

Transportation Burdens and Emissions in Connecticut

Marcos Luna and Neenah Estrella-Luna

2021-01-20

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1 Analysis of transportation-related emissions in Connecticut

This is an analysis of transportation-related emissions and related externalities in Connecticut.

1.1 PM_{2.5} in Connecticut

PM_{2.5} refers to particulate matter in the air that is 2.5 microns or less in diameter (about 30 times smaller than the width of a human hair). These small particulates pose a threat to human health because they can penetrate deeply into the lungs and even enter the bloodstream. The EPA has documented that exposure to PM_{2.5} is associated with health effects such as elevated risk of premature mortality from cardiovascular diseases or lung cancer, and increased health problems such as asthma attacks.¹ Moreover, the EPA has found that people with pre-existing heart or lung disease, children and older adults, and nonwhite populations are at particular risk.²

Sources of PM_{2.5} emissions include power plants and industrial facilities that burn coal or petroleum-based fuels (i.e., oil or natural gas). However, most PM_{2.5} forms in the atmosphere as a result of chemical reactions between gases such as oxides of nitrogen (NO_x) or sulfur dioxide (SO₂), which are pollutants emitted from power plants, industries, and automobiles. PM_{2.5} has been regulated by the US EPA under the National Ambient Air Quality Standards (NAAQS) since 1997. As of April 2020, the EPA's primary (health-based) standard for PM_{2.5} is an annual average of 12µg/m³ (12 micrograms per cubic meter of air).³ Research shows that PM_{2.5} continues to have a significant negative impact on mortality at concentrations below the EPA's standard.⁴ Former EPA officials and scientists in an Independent Particulate Matter Review Panel have found that the current standard is not protective of public health and recommend that the annual standard be revised to a range of 10µg/m³ to 8µg/m³. However, even at the lower end of the range, risk is not reduced to zero.⁵

The analysis of PM_{2.5} presented here is based on data from the EPA's EJSCREEN.⁶ EJSCREEN data provides PM_{2.5} annual concentrations at the Census Block Group level for the years 2011 to 2016 (as of December 2019).

PM_{2.5} levels vary significantly across Connecticut, with highest concentrations in southwest Connecticut, with concentration declining from Stamford to Hartford (see Figure 1 below).

¹See EPA Particulate Matter (PM) Basics. <https://www.epa.gov/pm-pollution/particulate-matter-pm-basics>

²See EPA SUMMARY OF PROPOSAL TO RETAIN THE AIR QUALITY STANDARDS FOR PARTICLE POLLUTION. https://www.epa.gov/sites/production/files/2020-04/documents/fact_sheet_pm_naaqs_proposal.pdf

³An area would meet the primary standard if the three-year average of its annual average PM_{2.5} concentration is less than or equal to the level of the standard. See EPA National Ambient Air Quality Standards (NAAQS) for PM. <https://www.epa.gov/pm-pollution/national-ambient-air-quality-standards-naaqs-pm>

⁴See Liuhua Shi, Antonella Zanobetti, Itai Kloog, Brent A. Coull, Petros Koutrakis, Steven J. Melly, and Joel D. Schwartz. 2016. Low-Concentration PM_{2.5} and Mortality: Estimating Acute and Chronic Effects in a Population-Based Study. *Environmental Health Perspectives* 124:1 CID: <https://doi.org/10.1289/ehp.1409111>

⁵See Letter to US EPA Administrator regarding Advice from the Independent Particulate Matter Review Panel (formerly EPA CASAC Particulate Matter Review Panel) on EPA's Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter (External Review Draft –September 2019). <https://ucs-documents.s3.amazonaws.com/science-and-democracy/IPMRP-FINAL-LETTER-ON-DRAFT-PA-191022.pdf>

⁶U.S. Environmental Protection Agency (EPA), 2019. EJSCREEN Technical Documentation. For more information see www.epa.gov/ejscreen

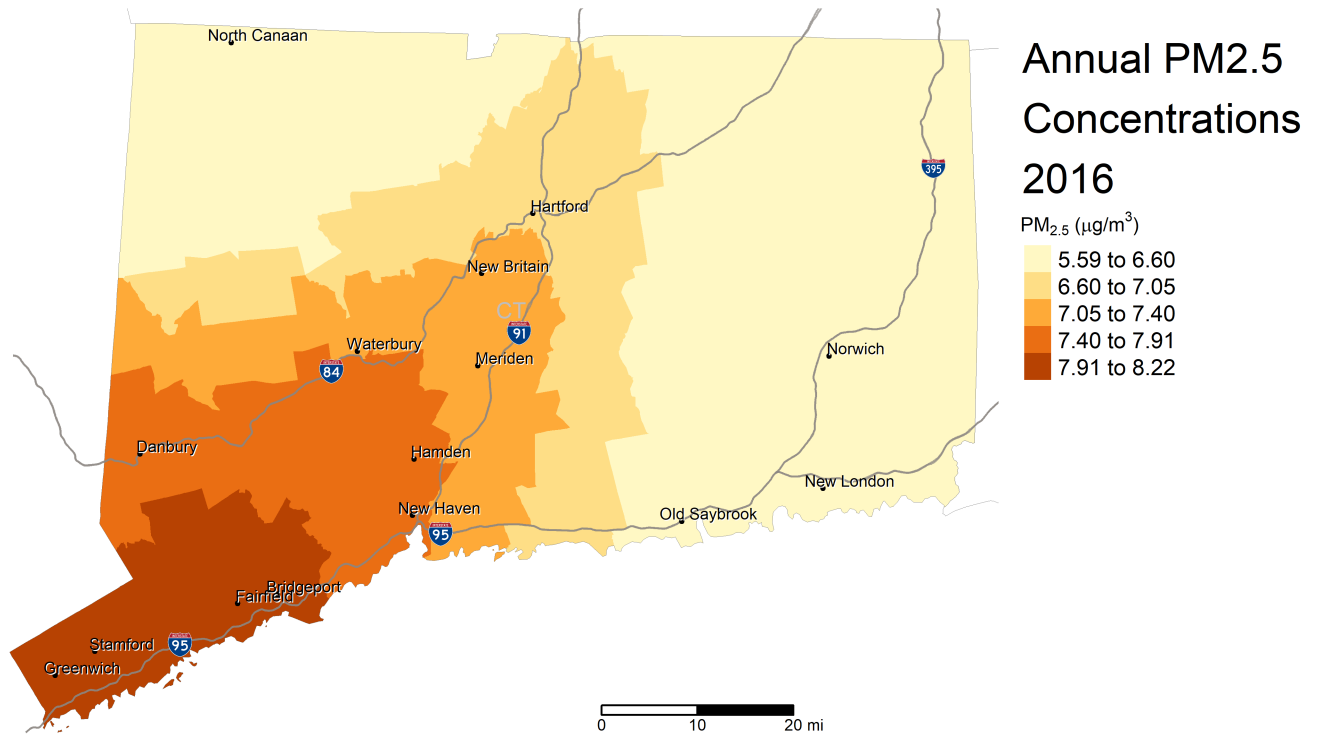


Figure 1: Map of 2016 annual PM_{2.5} concentrations across Connecticut at Census Block Group level.

PM_{2.5} concentrations exhibit spatial clustering of both hot spots (i.e. geographic clusters of high values) and cold spots (i.e. geographic clusters of lower values). The map below (Figure 2) shows statistically significant PM_{2.5} hot spots.

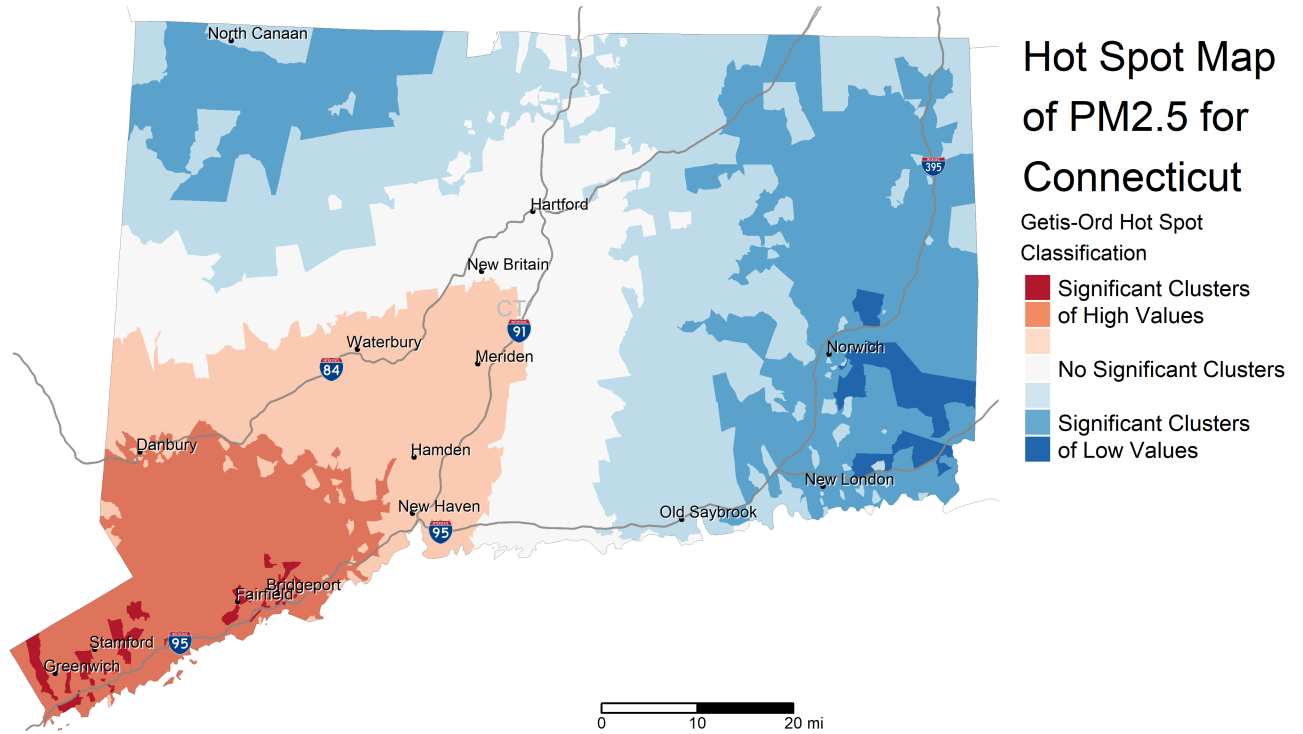


Figure 2: Hot spot map of 2016 annual PM_{2.5} concentrations at Census Block Group level.

There is a statistically significant hot spot of PM_{2.5} around Stamford to Danbury and Bridgeport. Warm clusters extend to just south of New Britain.

These PM_{2.5} levels vary significantly across the state (see Table 1 and Figure 3). See Table 13 in Appendix B for concentrations by municipality.

Table 1: Annual 2016 PM_{2.5} concentrations (micrograms per cubic meter) by Census block group for the state.

Mean	Median	Min	Max
7.18	7.2	5.59	8.22

The Block Group with highest PM_{2.5} concentration value in the state is found in Greenwich and the lowest is found in Voluntown.

Clusters of Block Groups with high PM_{2.5} values remains apparent. Figure 3 is a boxplot of PM_{2.5} concentrations by Block Group. The box represents concentration values ranging between the 25th and 75th percentiles. The line that divides the box into 2 parts represents the median PM_{2.5} concentration for all Block Groups, which in this case is 7.2. Half of the state's Block Groups are below the median and half are above the median. Each dot represents an individual Block Group. Note that a large cluster of dots is concentrated on the far right, at the upper end of concentration values. Most of these are in southwest Connecticut.

PM_{2.5} Annual Concentrations in Connecticut, 2016

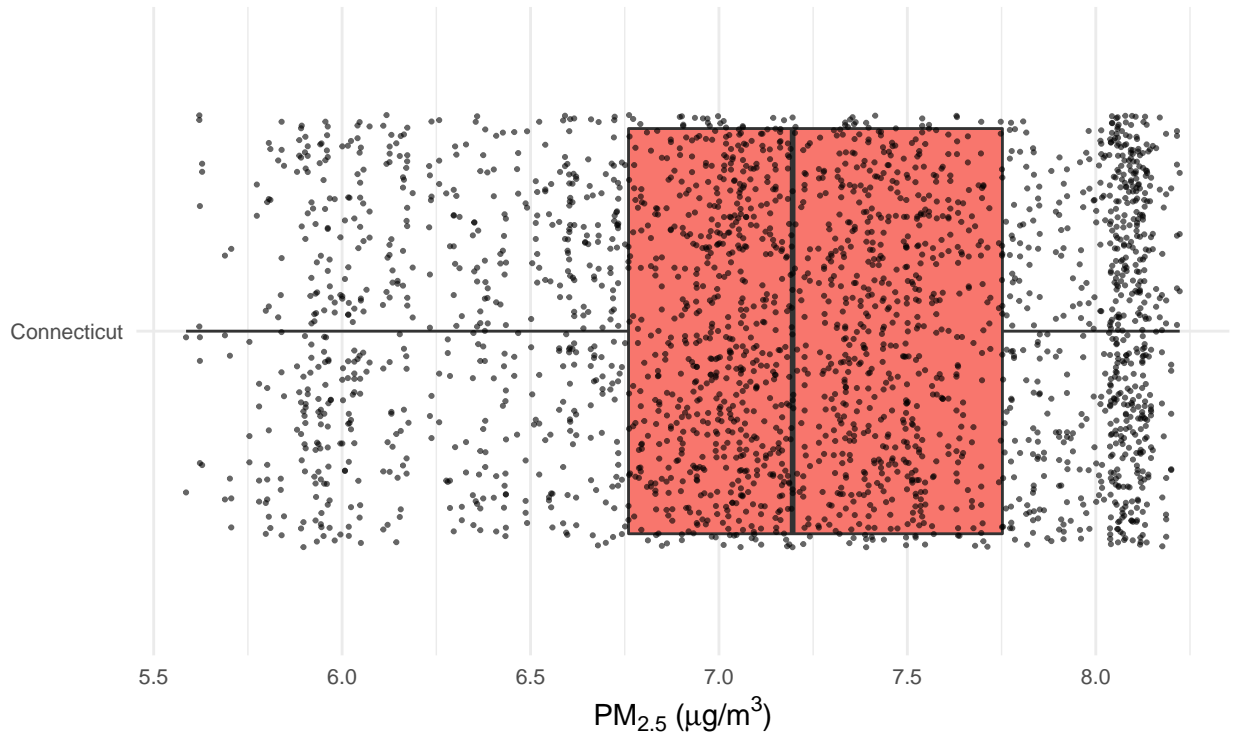


Figure 3: Boxplot of 2016 annual PM_{2.5} concentrations at Census Block Group level. 1 dot = 1 Block Group.

Since 2011, PM_{2.5} levels have declined across the state, on average by 22.8%. Unsurprisingly, this decline has not been uniform (see Figure 4 below). The greatest declines, up to 32.4%, have been in the eastern half of the state.

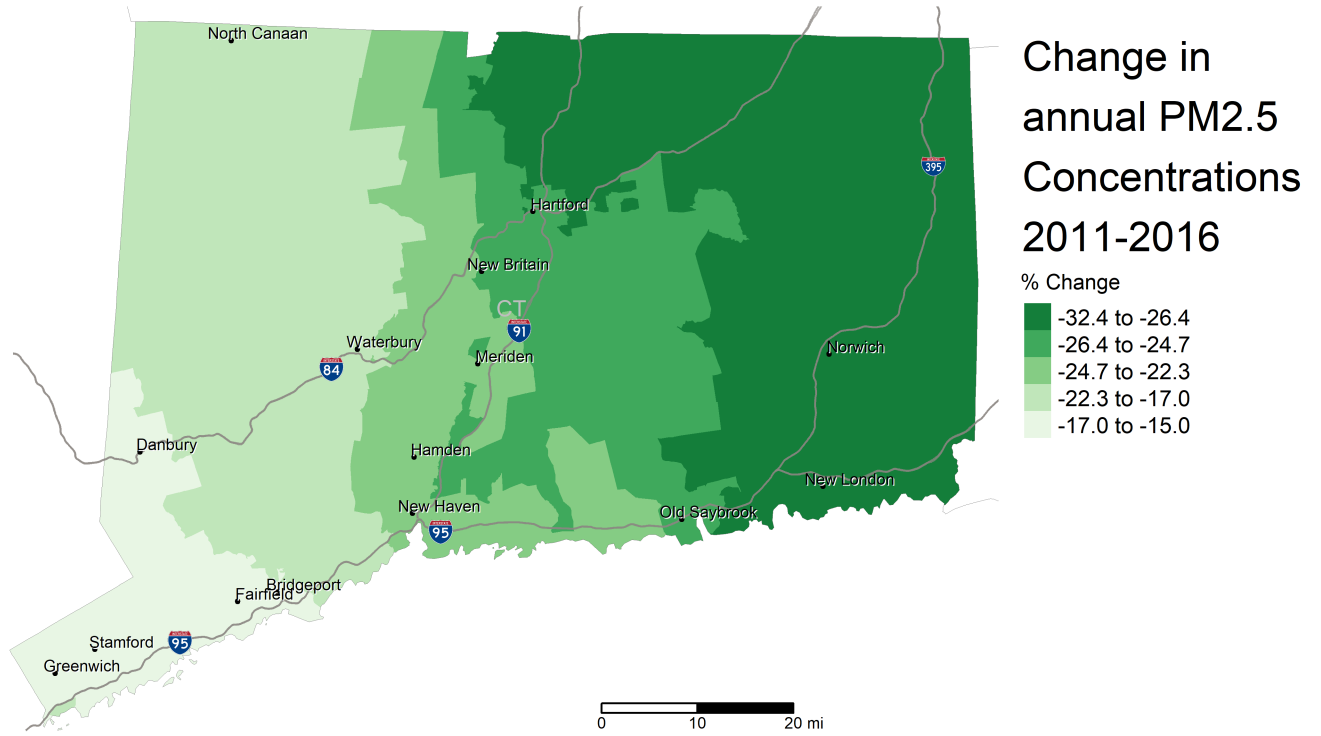


Figure 4: Map of percent change in annual PM_{2.5} concentrations across Connecticut between 2011 and 2016 at Census Block Group level.

Figure 5 below compares the average annual PM_{2.5} concentrations for the state and the region between 2011 and 2016. The region and the state both showed significant declines since 2011, although note that concentrations in Connecticut have remained consistently well above the rest of the region.

Annual Average PM_{2.5} Concentrations

PM_{2.5} (µg/m³)

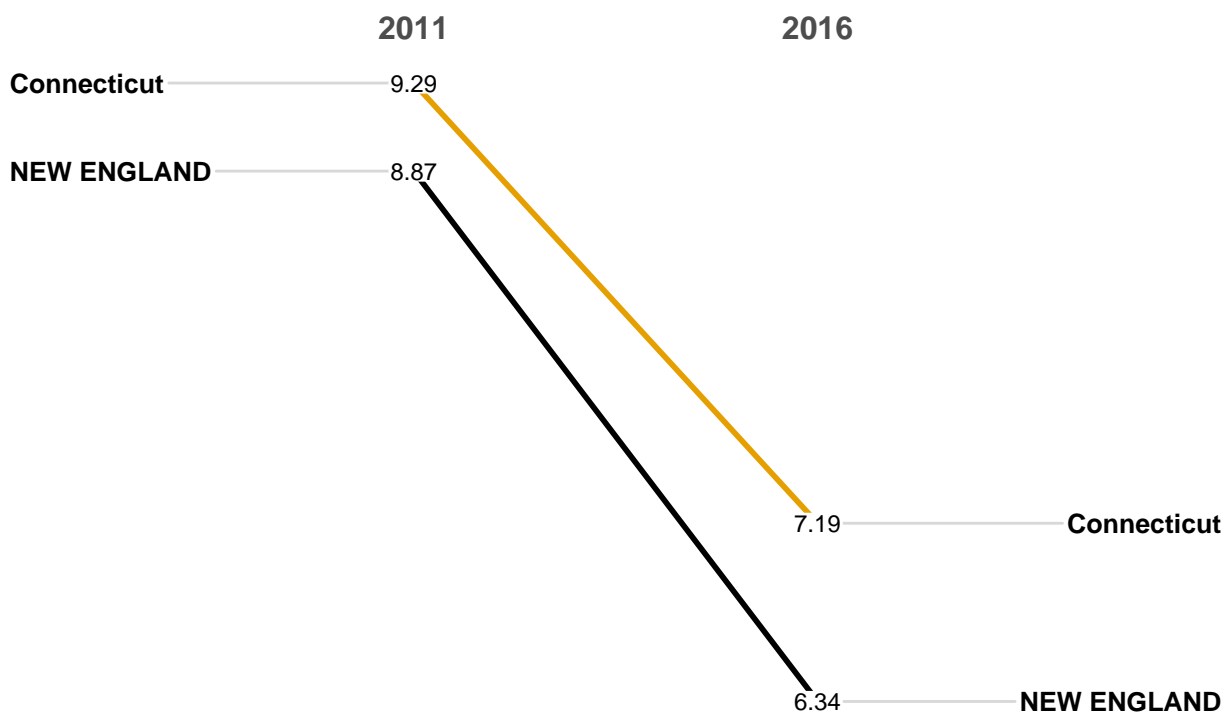


Figure 5: Change in population-weighted concentrations of PM_{2.5} between 2011 and 2016 for Connecticut and New England.

1.1.1 PM_{2.5} in Connecticut and Priority Populations

In addition to variations in the general geography of PM_{2.5} concentrations, exposure to these pollutants also varies demographically. Figure 6 below shows population-weighted exposures for priority populations relative to average PM_{2.5} concentrations for the state. For example, language isolated households in Connecticut are exposed to PM_{2.5} concentrations that are 2.8% above concentrations for the state as a whole. Similarly, People of Color are exposed to concentrations over 2% above the state average. By contrast, persons over age 64 are, on average, exposed to concentrations of PM_{2.5} at or below the state average.

