_{2.5}$  concentrations. This study estimated the association between  $\text{PM}_{2.5}$  and daily hospital admissions for chronic obstructive pulmonary disease; there was a 2.2% increase in these admissions for every 10  $\mu\text{g}/\text{m}^3$  increase in average daily  $\text{PM}_{2.5}$ .

A larger, national study (Zanobetti, 2009) analyzed hospital admissions for all respiratory causes

among adults more than 65 years of age living in 26 U.S. communities. The authors found increases in daily respiratory admissions ranging from 1.3% in the summer to 4.3% in the spring for every 10  $\mu\text{g}/\text{m}^3$  increase in average daily  $\text{PM}_{2.5}$ .

### Ozone Studies

Three studies were selected to provide concentration-response functions for ozone and mortality, emergency department visits for asthma and hospital admissions for asthma (Table 4). All studies provided estimates across all age groups for populations in New York City.

One study (Huang 2005) showed a 2.3% increase in daily cardiovascular and respiratory deaths for every 10 parts per billion increase in average ozone concentrations over the week before death. Another study (Ito, 2007) observed an increase in relative risk of 1.32 per 53.5 parts per billion increase in maximum ozone concentrations for emergency department visits for asthma. Another study (Silverman 2010) documented that the relative risk for hospitalization increased by 1.06 to 1.20 (depending on age) per 22 parts per billion increase in maximum ozone.

**Table 4. O<sub>3</sub> effect estimates used in this report.**

	Health Effect	Age Group	Acute or Chronic Exposure Metric	Effect Estimate	Study Location	Source of Effect Estimate
O <sub>3</sub>	Premature mortality	All ages	Acute, daily 24-hour average	2.33% increase in cardiovascular and respiratory mortality per 10ppb increase in ozone levels over the previous week	New York City	Huang, 2005
	Emergency department visits for asthma	All ages	Acute, daily 8-hour maximum	Relative risk of 1.32 per 53.5 ppb increase in ozone	New York City	Ito, 2007
	Hospital admissions for asthma	All ages	Acute, daily 8-hour maximum	Relative risk of 1.06-1.20 (varies by age group) per 22 ppb increase in ozone	New York City	Silverman, 2010

O<sub>3</sub>=ozone  
ppb=parts per billion

# Air Quality Data

## Particulate Matter

Current air quality conditions were based on measured daily  $PM_{2.5}$  from all regulatory monitors within New York City and adjacent counties over 3 years (2005-2007) (U.S. Environmental Protection Agency [Air Quality System](#)). The regulatory monitors do not capture the full range of neighborhood variations documented by the Health Department's [NYCCAS](#); these year-round estimates were not available for this report, but will be used in future health impact studies. Preliminary analyses by the Health Department indicate that using NYCCAS data will produce similar results for citywide health impact estimates, but somewhat different results by neighborhood.

The influence of year-to-year changes in meteorology and unique emissions patterns was minimized by calculating baseline  $PM_{2.5}$  concentrations as a 3-year average. Since air pollution levels and health events vary by season, current conditions were defined as quarterly averages of daily  $PM_{2.5}$  concentrations. First, at each monitor, quarterly averages were calculated for each year and then averaged across the 3 years. Daily average concentrations for each quarter were then assigned to each of 42 New York City United Hospital Fund neighborhoods, using a method that assigns greater weight to monitors in or near to a neighborhood (U.S. Environmental Protection Agency, 2010).

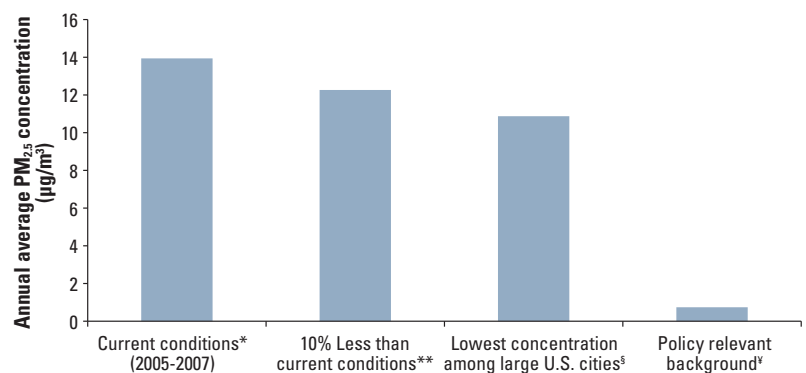
Baseline  $PM_{2.5}$  concentrations were compared to 3 comparison scenarios (**Figure 4**):

**1. Policy-relevant background.** This is an estimate, based on air pollution models, of the level of natural background  $PM_{2.5}$  concentrations that would exist without sources of air pollution from human activity in the United States, and which therefore cannot be affected by emissions control efforts (Environmental Protection Agency, 2009). Policy-relevant background is approximately 5% of current average  $PM_{2.5}$  concentrations in New York City. Although achieving policy-

relevant background is not possible, it provides a comparison for calculating the overall health burden from exposure to fine particles from man-made sources. Since background pollution levels vary by season, the quarterly average policy-relevant backgrounds modeled for the Northeast in were applied (U.S. Environmental Protection Agency, 2009).

- 2. 10% improvement.** This is an analysis of the health benefits that would result if  $PM_{2.5}$  concentration were 10% less, a modest improvement, than current concentrations New York City.
- 3. Lowest concentration among large U.S. cities.** In 2007, New York City's first comprehensive sustainability plan, [PlaNYC](#) set the goal of achieving "the cleanest air quality of any big U.S. city" by 2030. The benefits of achieving this goal was modeled by comparing levels in the city from 2005 through 2007 to the lowest levels measured in U.S. cities with populations larger than one million people. Achieving this goal would require a 22% reduction in average  $PM_{2.5}$  concentrations.

**Figure 4. Baseline annual average  $PM_{2.5}$  levels in New York City (2005-2007) and levels in comparison scenarios.**



$PM_{2.5}$ =particulate matter

\* Current conditions=annual average  $PM_{2.5}$  concentrations, 2005-2007 Source: United States Environmental Protection Agency Air Quality System (AQS)

\*\* 10% Less than Current Conditions=2005-2007 Annual average concentrations reduced by 10%, calculated from USEPA AQS

§ Lowest concentration among large US Cities: Lowest 2005-2007 annual average concentrations among the 9 US cities with greater than 1,000,000 residents.

¶ Policy relevant background – Annual average  $PM_{2.5}$  concentrations in U.S. Northeast assuming no anthropogenic emissions from sources within the U.S., as predicted by the Community Multiscale Air Quality Modeling System (CMAQ) and the Goddard Earth Observing System (GEOS)-Chem model Source: EPA 2009

## Ozone

Although ozone is always present in New York City's air, concentrations are much higher in the summer. Since many studies of ozone health effects focus on the warm season, this study included only New York City's ozone season (April 1st - September 30th).

Current air quality conditions were based on ozone data from all regulatory monitors within the city and adjacent counties over 3 years (2005-2007) ([EPA Air Quality System](#)). Using 3 years of data reduces the influence of year-to-year weather and emission changes on the estimates. Since epidemiological studies model the risk estimates using a variety of averaging times, several exposure metrics were computed for consistency with the effect estimates (24-hour average, daily 8-hour maximum). First, at each monitor, quarterly averages (April-June and July-September) were calculated for each year and then averaged across the 3 years. Average concentrations for each quarter were assigned to each of 42 New

York City United Hospital Fund neighborhoods, using a method that gives monitors in or near to a neighborhood a greater weight (EPA 2010).

**Figure 5** shows current baseline ozone concentrations and 2 comparison scenarios:

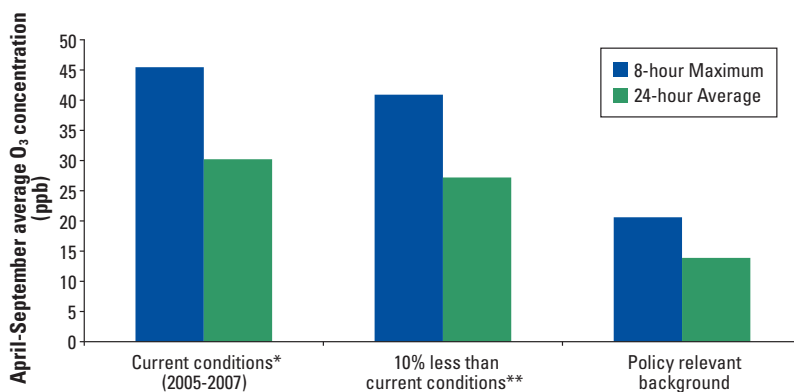
1. **Policy-relevant background** – This is an estimate based on air pollution models of the natural background ozone concentrations that would exist without sources of air pollution from human activity, and therefore cannot be affected by emissions control efforts (Fiore 2004). We converted the 4-hour, afternoon average policy-relevant background estimate in the Northeast to the policy-relevant background estimate for different metrics used in the ozone studies considered in the health impact assessment by computing the ratio of the 4-hour average to the 8-hour maximum or the 24-hour average, calculated from the hourly monitoring data from sites used in the analysis. Policy-relevant background is approximately 45% of current average ozone concentrations in New York City and a smaller proportion of the concentration on days with poor air quality. Although achieving this level is not possible, it provides a means for measuring the overall health burden from exposure to ozone.

2. **10% improvement** – A comparison ozone concentration 10% less than current concentrations was used to estimate the health benefits associated with a modest improvement in New York City air quality.

## Baseline Population and Health Data

Mortality data for New York City residents were provided by the Health Department's Bureau of Vital Statistics for 2005 through 2007. Based on the underlying cause of death, daily counts were summarized and rates of all-cause mortality were calculated across 22 age groups for the PM<sub>2.5</sub> impact estimates, and for the subset of mortality due to cardiovascular and respiratory causes matching a specific case definition (Huang, 2005) for ozone impact estimates.

**Figure 5. Baseline warm season average O<sub>3</sub> levels in New York City (2005-2007) and levels in comparison scenarios.**



O<sub>3</sub>=ozone

ppb=parts per billion

\* Current Conditions=average ozone concentrations, April-September 2005-2007, measured at monitors within New York City and adjacent counties. (Source: Environmental Protection Agency Air Quality System (AQS)).

\*\* 10% Less than current conditions=April-September 2005-2007 average concentrations reduced by 10%, calculated from USEPA AQS<sup>5</sup>

<sup>5</sup> Policy-relevant background=April-September 2005-2007 Northeast U.S. average ozone concentration assuming no anthropogenic emissions from U.S., as predicted by the GEOS-Chem Model. Source: Fiore 2004

Hospital admissions and emergency room visits for New York City residents (from the New York Statewide Planning and Research Cooperative System) for the same 3 years (2005-2007) was used to summarize daily counts and rates across 22 age groups. Using diagnostic codes in the hospital discharge data, case definitions were matched to each of the studies with concentration response functions.

All 3 datasets contain ZIP code of residence from which data were aggregated to the United Hospital Fund neighborhood definition, consisting of 42 adjoining ZIP code areas. The 22 age-specific [population denominators](#) for 2005 through 2007 were produced by the Health Department using data from the U.S. Census Bureau Population Estimate Program and housing unit data obtained from the New York City Department of City Planning.

# Results

The main analyses used for each pollutant to estimate health impacts of PM<sub>2.5</sub> and ozone in New York City included:

1. The total citywide health impact for each health endpoint studied, using the policy-relevant background comparison to estimate the overall burden (preventable events if all human sources of the pollutant were eliminated) and other comparisons to estimate the health events that could be prevented with air pollution improvements
2. For each health endpoint, maps showing the rate of air pollution-attributable health events for current conditions compared to the policy-relevant background by United Hospital Fund neighborhood
3. For each health endpoint, the estimated proportion and rate of air pollution-attributable health events for current conditions compared to the policy relevant background in different age groups and comparisons of United Hospital Fund neighborhoods grouped by the proportion of people living in poverty

An [online appendix](#) contains results from additional analyses using other studies to obtain concentration response functions and other data.

