Geographic Patterns of Asthma Rates and Air Quality in Delaware

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Introduction

Asthma is a chronic disease that causes the bronchial tubes (passageways that allow air to enter and exit the lungs) to become narrow and inflamed, making it difficult to breathe. Certain substances can act as triggers that worsen asthma symptoms and alter regular breathing patterns.[1] Allergic asthma occurs when exposure to allergens occurs, and non-allergic asthma occurs due to stress, exercise, illness, irritants in the air, extreme weather, and even some medications.[1] Currently, there is no cure for asthma and means of prevention are unclear.[2] Awareness of asthma triggers, particularly those occurring outside the home environment, can offer the greatest public health impact in terms of reducing harmful exposures at the population level.

Asthma prevalence increased from 7.3% to 8.4% from 2000 to 2010, at which time a total of 25.7 million people had asthma.[2] Prevalence appears to have plateaued and remained at 8.3% through 2016.[3] Asthma is more prevalent among females (9.7%) than males (6.9%). Asthma also disproportionately affects African-American individuals, with 11.6% of African-American individuals experiencing asthma compared to 8.3% of Caucasian individuals.[3]

Asthma attacks can result in missed work, school absenteeism, emergency room visits, health care expenditures, and mortality, the associated costs of which exceeded $81 billion in the United States in 2013. A person with asthma spends approximately $3,266 annually on medical care, and prescription medications account for more than half of these costs. The estimated annual cost burden of asthma for individuals living below the poverty line is more than $300 greater.[4]

In the state of Delaware, the geographic area of focus for these maps, the Division of Public Health published "The Burden of Asthma in Delaware" in 2005 and an update to this report in 2016. From the initial report in 2005 to the update in 2016, the state saw a slight increase in the prevalence of adults with asthma - from about 7.5% to 9.2%. This was not found to be a statistically significant difference, with some of the increase in asthma diagnoses due to the population increase in Delaware during this time.[5] It was reported that adult women had a higher rate of "current asthma" diagnoses (meaning people who currently have an asthma diagnosis) than men did, and those with a disability were 2.75 times more likely to have asthma as well.[5] Overweight or obese adults were also found more likely to currently have asthma, and African-American rates of hospitalizations and deaths due to asthma were disproportionately high.[5] With the cost of asthma per person per year estimated to be about $3,300, asthma is costing Delaware over $200 million each year.[6]

The Delaware Department of Public Health has also released data that indicate socioeconomic disparities in asthma prevalence, with higher rates of asthma among minorities and those with lower levels of education.[5] Asthma prevalence in Delaware differs based on gender, race/ethnicity, and education. In 2015, adult asthma prevalence was 4.4% for males and 13.7% for females, 9.6% for Non-Hispanic White individuals, 8.3% for Black/ African American individuals, 8.7% for Hispanic/Latino individuals, 13.1% among individuals with less than a high school diploma or GED and 8.9% and 8.8% for individuals with a high school diploma /GED or college degree, respectively. Hospitalizations due to asthma were found to be disproportionately high among Black/African-American individuals. Women with asthma were found to utilize hospital inpatient services more than men.[6]

Current asthma prevalence does not differ significantly by county. In 2015, the prevalence in New Castle County was 9.5%, the prevalence in Kent County was 10.2%, and the prevalence in Sussex County was 7.5%. There are, however, significantly higher rates of asthma in the City of Wilmington. In 2013-2014 the rate of "current asthma" prevalence in Wilmington was 13.6% compared to 9.3% in suburban New Castle County, 9.9% in Kent County, and 8.9% in Sussex County.[6]

Air pollution is a known asthma trigger. The Delaware Department of Natural Resources and Environmental Control monitors carbon monoxide, nitrogen oxides, sulfur dioxide, ozone, particles smaller than 10 micrometers and particles smaller than 2.5 microns.[7] Ground-level ozone is a by-product of reactions involving Volatile Organic Chemicals (VOCs) and nitrogen oxides.[8] Increased ozone exposure has been shown to worsen the effects of asthma, leading to increased school absences and hospitalizations when it is high.[9] Ground-level ozone continues to be a problem in Delaware due to the high amounts of (VOCs) and nitrogen oxides from in-state industrial facilities, vehicle exhaust, and upwind pollution from Baltimore and Washington, D.C.[10] Asthma is monitored in Delaware, as is ground-level ozone. Ground-level ozone is one of only two air pollutants which are documented to be at "unhealthy" levels in Delaware.[10]