Population-Weighted PM_{2.5} Exposure (relative to Connecticut average)

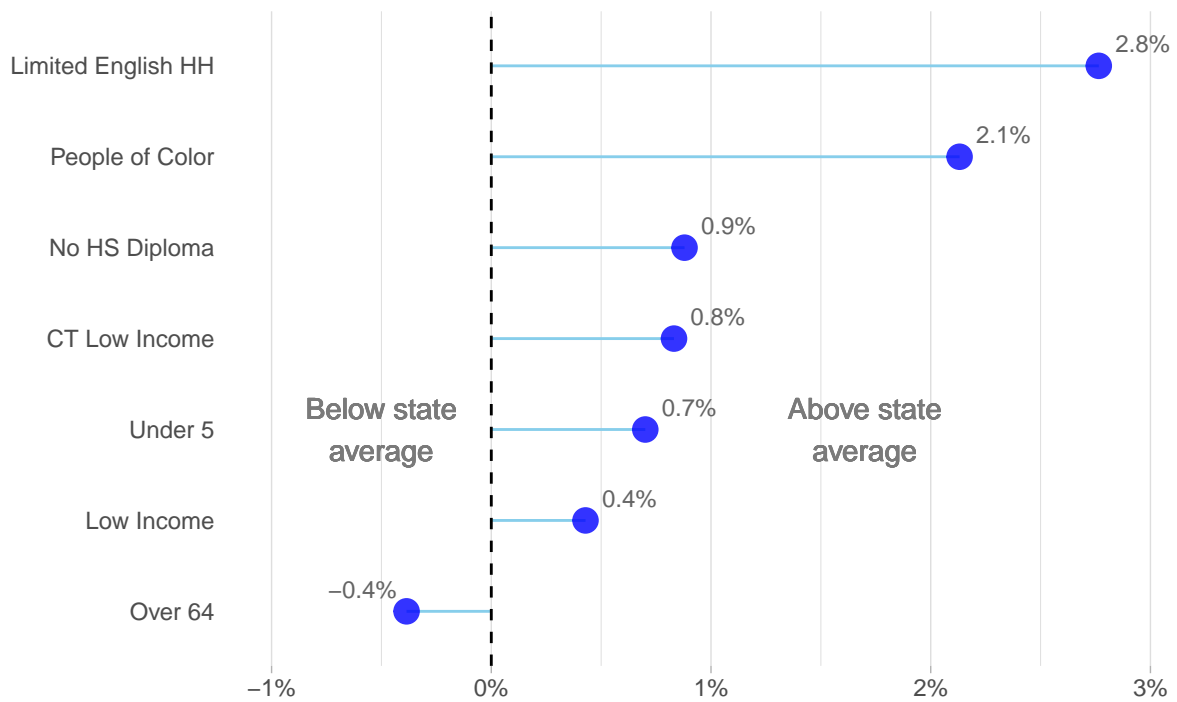


Figure 6: Population-weighted average exposures to PM_{2.5} for priority populations in Connecticut relative to the state average.

Like the region as a whole, these populations have also experienced a decline in exposure since 2011. The comparison between exposure for these groups since 2011 is displayed below in Figure 7. Note however that all priority populations continue to experience exposures greater than the regional average, with language isolated households leading on this measure.

Population-Weighted PM2.5 Exposure

PM_{2.5} (μg/m³)

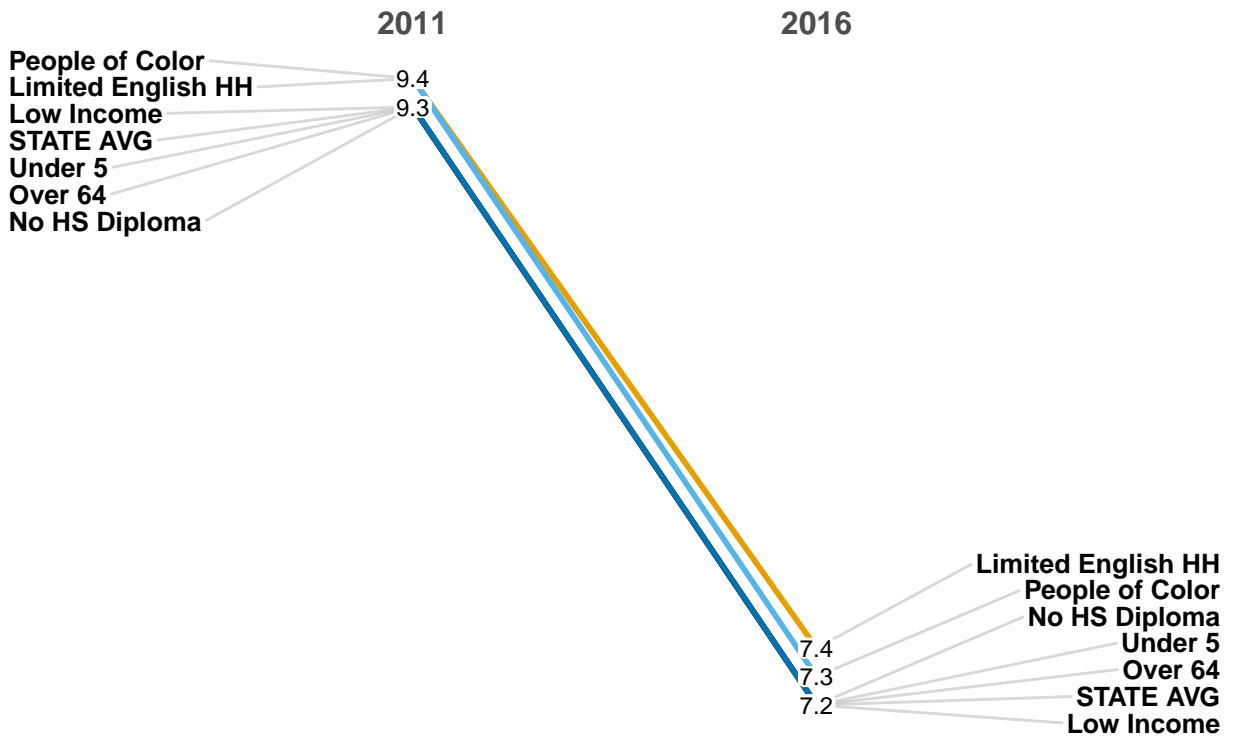


Figure 7: Change in population-weighted exposure to PM_{2.5} for priority populations between 2011 and 2016.

There is a weak positive relationship between the proportion of people of color or language-isolated households and the concentration of PM_{2.5} (see Figure 36 in Appendix B).

1.2 Ozone (O₃) in Connecticut

Ground-level ozone (O₃) is the primary constituent of smog.⁷ However, ozone is not usually emitted directly into the air. It is created at ground level by a chemical reaction in the air between oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. These ozone precursor pollutants are emitted from automobile exhaust, gasoline vapors, industrial boilers, refineries, chemical plants, and other sources. Ozone concentrations tend to be highest during the summer months due to increased sunlight and heat. Ozone can also be carried long distances by wind, affecting areas far from the sources of precursor pollutants.

The EPA has documented an association between exposure to ambient ozone and a variety of health outcomes, including reduction in lung function, increased inflammation and increased hospital admissions and mortality.⁸ People most at risk from breathing air containing ozone include people with asthma, children, older adults, and people who are active outdoors, especially outdoor workers. Children are at greatest risk from exposure to ozone because their lungs are still developing and they are more likely to be active outdoors when ozone levels are high, which increases their exposure. Children are also more likely than adults to have asthma.⁹

Ground level ozone has been regulated by the US EPA under the National Ambient Air Quality Standards (NAAQS) since 1971. As of April 2020, the EPA's primary (health-based) standard for ground level ozone is 70 parts per billion (ppb).¹⁰ However, the EPA has acknowledged that clinical and epidemiological evidence has been inconclusive about a possible threshold for ozone-induced health effects. EPA concluded that if a population threshold level exists, it is near the lower limit of ambient ozone concentrations in the United States.¹¹

The analysis of ozone (O₃) presented here is based on data from the EPA's EJSCREEN.¹² EJSCREEN data provides ozone (O₃) May–September (summer/ ozone season) average of daily-maximum 8-hour-average ozone concentrations, in parts per billion (ppb) at the Census Block Group level for the years 2011 to 2016 (as of December 2019).

Ozone (O₃) levels vary significantly across Connecticut, with highest concentrations in southwest Connecticut, and declining toward the north and east (see Figure 8 below).¹³

⁷Tropospheric, or ground-level ozone, is not to be confused with the stratospheric ozone layer. The latter occurs naturally high in the atmosphere and protects us from ultraviolet radiation.

⁸See EPA SUMMARY OF PROPOSAL TO RETAIN THE AIR QUALITY STANDARDS FOR PARTICLE POLLUTION. https://www.epa.gov/sites/production/files/2020-04/documents/fact_sheet_pm_naaqs_proposal.pdf

⁹See EPA Health Effects of Ozone Pollution. <https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution>

¹⁰An area would meet the primary standard if the fourth-highest daily maximum 8-hour average of ozone, averaged across three consecutive years, is less than equal to the standard. See EPA 2015 National Ambient Air Quality Standards (NAAQS) for Ozone. <https://www.epa.gov/ground-level-ozone-pollution/2015-national-ambient-air-quality-standards-naaqs-ozone>

¹¹See U.S. EPA. (2006). Air Quality Criteria for Ozone and Related Photochemical Oxidants. Washington, DC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923>.

¹²U.S. Environmental Protection Agency (EPA), 2019. EJSCREEN Technical Documentation. For more information see www.epa.gov/ejscreen

¹³Note that the EJSCREEN values do not directly indicate nonattainment of the NAAQS standard because the EJSCREEN data is based on estimates from a combination of modeling and monitoring for a single year, while nonattainment is determined for a large area (often a county) based on three years of monitoring data. For example, five counties in Connecticut have been designated as “nonattainment” status for NAAQS ozone standards as of March 2020. For a list of nonattainment counties see EPA 8-Hour Ozone Designated Area State/Area/County Report. <https://www3.epa.gov/airquality/greenbook/jbcs.html#CT>

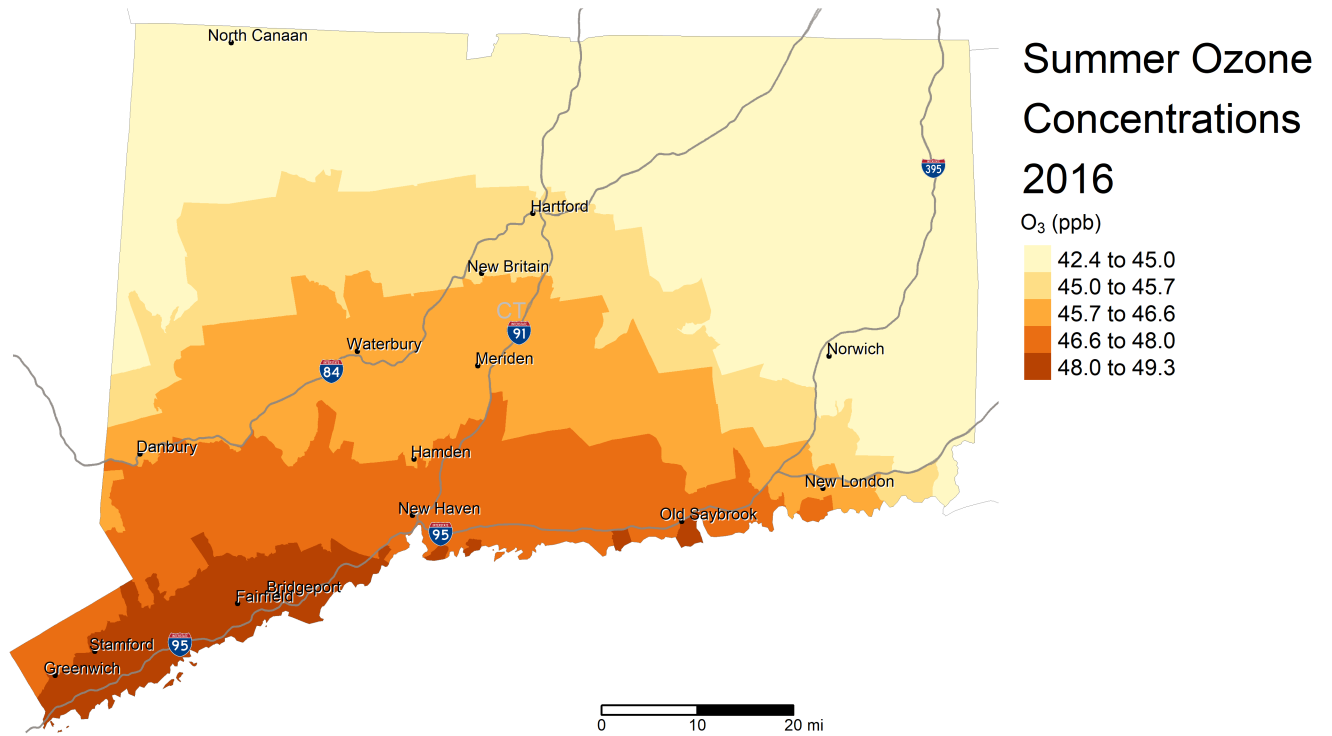


Figure 8: Map of 2016 Ozone summer seasonal average of daily maximum 8-hour concentration in air in parts per billion across Connecticut at Census Block Group level.

Ozone (O_3) concentrations exhibit spatial clustering of both hot spots (i.e. geographic clusters of high values) and cold spots (i.e. geographic clusters of lower values). The map below (Figure 9) shows statistically significant Ozone (O_3) hot spots.

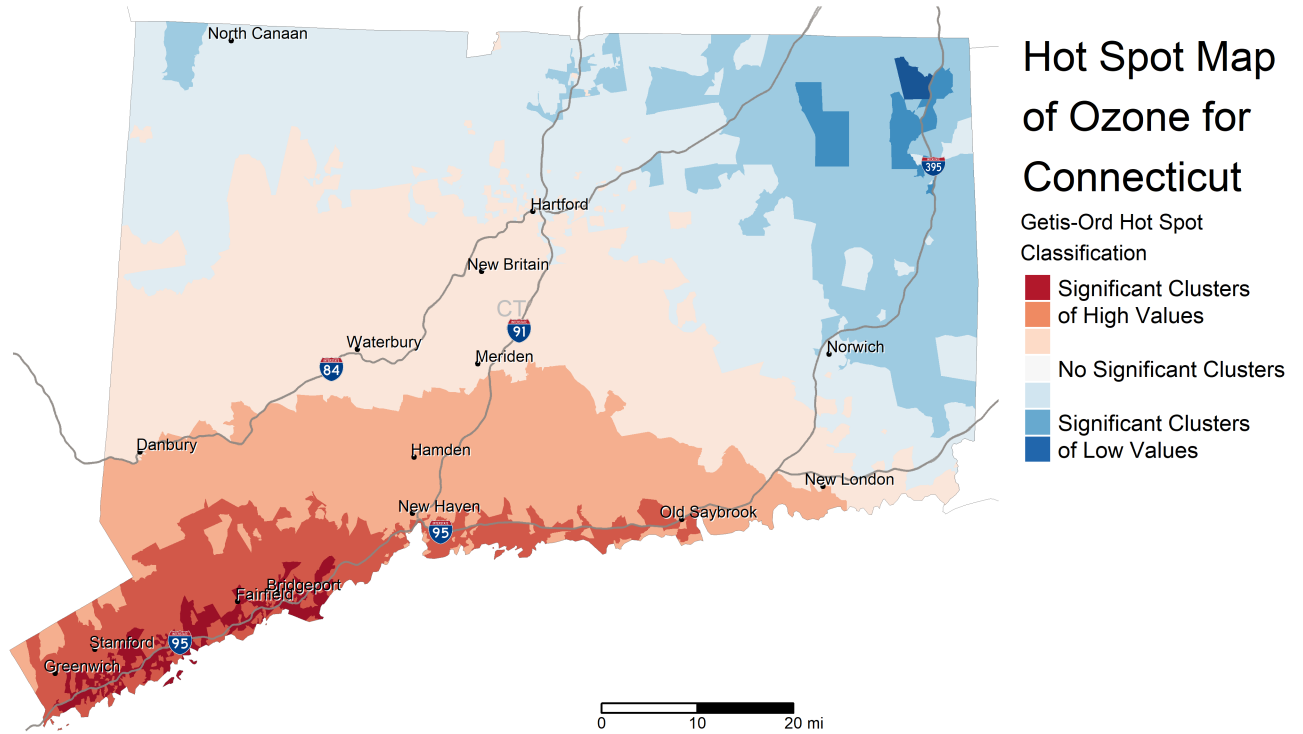


Figure 9: Hot spot map of 2016 Ozone concentrations at Census Block Group level.

There are statistically significant hot spots of Ozone (O_3) primarily between Stamford and Bridgeport. A warm cluster extends as north as New Britain.

These Ozone (O_3) levels vary significantly across the state (see Table 2 and Figure 10). See Table 13 in Appendix B for concentrations by municipality.

Table 2: Annual 2016 ozone concentrations (parts per billion) by Census block group for the state.

Mean	Median	Min	Max
46.32	46.1	42.38	49.28

The Block Group with highest O_3 concentration value in the state is found in Stamford and the lowest is found in Thompson.

Figure 10 is a boxplot of O_3 concentrations by Block Group . The box represents concentration values ranging between the 25th and 75th percentiles. The line that divides the box into 2 parts represents the median O_3 concentration for all Block Groups, which in this case is 46.1. Half of the state's Block Groups are below the median and half are above the median. Each dot represents an individual Block Group.

Ozone (O₃) Summer Concentration 2016

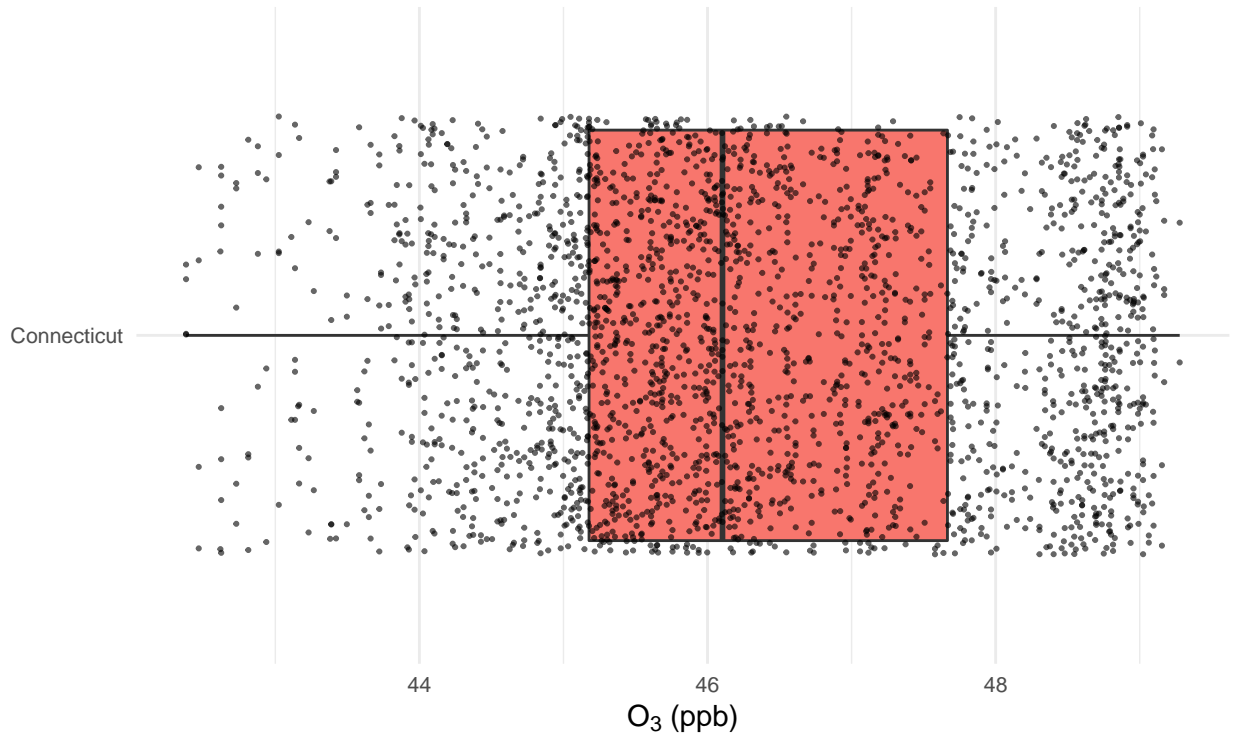


Figure 10: Boxplot of 2016 Ozone summer seasonal average of daily maximum 8-hour concentrations in air in parts per billion by state at Census Block Group level. 1 dot = 1 Block Group.

Since 2011, Ozone (O₃) levels have increased slightly across the state, on average by 4.8%. These changes have not been uniform (see Figure 11 below). The greatest declines, up to -3.6%, have been along the eastern edge of the state. By contrast, increases in summer ozone concentrations of up to 8.1% appear in the extreme southwest and center of the state.

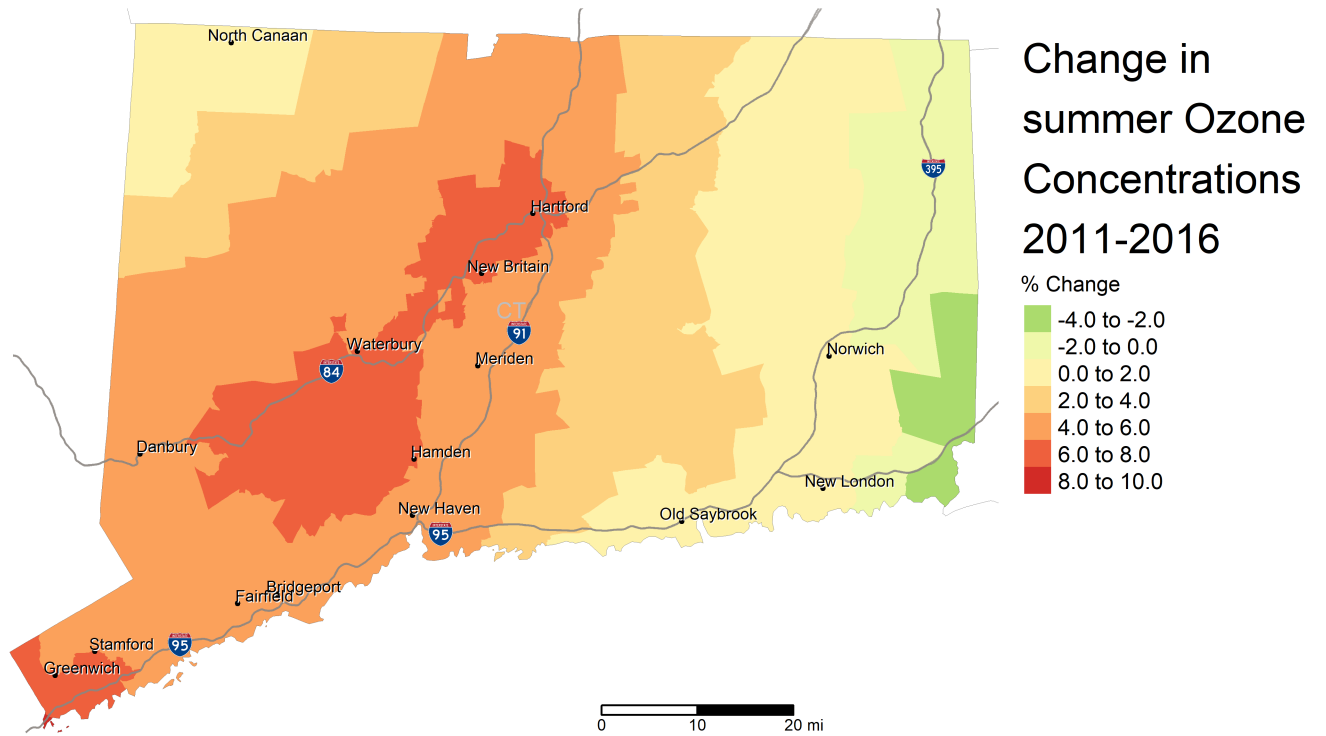


Figure 11: Map of percent change in summer seasonal Ozone concentrations across Connecticut between 2011 and 2016 at Census Block Group level.