## Particulate Matter Health Impacts

Current exposures to the annual average concentrations of PM<sub>2.5</sub> above background concentrations cause more than 3,000 premature deaths, more than 2,000 hospitalizations due to respiratory and cardiovascular causes, and approximately 6,000 emergency department visits for asthma (**Table 5**) in New York City annually. Even a feasible, modest reduction (10%) in PM<sub>2.5</sub> concentrations could prevent more than 300 premature deaths, 200 hospital admissions and 600 emergency department visits. Achieving the [PlaNYC](#) goal of “cleanest air of any big city” would result in even more substantial public health benefits.

**Table 5. Annual health events attributable to citywide PM<sub>2.5</sub> levels and the health benefits of reduced PM<sub>2.5</sub> levels.**

Health Effect	Age Group	Annual Health Events Attributable to Current PM <sub>2.5</sub> Compared to Background Levels			Annual Health Events Prevented: PM <sub>2.5</sub> Levels Reduced 10%			Annual Health Events Prevented: PM <sub>2.5</sub> Levels Reduced to Cleanest Air of Any Large City		
		Number of Events (95% CI)*	Rate per 100,000 people	Percent (%) of Events**	Number of Events (95% CI)	Annual Rate per 100,000 people	Percent (%) of Events**	Number of Events (95% CI)*	Annual Rate per 100,000 people	Percent (%) of Events**
Premature mortality	30 and older	3,200 (2200,4100)	65	6.4	380 (240,460)	7.1	0.7	760 (520,1000)	16	1.5
Hospital admissions for respiratory conditions	20 and older	1,200 (460,1900)	20	2.6	130 (50,210)	2.1	0.3	280 (109,460)	4.7	0.6
Hospital admissions for cardiovascular conditions	40 and older	920 (210,1630)	26	1.1	100 (20,170)	2.8	0.1	220 (50,380)	6.0	0.3
Emergency department visits for asthma	Under 18	2,400 (1400,3400)	130	5.6	270 (160,370)	14	0.6	580 (340,810)	30	1.3
Emergency department visits for asthma	18 and older	3,600 (2200,4900)	57	6.1	390 (240,550)	6.3	0.7	850 (520,1200)	14	1.5

PM<sub>2.5</sub>=particulate matter  
 \* CI=Confidence Interval  
 \*\* Percent of certain citywide health events attributable to PM<sub>2.5</sub> in the specified age range.



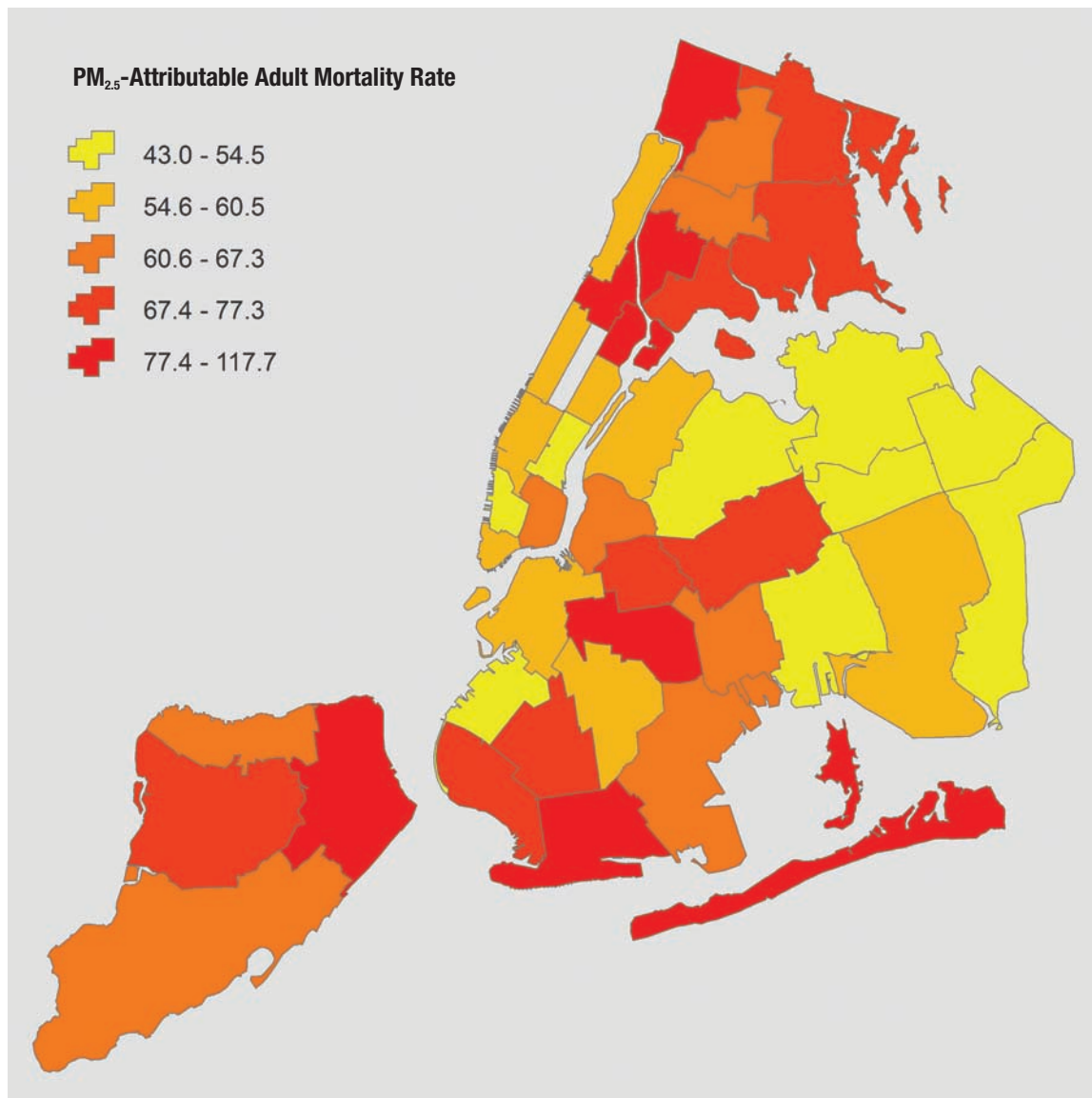
### Mortality

An estimated 3,200 deaths annually among adults 30 years of age and older are attributed to  $PM_{2.5}$  at current levels in New York City (**Table 5**). Chronic  $PM_{2.5}$ -attributable premature mortality varies considerably across demographic groups and neighborhoods. The  $PM_{2.5}$ -attributable mortality rates per 100,000 population varied by

more than 2-fold, with the highest burdens in sections of the Bronx, Northern Manhattan, parts of Southern Brooklyn and the Rockaways (**Figure 6**).

Nearly 3 in 4 deaths (73%) attributable to  $PM_{2.5}$  occur in adults age 65 years and older (**Figure 7**), reflecting the higher overall mortality rates this age group.

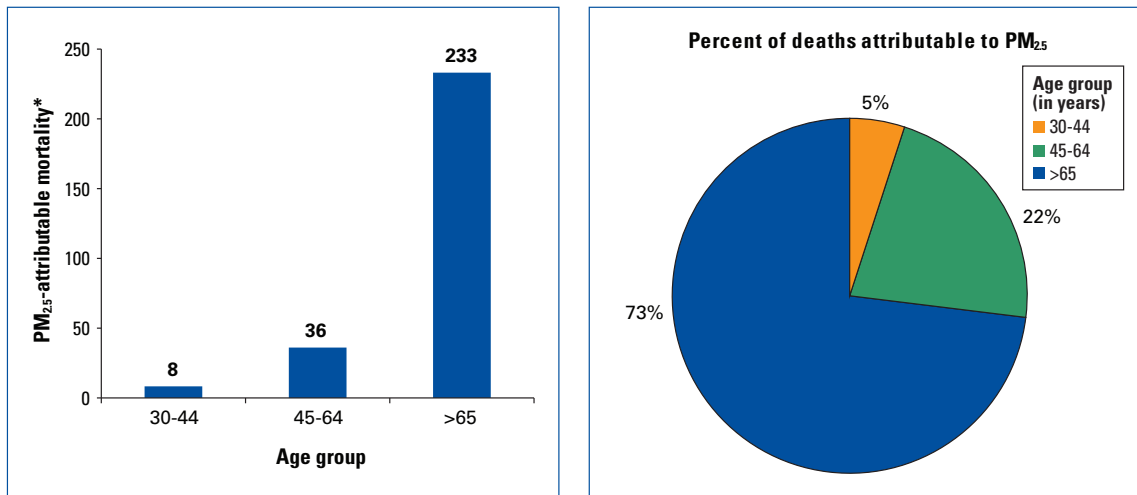
**Figure 6. Rates of  $PM_{2.5}$ -attributable mortality vary by 2.7-fold across New York City neighborhoods.**



$PM_{2.5}$ =particulate matter

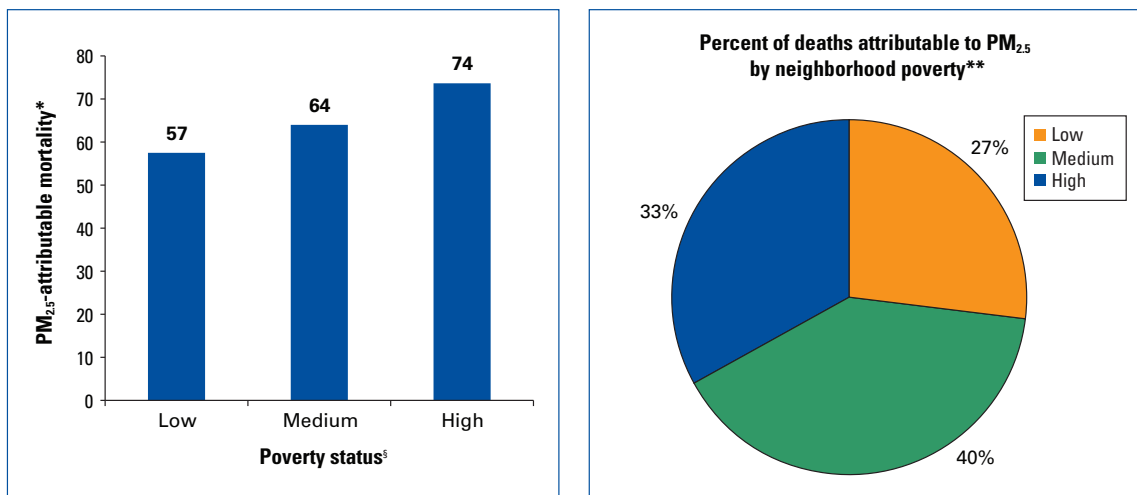
The rate of PM<sub>2.5</sub>-attributable deaths is highest in the poorest neighborhoods, but more than 1 in 4 (27%) attributable deaths occurs in more affluent neighborhoods (Figure 8).