One asthma trigger gaining recent attention is that of exposure to particulate matter. The Environmental Protection Agency (EPA) defines particulate matter as "a mixture of solid particles and liquid droplets found in the air" (United States Environmental Protection Agency, 2016). Particulate matter is generally classified by those between 2.5-10 micrometers in diameter (PM_{10}) and those less than 2.5 micrometers in diameter ($PM_{2.5}$) and thus cannot be seen by the naked eye. They come from sources such as construction sights, roads, fields, pests, mold, and smoke and commonly result from chemical reactions of air pollutants produced by factories and machines.[11] Many studies have shown that combined exposure to chemical air pollution and allergies have a synergistic effect on the exacerbation of asthma, further validating previous findings.[12] Particulate matter has been found to trigger asthma and increase wheezing severity. Studies have also showed that this association is magnified by geographic location, leading to socioeconomic disparities in exposure to particulate matter and thus asthma and asthma severity.[13]

Studies have also shown that while the number of days each year that Delaware residents are exposed to an Air Quality Index (AQI) of unhealthy levels according to the CDC has fluctuated greatly, air quality has continued to worsen over the past few decades. The AQI accounts for carbon monoxide, nitrogen oxides, ozone, sulfur dioxide, PM_{10}, and $PM_{2.5}$; however, levels of each chemical have shown different fluctuations in surveillance data.[6] By mapping asthma prevalence and particulate matter levels across Delaware, we can generate hypotheses about the

relationships between these and other variables. Some evidence suggests that asthma symptoms might be affected by air pollutants resulting from traffic. One potential trigger of asthma is carbon monoxide (CO), which is a result of vehicle emissions in traffic.[5]

Pollutants attributable to traffic-related air pollution (TRAP) include sulfur dioxide and nitrogen dioxide (NO) which increase cell membrane permeability, decrease ciliary beat frequency and induce airway inflammation and airway hyper-responsiveness.[14] Traffic-related air pollution induces asthma, exacerbates symptoms, and increases susceptibility to other irritants by increasing permeability of airways. European studies have found that traffic-related air pollution is associated with increased emergency room attendance.[15] Research suggests that traffic-related air pollution causes exacerbations of asthma through airway remodeling and increased susceptibility to other triggers, as opposed to new onset of asthma.[14]

Higher traffic counts could result in higher emissions of CO and other pollutants. One study, which looked at effects of traffic air pollution on children, found that a relationship existed between higher rates of traffic air pollution and hospital readmission rates for white, but not African American, pediatric patients.[16] Another study found a relationship between gender and asthma onset due to traffic air pollution, where female pediatric patients were affected more than male patients.[17] Since genders and races are affected differently, it is important to further examine these disparities to direct interventions, policies, and resources more effectively.

This study aims to describe the state of asthma in Delaware as it relates to air quality. This study will describe the geographic distribution of asthma and analyze related environmental and socioeconomic variables. Specifically, we will seek to describe correlations between asthma rates and traffic counts, fine particle matter, and ozone as well as the ways in which these relationships are mediated by race, gender, and poverty.

We hypothesize that increased levels of fine particle matter and ozone, high traffic counts, having a lower income, being female and being African-American will all be positively correlated with higher rates of asthma. Our findings may be used to inform policymakers about decisions regarding emissions regulations and asthma-related health programming.

Methods

Data were collected from one of four sources: the U.S. Census 2010,[18] the Centers for Disease Control and Prevention Behavioral Risk Factor Surveillance System (CDC BRFSS),[19] the Delaware Division of Air Quality,[7] and FirstMap Delaware[20–22] PolicyMap,[23–25] 2018. Each layer is composed of a shapefile and tabular data joined by Object ID. The Division of Air Quality collects ozone and $PM_{2.5}$ levels from seven different sites across Delaware and report three-year average levels for each of these measures.[7] The Delaware Division of Air Quality ozone and $PM_{2.5}$ monitoring sites show average levels from 2011-2013. These data were imported into Excel 2010 and geocoded in ArcMap. Based on the World Population Review, the four cities in Delaware with populations greater the 20,000 were extracted as a new layer.[26] All maps use the Delaware State Plane NAD 1983 (meters) Coordinate System and are scaled at 1:750,000 meters. A summary of each layer and its use can be seen in Table 1.