Figure 12 below compares the average summer Ozone (O_3) concentrations for the state and for the region between 2011 and 2016. Connecticut's increase has been greater than the region.

Summer Average Ozone (O₃) Concentrations

O₃ (ppb)

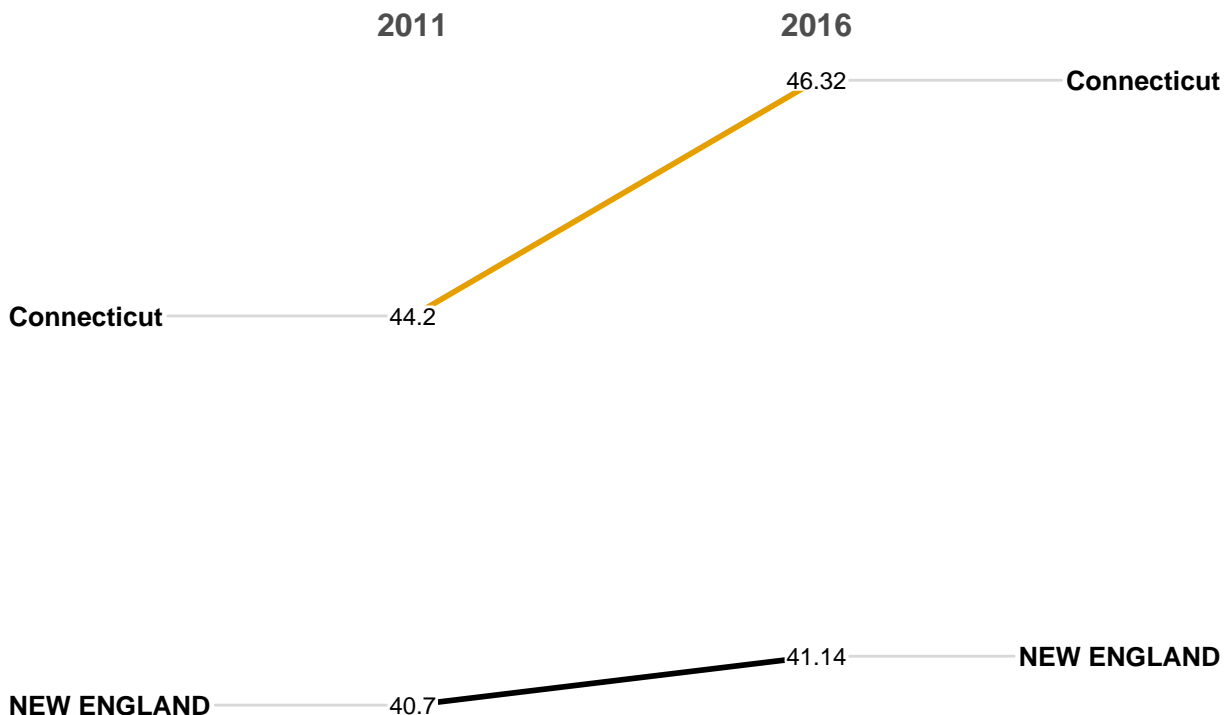


Figure 12: Change in summer average ozone concentrations between 2011 and 2016 for Connecticut and New England.

1.2.1 Ozone (O₃) in Connecticut and Priority Populations

In addition to variations in the general geography of Ozone (O₃) concentrations, exposure to this pollutant also varies demographically. Figure 13 below shows population-weighted exposures for priority populations relative to average Ozone concentrations for the region. For example, language isolated households in Connecticut are exposed to summer Ozone concentrations that are more than 0.76% above concentrations for the region as a whole. Similarly, People of Color are exposed to concentrations 0.55% above the regional average. By contrast, persons over age 64 are, on average, exposed to concentrations of Ozone at or below the regional average.

Population-Weighted Ozone (O₃) Exposure (relative to Connecticut average)

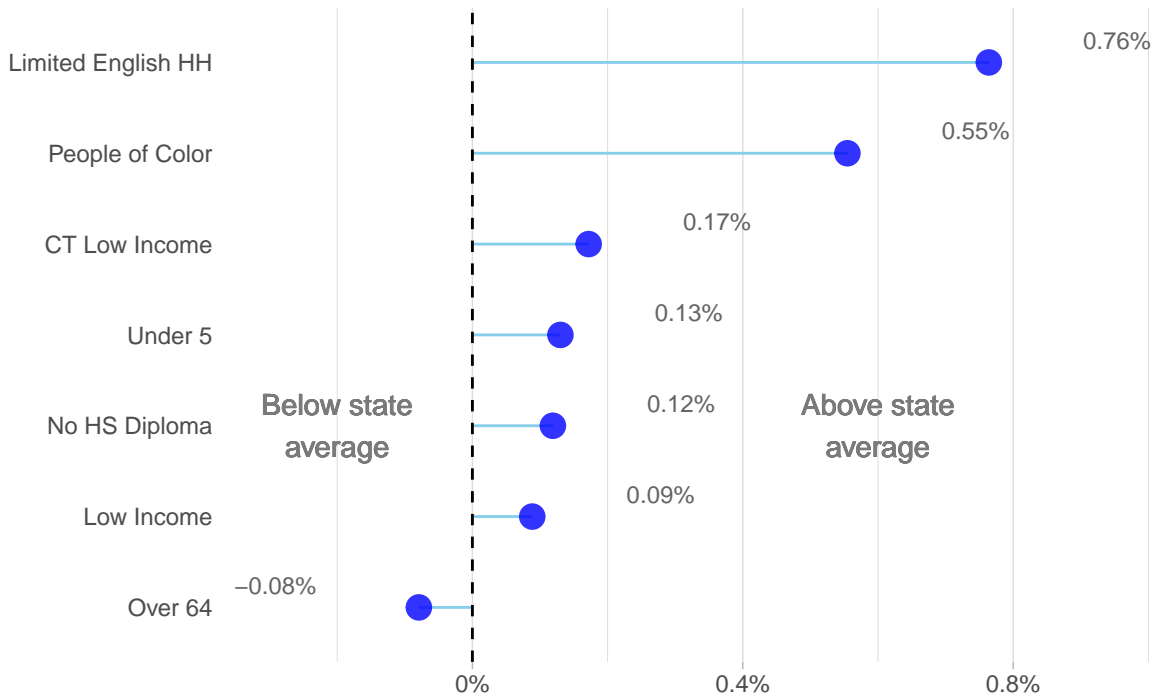


Figure 13: Population-weighted average exposures to Ozone for priority populations in Connecticut relative to the regional average.

Like the region as a whole, these populations have also experienced changes in exposure since 2011. The comparison between exposure for these groups since 2011 is displayed below in Figure 14. All priority populations have experienced an increase in population-weighted exposure to Ozone, with persons in language-isolated households and People of Color experiencing the greatest increase in exposure.

Population-Weighted Ozone Exposure

O₃ (ppb)

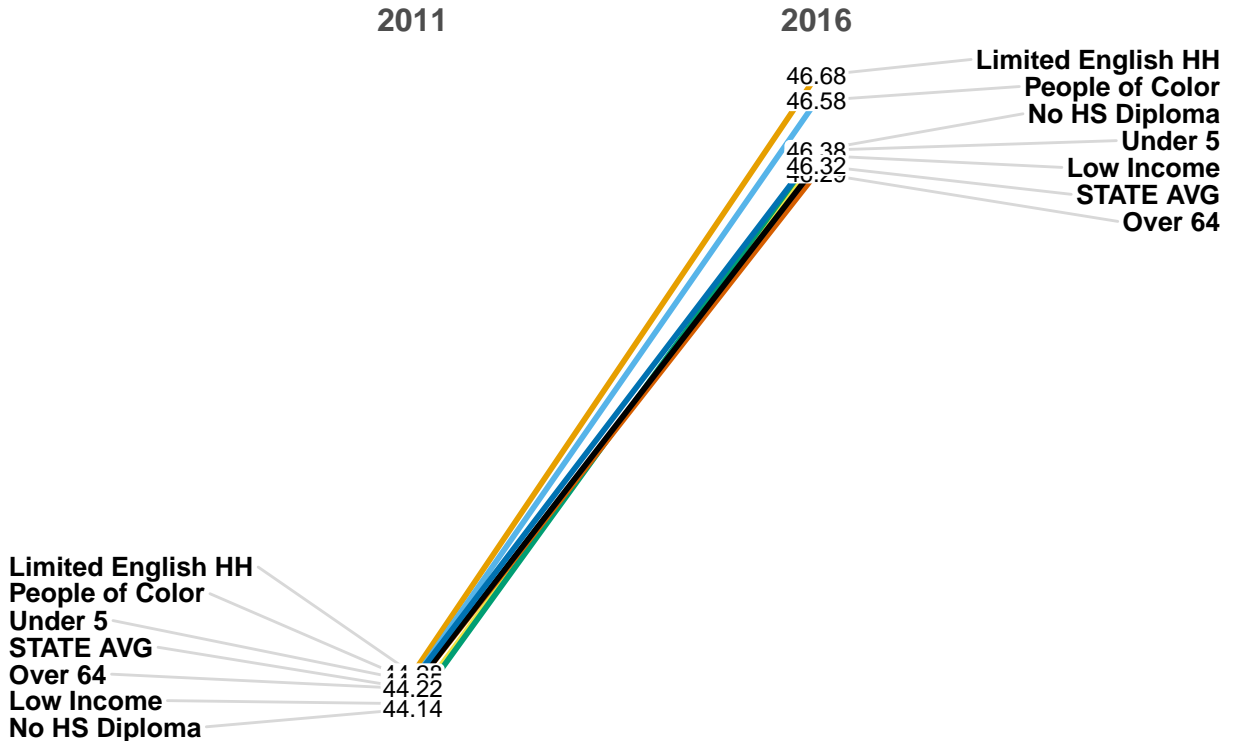


Figure 14: Change in population-weighted exposure to summer ozone for priority populations between 2011 and 2016.

1.3 Carbon Dioxide (CO₂) in Connecticut

Carbon dioxide (CO₂) emissions are the primary driver of human-induced climate change.¹⁴ Direct exposure to CO₂ is not a significant health concern, but its cumulative effects on the climate and global environment are. In addition to risks such as sea level rise, increasing frequency and intensity of extreme weather (e.g., flooding, storms, droughts, heat waves), and economic disruption, climate change is likely to degrade air quality by exacerbating smog formation and other airborne irritants.¹⁵ The single largest source of CO₂ emissions is the transportation sector, especially automobiles. Other sources of CO₂ emissions include the combustion of coal or petroleum-based fuels for electricity production, industry, heating of commercial and residential buildings, agriculture, and land use and forestry.¹⁶

In 2007, the US Supreme Court ruled that CO₂ is a pollutant under the terms of the Clean Air Act and therefore the EPA has statutory authority to regulate greenhouse gas (GHG) emissions. The EPA and National Highway Traffic Safety Administration (NHTSA) subsequently issued new fuel economy standards which included GHG standards for light-duty vehicles (passenger cars and trucks) for model years 2012 - 2016 and then model years 2017 - 2025. The latter required auto manufacturers to reduce average GHG emissions by approximately 23% by 2026.¹⁷ The Intergovernmental Panel on Climate Change (IPCC), the global authority on climate change science and policy, has warned that the world must bring GHG emissions down to “net zero” as soon as possible in order to avoid catastrophic climate change.¹⁸

The analysis of carbon dioxide (CO₂) presented here is based on data from the Database of Road Transportation Emissions (DARTE), a product of the NASA Carbon Monitoring System (CMS). DARTE provides CO₂ emissions from on-road transportation annually for 1980-2017 as a continuous surface at a spatial resolution of 1 km and also aggregated at the Census Block Group level.¹⁹

On-road CO₂ emissions closely follow major roadways across the state (see Figure 15 below).

¹⁴See Union of Concerned Scientists. Global Warming FAQ. <https://www.ucsusa.org/resources/global-warming-faq>

¹⁵See Union of Concerned Scientists. Climate Change and Your Health: Rising temperatures worsening ozone pollution. https://www.nrcm.org/wp-content/uploads/2013/09/UCS_climate_health_impact6.1.11.pdf

¹⁶See EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks. <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

¹⁷See The Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021-2026. <https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-final-rule>

¹⁸See IPCC. Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments. <https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/>

¹⁹Gately, C., L.R. Hutyrá, and I.S. Wing. 2019. DARTE Annual On-road CO₂ Emissions on a 1-km Grid, Conterminous USA, V2, 1980-2017. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAC/1735>

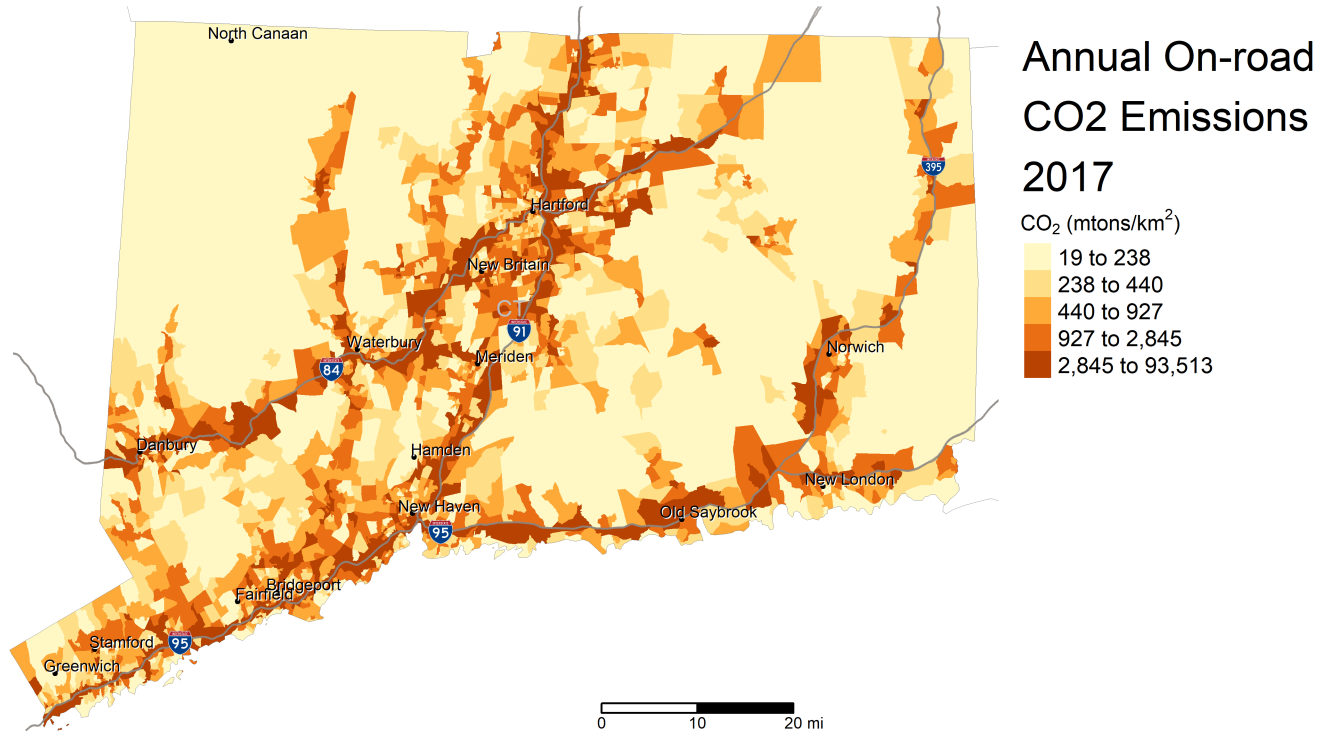


Figure 15: Map of 2017 Carbon Dioxide (CO₂) annual on-road emissions in metric tons per square kilometer across Connecticut at Census Block Group level.

Significant hot spots, or clusters of high CO₂ emissions, appear around along I-84 in Danbury and Hartford, and along I-95 in Greenwich, Bridgeport, and New Haven (see Figure 16 below).

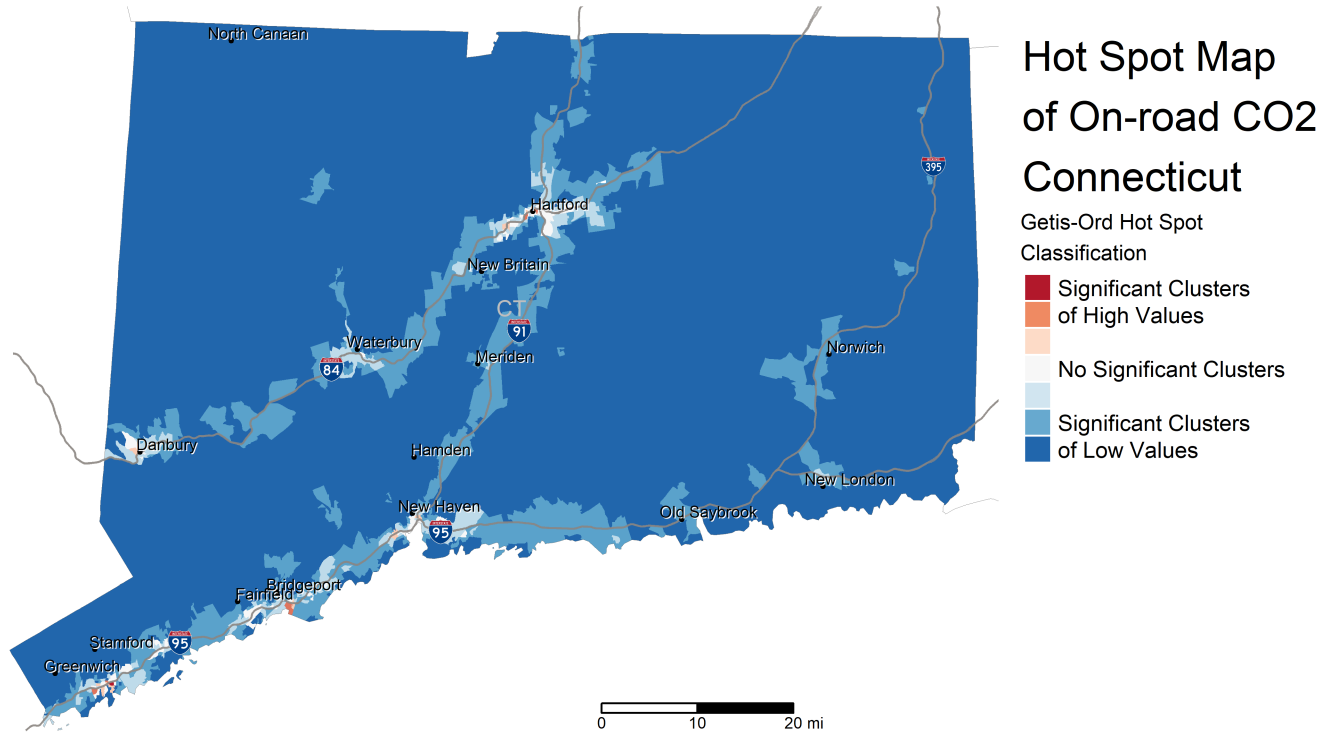


Figure 16: Hot spot map of 2017 CO₂ emissions at Census Block Group level.

CO₂ emissions vary across the state with significant outliers (see Table 3). See Table 13 in Appendix B for on-road emissions by municipality.

Table 3: Annual 2017 On-road CO₂ emissions (mtons) by Census block group by state

Mean	Median	Min	Max	State Total
5,924	1,517	5	258,320	15,284,098

The Block Group with highest CO₂ emissions value in the state is found in Manchester and the lowest is found in Stamford.

Since 1990, CO₂ emissions increased significantly across the state, on average by 14.2%. These changes have not been uniform (see Figure 17 below). The greatest declines have been in northwest Connecticut and in the eastern third of the state. By contrast, the south central and southern edges of the state have seen increased emissions, with the greatest increase occurring in Middletown.

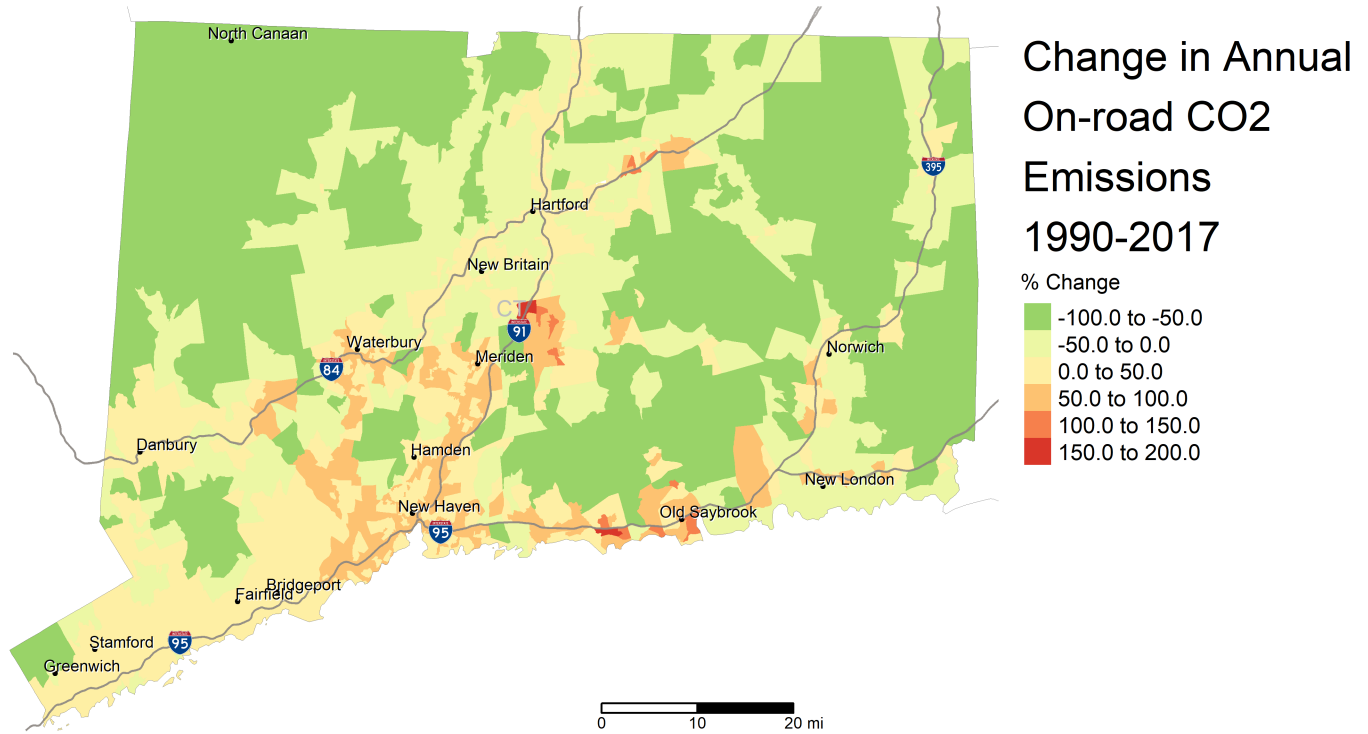


Figure 17: Map of percent change in annual CO₂ emissions across Connecticut between 1990 and 2017 at Census Block Group level.