**Figure 7. Nearly 3 in 4 deaths attributable to PM<sub>2.5</sub> occur in adults 65 years of age and older.\***



PM<sub>2.5</sub>=particulate matter  
 \*Attributable mortality rate per 100,000 persons, annually

**Figure 8. The PM<sub>2.5</sub>-attributable mortality rate is 28% higher in neighborhoods with high, as compared to low, poverty rates.**



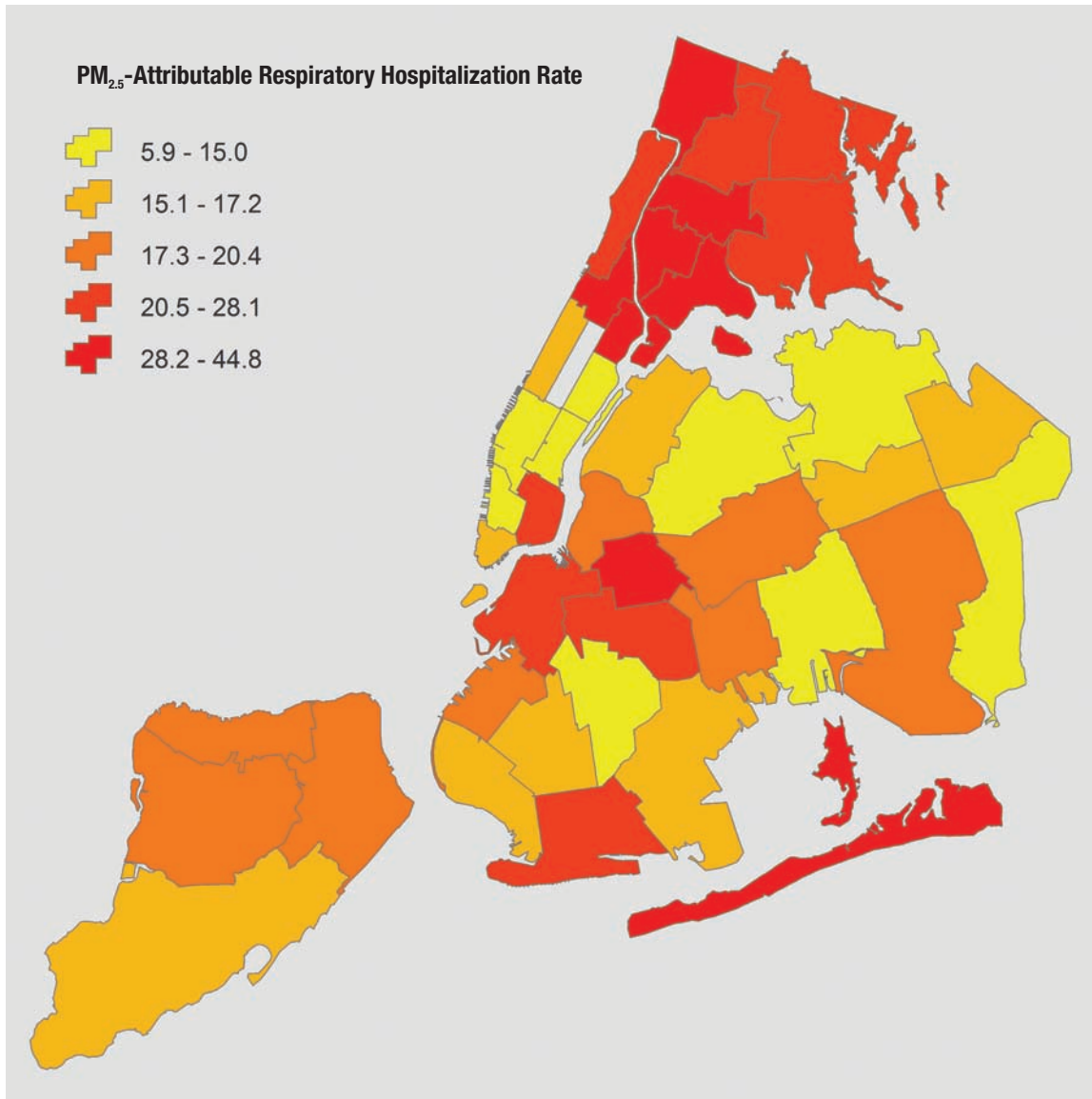
PM<sub>2.5</sub>=particulate matter  
 \* Attributable mortality rate per 100,000 persons above 30 years of age, annually  
 \*\* Among adults 30 years of age and older  
 § Poverty Status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

**Hospital Admissions for Respiratory Disease**

Approximately 1,200 annual hospital admissions for respiratory disease among New York City adults age 20 years and older are attributable to current levels of PM<sub>2.5</sub> (Table 5). Across city neighborhoods, the rate of respiratory hospital-

ization among adults attributable to PM<sub>2.5</sub> per 100,000 persons varies more than 7-fold, with the highest burdens found in sections of the South Bronx, Northern Manhattan and Northern Brooklyn (Figure 9). This pattern reflects the variation, by neighborhood, in overall respiratory hospitalization rates in adults.

**Figure 9. PM<sub>2.5</sub>-attributable respiratory hospitalization rates vary 7.6-fold across New York City neighborhoods.**

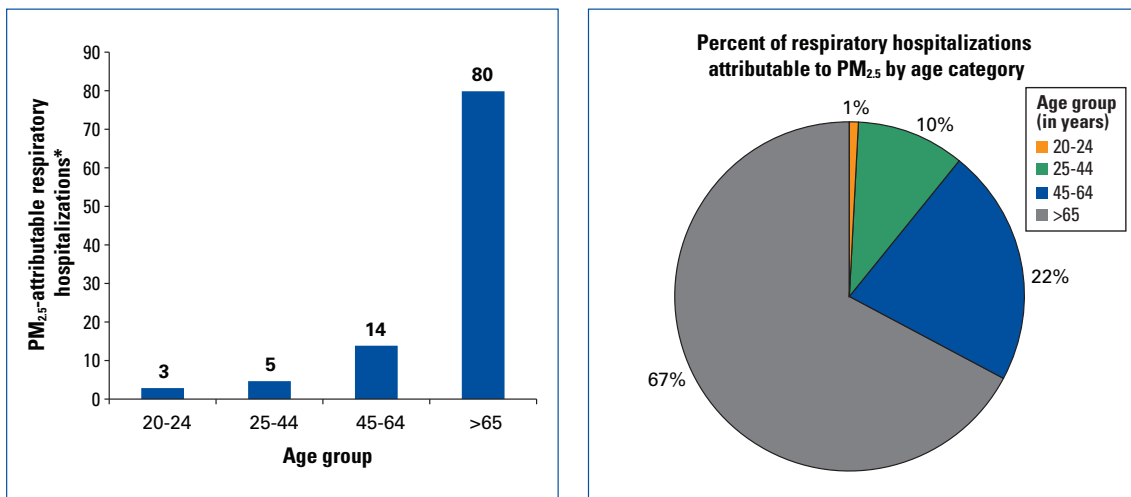


PM<sub>2.5</sub>=particulate matter

Overall, older adults (65 years of age and older) have much higher rates of respiratory hospitalizations and account for 67% of estimated PM<sub>2.5</sub>-attributed respiratory hospitalizations (Figure 10).

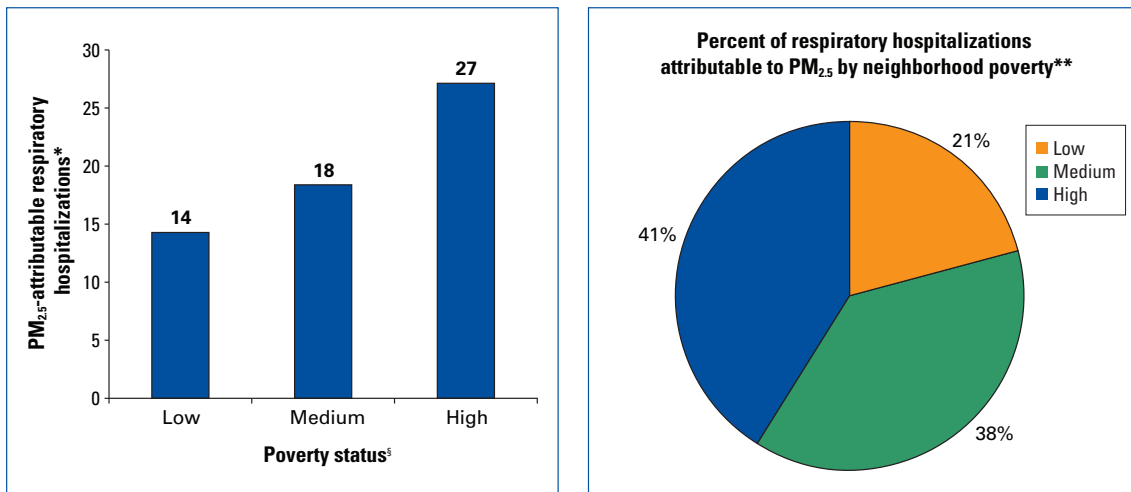
The estimated rate of PM<sub>2.5</sub>-attributable respiratory hospitalization is nearly twice as high in high poverty, compared to low poverty, neighborhoods (Figure 11).

**Figure 10. Two-thirds of respiratory hospitalizations attributable to PM<sub>2.5</sub> occur in adults 65 years of age and older.**



PM<sub>2.5</sub>=particulate matter  
 \*Attributable mortality rate per 100,000 persons, annually

**Figure 11. The PM<sub>2.5</sub>-attributable respiratory hospitalization rate is 90% higher in neighborhoods with high, as compared to low, poverty rates.**



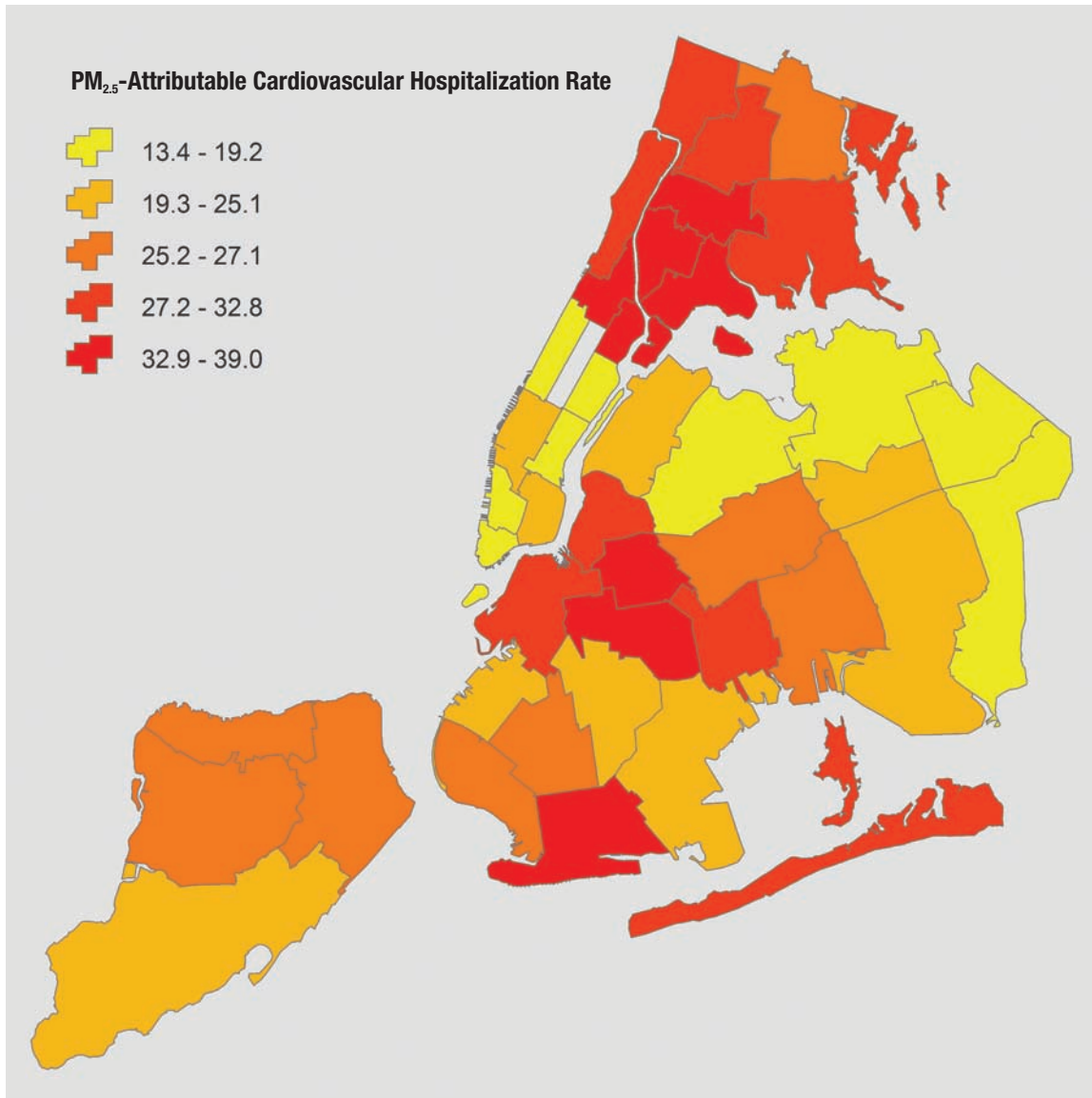
PM<sub>2.5</sub>=particulate matter  
 \*Attributable respiratory hospitalization rate per 100,000 persons >20 years of age  
 \*\* Among adults above 20 years of age  
 § Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

**Hospital Admissions for Cardiovascular Disease**

Among residents age 40 years and older, an estimated 920 annual hospitalizations for cardiovascular events are attributable to current PM<sub>2.5</sub> levels

in New York City (Table 5). These rates vary much less (3-fold) across the city than rates of respiratory hospital admissions (7.5-fold); the highest rates occur in the Bronx, Northern Manhattan, North-Central Brooklyn and parts of Southern Brooklyn (Figure 12).