Table 1: A summary of all the layers created and used to create Figures 1-4

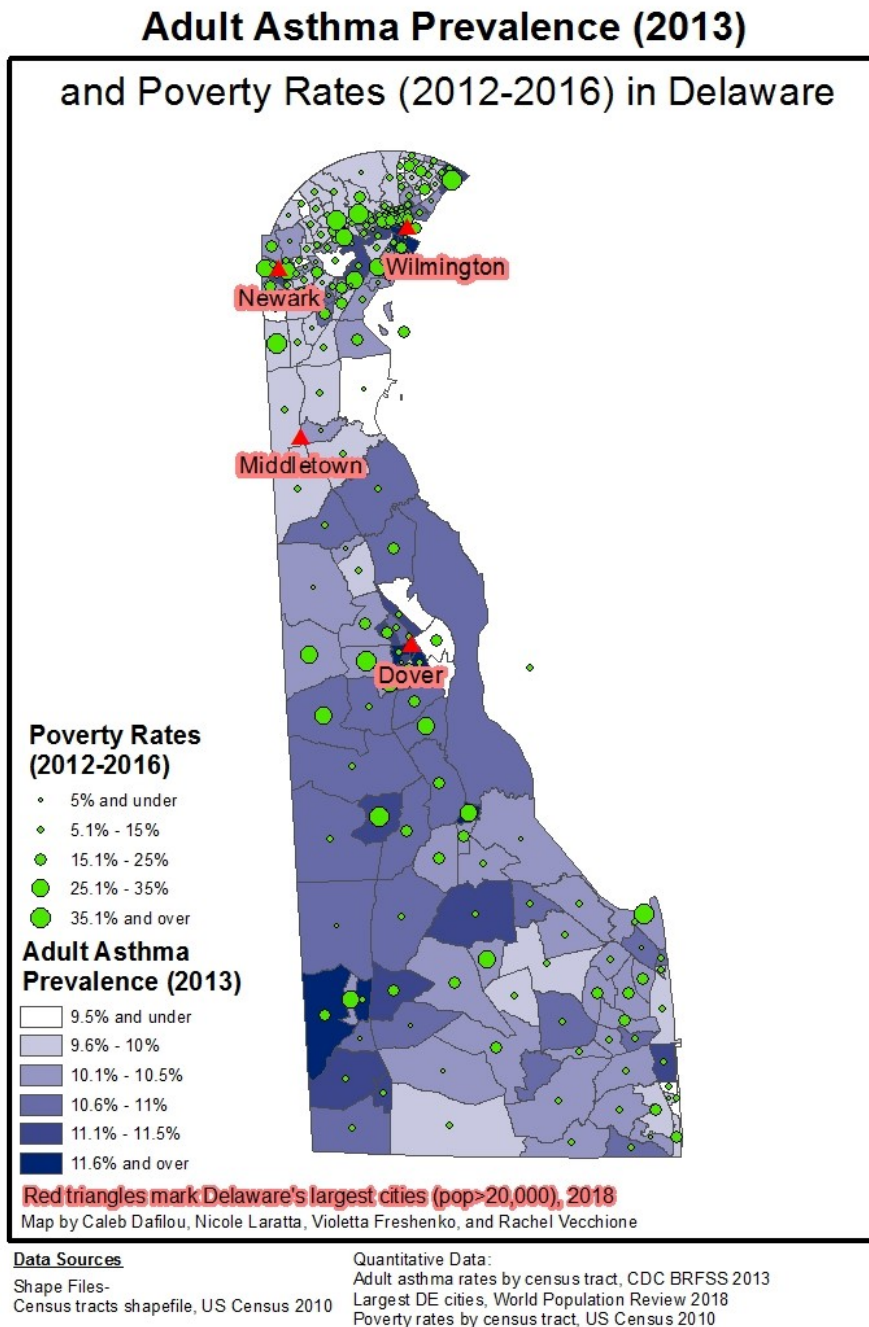| Layer (Type)	Data [S]= shapefile [T] = Table	Downloaded	Source

Poverty Rates (Graduated Circles)	Census Tracts [S]	US Census Tiger Line	US Census, 2010
	Poverty Rates [T]	PolicyMap	US Census, 2010
Adult Asthma Prevalence (Chloropleth)	Census Tracts [S]	US Census Tiger Line	US Census, 2010
	Adult Asthma Prevalence [T]	PolicyMap	CDC BRFSS, 2012-2016
Largest DE Cities (Triangles)	US Places [S]	US Census Tiger Line	US Census, 2010
Ozone Monitoring Site (Graduated Circles)	US Places [S]	US Census Tiger Line	US Census, 2010
	Average Ozone Levels [T]	Entered Manually from 2013 Report	DE Division of Air Quality
$PM_{2.5}$ Monitoring Site (Graduated Circles)	US Places [S]	US Census Tiger Line	US Census, 2010
	Average $PM_{2.5}$ Levels [T]	Entered Manually from 2013 Report	DE Division of Air Quality, 2013
County (Hollow Contour)	US Counties [S]	US Census Tiger Line	US Census, 2010
White Population (Chloropleth)	White Population [S]	First Map DE	Census 2010
Black Population (Chloropleth)	Black Population [S]	First Map DE	Census 2010
Traffic Count (Graduated Line)	Traffic Count [S]	First Map DE	Census 2010