At the state level the differences in these changes are also apparent, although less extreme than at the Census block group level. Table 4 shows summary statistics of CO₂ emissions for the state as a whole. Figure 18 shows annual CO₂ emissions between 1990 and 2017.

Table 4: Annual On-road CO₂ Emissions

1990 CO ₂ (mtons)	2017 CO ₂ (mtons)	Pct Change	1990 Per Capita (mtons/person)	2017 Per Capita (mtons/person)	Per Capita Pct Change
13,381,852	15,284,098	14%	4.07	4.28	5%

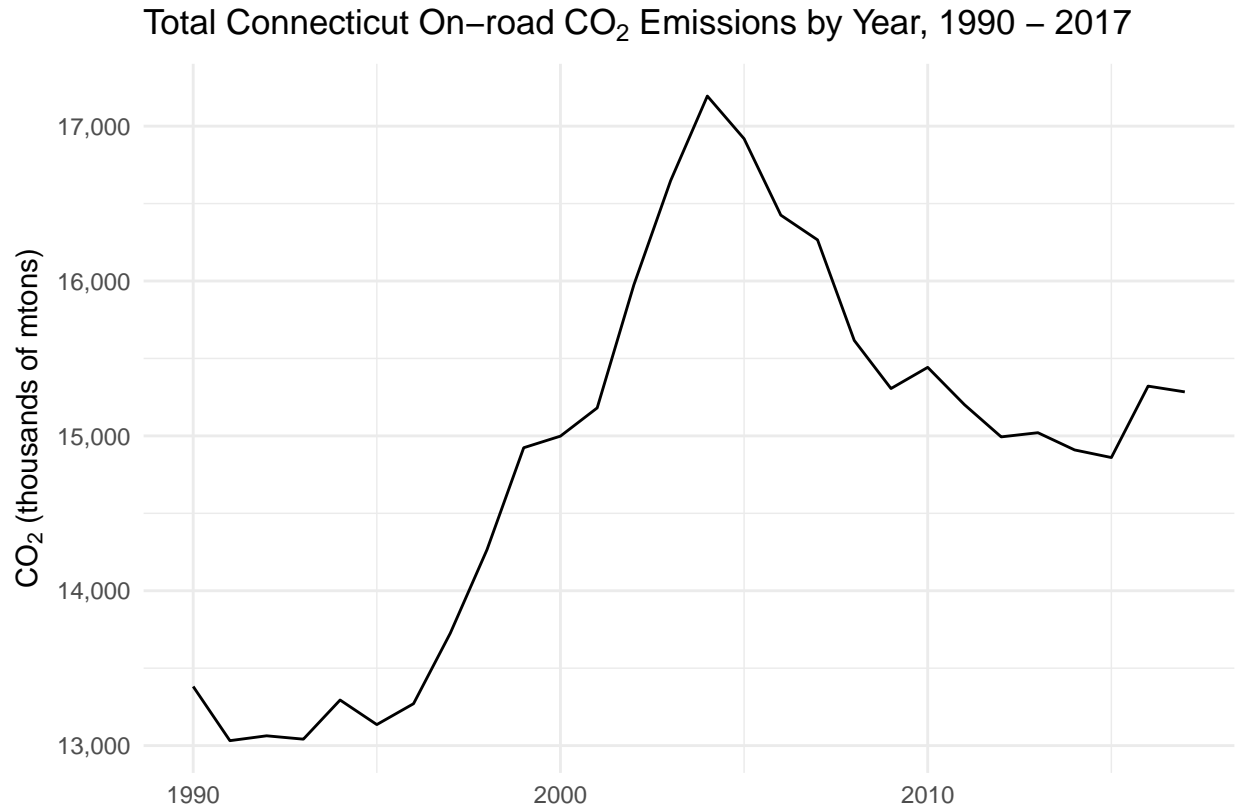


Figure 18: Total CO₂ emissions 1990 to 2017 for Connecticut.

The growth in CO₂ emissions since 1990 exceeds population growth in the state as is evident in the per capita emissions (see last three columns in Table 4).

1.4 Diesel Particulate Matter in Connecticut

Diesel particulate matter (DPM) refers to particulate matter generated from the combustion of diesel fuel. DPM mass (expressed as $\mu\text{gDPM}/\text{m}^3$) has historically been used as a surrogate measure of exposure for diesel exhaust more generally. Diesel exhaust is a complex mixture of thousands of gases and fine particles that contains more than 40 toxic air contaminants. These include many known or suspected cancer-causing substances, such as benzene, arsenic and formaldehyde. It also contains other harmful pollutants, including nitrogen oxides (a component of smog). In addition to long term cancer risk, exposure to diesel exhaust can have immediate health effects. It can irritate the eyes, nose, throat and lungs, and it can cause coughs, headaches, light-headedness and nausea. Exposure to diesel exhaust also causes inflammation in the lungs, which may aggravate chronic respiratory symptoms and increase the frequency or intensity of asthma attacks.²⁰

Major sources of diesel exhaust include engines and motorized vehicles that use diesel fuel, such as trucks, buses, trains, ships, and diesel-powered generators. DPM is classified by the EPA as a Hazardous Air Pollutant (HAP). HAPs are pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. The EPA has not quantified the cancer risk from exposure to DPM. However, it has established a diesel exhaust reference concentration (RfC) for noncancer health effects. The RfC is $5\mu\text{g}/\text{m}^3$ for diesel exhaust measured as diesel particulate matter (DPM). This RfC does not consider allergenic effects such as those associated with asthma, immunologic effects or the potential for cardiac effects.²¹

The analysis of DPM presented here is based on data from the EPA's EJSCREEN.²² EJSCREEN data provides annual DPM concentrations, in micrograms per cubic meter of air ($\mu\text{g}/\text{m}^3$), at the Census Block Group level for 2014, the latest year of data available from the National Air Toxics Assessment.

DPM emissions are concentrated along the I-95 highway traffic corridor from Stamford to New Haven, and north to Hartford along I-91 (see Figure 19 below).

²⁰See CalEPA Office of Environmental Health Hazard Assessment and the American Lung Association. Health Effects of Diesel Exhaust. <https://oehha.ca.gov/media/downloads/calenviroscreen/indicators/diesel4-02.pdf>

²¹See 2014 NATA Technical Support Document. https://www.epa.gov/sites/production/files/2018-09/documents/2014_nata_technical_support_document.pdf

²²U.S. Environmental Protection Agency (EPA), 2019. EJSCREEN Technical Documentation. For more information see www.epa.gov/ejscreen

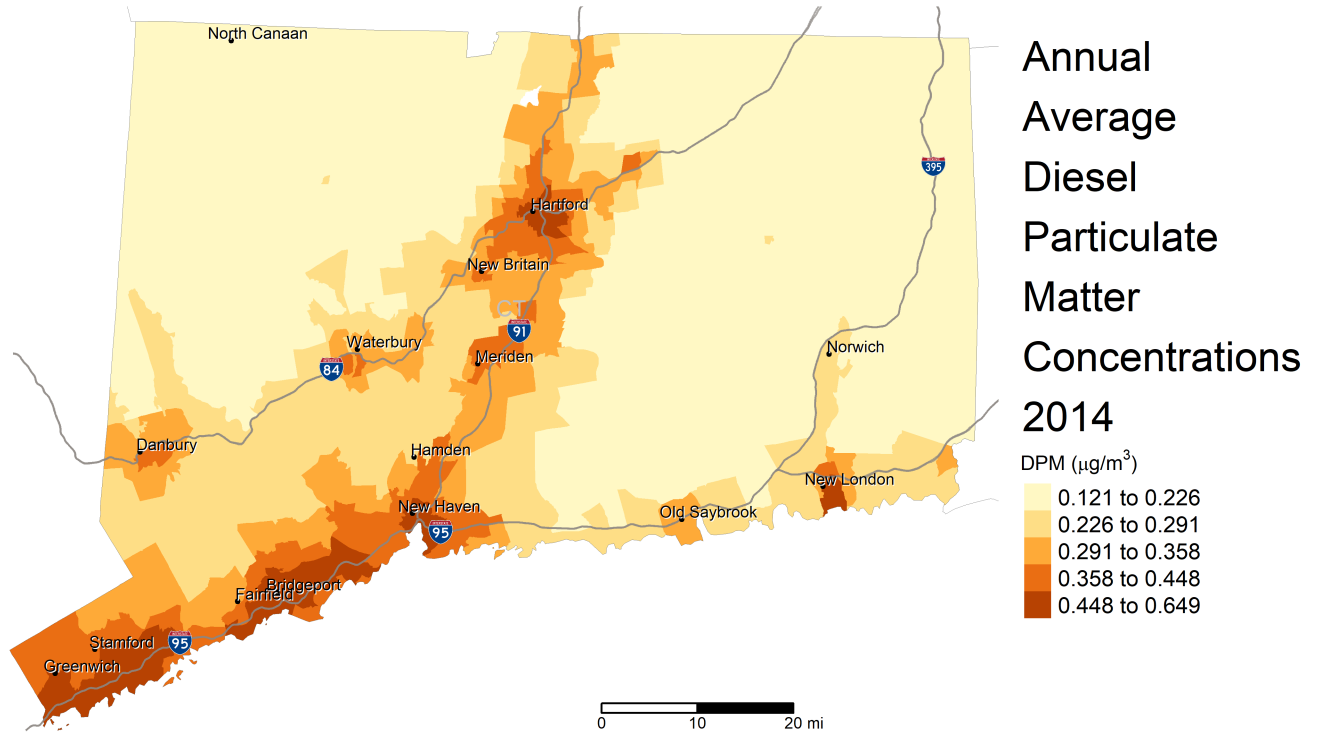


Figure 19: Map of 2014 annual average ambient concentrations of Diesel Particulate Matter in micrograms per cubic meter across Connecticut at Census Block Group level.

There are significant spatial clusters of high Diesel Particulate Matter concentrations in Stamford, Fairfield, New Haven, and Hartford (see Figure 20 below).

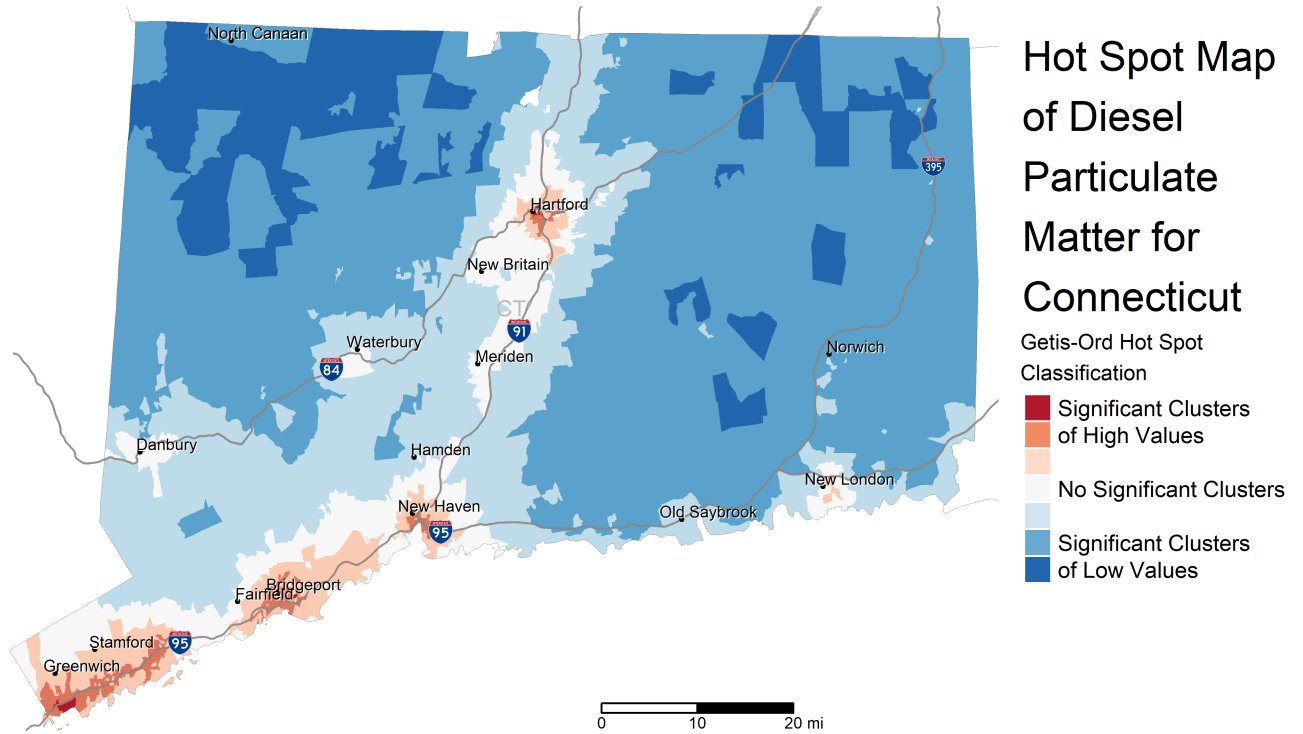


Figure 20: Hot spot map of 2014 Diesel Particulate Matter emissions at Census Block Group level.

Diesel Particulate Matter concentrations vary across the state (see Table 5 and Figure 21 below).

Table 5: Annual 2014 Diesel Particulate Matter concentrations by Census block group

Mean	Median	Min	Max
0.335	0.326	0.121	0.649

The Block Group with highest Diesel Particulate Matter emissions value in the state is found in New London and the lowest is found in Cornwall. See Table 13 in Appendix B for concentrations by municipality.

Figure 21 is a boxplot of DPM concentrations by Block Group . The box represents concentration values ranging between the 25th and 75th percentiles. The line that divides the box into 2 parts represents the median DPM concentration for all Block Groups, which in this case is 0.33. Half of the state's Block Groups are below the median and half are above the median. Each dot represents an individual Block Group.

Diesel Particulate Matter (DPM) concentrations by Census block group, 2017

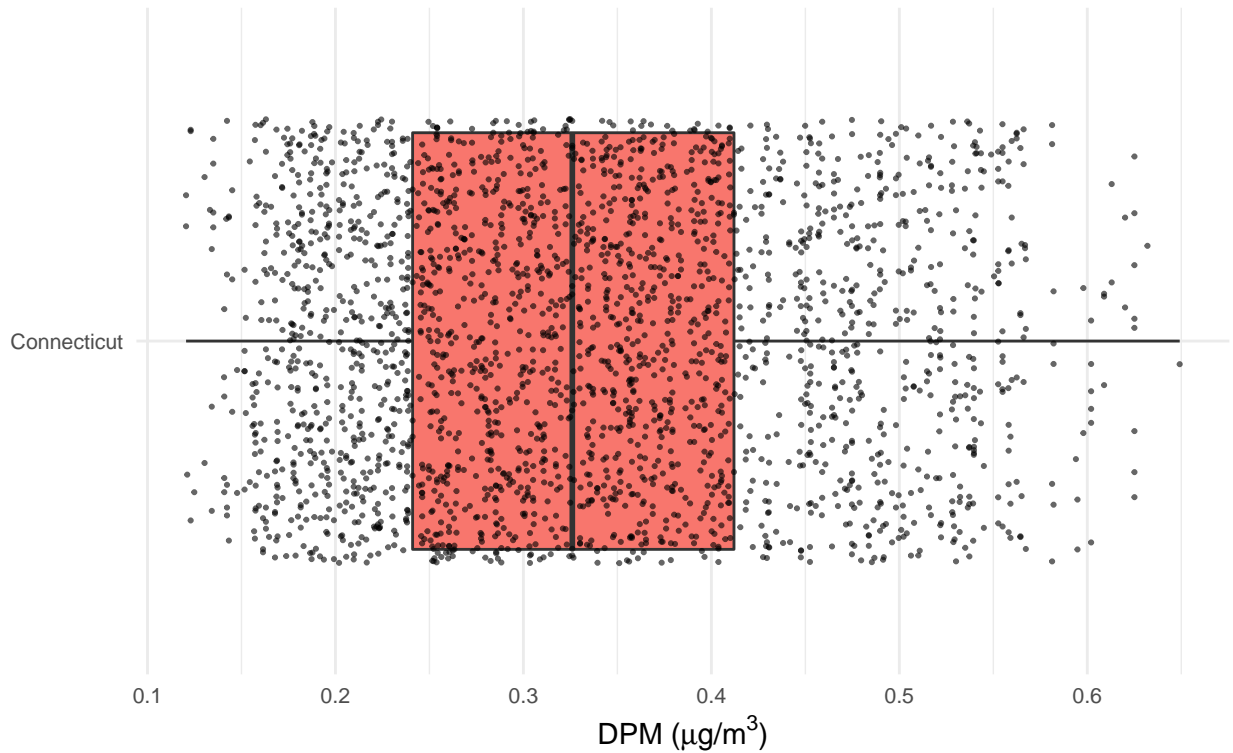


Figure 21: Boxplot of 2014 diesel particulate matter (DPM) concentrations in micrograms per cubic meter by state at Census Block Group level. 1 dot = 1 Block Group.

1.4.1 Diesel Particulate Matter in Connecticut and Priority Populations

In addition to variations in the general geography of Diesel Particulate Matter concentrations, exposure to these concentrations also varies demographically. Figure 22 below shows population-weighted exposures for priority populations relative to average Diesel Particulate Matter concentrations for the state. For example, linguistically isolated households in Connecticut are exposed to Diesel Particulate Matter concentrations that are almost 20% above concentrations for the region as a whole. Similarly, low income persons (following Connecticut's definition) are exposed to concentrations more than 16% above the regional average. By contrast, persons over age 64 are, on average, exposed to concentrations of Diesel Particulate Matter 5% below the regional average.

Population-Weighted Exposure to Diesel Particulate Matter (relative to Connecticut average)

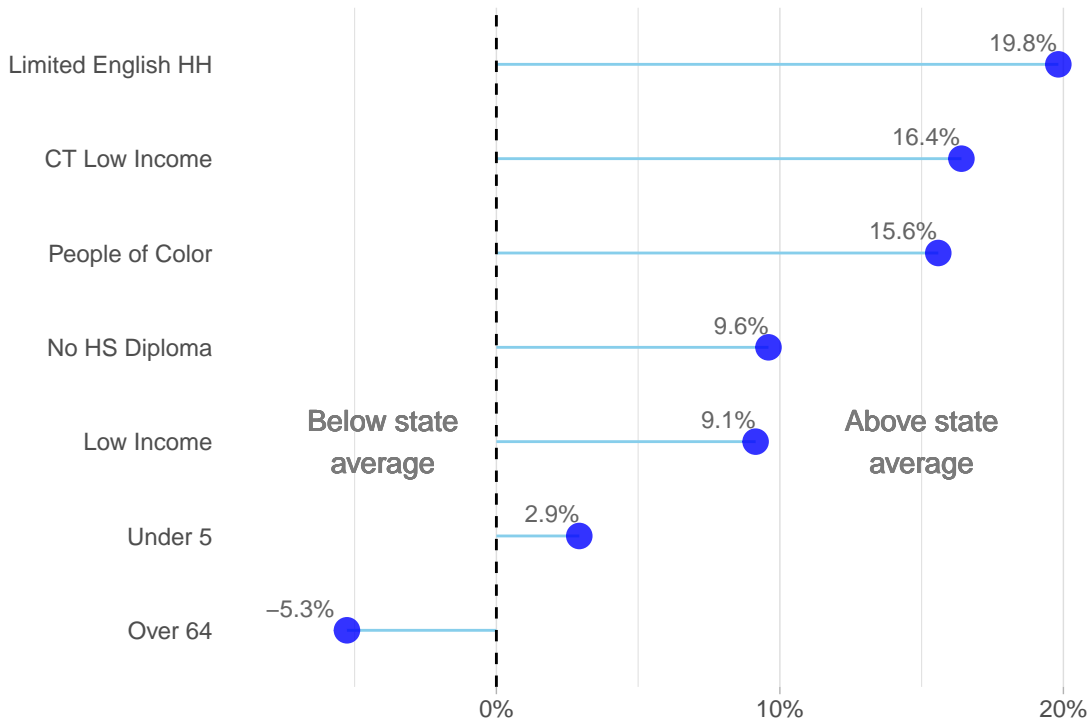


Figure 22: Population-weighted average exposures to annual average ambient concentrations of Diesel Particulate Matter across Connecticut relative to the regional average.

There is a moderate to strong positive correlation between the proportions of limited English speaking households and People of Color and ambient concentrations of Diesel Particulate Matter (see Figure 39 in Appendix B).

1.5 Air Toxics Cancer Risk in Connecticut

Air toxics, often referred to as hazardous air pollutants (HAPs), are pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.

Most air toxics originate from transportation and industry, including automobiles, industrial facilities, and power plants. EPA regulates 187 chemicals under its HAP program. Since 1996, the EPA's National Air Toxics Assessment (NATA) program has provided nationwide assessments of outdoor air quality with respect to emissions of air toxics. NATA uses emissions estimates from the National Emissions Inventory (NEI), which is updated every three years. The NEI includes all of the Toxics Release Inventory (TRI) reporting facilities that release hazardous air pollutants, along with many other sources of air pollutants, such as motor vehicles. NATA estimates the cancer risks from breathing these air toxics over a lifetime.²³

The analysis of air toxics cancer risk presented here is based on data from the EPA's EJSCREEN.²⁴ EJSCREEN data provides lifetime cancer risk from inhalation of air toxics, as risk-in-1 million, at the Census Block Group level for 2014, the latest year of data available from the National Air Toxics Assessment.

Air toxics cancer risks are concentrated along the highway traffic corridor from Stamford to New Haven along I-95 and from New Haven to Hartford along I-91 (see Figure 23 below).