**Figure 12. PM<sub>2.5</sub>-attributable cardiovascular hospitalization rates vary 2.9-fold across New York City neighborhoods.**

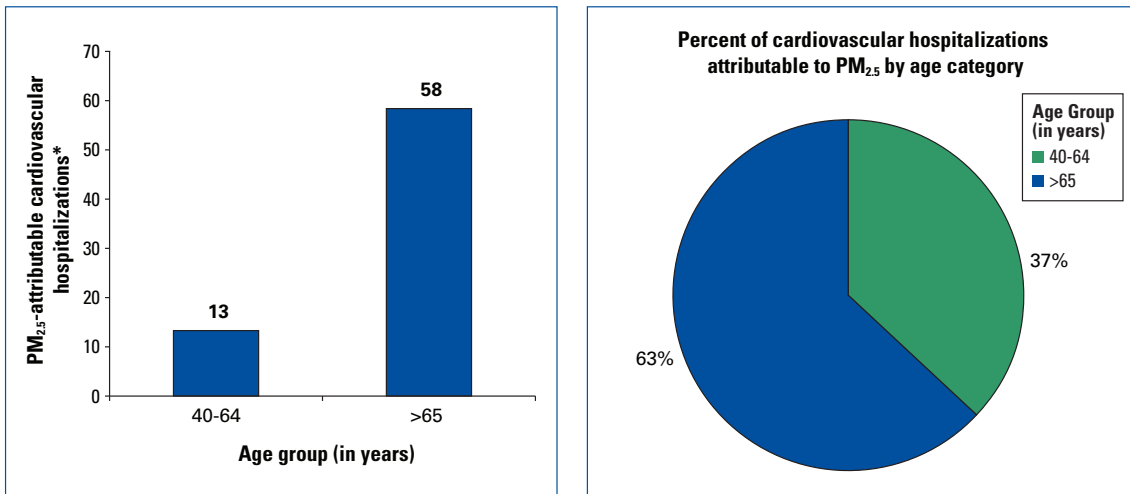


PM<sub>2.5</sub>=particulate matter

Adults older than 65 years of age have rates 4.5 times higher than younger adults of  $PM_{2.5}$ -attributable hospitalization for cardiovascular events; overall, an estimated 63% of  $PM_{2.5}$ -attributed cases occur in older adults (Figure 13).

Neighborhoods with a high rate of poverty have a 1.6-fold higher rate of  $PM_{2.5}$ -attributable cardiovascular hospital admissions than do low poverty neighborhoods (Figure 14).

**Figure 13. More than three-fifths of hospital admissions for cardiovascular disease attributable to  $PM_{2.5}$  occur in adults older than 65 years of age.**

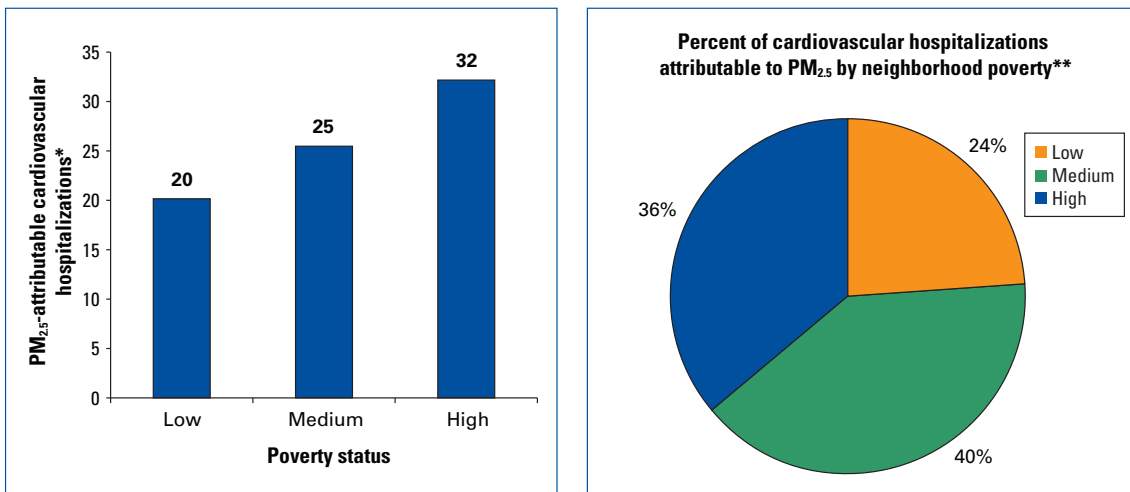


$PM_{2.5}$ =particulate matter

\* Attributable cardiovascular hospitalization rate per 100,000 persons, annually

§ Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000.

**Figure 14. The  $PM_{2.5}$ -attributable cardiovascular hospitalization rate is 60% higher in neighborhoods with high, as compared to low, poverty rates.**



$PM_{2.5}$ =particulate matter

\* Attributable cardiovascular hospitalization rate per 100,000 persons above 40 years of age

\*\* Among adults above 40 years of age

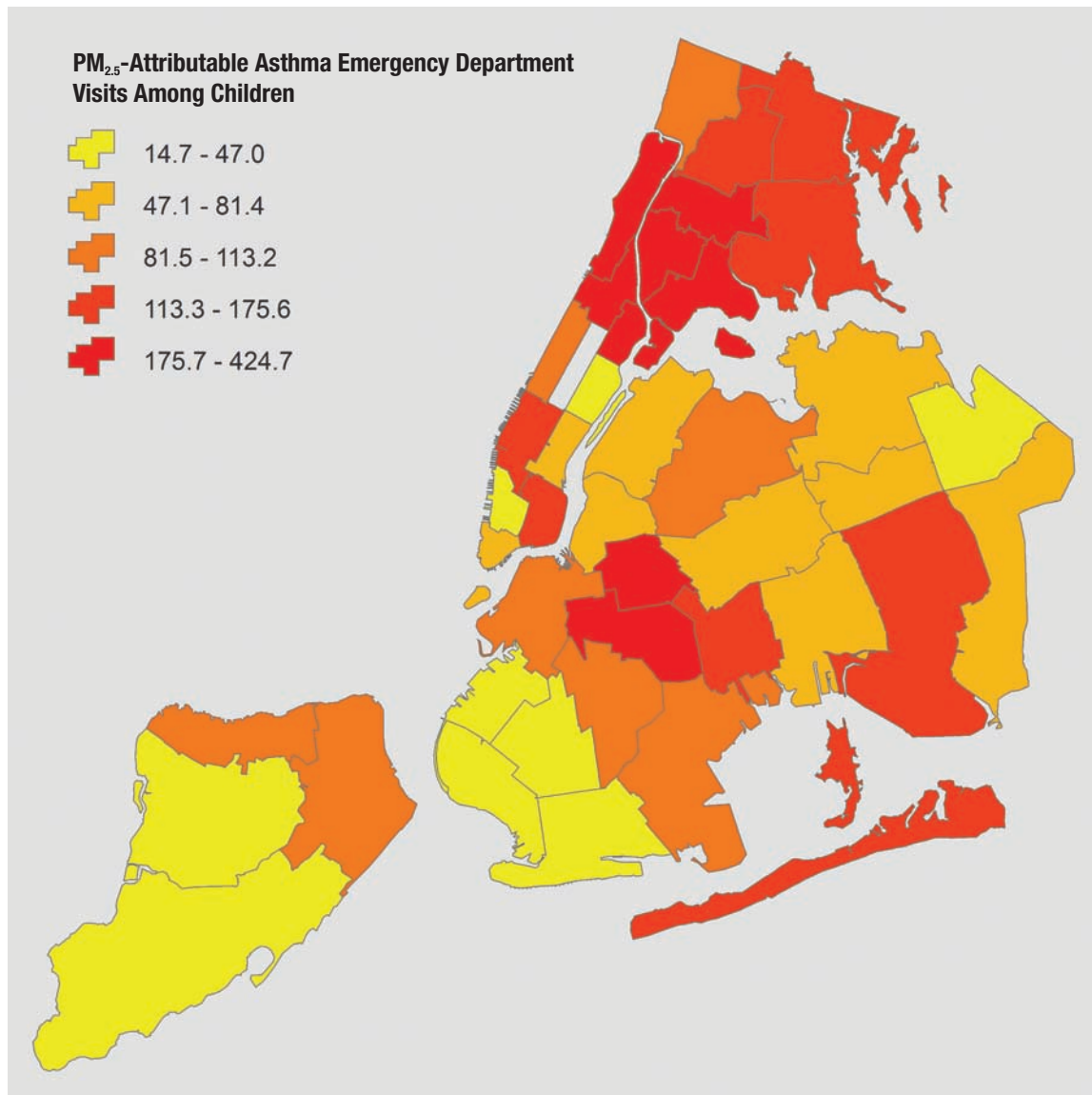
Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

### Emergency Department Visits for Asthma in Children

More than 2,400 emergency department visits annually for asthma among New York City children are attributable to current  $PM_{2.5}$  levels (Table 5). These rates vary greatly, from approximately 15 per 100,000 people younger

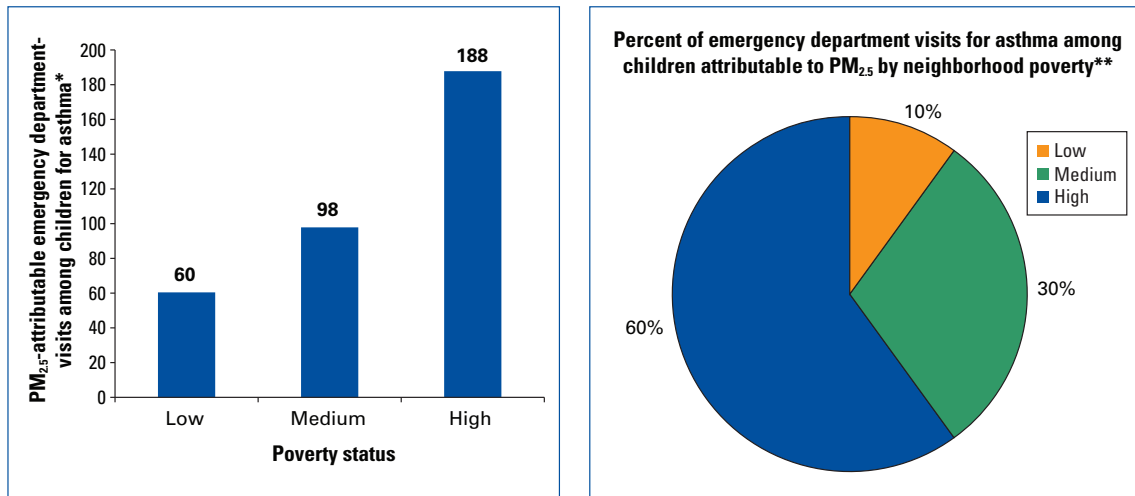
than 18 years of age, to more than 175 visits per 100,000 in areas with the higher poverty rates (Northern Manhattan, large areas of the Bronx, Central Brooklyn, parts of Eastern Queens and the Rockaways), reflecting the variation in overall asthma emergency department visit rates in children (Figure 15).

**Figure 15.  $PM_{2.5}$ -attributable asthma emergency department visit rates among children younger than 18 years of age vary nearly 30-fold across New York City neighborhoods.**



$PM_{2.5}$ =particulate matter

**Figure 16.  $PM_{2.5}$ -attributable asthma emergency department rates among children are more than 3 times higher in high poverty, compared to low poverty, neighborhoods.**



$PM_{2.5}$ =particulate matter

\* Attributable rate of emergency department visits for asthma per 100,000 persons under 18 years of age

\*\* Among children <18 years of age

Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

The rates are 3 times higher in the most impoverished neighborhoods (**Figure 16**), which are responsible for more than 60% of  $PM_{2.5}$ -attributable emergency department visits for pediatric asthma.