Results

Though there is no statistically significant difference in adult asthma prevalence by county,[6] there are census tracts throughout the state which have higher rates of asthma than the surrounding census tracts. A visual review of these maps (see Figure 1) shows that Kent County has the greatest number of census tracts with higher rates of asthma (i.e., rates exceeding 10%), followed by Sussex and then New Castle Counties. The census tracts with the highest rates are spread across the state. There are spikes in adult asthma prevalence around the four largest cities (Wilmington, Newark, Middletown, Dover) in the state. The census tracts around Wilmington, Newark and Dover have some of the highest levels of adult asthma prevalence. The census tract east of Middletown also has a higher prevalence of asthma than the census tracts surrounding it, but this still represents low to moderate tiers of asthma prevalence compared to the rest of the state.

Poverty rates vary across the state, with the largest clusters of increased poverty being in the northernmost part of Delaware and the central part of the state west of Dover (see Figure 1). Certain census tracts throughout the state, such as two in the central region of the state, one in the most northeastern region of the state and one neighboring Newark to the east, show both higher rates of poverty and asthma than surrounding census tracts.

Figure 1. Adult Asthma Prevalence (2013) and Poverty Rates (2012-2016) in Delaware

Adult Asthma Prevalence (2013)
and Poverty Rates (2012-2016) in Delaware

Poverty Rates (2012-2016)
- · 5% and under
- ◦ 5.1% - 15%
- ○ 15.1% - 25%
- ⬤ 25.1% - 35%
- ⬤ 35.1% and over

Adult Asthma Prevalence (2013)
- 9.5% and under
- 9.6% - 10%
- 10.1% - 10.5%
- 10.6% - 11%
- 11.1% - 11.5%
- 11.6% and over

Red triangles mark Delaware's largest cities (pop>20,000), 2018

Map by Caleb Dafilou, Nicole Laratta, Violetta Freshenko, and Rachel Vecchione

Data Sources
Shape Files-
Census tracts shapefile, US Census 2010

Quantitative Data:
Adult asthma rates by census tract, CDC BRFSS 2013
Largest DE cities, World Population Review 2018
Poverty rates by census tract, US Census 2010

Average Ozone levels are fairly consistent across the state at an average value of .075 ppm with no station showing disproportionately high levels compared to other stations (see Figure 2). In the middle and southern regions of the state $PM_{2.5}$ levels are fairly consistent at an average value of 8.4 $\mu g/m^3$. The $PM_{2.5}$ values in the northernmost part of the state are much higher at an average value of 9.6 $\mu g/m^3$. The three stations in the northernmost part of the state which have the highest $PM_{2.5}$ levels in the state surround the cities of Newark and Wilmington. These two cities are surrounded by census tracts with some of the highest rates of asthma in the state. The northernmost part of the state (around and to the north of Newark and Wilmington) has increased rates of poverty, $PM_{2.5}$ levels, and traffic counts (see Figure 3).