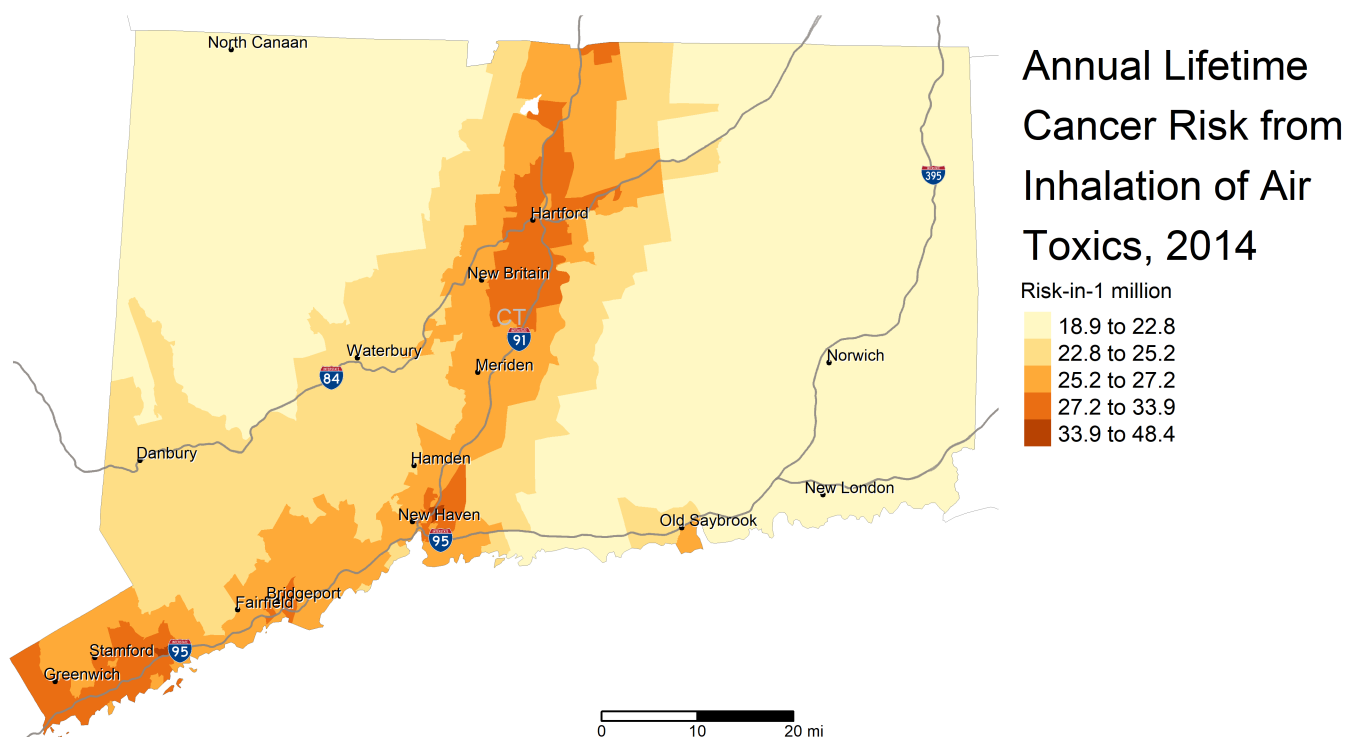


Figure 23: Map of 2014 lifetime cancer risk from inhalation of air toxics (expressed as risk in-1 million) across Connecticut at Census Block Group level.

There appear to be significant spatial clusters of high lifetime cancer risk from inhalation of air toxics north of Stamford, New Haven, and in Hartford (see Figure 24 below).

²³National Air Toxics Assessment Overview. <https://www.epa.gov/national-air-toxics-assessment/nata-overview>

²⁴U.S. Environmental Protection Agency (EPA), 2019. EJSCREEN Technical Documentation. For more information see www.epa.gov/ejscreen

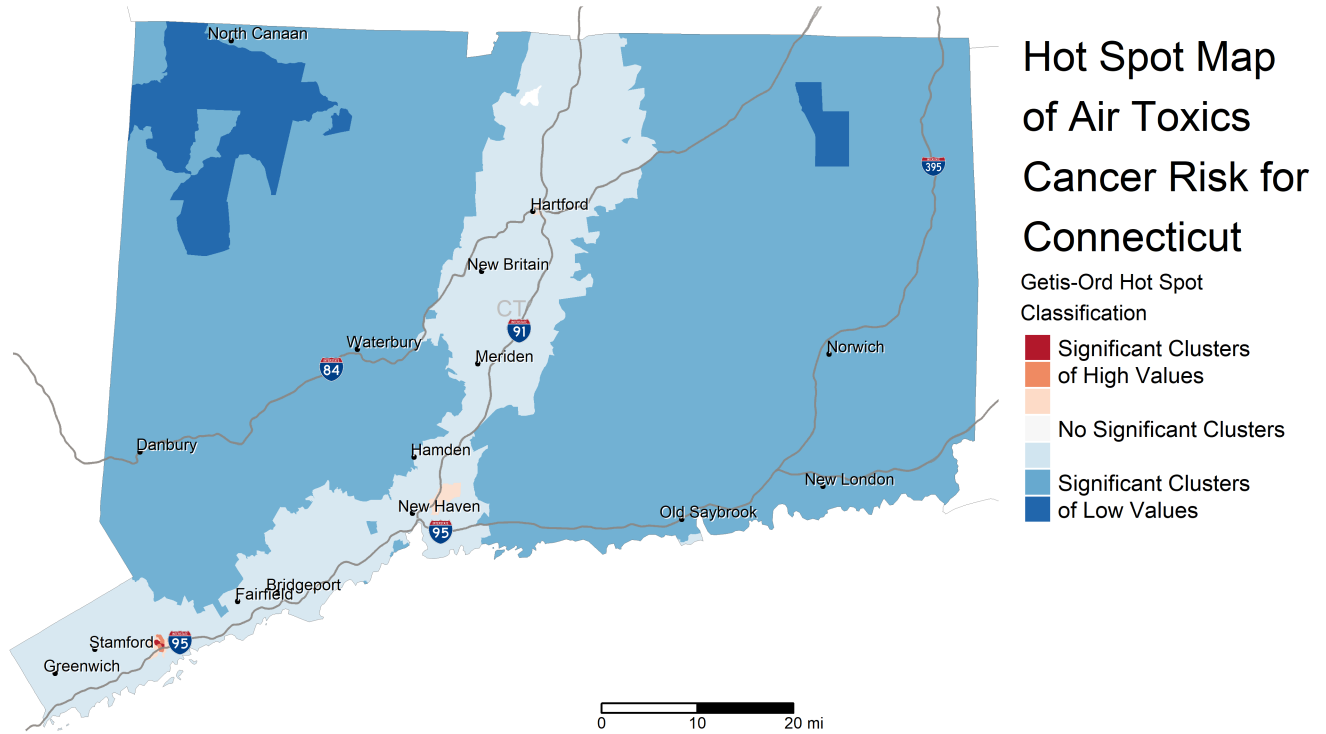


Figure 24: Hot spot map of 2014 lifetime cancer risk from inhalation of air toxics at Census Block Group level.

Lifetime cancer risk from inhalation of air toxics varies across the state (see Table 6 and Figure 25 below).

Table 6: Cancer Risk from Inhalation of Air Toxics by Census block group (risk-in-1 million)

Mean	Median	Min	Max
25.1	25.4	18.9	48.4

The Block Group with highest cancer risk value in the state is found in Norwalk and the lowest is found in Norfolk.

Figure 25 is a boxplot of cancer risk by Block Group . The box represents risk values ranging between the 25th and 75th percentiles. The line that divides the box into 2 parts represents the median lifetime cancer risk value for all Block Groups, which in this case is 25.43. Half of the state’s Block Groups are below the median and half are above the median. Each dot represents an individual Block Group. The large dots represent outliers, or unusually high values. In this case, outliers would be represented by cancer risk values greater than 32.3632712, which occur in Block Groups in Norwalk and New Haven. See Table 13 in Appendix B for concentrations by municipality.

Lifetime Cancer Risk from
Inhalation of Air Toxics
by Census block group, 2014

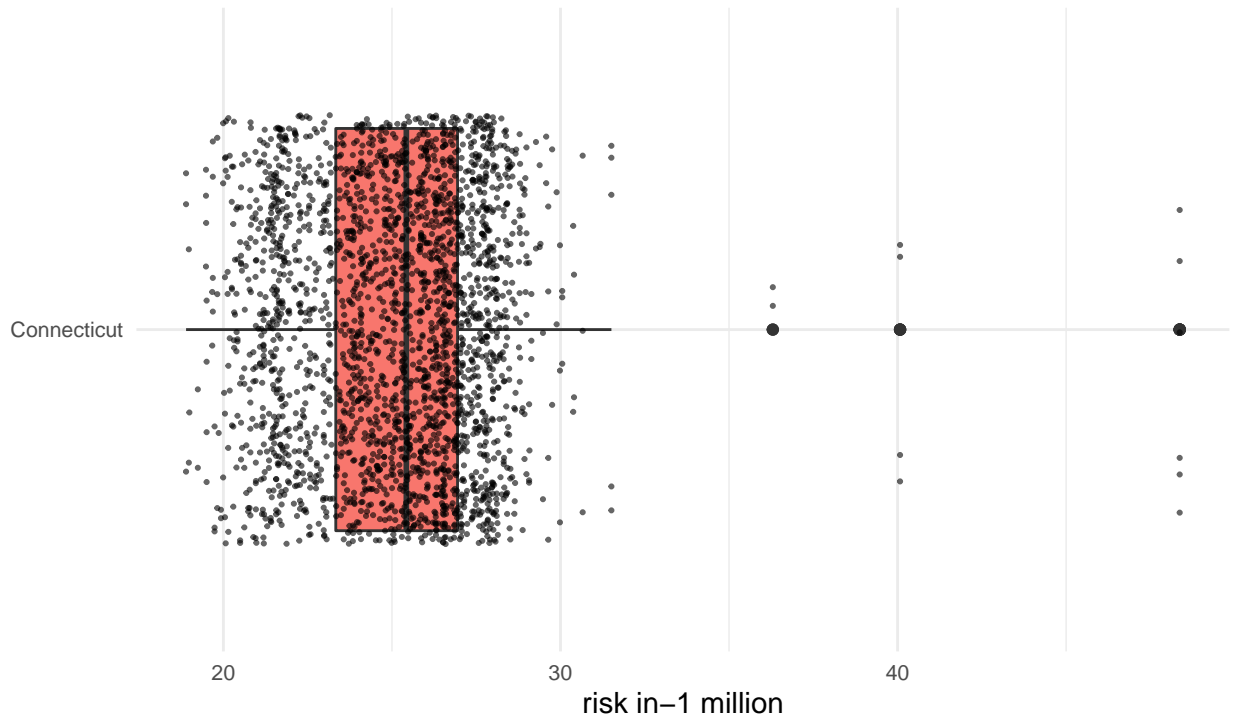


Figure 25: Boxplot of lifetime cancer risk from inhalation of air toxics (expressed as risk in-1 million) across Connecticut by state at Census Block Group level. 1 dot = 1 Block Group.

1.5.1 Lifetime Cancer Risk from Inhalation of Air Toxics in Connecticut and Priority Populations

In addition to variations in the general geography of lifetime cancer risk from inhalation of air toxics, exposure to these risks also varies demographically. Figure 26 below shows population-weighted exposures for priority populations relative to average cancer risk for the state. For example, limited English speaking households in Connecticut experience lifetime cancer risks from inhalation of air toxics that are 4.5% above the region as a whole. Similarly, People of Color experience lifetime cancer risks almost 4% above the state average. By contrast, persons over age 64 are, on average, exposed to lifetime cancer risks 1% below the state average.

Population-Weighted Average Lifetime Cancer Risk (relative to Connecticut average)

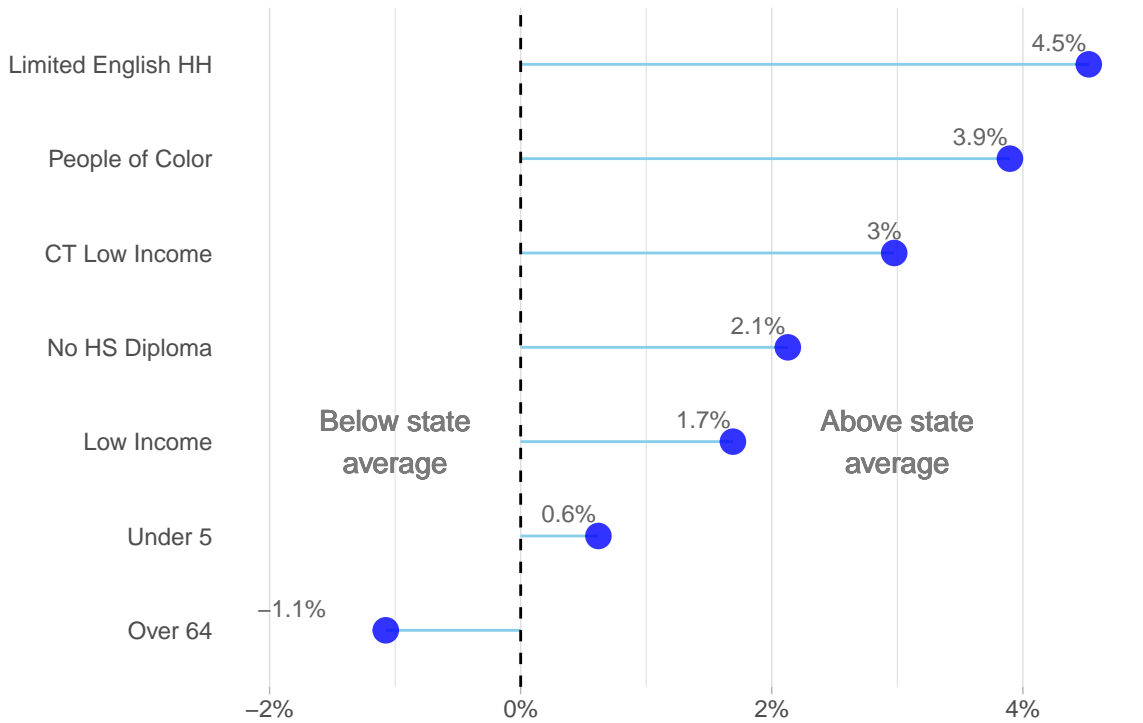


Figure 26: Population-weighted average lifetime cancer risk from inhalation of air toxics (expressed as risk in-1 million) across Connecticut at Census Block Group level relative to the state average.

There is a moderately positive correlation between the proportions of People of Color and limited English households and cancer risk (see Figure 40 in Appendix B).

1.6 Respiratory Hazard Index in Connecticut

Respiratory hazard from air toxics refers to noncancer effects caused by a lifetime of exposure to air toxics listed as Hazardous Air Pollutants (HAPs).²⁵ EPA's National Air Toxics Assessment (NATA) program calculates a hazard quotient, which is the ratio of ambient air concentration to a chemical's health-based reference concentration (RfC). No adverse health effects are expected from exposure if the hazard quotient is less than one. This hazard quotient represents the cumulative impacts of all the relevant air toxics for which respiratory effects were the key health effect.²⁶

The analysis of respiratory hazard presented here is based on data from the EPA's EJSCREEN.²⁷ EJSCREEN data provides respiratory hazard, as a ratio of exposure concentration to a health-based reference concentration (RfC), at the Census Block Group level for 2014, the latest year of data available from the National Air Toxics Assessment.

Higher respiratory hazard indices are concentrated along the I-95 to I-91 highway traffic corridor from Stamford to Hartford (see Figure 27 below).

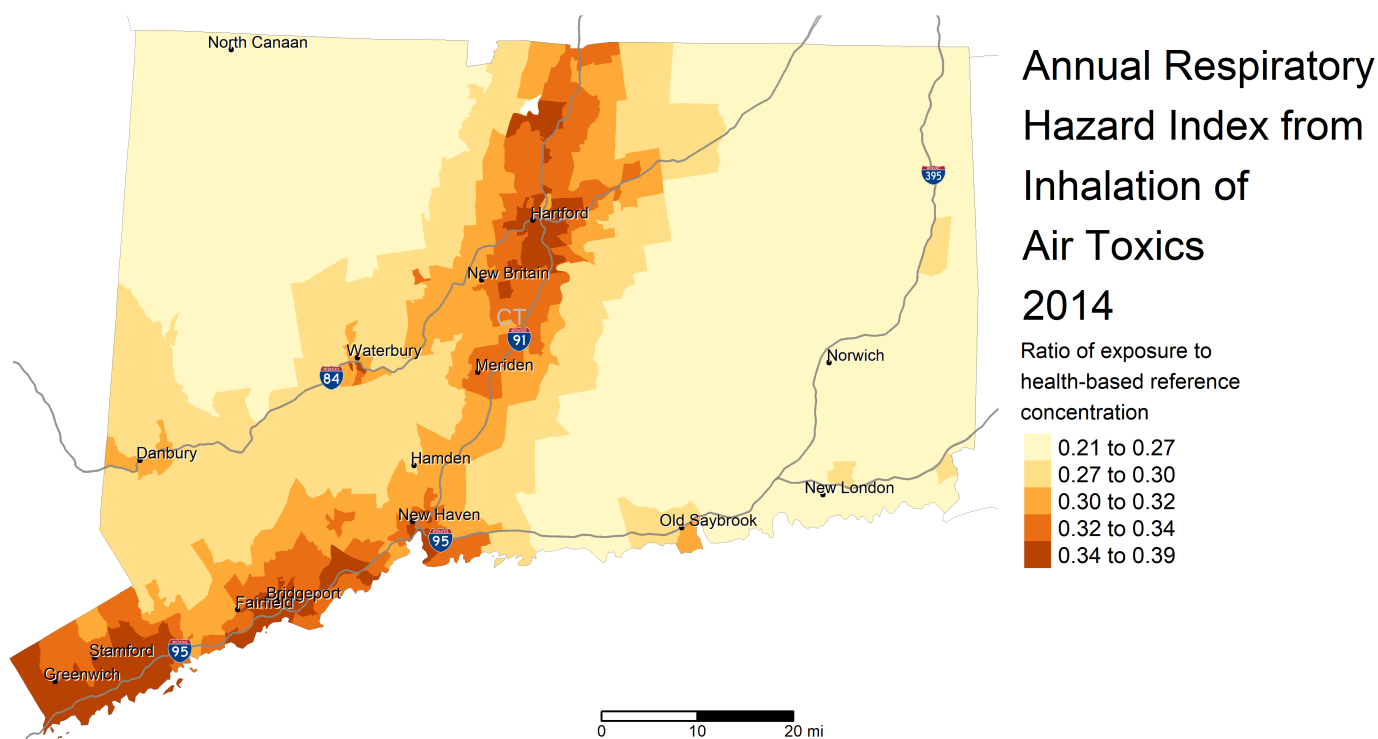


Figure 27: Map of 2014 respiratory hazard index from inhalation of air toxics across Connecticut at Census Block Group level.

There appear to be significant spatial clusters of high indices of respiratory hazard index from inhalation of air toxics along the I-95 to I-91 highway traffic corridor from Stamford to Hartford (see Figure 28 below).

²⁵National Air Toxics Assessment Overview. <https://www.epa.gov/national-air-toxics-assessment/nata-overview>

²⁶See "Characterizing Effects of Air Toxics" in Technical Support Document: EPA's 2014 National Air Toxics Assessment. <https://www.epa.gov/national-air-toxics-assessment/2014-nata-technical-support-document>

²⁷U.S. Environmental Protection Agency (EPA), 2019. EJSCREEN Technical Documentation. For more information see www.epa.gov/ejscreen

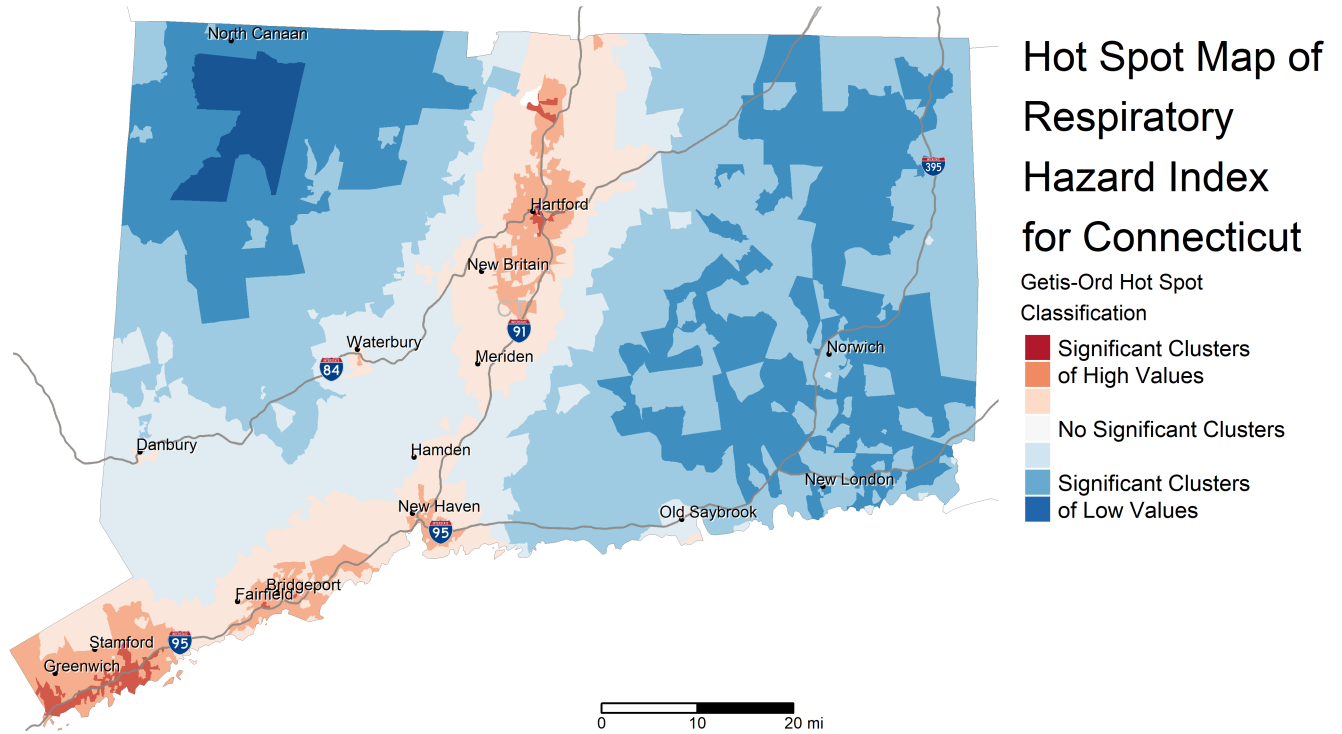


Figure 28: Hot spot map of 2014 respiratory hazard index from inhalation of air toxics at Census Block Group level.

Respiratory hazard indices from inhalation of air toxics vary across the state (see Table 7 and Figure 29 below).

Table 7: Respiratory Hazard Index from Inhalation of Air Toxics by Census block group (ratio of exposure concentration to health-based reference concentration)

Mean	Median	Min	Max
0.31	0.31	0.21	0.39

The Block Group with highest respiratory hazard index value in the state is found in Greenwich and the lowest is found in Norfolk. See Table 13 in Appendix B for concentrations by municipality.

Figure 29 is a boxplot of respiratory hazard indices by Block Group . The box represents index values ranging between the 25th and 75th percentiles. The line that divides the box into 2 parts represents the median respiratory hazard index value for all Block Groups, which in this case is 0.31. Half of the state’s Block Groups are below the median and half are above the median. Each dot represents an individual Block Group.