### Emergency Department Visits for Asthma in Adults

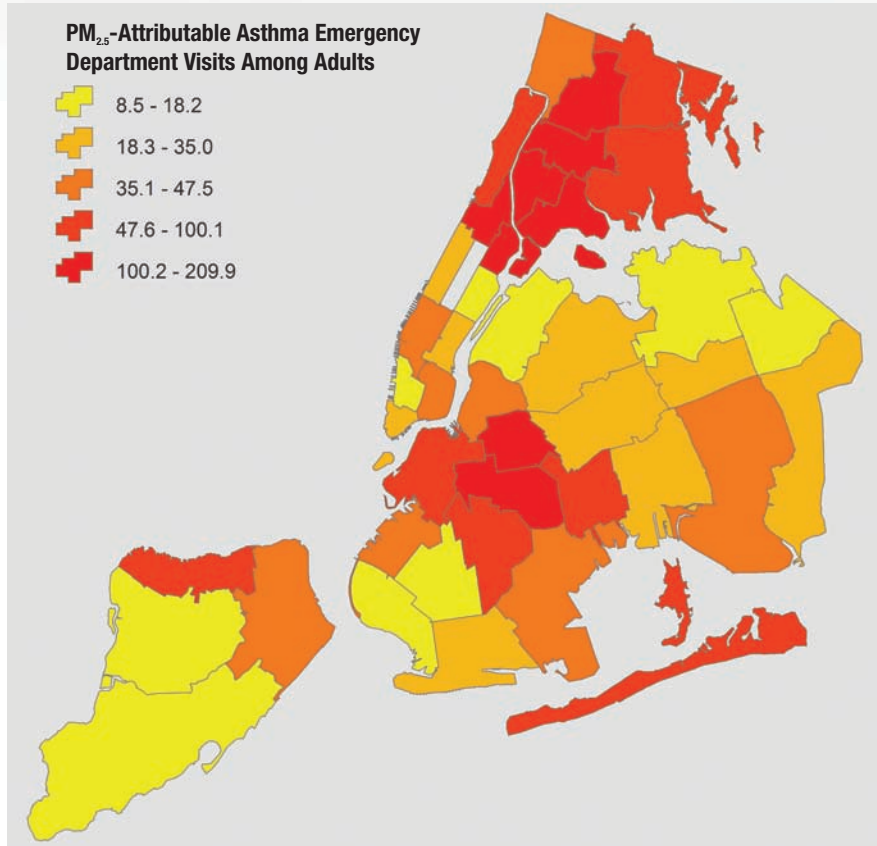
An estimated annual 3,600 emergency department visits for asthma among New York City adults every year in New York City are attributable to  $PM_{2.5}$  (**Table 5**). These rates vary considerably, from as

low as 9 per 100,000 population in Southern Staten Island and Southwest Brooklyn, to as high as 100 to 200 visits per 100,000 in Northern Manhattan, large areas of the Bronx, Central Brooklyn, parts of Eastern Queens, the Rockaways and parts of Northern Staten Island (**Figure 17**).

Disparities by neighborhood poverty are large; there is a 5-fold increase in high poverty, compared to low poverty, neighborhoods (**Figure 18**).

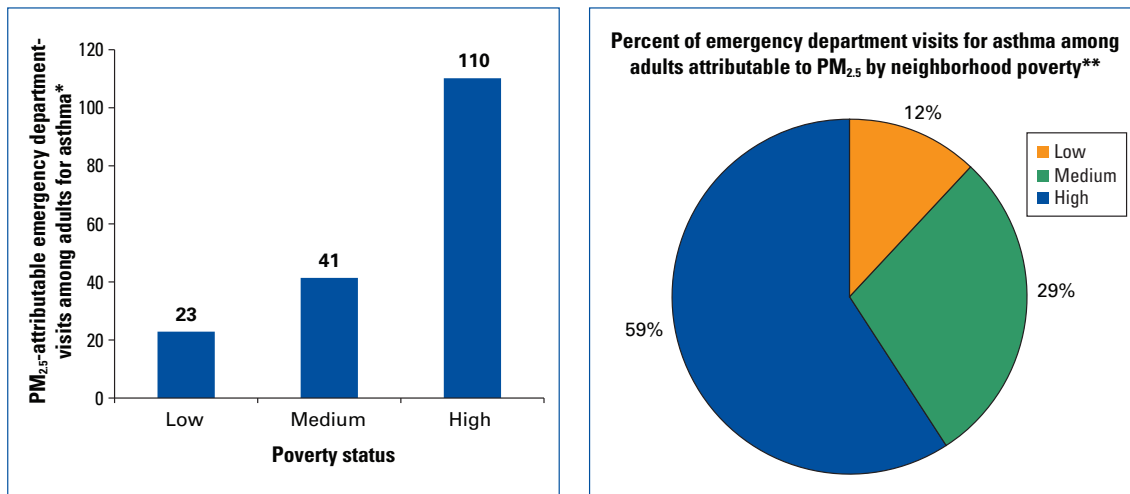


**Figure 17. PM<sub>2.5</sub>-attributable asthma emergency department visit rates among adults 18 years and older vary 25-fold across New York City neighborhoods.**



PM<sub>2.5</sub>=particulate matter

**Figure 18. PM<sub>2.5</sub>-attributable asthma emergency department visit rates in adults is nearly 5 times higher in neighborhoods with high, as compared to low, poverty.**



PM<sub>2.5</sub>=particulate matter

\* Attributable rate of emergency department visits for asthma per 100,000 persons above 18 years of age

\*\* Among adult >18 years of age

Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

## Ozone Health Impacts

In New York City, based on the concentration-response functions used in the main analysis of this report, current exposures to average concentrations of ozone from April through September above background concentrations cause more than 400

premature deaths, 850 hospitalizations for asthma and 4,500 emergency department visits for asthma annually (**Table 6**). Even a feasible, modest reduction of 10% in ozone concentrations could prevent more than 80 premature deaths, 180 hospital admissions and 950 emergency department visits.

**Table 6. Annual health events attributable to citywide O<sub>3</sub> levels and the health benefits of reduced O<sub>3</sub> levels.**

	Health Effect	Age Group	Annual Health Events Attributable to Current Ozone Compared to Background Levels			Annual Health Events Prevented If Ozone Levels Reduced by 10%		
			Number of Events (95% CI)**	Annual Rate per 100,000 people	Percent (%) of Events*	Number of Events (95% CI)**	Annual Rate per 100,000 people	Percent (%) of Events
O <sub>3</sub> -Related Health Effects	Premature mortality	All Ages	400 (200,600)	4.9	3.1	80 (40,120)	1.0	0.6
	Hospital admissions-asthma	Less than 18 years	420 (260,580)	21	11	90 (50,130)	4.4	2.4
	Hospital admissions-asthma	18 and older	450 (240,650)	7.2	6.1	90 (50,130)	1.5	1.2
	Emergency department visits for asthma	Less than 18 years	1,800 (1300,2200)	91	10	370 (260,470)	19	2.0
	Emergency department visits for asthma	18 and older	2,900 (2100,3600)	45	11	600 (430,770)	9.5	2.2

O<sub>3</sub>=ozone

\* Annual Percent of April through September health events of a given type and in the specific age group that is attributable to O<sub>3</sub>

\*\* CI=Confidence interval

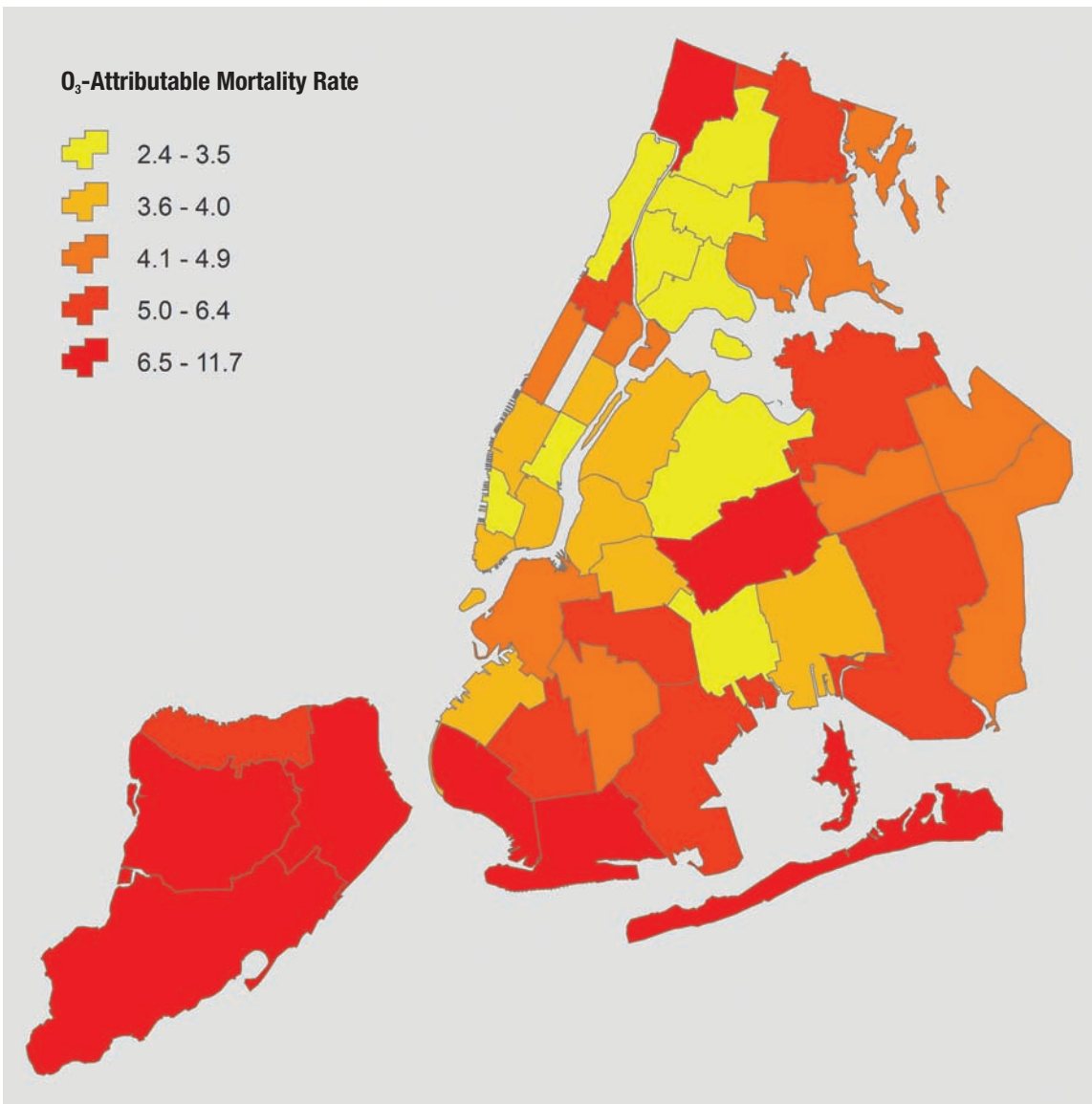
**Mortality**

An estimated 400 ozone-attributable deaths occur in New York City annually. By neighborhood, rates of ozone-attributed mortality vary from 2.4 to 11.7 per 100,000 persons. Areas with the highest

burden are located outside the city center, in Southern Brooklyn and Staten Island, Central Queens and Northwestern Bronx (Figure 19).

Nearly 85% of ozone-attributed mortality is among adults older than age 65 years of age (Figure 20).