Figure 2. Adult Asthma Prevalence (2013) and Average Ozone Levels (2011-2013) by Ozone Monitoring Site in Delaware
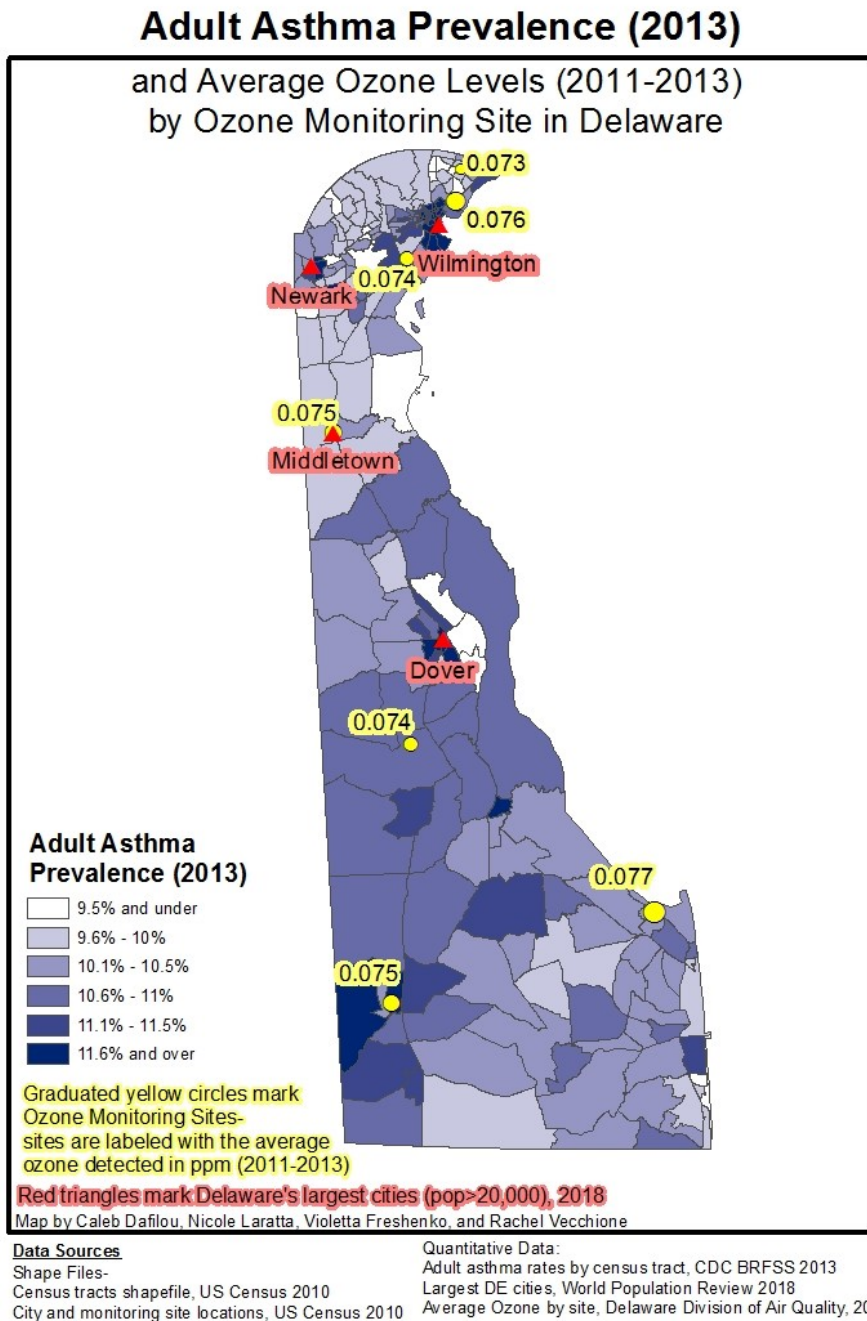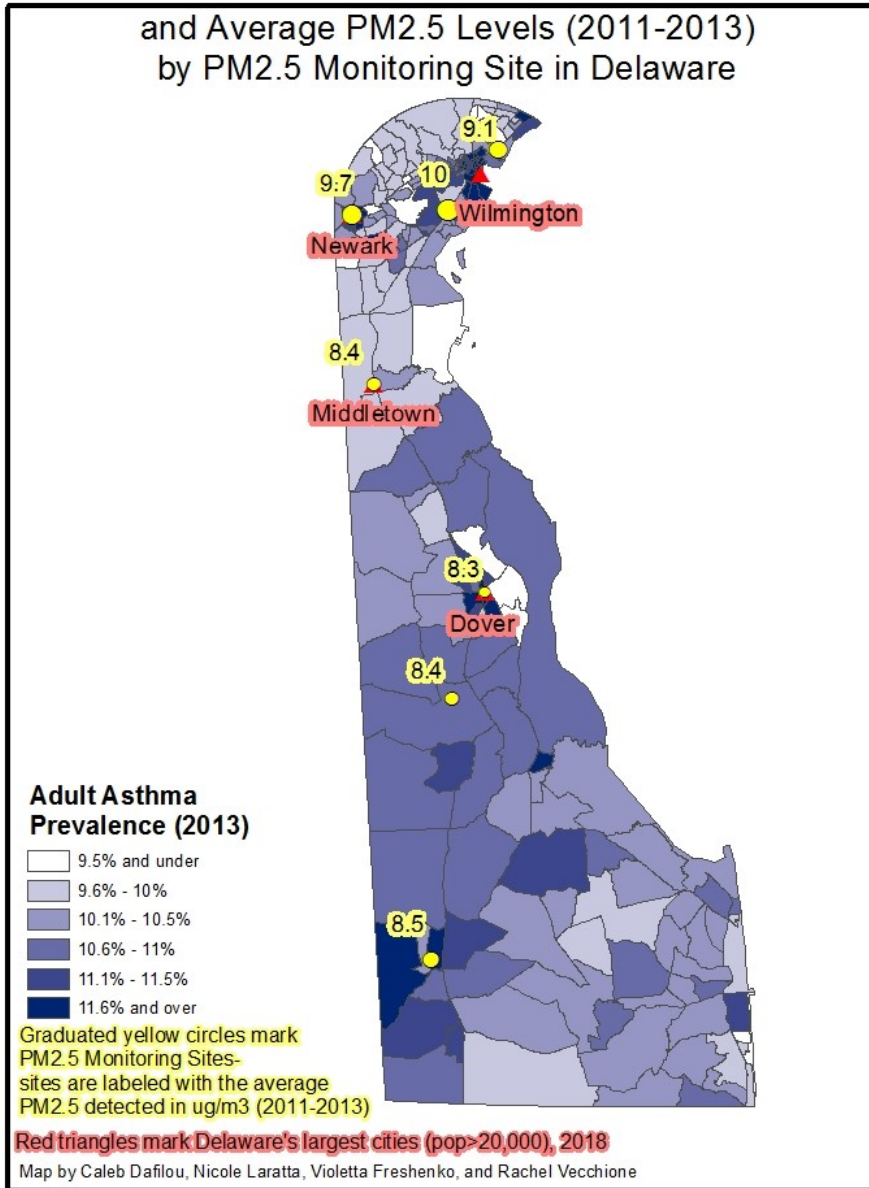
Adult Asthma Prevalence (2013)
and Average Ozone Levels (2011-2013) by Ozone Monitoring Site in Delaware