Respiratory Hazard Index from Inhalation of Air Toxics by Census block group, 2017

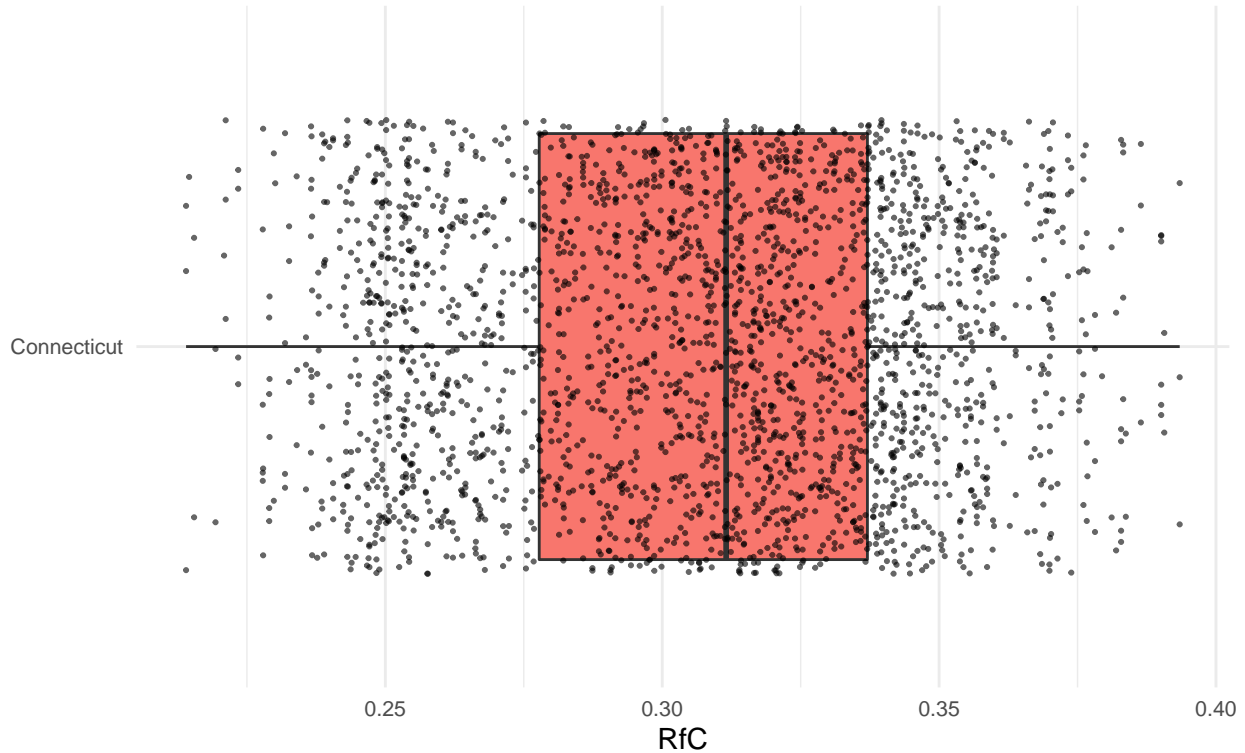


Figure 29: Boxplot of respiratory hazard index from inhalation of air toxics across Connecticut by state at Census Block Group level. 1 dot = 1 Block Group.

1.6.1 Respiratory Hazard Index from Inhalation of Air Toxics in Connecticut and Priority Populations

In addition to variations in the general geography of the respiratory hazard index, exposure to these risks also varies demographically. Figure 30 below shows population-weighted exposures for priority populations relative to average respiratory hazard index for the state. For example, limited English speaking households in Connecticut experience respiratory hazard indices that are 6.1% above the region as a whole. Similarly, People of Color are experience hazard index values almost 5% above the regional average. By contrast, persons over age 64 are, on average, exposed to respiratory hazard indices 1.5% below the regional average.

Population-Weighted Average Respiratory Hazard Index (relative to Connecticut average)

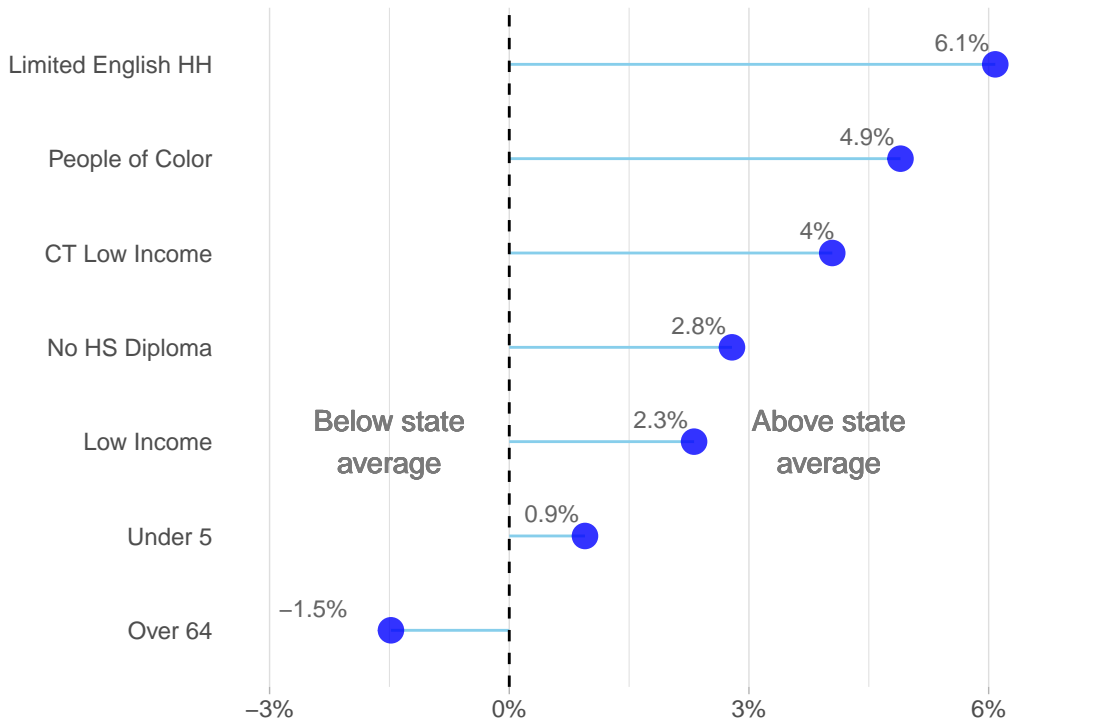


Figure 30: Population-weighted average respiratory hazard index from inhalation of air toxics (expressed as ratio of exposure concentration to health-based reference concentration) across Connecticut at Census Block Group level relative to the regional average.

There is a moderate to strong positive correlation between the proportions of People of Color and respiratory hazard index (see Figure 41 in Appendix B).

1.7 Traffic Proximity and Volume in Connecticut

Proximity to motor vehicle traffic is associated with greater exposure to toxic gases and particulate matter, as well as increased noise. Vehicle-related emissions include ultrafine particulates and other components of PM_{2.5}, lead and other metals, air toxics such as benzene, nitrogen oxides (NO_x), hydrocarbons and carbon monoxide (CO), as well as precursors that add to the formation of ground level ozone (O₃) and smog. Research has repeatedly shown that living near highly trafficked roads is related to increased risk of a variety of adverse health outcomes, including asthma, cardiovascular disease, hypertension, stroke, stress, and increased rates of mortality. EPA's 2005 National Air Toxics Assessment (NATA) estimated that mobile emissions accounted for about 30% of average cancer risk from Hazardous Air Pollutants.²⁸

EPA's EJSCREEN provides an indicator of traffic exposure measured as residential proximity to roads weighted by traffic volume. More specifically, EJSCREEN's Traffic Proximity and Volume indicator is a count of vehicles (average annual daily traffic) at major roads within 500 meters of residential areas (i.e., Census Blocks) divided by distance in kilometers (km).²⁹ For example, a residential area at 100 meters distance from a single highway with 33,000 AADT (average annual daily traffic) would result in a score of 33,000/100=330, which is approximately the median block group traffic proximity indicator value in New England. The Traffic Proximity and Volume indicator values are aggregated at the Census Block Group level.

Exposure to high annual daily traffic volume is concentrated along the I-95 to I-91 highway traffic corridor from Stamford to Hartford (see Figure 31 below).

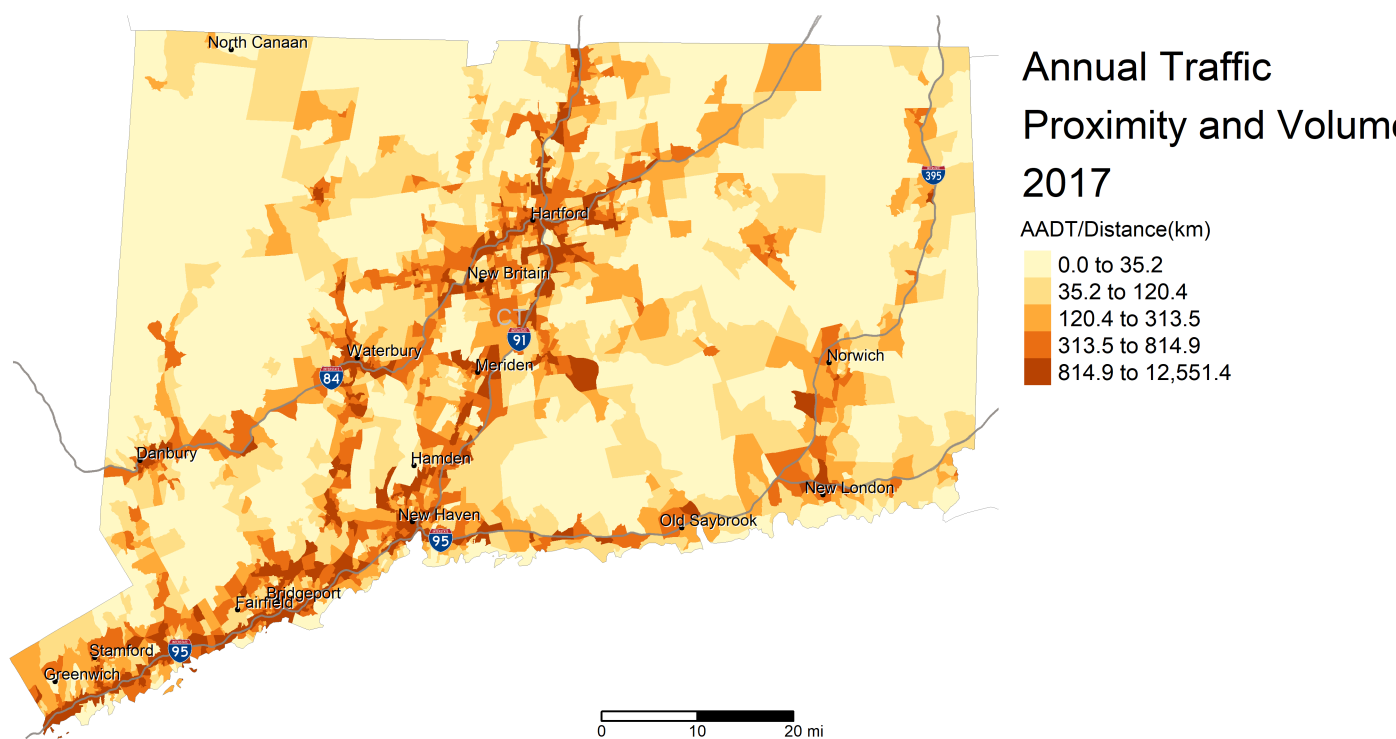


Figure 31: Map of 2017 traffic proximity and volume at major roads within 500 meters, divided by distance in kilometers (km) across Connecticut at Census Block Group level.

²⁸See "Details on Environmental Indicators: Traffic Proximity" in EJSCREEN Environmental Justice Mapping and Screening Tool: EJSCREEN Technical Documentation 2019. www.epa.gov/ejscreen

²⁹Measures of traffic proximity in EJSCREEN are based on average annual daily traffic (AADT) estimates in the Highway Performance Monitoring System (HPMS) dataset in the Department of Transportation (DOT) National Transportation Atlas Database (NTAD).

There appear to be significant spatial clusters of traffic proximity and volume in Fairfield, New Haven, and Hartford (see Figure 32 below).

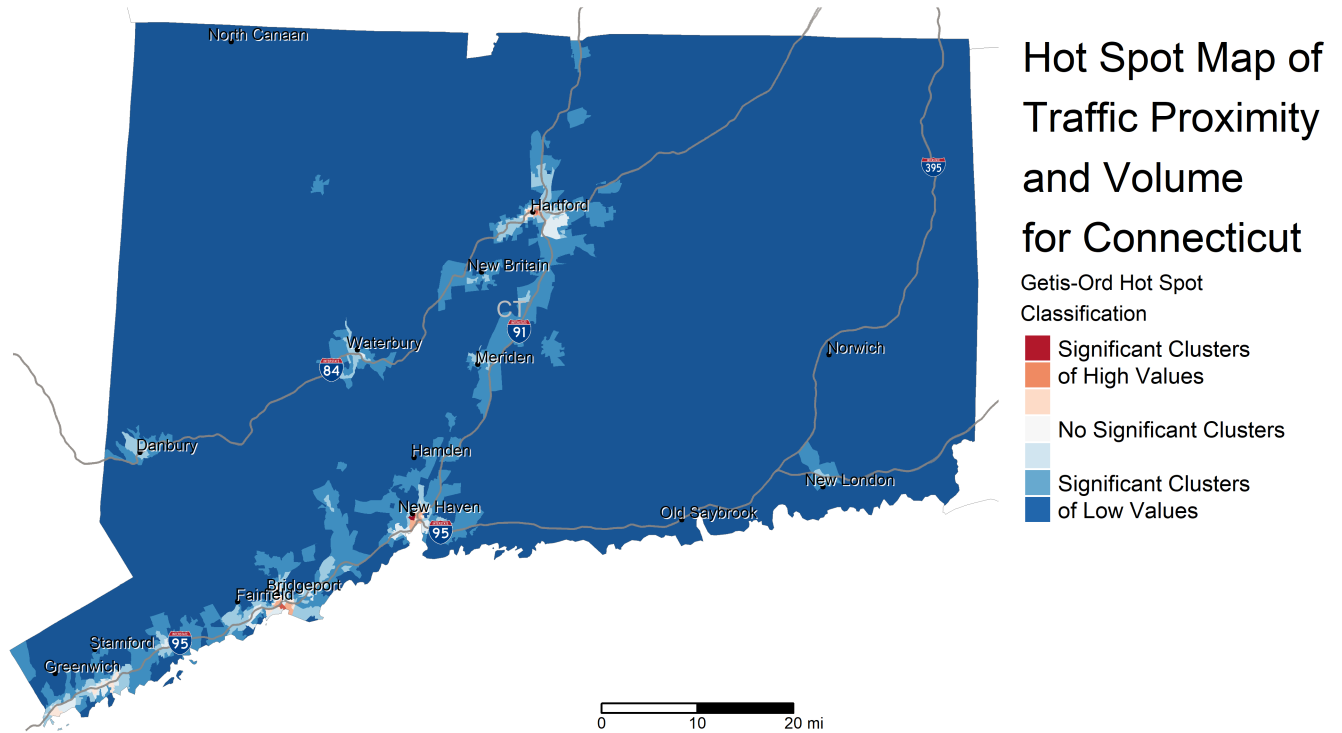


Figure 32: Hot spot map of 2017 traffic proximity and volume at Census Block Group level.

Traffic Proximity and Volume exposure vary across the state (see Table 8 and Figure 33 below).

Table 8: Annual traffic proximity and volume (AADT/Distance(km))

Mean	Median	Min	Max
651	201	0	12,551

The Block Group with highest Traffic Proximity and Volume value in the state is found in New Haven and the lowest is found in Redding. See Table 13 in Appendix B for values by municipality.

Figure 33 is a boxplot of Traffic Proximity and Volume values by Block Group . The box represents values ranging between the 25th and 75th percentiles. The line that divides the box into 2 parts represents the median Traffic Proximity and Volume value for all Block Groups, which in this case is 201. Half of the state's Block Groups are below the median and half are above the median. Each dot represents an individual Block Group. The large black dots represent outliers, or unusually high values.

Traffic Proximity and Volume by Census block group, 2017

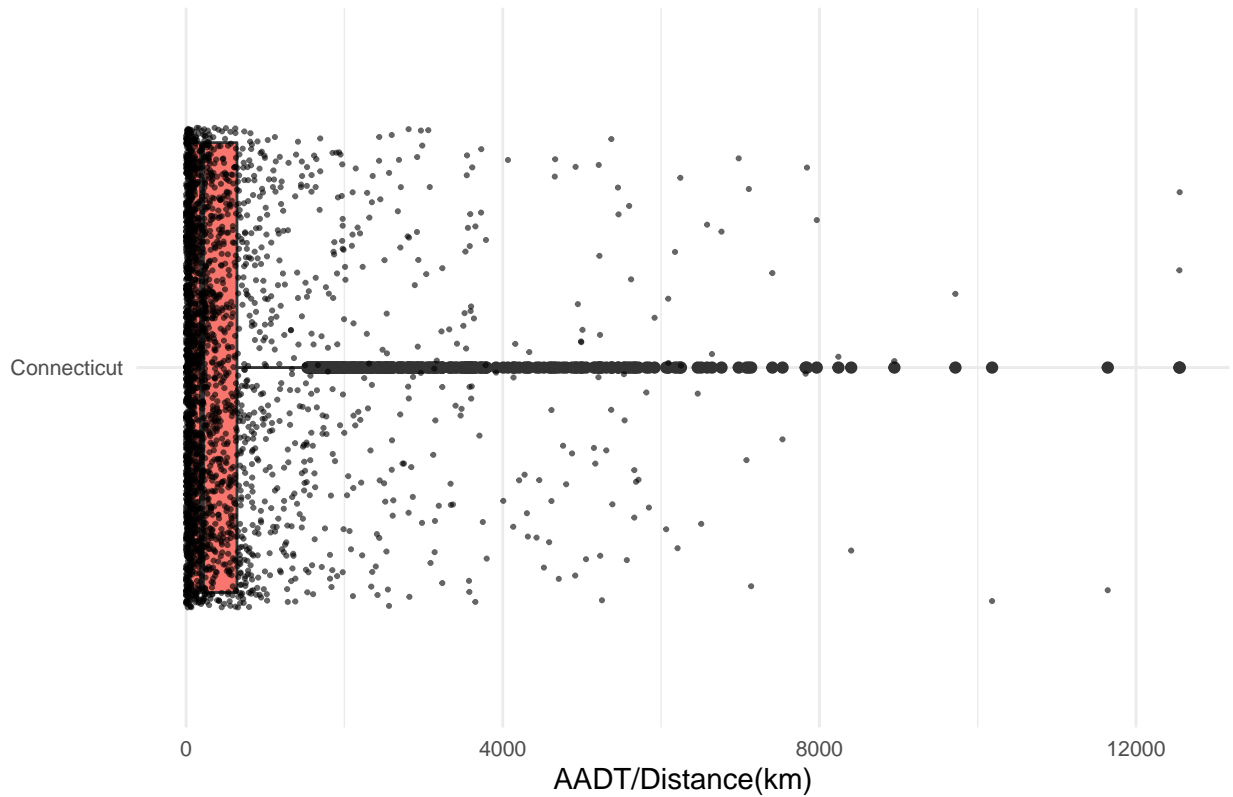


Figure 33: Boxplot of 2017 traffic proximity and volume at major roads within 500 meters, divided by distance in kilometers (km)) across Connecticut at Census Block Group level.

1.7.1 Traffic Proximity and Volume Exposure in Connecticut and Priority Populations

In addition to variations in the general geography of the Traffic Proximity and Volume exposure, this exposure also varies demographically. Figure 34 below shows population-weighted exposures for priority populations relative to average Traffic Proximity and Volume for the state. For example, low income persons (following Connecticut's definition) are exposed to Traffic Proximity and Volume almost 70% above the state as a whole. Similarly, low income persons, as defined by the state's environmental justice policy, are exposed to Traffic Proximity and Volume almost 64% above the state average. By contrast, persons over age 64 are, on average, are exposed to Traffic Proximity and Volume of more than 24% below the regional average.

Population-Weighted Average Traffic Proximity and Volume (relative to Connecticut average)

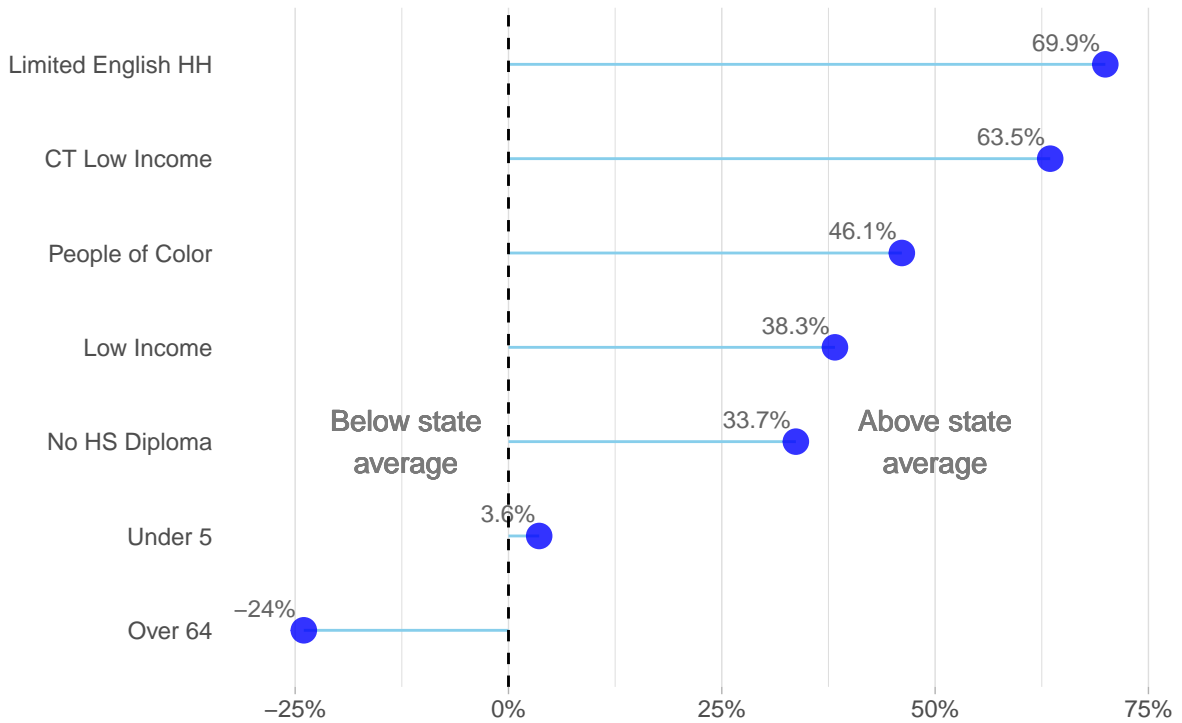


Figure 34: Population-weighted average Traffic Proximity and Volume (calculated as a count of vehicles (average annual daily traffic) at major roads within 500 meters, divided by distance in kilometers (km)) across Connecticut at Census Block Group level relative to the state average.

There is a moderate positive correlation between the proportions of People of Color, low income persons, limited English households, adults with less than a high school education, and traffic proximity and volume (see Figure 42 in Appendix B).