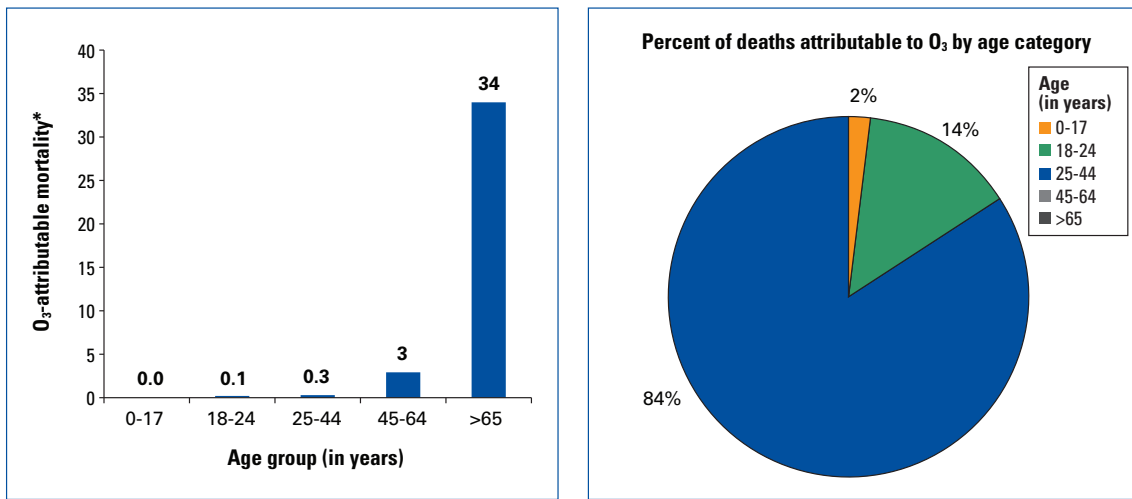
**Figure 19. O<sub>3</sub>-attributable mortality rates vary 5-fold across New York City neighborhoods.**



O<sub>3</sub>=ozone

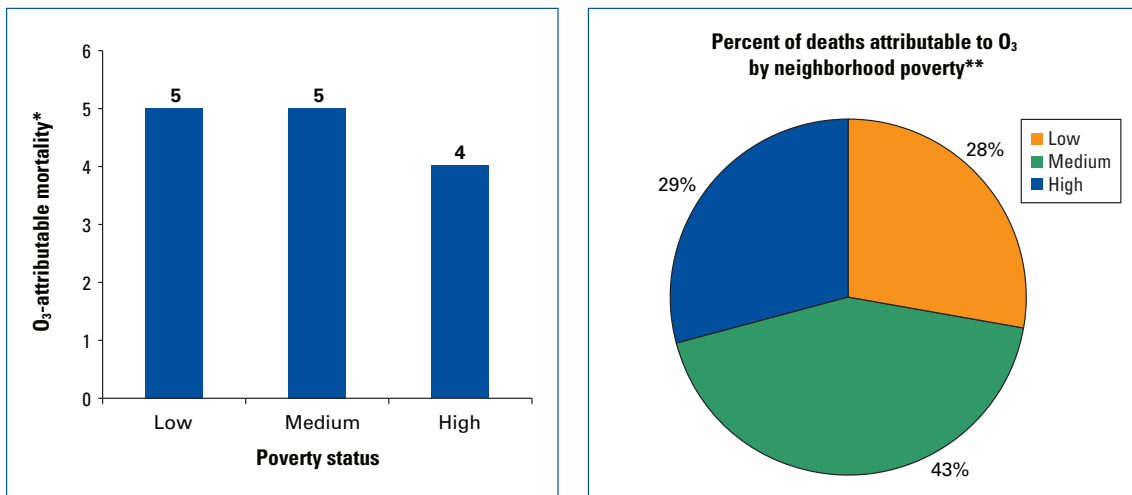
Contrary to the trends evident in PM<sub>2.5</sub> morbidity and mortality rates, ozone-attributable mortality is relatively evenly distributed according to neighborhood income (Figure 21).

**Figure 20. More than four-fifths of deaths attributable to O<sub>3</sub> occur in adults 65 years of age and older.**



O<sub>3</sub>=ozone  
\* Attributable mortality rate per 100,000 persons, annually

**Figure 21. Ozone-attributable mortality rates are similar in neighborhoods with high, as compared to low, poverty rates.**



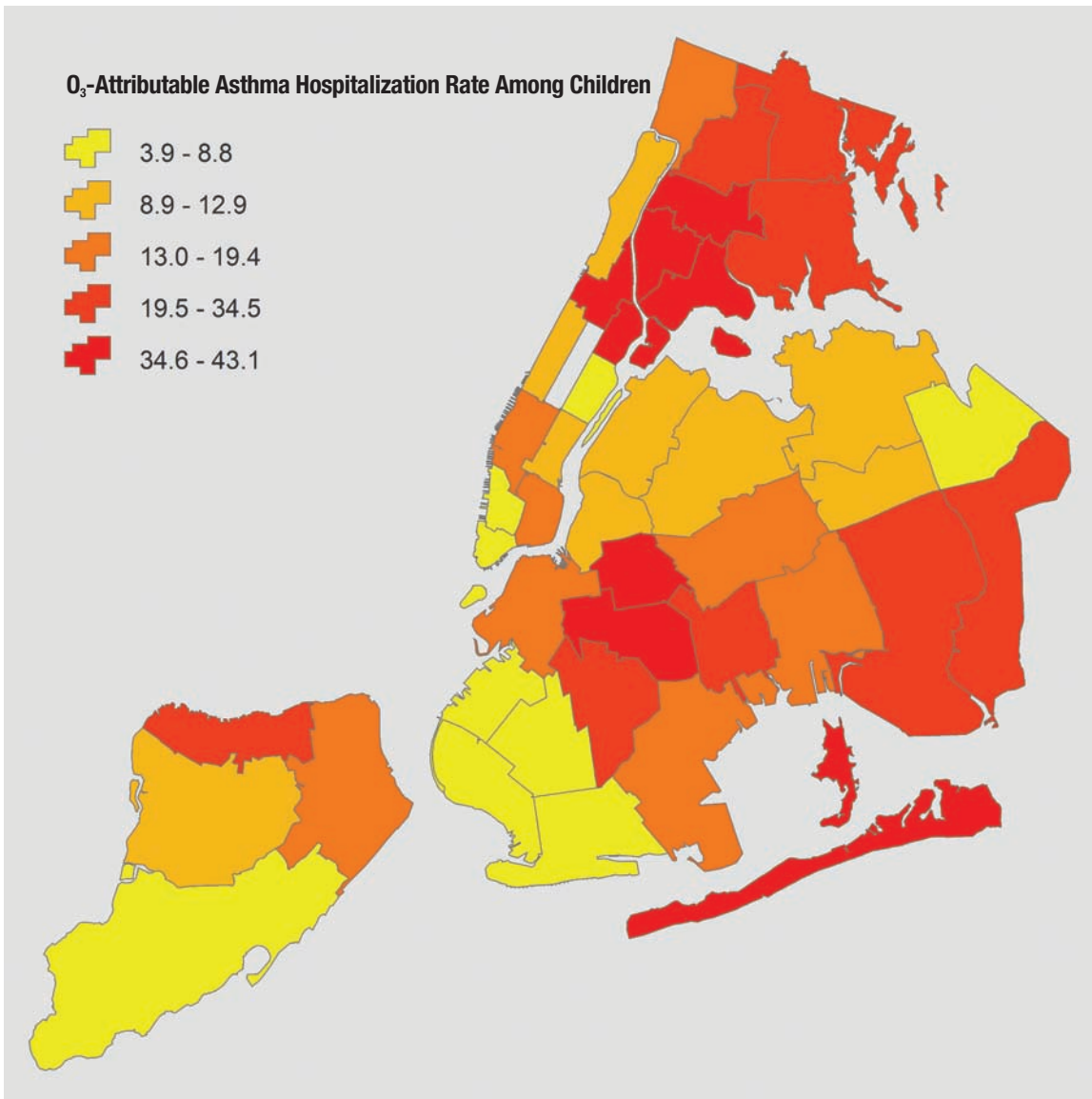
O<sub>3</sub>=ozone  
\* Attributable mortality rate per 100,000 persons, annually  
Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

**Hospital Admissions and Emergency Department Visits for Asthma in Children**

More than 400 hospital admissions and 1,700 emergency department visits annually for asthma among children are likely attributable to ozone

exposure in New York City (Table 6). As is the case for underlying rates of urgent care for asthma, rates vary by neighborhood, from approximately 4 to 43 ozone-attributable hospital admissions per 100,000 children. Ozone-attributable asthma admissions are most

**Figure 22. O<sub>3</sub>-attributable asthma hospitalization rates among children younger than 18 years of age vary 11-fold across New York City neighborhoods.**

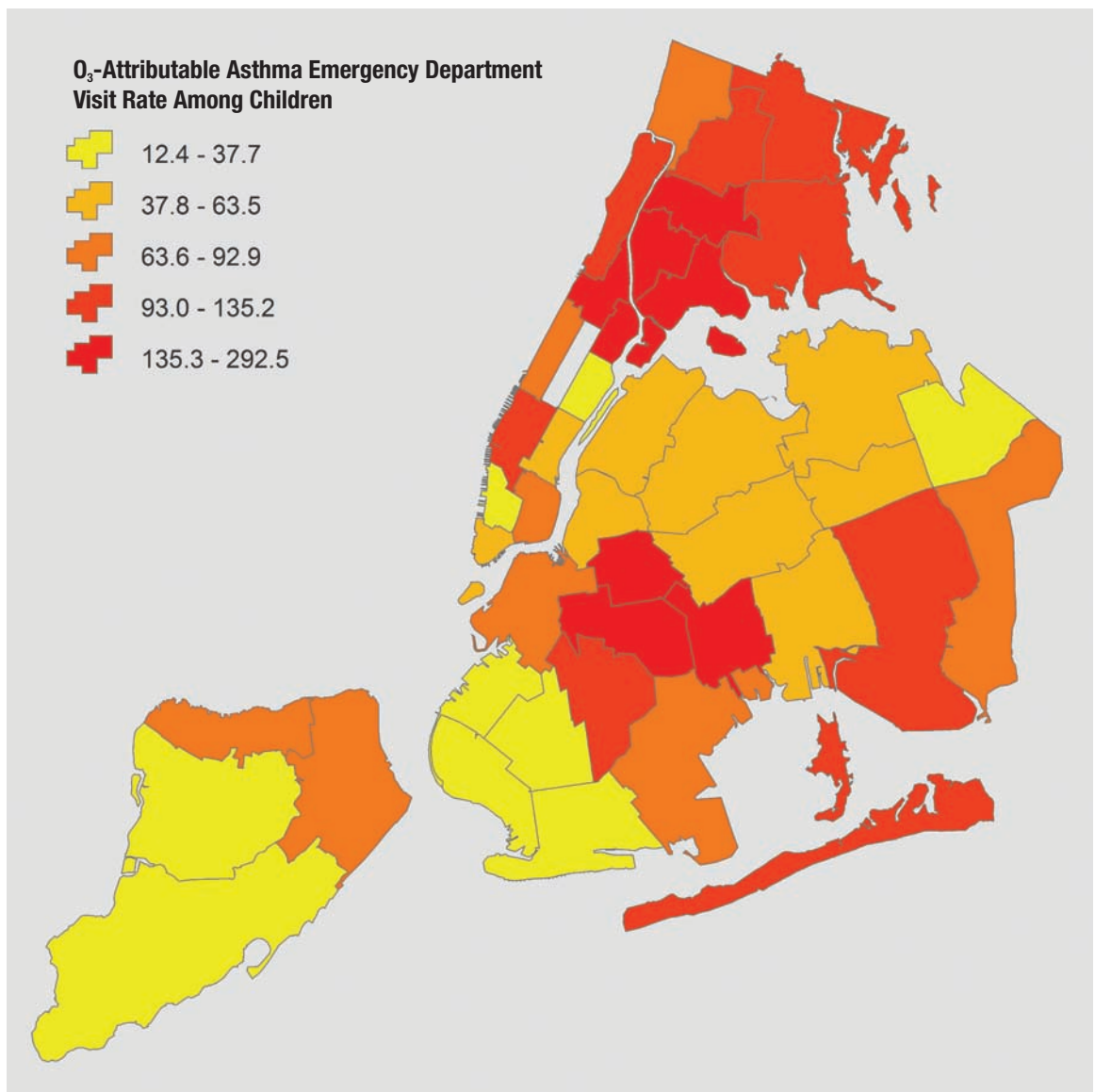


O<sub>3</sub>=ozone

concentrated in Northern Manhattan, the Bronx, Central Brooklyn, and parts Eastern-Central Queens and the Rockaways (Figure 22). Asthma emergency department visits attributable to ozone

follow a similar geographic pattern, ranging from 12 to nearly 300 emergency department visits per 100,000 children (Figure 23).