0.073

0.076

Wilmington

0.074

Newark

0.075

Middletown

Dover

0.074

0.077

0.075

Adult Asthma Prevalence (2013)

- 9.5% and under
- 9.6% - 10%
- 10.1% - 10.5%
- 10.6% - 11%
- 11.1% - 11.5%
- 11.6% and over

Graduated yellow circles mark Ozone Monitoring Sites- sites are labeled with the average ozone detected in ppm (2011-2013)

Red triangles mark Delaware's largest cities (pop>20,000), 2018

Map by Caleb Dafilou, Nicole Laratta, Violetta Freshenko, and Rachel Vecchione

Data Sources
Shape Files-
Census tracts shapefile, US Census 2010
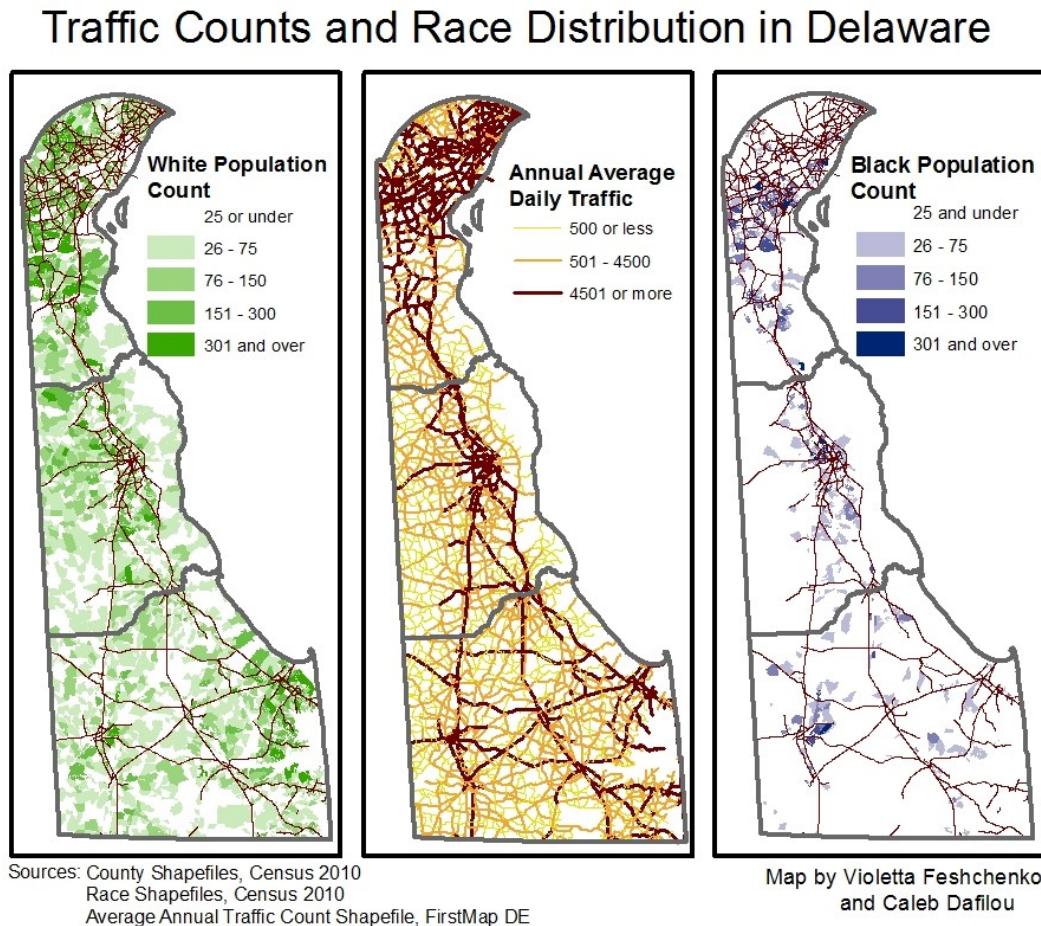City and monitoring site locations, US Census 2010