Appendix A: Data and Methodology

The analyses presented here are based on data from three sources:

- U.S. EPA’s EJSCREEN
 - PM_{2.5}
 - Ozone (O₃)
 - Diesel Particulate Matter
 - Air Toxics Cancer Risk
 - Respiratory Hazard Index from Air Toxics
 - Traffic Proximity and Volume
- Database of Road Transportation Emissions (DARTE)
 - On-road Carbon Dioxide (CO₂) Emissions
- American Community Survey 5-year Estimates
 - Population demographics

EPA’s EJSCREEN

The U.S. EPA’s EJSCREEN is an online environmental justice mapping and screening tool that provides a “nationally consistent dataset and approach for combining environmental and demographic indicators.” EJSCREEN provides data on 11 environmental indicators, ranging across air, land, and water. The six indicators analyzed here were chosen based on their relationship to transportation sources, especially motor vehicles. Data for each indicator is available by Census Block Group across the U.S. The 2015 (earliest available) and 2019 (latest available) data sets were downloaded from <https://www.epa.gov/ejscreen/download-ejscreen-data> as CSV files and processed in R.

All data was analyzed or aggregated geographically by Census Tract and Block Group. A Census Tract is a small, relatively permanent statistical subdivision of a county that contains between 1,200 and 8,000 people. The entire area of a county is covered by Census Tracts, just as the entire area of a state is covered by counties or county equivalents. Census Tracts range in areal size depending on the population density; smaller areas in denser areas and larger areas in less densely populated areas. Census Block Groups are subdivisions of Census Tracts that contain between 600 and 3,000 people. Like Tracts, Block Groups range in areal size depending on the population density of the area. Block Groups are the smallest geographic unit at which detailed demographic and household data from the American Community Survey is made available by the U.S. Census Bureau.

Below is a summary of the measurement unit and source of each environmental indicator. For more detail on these data sources, see the EJSCREEN Environmental Justice Mapping and Screening Tool: EJSCREEN Technical Documentation 2019. www.epa.gov/ejscreen.

PM_{2.5}

PM_{2.5} refers to particulate matter less than 2.5 microns (millionths of a meter) in diameter. PM_{2.5} ambient concentrations are measured as mass in micrograms (millionths of a gram) per cubic meter of air ($\mu\text{g}/\text{m}^3$). Ambient concentrations are provided by Census Block Group across the U.S. These concentrations are estimated from a combination of monitoring data and air quality modeling. Ambient PM_{2.5} concentration is estimated by EPA’s Office of Research and Development using a Bayesian space–time downscaling fusion model approach. EPA’s Office of Air and Radiation originally estimated these concentrations at Census Tract level and then assigned the same values to all Block Groups within their respective Tracts.

PM_{2.5} data from EJSCREEN’s 2019 data set is for 2016. PM_{2.5} data from EJSCREEN’s 2015 data set is for 2011.

Ozone (O₃)

Ozone (O₃) refers to ground level (i.e. Tropospheric) ozone formed as a result of chemical interactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. Ambient

concentrations of ozone are measured as a summer seasonal average (May to September) of daily maximum 8-hour concentration in air in parts per billion (ppb). Ambient concentrations are provided by Census Block Group across the U.S. These concentrations are estimated from a combination of monitoring data and air quality modeling. Ambient ozone concentration is estimated by EPA's Office of Research and Development using a Bayesian space-time downscaling fusion model approach. EPA's Office of Air and Radiation originally estimated these concentrations at Census Tract level and then assigned the same values to all Block Groups within their respective Tracts.

Ozone data from EJSCREEN's 2019 data set is for 2016. Ozone data from EJSCREEN's 2015 data set is for 2011.

Diesel Particulate Matter

Diesel Particulate Matter (DPM) refers to particulate matter emitted in diesel exhaust and is typically used as a surrogate measure of diesel exhaust more generally. DPM ambient concentrations are measured as mass in micrograms (millionths of a gram) per cubic meter of air ($\mu\text{g}/\text{m}^3$). Ambient concentrations are provided by Census Block Group across the U.S. These concentrations are estimated from EPA's National Air Toxics Assessment (NATA) program. NATA uses emissions estimates from the National Emissions Inventory (NEI), which is updated every three years. The NEI includes all of the Toxics Release Inventory (TRI) reporting facilities that release hazardous air pollutants, along with many other sources of air pollutants, such as motor vehicles. NATA estimates are at Tract resolution. Each Block Group was assigned the DPM score of the tract containing it.

The 2019 version of EJSCREEN uses 2014 NATA data, which is based on NEI emissions estimates for 2014.

Air Toxics Cancer Risk

Air Toxics Cancer Risk refers to lifetime risk (i.e. over 70 years) of developing cancer as a result of breathing ambient levels of toxic or Hazardous Air Pollutants (HAPs). This risk is reported as the risk-in-1 million of developing cancer. EJSCREEN uses the most recent data from EPA's National-Scale Air Toxics Assessment (NATA). NATA estimates cancer risk from the health implications of 138 air pollutants classified as HAPs. NATA uses emissions estimates from the National Emissions Inventory (NEI), which is updated every three years. The NEI includes all of the Toxics Release Inventory (TRI) reporting facilities that release hazardous air pollutants, along with many other sources of air pollutants, such as motor vehicles. NATA estimates are at Tract resolution. Each Block Group was assigned the hazard score of the tract containing it.

The 2019 version of EJSCREEN uses 2014 NATA data, which is based on NEI emissions estimates for 2014.

Respiratory Hazard Index

Respiratory Hazard Index refers to noncancer effects caused by a lifetime of exposure to air toxics listed as Hazardous Air Pollutants (HAPs). EPA's National Air Toxics Assessment (NATA) program calculates a hazard quotient, which is the ratio of ambient air concentration to a chemical's health-based reference concentration (RfC). No adverse health effects are expected from exposure if the hazard quotient is less than one. This hazard quotient represents the cumulative impacts of all the relevant air toxics for which respiratory effects were the key health effect. NATA uses emissions estimates from the National Emissions Inventory (NEI), which is updated every three years. The NEI includes all of the Toxics Release Inventory (TRI) reporting facilities that release hazardous air pollutants, along with many other sources of air pollutants, such as motor vehicles. NATA estimates are at Tract resolution. Each Block Group was assigned the hazard score of the tract containing it.

The 2019 version of EJSCREEN uses 2014 NATA data, which is based on NEI emissions estimates for 2014.

Traffic Proximity and Volume

Traffic Proximity and Volume refers to an index of exposure to road traffic. This index is calculated as a count of vehicles (average annual daily traffic) at major roads within 500 meters of residential areas (i.e.,

Census Block centroids) divided by distance in kilometers (km). Traffic volume is based on average annual daily traffic (AADT) estimates in the Highway Performance Monitoring System (HPMS) dataset in the Department of Transportation (DOT) National Transportation Atlas Database (NTAD). Each Block Group was assigned a Traffic Proximity and Volume score based on a population-weighted average of the scores for the Census Blocks within the respective Block Group.

The 2019 version of EJSCREEN uses 2017 HPMS data.

Database of Road Transportation Emissions (DARTE)

The Database of Road Transportation Emissions (DARTE) provides a 38-year, 1-km resolution inventory of annual on-road CO₂ emissions for the conterminous United States based on roadway-level vehicle traffic data and state-specific emissions factors for multiple vehicle types on urban and rural roads as compiled in the Database of Road Transportation Emissions (DARTE). For more details about DARTE, see the User Guide for DARTE Annual On-road CO₂ Emissions on a 1-km Grid, Conterminous USA, V2, 1980-2017 at https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1735.

On-road Carbon Dioxide (CO₂) Emissions

DARTE CO₂ emissions data from the on-road transportation sector are provided annually for 1980-2017 as a continuous surface at a spatial resolution of 1km in the form of GeoTIFF files for each year. The same data is also provided aggregated to U.S. 2010 Census Block Group polygons. Units of data are total emissions in kilograms of CO₂ per year for each Block Group.

For the purposes of this analysis, DARTE Block Group data for the years 1990 to 2017 was downloaded as a geodatabase and processed in R.

American Community Survey 5-year Estimates

The American Community Survey (ACS) is an ongoing survey by the U.S. Census Bureau that provides information on a yearly basis about the U.S. and its people. The ACS provides detailed information on economic, housing, and demographic characteristics about the population that are not captured by the decennial Census.

The ACS provides greater demographic detail and temporal resolution than the decennial Census, but its geographic resolution is more limited. While the decennial Census is based on an enumeration (i.e., a total count) of everyone in the U.S. once every decade, the ACS is based on a statistical sample of approximately 3.5 million addresses across the country each year. As a result of this sampling approach, the ACS estimates must be pooled, or combined, across multiple years in order to provide reliable estimates for smaller areas (i.e. areas with less than 20,000 people), such as at the Tract or Block Group levels. While it is possible to know the number of low income households across the U.S. annually, one may only know this about a Tract or Block Group based on 5-year estimates. Since 2010, the ACS has published 5-year data (beginning with 2005–2009 estimates) for all geographic areas down to the census Tract and Block Group levels. For more detail on the ACS, see Understanding and Using American Community Survey Data: What All Data Users Need to Know at <https://www.census.gov/programs-surveys/acs/guidance/handbooks/general.html>.

For the purposes of this analysis ACS 5-year estimates for the period 2014 - 2018 for Census Tracts and Block Groups in New England, as well as their associated TIGER/Line spatial files, were downloaded from the Census Bureau via API using the tigris package in R. Demographic variables consistent with those used by the EPA in EJSCREEN were chosen, as well as environmental justice population thresholds used by states where available. Table 9 below lists the demographic variables that were downloaded directly or computed from ACS variables:

Table 9: Demographic Variables

Variable	Description	ACS Table ID	Geography
Total Population	Total population	B03002: Hispanic or Latino Origin by Race	Block Group
People of Color	Persons of Hispanic or Latino origin or persons who are not White	B03002: Hispanic or Latino Origin by Race	Block Group
Low Income	People in households where the household income is less than or equal to twice the federal poverty level	C17002: Ratio of Income to Poverty Level	Block Group
Limited English Household	People in households where all adults speak English less than "very well"	C16002: Household Language by Household Limited English Speaking Status	Block Group
Less than High School Education	Adults 25 years+ with less than a high school education	B15002: Sex by Educational Attainment	Block Group
Under 5	Persons under 5 years of age	B01001: Sex by Age	Block Group
Over 64	Persons over 64 years of age	B01001: Sex by Age	Block Group
CT Income	Connecticut Low Income threshold: 30% or more people in households where the household income is less than or equal to twice the federal poverty level	B01001: Sex by Age	Block Group

Population-weighted averages

Wherever feasible, population exposure to pollutants or other risks is reported as a population-weighted average. A population weighted-average is equivalent to a weighted mean in which the raw values for which a mean (or average) is calculated are multiplied by a weight factor. For example, we are interested in knowing whether People of Color are exposed to higher average PM_{2.5} concentrations than the general or Total Population. Consider the table below.

Table 10: Block Group Populations and PM_{2.5}

BG	PM25	People of Color	Non-POC	TotalPop
BG1	2.5	5	20	25

Table 10: Block Group Populations and PM2.5 (*continued*)

BG	PM25	People of Color	Non-POC	TotalPop
BG2	6.2	10	12	22
BG3	10.0	20	5	25
BG4	5.0	10	10	20

Population numbers of People of Color, as well as the total population, and PM_{2.5} concentrations, are each reported by Block Group. Since each Block Group is associated with one PM_{2.5} concentration value, we might assume (incorrectly) that everyone is equally exposed to the average PM_{2.5} values of all Block Groups (5.92). However, not all Block Groups have the same number of people or categories, which means that each PM_{2.5} concentration value is associated with different categories and numbers of people. Do more People of Color occupy Block Groups with higher concentrations than the simple average would indicate?

To calculate the population-weighted average PM_{2.5} exposure for People of Color, the number of People of Color in each Block Group is used as a ‘weight’. The PM_{2.5} concentrations of each Block Group is multiplied by its respective number of People of Color. See the table below. The light gray column on the right is the product of PM_{2.5} values and numbers of People of Color.

Table 11: Block Group Populations and PM2.5

BG	PM25	People of Color	Non-POC	TotalPop	PM25xPOC
BG1	2.5	5	20	25	12.5
BG2	6.2	10	12	22	62.0
BG3	10.0	20	5	25	200.0
BG4	5.0	10	10	20	50.0
Total	23.7	45	47	92	324.5

The total or sum of the products (i.e., People of Color x PM_{2.5} concentrations) is then divided by the sum of the weights (i.e., total People of Color), so that $324.5/45 = 7.21$. The result is a weighted average PM_{2.5} concentration that is influenced by the number of People of Color.

This process is repeated for the Total Population so that the two population-weighted average PM_{2.5} concentrations can be compared. Below is the calculation of population-weighted calculation for the total population.

Table 12: Block Group Populations and PM2.5

BG	PM25	People of Color	Non-POC	TotalPop	PM25xTotalPop
BG1	2.5	5	20	25	62.5
BG2	6.2	10	12	22	136.4
BG3	10.0	20	5	25	250.0
BG4	5.0	10	10	20	100.0
Total	23.7	45	47	92	548.9

For the TotalPop, the population-weighted average of PM_{2.5} is $548.9/92 = 5.97$. Thus we can see that People of Color experience a higher population-weighted average PM_{2.5} concentration than the general or total population.

Appendix B: Supplementary Figures

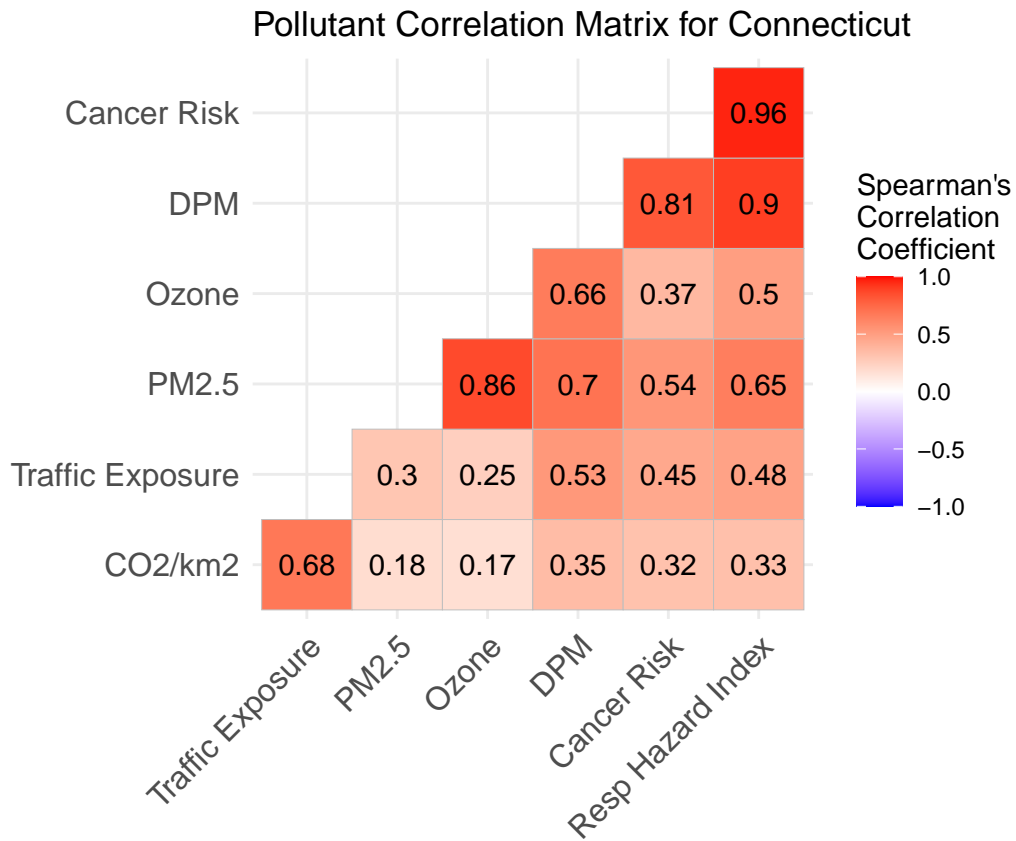


Figure 35: Spearman's correlation matrix of pollutants by Census Block Group.

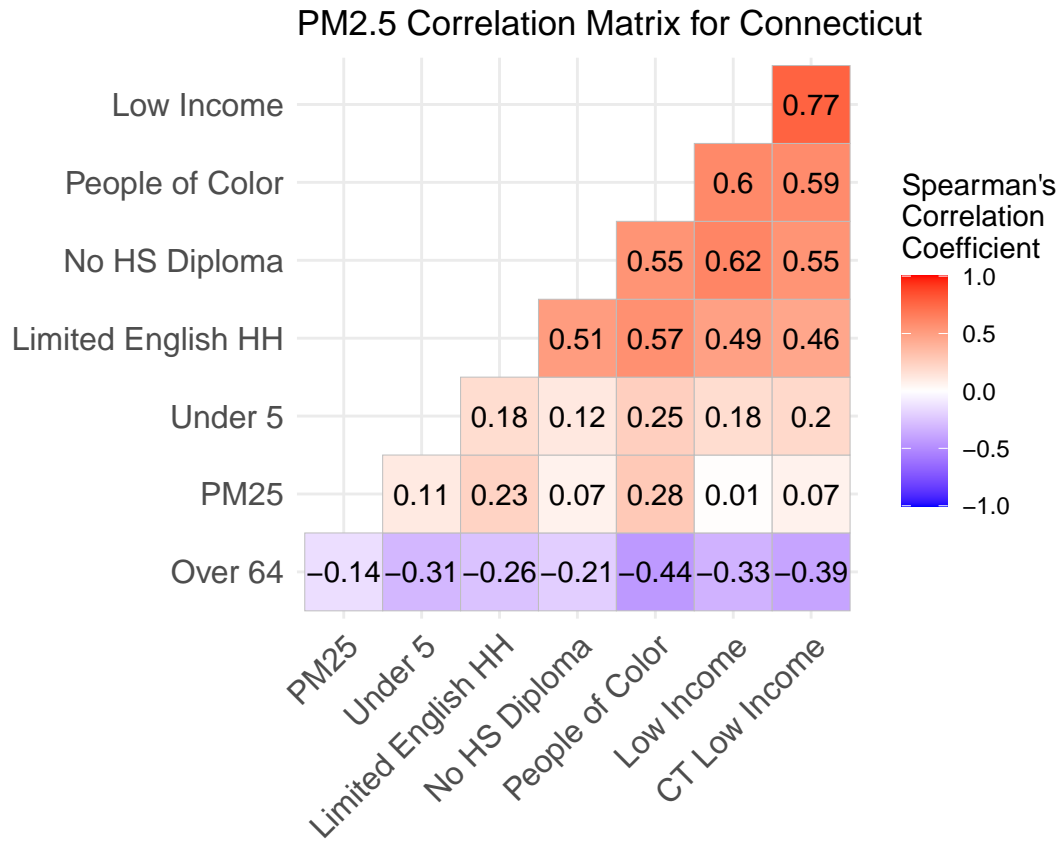


Figure 36: Spearman's correlation matrix of annual PM2.5 concentrations and the proportions of priority populations by Census Block Group.

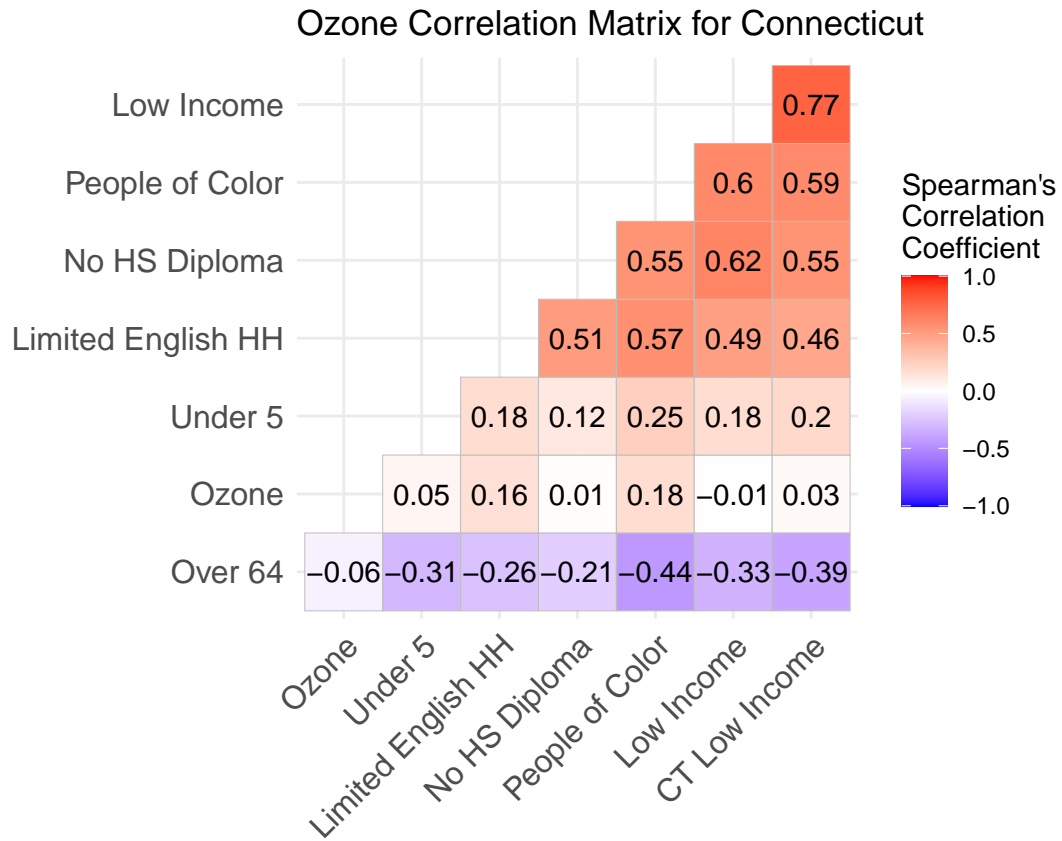


Figure 37: Spearman’s correlation matrix of summer Ozone concentrations and the proportions of priority populations by Census Block Group.