**Figure 23. O<sub>3</sub>-attributable rates of emergency department visits for asthma among children younger than 18 years vary 24-fold across New York City neighborhoods.**

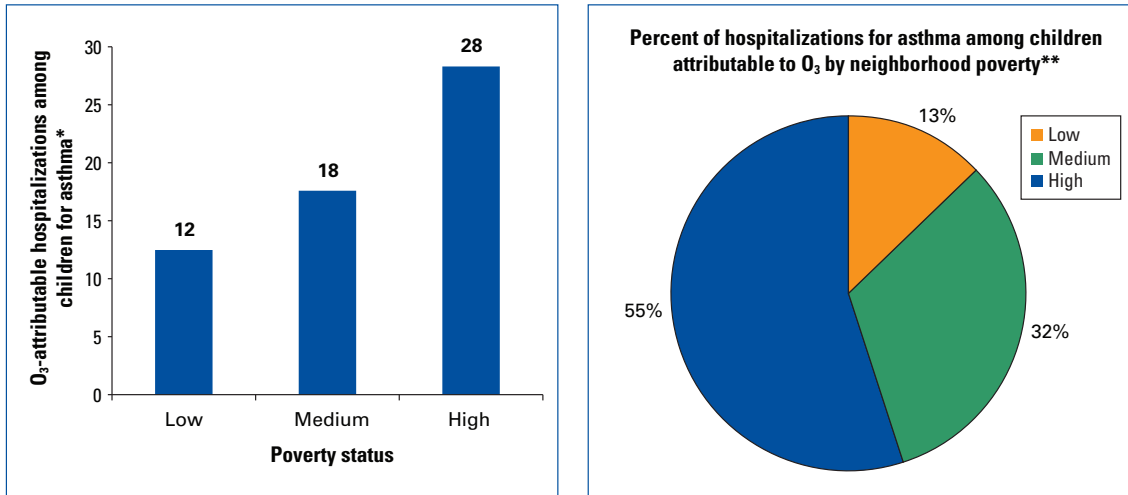


O<sub>3</sub>=ozone

High poverty neighborhoods bear 55% of the burden of ozone-attributable asthma hospital admissions (Figure 24) and account for 56% of

emergency department visits (Figure 25) among children.

**Figure 24. O<sub>3</sub>-attributable asthma hospitalization rates among children younger than 18 years of age is more than two times higher in neighborhoods with high, as compared to low, poverty rates.**



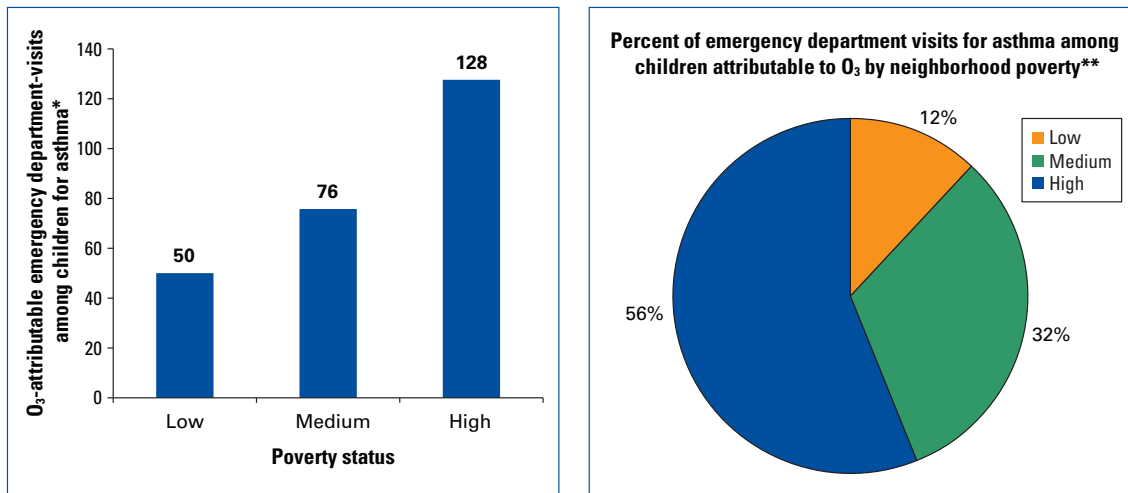
O<sub>3</sub>=ozone

\* Attributable asthma hospitalization rate per 100,000 persons under 18 years of age

\*\* Among children younger than 18 years of age

Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

**Figure 25. O<sub>3</sub>-attributable rates of emergency department visits for asthma among children younger than 18 years are more than twice as high in neighborhoods with high, as compared to low, poverty rates.**



O<sub>3</sub>=ozone

\* Attributable rate of emergency department visits for asthma per 100,000 persons under 18

\*\* Among children younger than 18 years of age

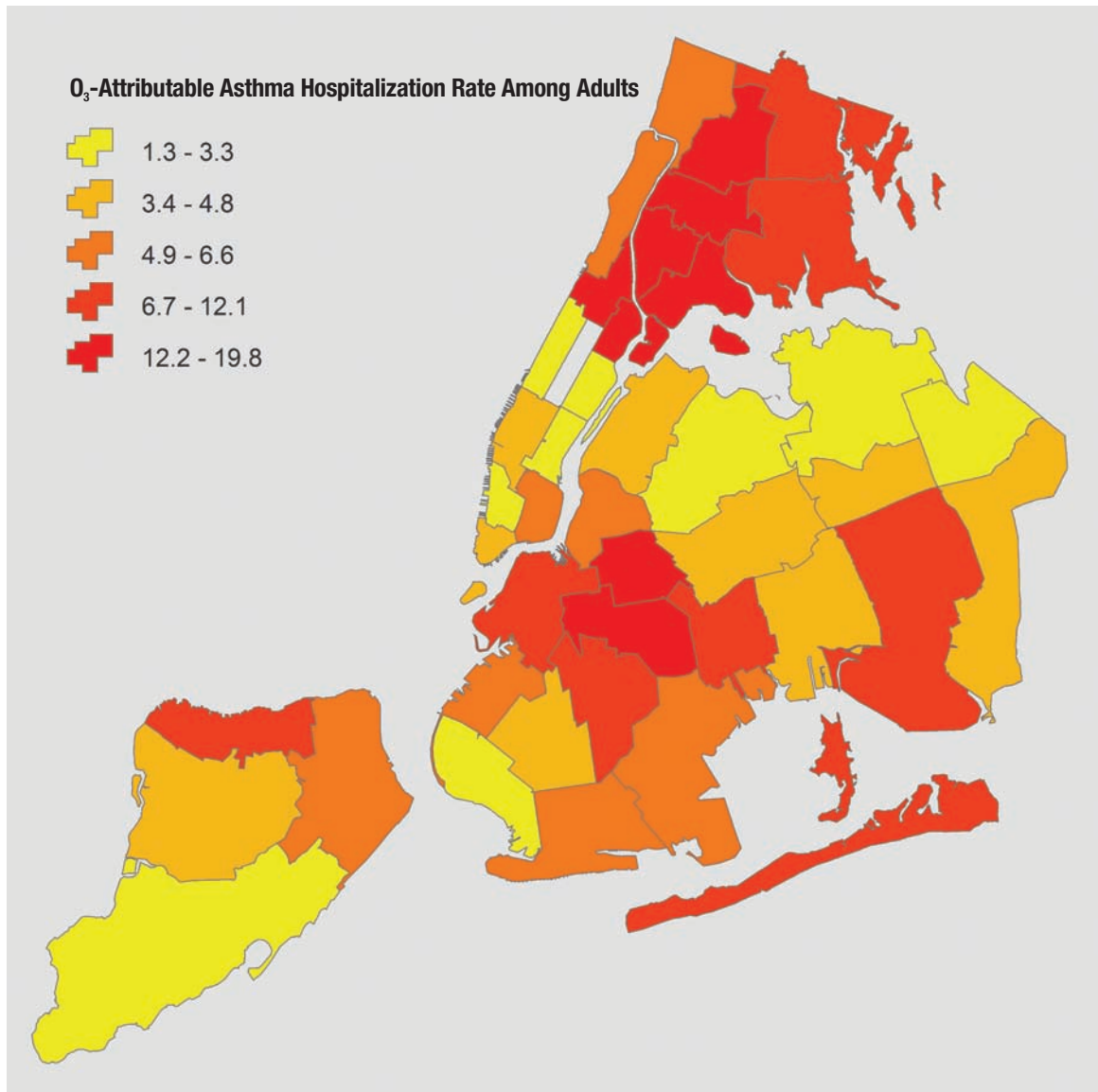
Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

**Hospital Admission and Emergency Department Visits for Asthma in Adults**

Nearly 450 annual hospital admissions and nearly 3,000 emergency department visits for asthma among New York City adults are likely attributed

to ozone (Table 6). Rates of ozone-attributable asthma hospitalization range from approximately 1 to 20 people per 100,000 adults older than 18 years of age (Figure 26, and ozone-attributable emergency visits range from 7 to 156 people per 100,000 (Figure 27).

**Figure 26. O<sub>3</sub>-attributable asthma hospitalization rates vary 15-fold among adults 18 years and older across New York City neighborhoods.**



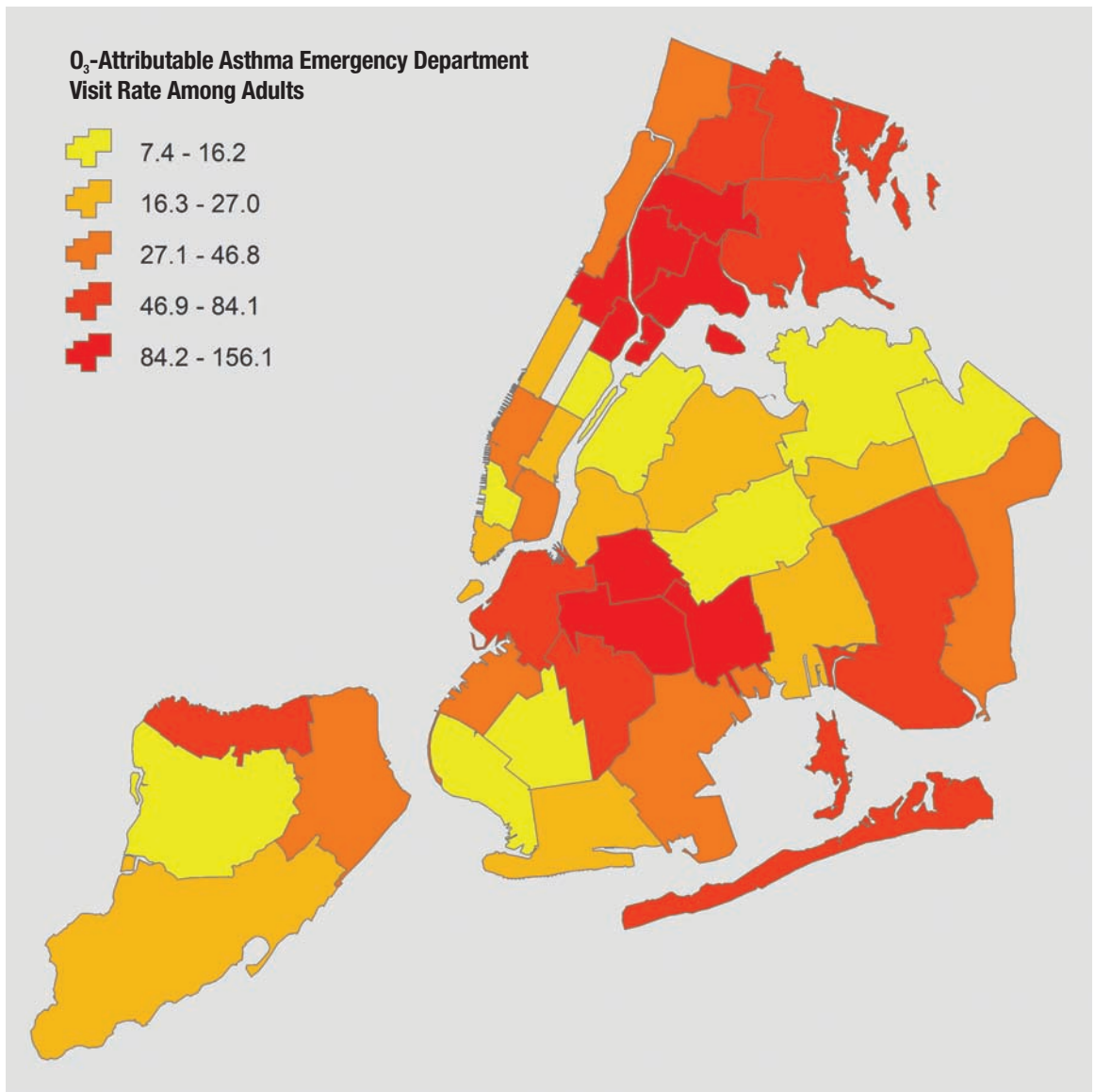
O<sub>3</sub>=ozone



Neighborhood patterns of ozone-attributable hospitalizations and emergency department visits for asthma are similar in adults and children. In high poverty neighborhoods, rates are 4-fold