Quantitative Data:
Adult asthma rates by census tract, CDC BRFSS 2013
Largest DE cities, World Population Review 2018
Average Ozone by site, Delaware Division of Air Quality, 2013

Figure 3. Adult Asthma Prevalence (2013) and Average PM2.5 Levels (2011-2013) by PM2.5 Monitoring Site in Delaware

Adult Asthma Prevalence (2013)

and Average PM2.5 Levels (2011-2013)
by PM2.5 Monitoring Site in Delaware

Adult Asthma Prevalence (2013)

- 9.5% and under
- 9.6% - 10%
- 10.1% - 10.5%
- 10.6% - 11%
- 11.1% - 11.5%
- 11.6% and over

Graduated yellow circles mark PM2.5 Monitoring Sites- sites are labeled with the average PM2.5 detected in ug/m3 (2011-2013)

Red triangles mark Delaware's largest cities (pop>20,000), 2018

Map by Caleb Dafilou, Nicole Laratta, Violetta Freshenko, and Rachel Vecchione

Data Sources
Shape Files-
Census tracts shapefile, US Census 2010
City and monitoring site locations, US Census 2010

Quantitative Data:
Adult asthma rates by census tract, CDC BRFSS 2013
Largest DE cities, World Population Review 2018
Average PM2.5 by site, Delaware Division of Air Quality, 2013

The traffic counts represented in Figure 4 are Annual Average Daily Traffic counts. Delaware has a network of Automatic Traffic Recorder (ATR) Stations which "count the number of vehicles passing through each location, continuously throughout the year."[27] Traffic counts vary across the state with the highest levels concentrated in the northernmost part of the state. Distributions of African American and Caucasian populations also vary across the state. While the State's population is predominantly white, census tracts with higher proportions African Americans are found primarily in the northern half of New Castle County, with smaller areas in the middle of Kent County and eastern Sussex County. Areas with higher numbers of black residents correspond to roadways with the highest annual traffic counts. Areas with higher

numbers of black residents also correspond to areas with higher rates of asthma and poverty, such as the area around Wilmington in New Castle County, the area around Dover in Kent County and the area in eastern Sussex County (see Figures 1 and 4).

Figure 4. White Population Count (left), Annual Average Daily Traffic (center), Black Population Count (right) in Delaware

Traffic Counts and Race Distribution in Delaware

Sources: County Shapefiles, Census 2010
Race Shapefiles, Census 2010
Average Annual Traffic Count Shapefile, FirstMap DE

Map by Violetta Feshchenko and Caleb Dafilou

We examined maps displaying the distribution of black and white residents per census tract, combined with average traffic count. Roads with light traffic had an AADT count of 500 or less, those with medium traffic had an AADT count between 501 and 4500, and roads with high traffic had an AADT count of 4501 or greater. The greatest concentration of high-traffic roadways is in the northern half of New Castle County. Areas of high traffic correspond to the presence of large cities such as Wilmington, Newark, and Dover.

We also examined hospital discharges due to asthma by county, sex, and race. Data were obtained from the Division of Public Health[5] and crude rates per 10,000 were calculated.

Table 2 shows that female individuals have a much higher rate of hospital discharge (and thus hospitalization) due to asthma at 15.1 per 10,000 compared to the male rate of asthma-related discharge at 10.6 per 10,000. Additionally, Black individuals also have a rate of hospital discharge due to asthma that is almost four times higher than that of White individuals (27.3 per 10,000 vs. 7.4 per 10,000, respectively). These values are consistent with national rates. The national rate of asthma hospital inpatient discharges in 2010 was 13.0 per 10,000 among adults,

8.7 per 10,000 among White individuals, and 29.9 per 10,000 among Black individuals (CDC, 2010). Table 2 also shows that New Castle County has the highest rates of hospital discharge at 14.8 per 10,000, whereas Kent County has a rate of 12.9 per 10,000 and Sussex County has a rate of 7.6 per 10,000.