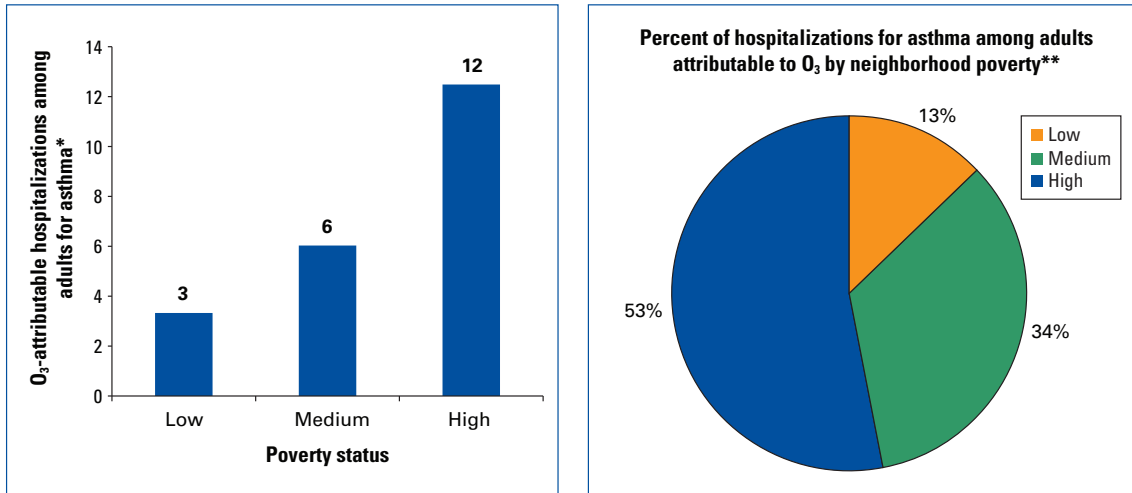
higher for ozone-attributable asthma hospital admissions (**Figure 28**) and 4.5-fold higher for ozone-attributable emergency department visits (**Figure 29**).

**Figure 27. O<sub>3</sub>-attributable rates of emergency department visits for asthma among adults 18 years and older vary 21-fold across New York City neighborhoods**



O<sub>3</sub>=ozone

**Figure 28. O<sub>3</sub>-attributable asthma hospitalization rates among adults 18 years and older are 4 times higher in neighborhoods with high, as compared to low, poverty rates.**



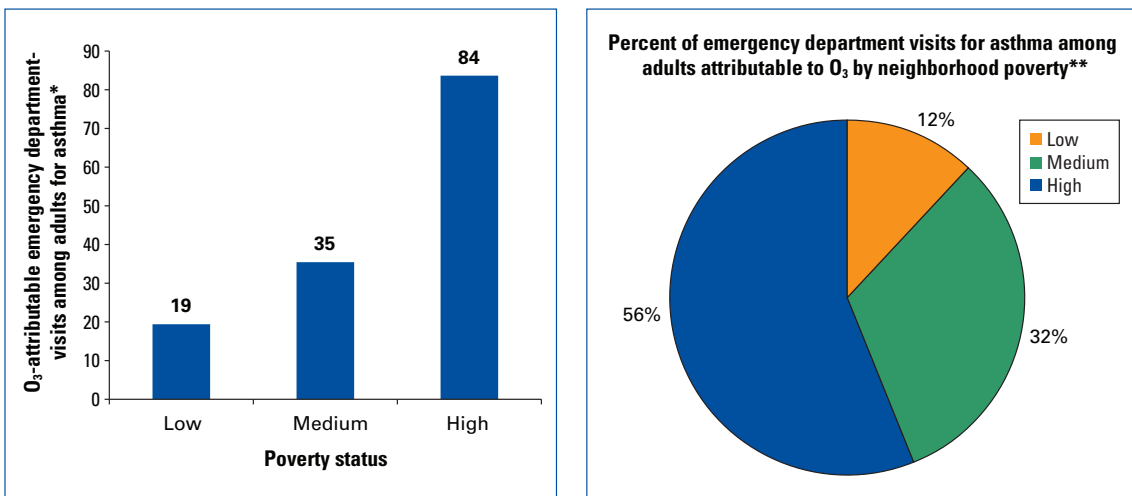
O<sub>3</sub>=ozone

\* Attributable rate of emergency department visits for asthma per 100,000 person 18 years of age and older

\*\* Among adults 18 years of age and older

Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

**Figure 29. O<sub>3</sub>-attributable rates of emergency department visits for asthma among adults 18 years and older is over 4 times higher in neighborhoods with high, as compared to low, poverty rates.**



O<sub>3</sub>=ozone

\* Attributable rate of emergency department visits for asthma per 100,000 person 18 years of age and older

\*\* Among adults 18 years of age and older

Poverty status: Low, medium and high poverty tertiles are calculated using percent of residents within a neighborhood who are at <200% federal poverty level, based on data from U.S. Census 2000

# Limitations

While health impact assessment is a useful tool to translate complex technical studies into their implications for the health of a populations, the estimates produced have limitations to consider in their interpretation.

**Health endpoints.** This report is limited to health outcomes for which reliable neighborhood level data for New York City are available—deaths, hospital admissions and emergency department visits. For each serious health event caused by air pollution, there are many more individuals who have symptoms related to air pollution that limit their activities, cause school and work absences and reduce their quality of life.

**Concentration-response functions.** Estimated concentration response functions vary among scientific studies because:

- Concentration-response functions are based on an estimate that has some sampling (random) errors that are reflected in the confidence intervals (see **Tables 5 and 6**).
- Different populations may respond differently to air pollution; for example, some studies show that people with asthma that take inhaled corticosteroids may respond less to air pollution exposure (Hernandez-Cadena 2009, Koenig 2003).
- Stress associated with poverty may increase the effects of air pollution.
- The mixtures of air pollutants in different cities might interact to enhance the toxicity of individual pollutants.
- Fine particles vary in their composition and likely vary in their effects, depending on their source (for example, PM<sub>2.5</sub> emitted by residual oil-burning contains higher concentrations of nickel and other metals, which may make them more harmful).

An example of the uncertainty related to choice of concentration-response functions, the main analysis of PM<sub>2.5</sub>-attributable mortality in this

report used a concentration-response functions estimate based on the Krewski (2009) analysis of the American Cancer Society (ACS) Cohort. Although this is the largest and most recent study on the effects of PM<sub>2.5</sub> on mortality, the ACS population includes a smaller proportion of low-income and minority people than as is the case in New York City. A sensitivity analysis ([see online appendix](#)) shows the estimated mortality burden using a concentration-response function based on the Laden (2006) analysis of the Harvard Six Cities cohort. Although smaller than the American Cancer Society cohort, the Harvard Six Cities cohort includes a more diverse population similar to New York City's, and the Harvard Six Cities concentration-response function estimates a much stronger effect of PM<sub>2.5</sub> on mortality. Although a larger estimate of PM<sub>2.5</sub>-attributable deaths (approximate 8,000 per year) calculated based on the Harvard Six Cities study may be more realistic, this report relied on the American Cancer Society study to produce a more conservative estimate.

**Single vs. multi-pollutant models.** Studies have already shown that PM<sub>2.5</sub> and O<sub>3</sub> are harmful. In addition, their presence indicates the presence of other harmful pollutants that are influenced by the same sources and weather patterns. Motor vehicles that emit PM<sub>2.5</sub>, for example, also emit harmful oxides of nitrogen, toxic volatile organic compounds and ultrafine particles. Weather conditions that trap PM<sub>2.5</sub> emissions near ground level also trap other pollutants. As a result, the times of year and locations of high PM<sub>2.5</sub> concentrations tend to have higher concentrations of multiple pollutants. Multi-pollutant models are used by researchers to distinguish the health effects of one pollutant while controlling for co-pollutants that tend to vary with the pollutant under study. These studies are less useful, however, in estimating the impacts and benefits of reducing pollution because measures to reduce PM<sub>2.5</sub> emissions will often reduce emissions of other harmful pollutants. Studies on concentrations of individual

air pollutants and the risk of health effects that don't control for other pollutants (single pollutant models) are more appropriate for estimating the impact of increasing or decreasing PM<sub>2.5</sub> concentrations and other pollutants that tend to vary with PM<sub>2.5</sub>. This report mainly relies on similar single pollutant models.

**Air pollution can cause and exacerbate chronic diseases.** It has been known for many years that PM<sub>2.5</sub> and ozone can exacerbate acute health problems; for example, both can trigger an asthma attack in someone with asthma. In this report, the estimates of the acute effects of air pollution on hospital care for respiratory and cardiovascular disease are for exacerbation only. Recent evidence has shown, however, that exposure to air pollutants near busy roads can also cause new cases of chronic lung and heart diseases. In a recent [health impact assessment for European cities](#), the authors applied this new evidence and estimated that air pollution may

cause as much as 25% to 30% of strokes and heart attacks in adults age 65 years and older, and 15% to 25% of hospitalizations and other respiratory illnesses among asthmatic children. These amounts are much higher than those estimated for New York City; the numbers in this report are very conservative.

**Other limitations.** Regulatory monitors do not capture the full range of neighborhood variation in air quality throughout the city. Future reports will apply measurements from the New York City Community Air Survey (NYCCAS) to estimate health impacts. In this report, the burden of air pollution is defined as the difference between current levels and a theoretical policy relevant background that has never been measured by researchers. This model assumes that the same relationship between pollutant levels and health effects is found below the lowest measured level, an assumption supported by the lack of evidence of a health effect threshold.

# Discussion

The scientific evidence for the harmful effects of  $PM_{2.5}$  and ozone is extensive, but studies do not easily convey the public health dimensions of the air pollution problem or how it compares to other challenges facing the city. In this report, methods used by regulators to evaluate the risks of air pollution and benefits of control measures are combined with New York City neighborhood health data that reflect the wide disparities in health and susceptibility to air pollution effects. The resulting estimates better reflect the large overall burden of air pollution and its distribution across the city, which falls especially hard on high poverty communities, seniors and children and adults with asthma. While these estimates are useful, they cannot capture the human toll behind the statistics—frightening trips to the emergency room for children with asthma and their families, heart attacks and disabling strokes, and the untimely deaths of loved ones.

How do the estimates in this report compare to other estimates for New York City alone, the nation and the world? The U.S. Environmental Protection Agency has estimated that in New York City, 1,500 to 2,000 deaths, 800 to 950 hospital admissions for cardiovascular disease, and 4,500 to 5,200 asthma related emergency department visits annually are attributed to exposures to  $PM_{2.5}$  (Environmental Protection Agency). Anenberg (2010) estimated that current levels of fine particles and ozone are responsible for 35,000 respiratory deaths, 124,000 cardiopulmonary deaths and 17,000 lung cancer deaths in North America. Studies by the World Health Organiza-

tion have estimated that outdoor particulate matter air pollution is responsible for 800,000 premature deaths globally each year (Cohen 2005). Worldwide, outdoor air pollution ranks third only behind indoor air pollution from fuel combustion, and unsafe water, sanitation and hygiene in terms of attributable deaths due to environmental risk factors (Ezatti 2006). Much of the global burden of air pollution falls in developing countries where rapid urbanization is combined with a lack of pollution controls.

Why are these results important for New Yorkers? While the city's air quality has improved in recent decades, air pollution causes (conservatively) 6% of annual deaths in the city each year, making it one of the most significant environmental health problems. Furthermore, air quality improvements will have significant and immediate health benefits at a scale second only to reductions in smoking rates, among recent city initiatives. To reduce the toll from air pollution, actions are needed to address important local sources, such as motor vehicle exhaust, building heating oil and aging power plants with outmoded technology. As part of the city's sustainability plan, [PlaNYC](#), many emission reduction initiatives have been completed or launched; others are planned. The steps needed will produce many benefits beyond health, such as reducing greenhouse gas emissions. But investments and behavior changes are also needed, making it important for New Yorkers to understand the burden of air pollution on New Yorkers' health, the health benefits of addressing it and the costs of inaction.

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