Table 2. Hospital discharge rates in Delaware due to asthma in 2012 per 10,000. Population estimates based on 2010 Census.[6,28]

	Population	Hospital Discharges	Rate per 10,000
County			
Kent	162,349	210	12.9
New Castle	538,477	799	14.8
Sussex	197,110	149	7.6
Gender			
Male	434,601	462	10.6
Female	463,335	698	15.1
Race			
White	625,861	464	7.4
Black	204,729	559	27.3
Total			
Total Delaware Population	897,936	1160	12.9

Discussion

Asthma rates are high in Delaware, particularly in the central region of the state and around major urban centers. The high rates of asthma around Wilmington are consistent with the previous reports showing that Wilmington has a higher prevalence of adults with asthma than did suburban Kent, New Castle, and Sussex counties.[5] While excessive ozone levels are known to exacerbate asthma, these levels did not vary greatly across the state and we could not identify clear correlations between ozone and asthma prevalence in this study. However, since ozone levels in Delaware near the U.S. National Ambient Air Quality Standards (NAAQS) of 0.075 ppm, small fluctuations could be harmful to health.[7]

$PM_{2.5}$ levels are highest in the northern-most part of the state around Newark and Wilmington, two cities which also have increased rates of asthma. Higher particle matter may indicate worse air quality in this part of the state. This is consistent with reports indicating that air quality in New Castle County is worse than the rest of the state. Based on the AQI, New Castle County had the most categorized "unhealthy" days compared to the rest of the state.[5] Furthermore, the finding that higher levels of particulate matter are correlated with higher rates of asthma is consistent with existing literature.[12] Each state monitoring site recorded average $PM_{2.5}$ levels below the U.S. NAAQS of 15 ug/m^3, which indicates that it is unlikely $PM_{2.5}$ levels alone are unlikely to result in increased rates of asthma.[7]

Areas around the most heavily trafficked roadways were more likely to also be areas with higher numbers of Black individuals. Black individuals were also found to experience disproportionately high rates of asthma and associated hospitalization. This correlation between

traffic counts and higher asthma rates is supported by existing literature.[14] The area in the northern half of New Castle County encompassing Wilmington has the highest concentration of heavily trafficked roads. This area also has the largest cluster of high poverty rates, pockets of high adult asthma prevalence. These results are all consistent with the findings that New Castle has the highest hospital discharge rates due to asthma and Wilmington has statistically significant higher rates of asthma prevalence than surrounding areas.[6]

Our findings support existing literature showing significant correlations between contributors to poor air quality and increased rates of asthma, findings which have significant policy implications. These findings can be used to target interventions to people who need them most by showing, for example, that people living in urban centers and high-poverty areas, are at greater risk for asthma. The results of this study would support policies to improve asthma outcomes by reducing $PM_{2.5}$ levels or reducing and redirecting traffic. More research must be done on the effects of socioeconomic and demographic factors on asthma rates as well as the effect of ground-level ozone on asthma rates.

This study has several strengths. The maps incorporate multiple indicators of air quality (ozone, particulate matter, traffic counts) that provide a more comprehensive picture of environmental factors influencing asthma. These data, combined with poverty rates and adult asthma prevalence, show clear trends that are easy to visualize on the maps. These maps can be used to demonstrate geographic differences in asthma adult prevalence and air quality measures presented in this study.

This study also has several limitations. The data reviewed shows only asthma prevalence, not severity. Information about variations in asthma severity would better describe the true disease burden across the state. Another limitation is that asthma by age group is not described. Viewing the disease burden of asthma by age group would be valuable in informing and encouraging local policymakers to increase regulations in the vicinity of schools. A final limitation is that this study does not consider indoor air quality. Components of indoor air quality, such as mold, can trigger and exacerbate asthma.[29] The concentration of substandard housing in low-resource areas and housing discrimination create racial, ethnic and socioeconomic disparities in access to good quality housing, which has an impact on health.[30]

Conclusion

In this study, we examined rates of asthma, air quality measures, and sociodemographic characteristics across the state of Delaware This study showed clear associations between air pollutants and asthma rates, which were especially pronounced among Delaware's low-income and minority populations. Asthma, which affects large numbers of people across the United States and in Delaware, has an outsized impact on quality of life and health care spending. The information presented in this study can be valuable in informing policymakers of pathways where regulation could prevent and reduce the burden of asthma among populations at greatest risk.

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