Carbon Dioxide (CO₂) Emissions by Census block group, 2017

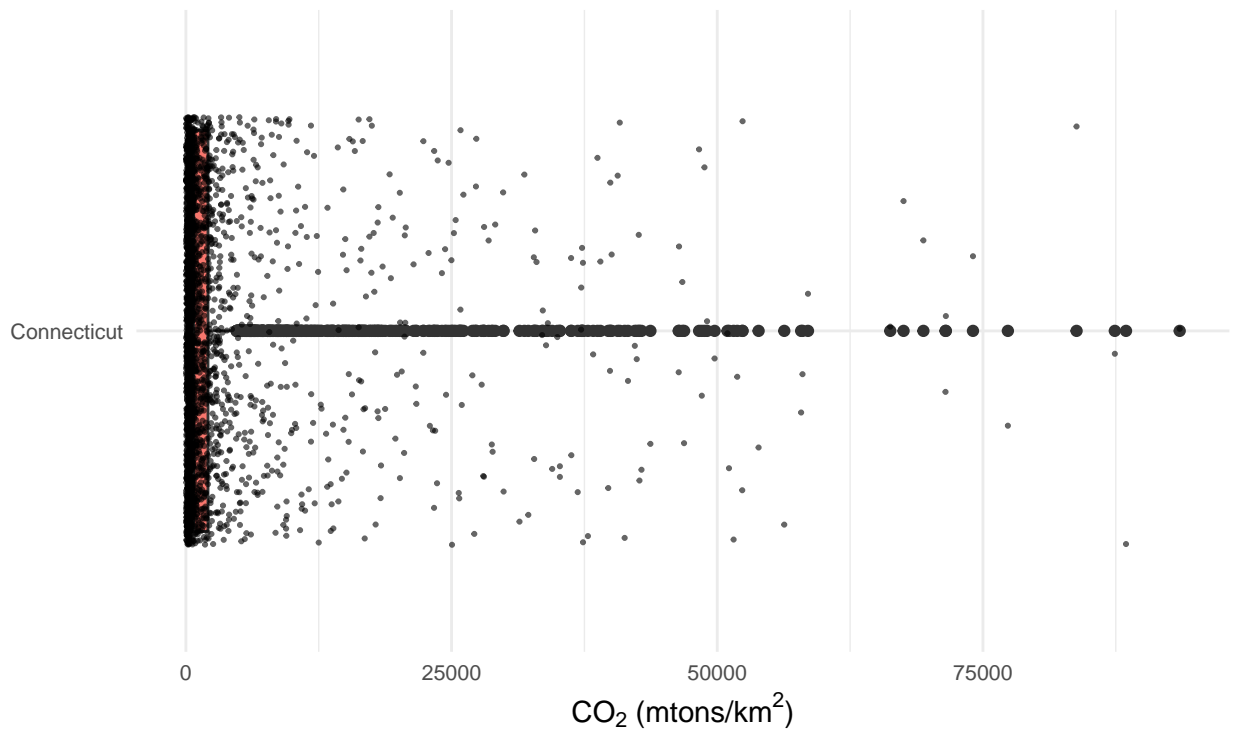


Figure 38: Boxplot of 7 Carbon Dioxide on-road emissions in metric tons per square kilometer by state at Census Block Group level. 1 dot = 1 Block Group.

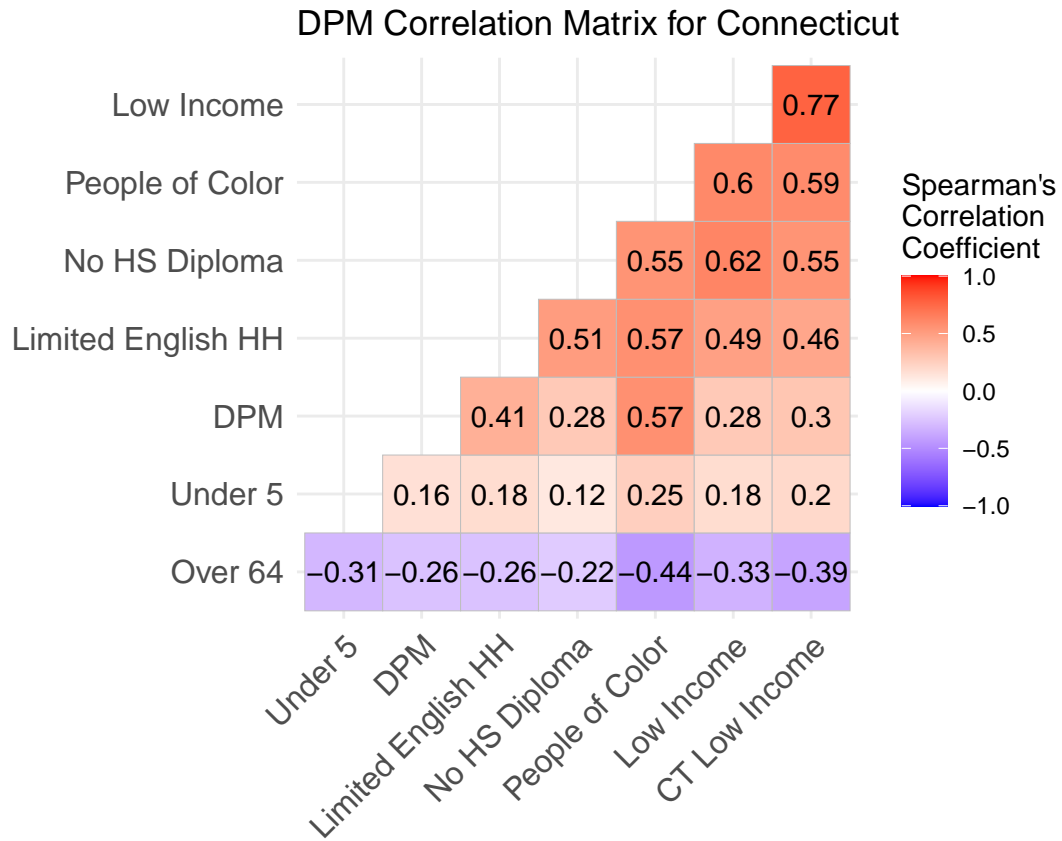


Figure 39: Spearman's correlation matrix of annual average Diesel Particulate Matter concentrations and the proportions of priority populations by Census Block Group.

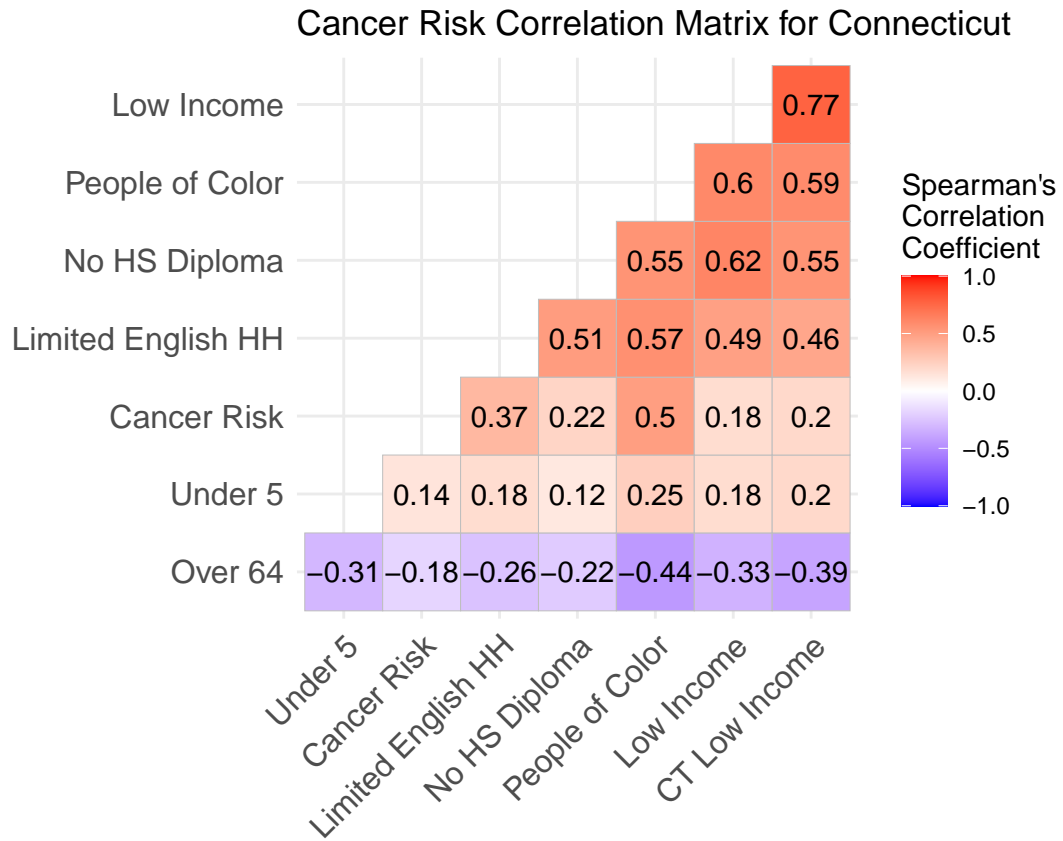


Figure 40: Spearman's correlation matrix of lifetime cancer risk and the proportions of priority populations by Census Block Group.

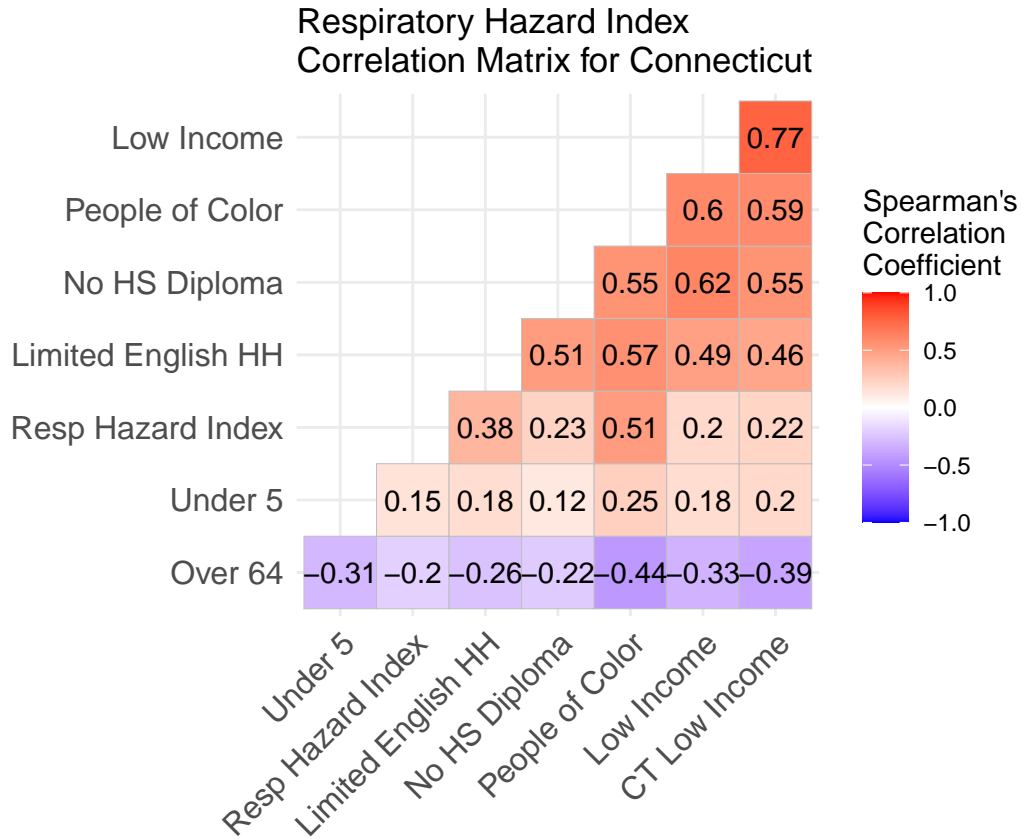


Figure 41: Spearman's correlation matrix of respiratory hazard index and the proportions of priority populations by Census Block Group.

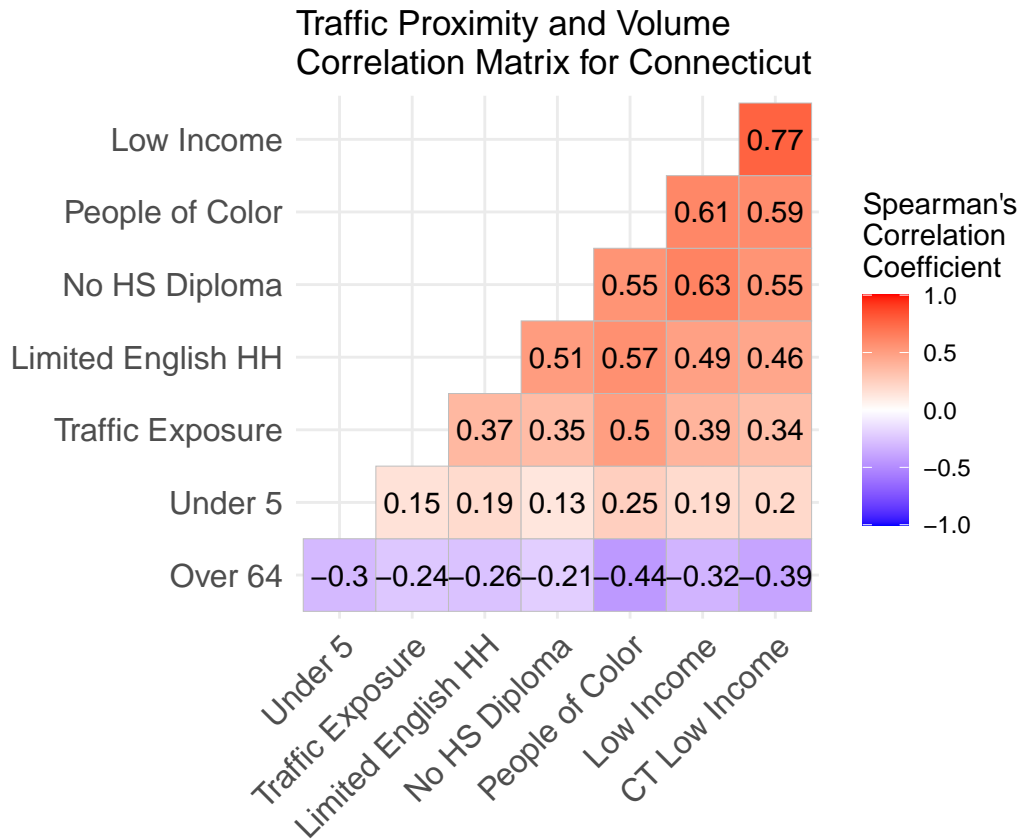


Figure 42: Spearman's correlation matrix of traffic proximity and volume and the proportions of priority populations by Census Block Group.

Table 13: Average Pollutant and Transportation Burden Values by Municipality in Connecticut

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Andover	6.44	44.68	0.177	3,023.8	21.6	0.252	54.2
Ansonia	7.76	47.14	0.333	1,832.3	25.1	0.304	398.1
Ashford	6.00	43.42	0.163	2,258.0	20.7	0.239	11.3
Avon	6.78	45.12	0.192	3,735.8	23.6	0.277	69.7
Barkhamsted	6.16	44.43	0.145	4,305.4	20.3	0.232	14.3
Beacon Falls	7.61	46.49	0.268	6,658.2	23.9	0.286	214.9
Berlin	7.24	45.93	0.306	10,467.0	27.0	0.325	217.0
Bethany	7.58	46.54	0.250	2,934.8	24.1	0.287	37.8
Bethel	7.82	46.80	0.295	3,798.2	24.0	0.293	135.2
Bethlehem	6.89	45.57	0.163	1,477.7	21.4	0.248	0.2
Bloomfield	6.76	44.80	0.258	6,431.9	25.8	0.314	122.7
Bolton	6.60	44.73	0.204	11,082.8	23.9	0.279	88.0
Bozrah	6.06	44.65	0.188	4,032.0	21.7	0.252	156.5
Branford	7.20	47.74	0.365	17,436.6	25.5	0.318	386.3
Bridgeport	8.10	48.64	0.509	5,691.3	26.9	0.347	1,706.4
Bridgewater	7.34	45.79	0.219	1,722.0	22.3	0.264	1.9
Bristol	7.03	45.60	0.234	1,498.8	23.7	0.284	236.0
Brookfield	7.55	46.10	0.258	6,815.0	24.0	0.287	118.0
Brooklyn	5.93	43.14	0.178	2,371.0	21.6	0.251	55.5
Burlington	6.73	45.29	0.178	1,909.0	22.4	0.259	16.0
Canaan	5.90	44.16	0.123	5,159.9	18.9	0.214	0.3
Canterbury	5.89	43.50	0.169	2,378.5	20.9	0.242	0.8
Canton	6.46	44.77	0.160	3,804.9	21.2	0.247	57.4
Chaplin	6.02	43.57	0.148	1,736.9	21.3	0.245	52.5
Cheshire	7.42	46.21	0.261	14,442.7	24.2	0.288	234.8
Chester	6.55	46.59	0.198	3,778.2	21.5	0.251	57.8
Clinton	6.63	47.71	0.234	13,311.8	21.2	0.253	207.5
Colchester	6.33	45.23	0.185	5,190.8	21.5	0.250	78.9
Colebrook	5.91	44.06	0.121	5,279.4	19.0	0.215	6.7
Columbia	6.29	44.57	0.180	1,950.5	21.4	0.249	43.5
Cornwall	6.02	44.84	0.121	4,141.9	19.2	0.219	0.0
Coventry	6.36	44.36	0.178	1,946.3	22.1	0.256	26.2
Cromwell	7.10	45.96	0.337	23,963.6	27.0	0.327	555.5
Danbury	7.73	46.32	0.328	16,500.9	24.2	0.301	327.7
Darien	8.08	48.91	0.501	10,190.3	28.2	0.368	836.8
Deep River	6.51	46.92	0.210	3,396.1	21.7	0.253	59.4
Derby	7.80	47.31	0.350	3,079.1	26.2	0.316	1,002.6
Durham	7.06	46.55	0.231	2,314.0	23.9	0.278	56.4
East Granby	6.52	44.23	0.192	3,783.7	24.1	0.293	26.0
East Haddam	6.39	45.85	0.177	3,814.0	20.9	0.243	1.0
East Hampton	6.69	45.80	0.190	2,015.5	22.4	0.261	46.6
East Hartford	6.95	45.12	0.415	17,660.0	27.8	0.348	1,344.6

Table 13: Average Pollutant and Transportation Burden Values by Municipality in Connecticut (*continued*)

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
East Haven	7.34	47.49	0.415	3,600.1	27.5	0.325	378.1
East Lyme	6.15	46.41	0.210	30,735.6	21.1	0.249	180.8
East Windsor	6.71	44.37	0.251	5,382.0	26.6	0.319	227.5
Eastford	5.95	43.16	0.133	5,652.8	20.0	0.232	0.0
Easton	8.01	47.82	0.257	3,246.6	24.4	0.294	19.0
Ellington	6.52	44.14	0.207	2,713.2	24.7	0.290	38.6
Enfield	6.62	44.02	0.271	8,517.8	26.7	0.319	300.7
Essex	6.43	47.12	0.217	3,982.1	21.5	0.249	100.2
Fairfield	8.08	48.65	0.395	6,780.0	25.7	0.327	759.2
Farmington	6.98	45.41	0.249	22,605.5	25.1	0.296	378.0
Franklin	6.02	44.22	0.187	2,449.3	21.2	0.245	42.2
Glastonbury	6.84	45.35	0.243	5,009.3	24.2	0.287	238.0
Goshen	6.03	44.99	0.130	3,140.7	19.0	0.215	0.0
Granby	6.28	44.12	0.152	2,630.6	21.2	0.247	26.5
Greenwich	8.16	48.23	0.471	8,113.9	27.7	0.359	617.3
Griswold	5.72	43.64	0.180	10,135.6	21.0	0.243	45.4
Groton	5.86	45.78	0.298	7,961.6	21.3	0.257	162.7
Guilford	7.01	47.37	0.246	10,746.7	22.7	0.268	85.5
Haddam	6.73	46.35	0.203	4,489.8	22.2	0.260	78.2
Hamden	7.51	46.71	0.310	1,535.5	25.4	0.306	304.7
Hampton	5.95	43.38	0.141	4,938.3	20.4	0.234	16.3
Hartford	7.00	45.18	0.462	19,836.8	28.0	0.348	1,123.7
Hartland	6.02	44.01	0.125	6,371.9	19.5	0.221	0.0
Harwinton	6.61	45.33	0.179	6,429.2	21.7	0.251	33.5
Hebron	6.44	45.01	0.178	2,862.1	21.3	0.247	21.3
Kent	6.50	44.57	0.154	4,032.2	20.3	0.239	0.1
Killingly	6.01	42.84	0.195	13,730.1	22.0	0.257	98.3
Killingworth	6.76	46.93	0.196	1,778.8	21.5	0.254	2.5
Lebanon	6.16	44.54	0.179	2,546.5	21.2	0.247	19.0
Ledyard	5.84	44.81	0.205	2,347.0	21.3	0.248	32.0
Lisbon	5.85	43.84	0.194	5,829.9	21.2	0.248	45.1
Litchfield	6.46	45.36	0.162	8,213.8	20.4	0.236	62.7
Lyme	6.30	46.38	0.178	1,546.4	20.8	0.243	0.3
Madison	6.85	47.30	0.228	13,844.7	21.8	0.260	138.4
Manchester	6.79	44.91	0.284	42,994.4	25.4	0.303	611.3
Mansfield	6.15	43.95	0.186	3,110.2	22.1	0.257	81.5
Marlborough	6.59	45.35	0.195	5,412.8	22.1	0.258	159.8
Meriden	7.31	46.20	0.342	9,747.9	26.3	0.321	878.9
Middlebury	7.40	46.07	0.248	29,269.7	23.1	0.277	390.0
Middlefield	7.20	46.32	0.304	3,073.4	26.7	0.320	58.8
Middletown	7.06	46.24	0.291	4,580.0	25.4	0.304	439.1
Milford	7.81	48.36	0.461	14,412.0	26.2	0.339	852.6
Monroe	7.88	47.25	0.264	3,034.8	23.9	0.288	45.7
Montville	6.03	45.12	0.200	11,655.4	20.9	0.245	199.5

Table 13: Average Pollutant and Transportation Burden Values by Municipality in Connecticut (*continued*)

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Morris	6.66	45.45	0.152	2,517.1	21.0	0.243	1.4
Naugatuck	7.53	46.25	0.286	2,176.9	23.8	0.285	383.5
New Britain	7.15	45.66	0.351	4,521.0	26.6	0.321	852.2
New Canaan	8.05	48.09	0.345	5,265.3	26.6	0.335	201.4
New Fairfield	7.46	45.54	0.213	2,748.6	22.9	0.273	14.8
New Hartford	6.38	44.92	0.162	2,073.9	21.6	0.247	57.8
New Haven	7.49	47.25	0.450	9,730.0	27.5	0.329	1,658.0
New London	5.97	46.27	0.428	4,335.0	20.6	0.253	966.5
New Milford	6.99	45.16	0.206	2,038.3	22.1	0.264	85.4
Newington	7.13	45.62	0.343	3,507.1	27.9	0.339	264.6
Newtown	7.74	46.75	0.265	24,902.9	23.7	0.284	171.8
Norfolk	5.90	44.16	0.123	3,491.4	18.9	0.214	59.5
North Branford	7.22	47.04	0.271	4,916.1	24.9	0.294	100.3
North Canaan	5.90	43.73	0.134	1,743.2	19.5	0.221	61.4
North Haven	7.39	46.83	0.359	16,415.3	27.6	0.313	537.8
North Stonington	5.62	43.93	0.190	5,339.4	20.0	0.233	38.2
Norwalk	8.05	48.81	0.468	5,124.6	28.6	0.346	797.2
Norwich	5.94	44.32	0.233	26,407.7	21.8	0.257	279.9
Old Lyme	6.26	47.24	0.245	11,353.1	21.8	0.255	98.8
Old Saybrook	6.40	47.82	0.295	44,293.8	24.5	0.297	313.7
Orange	7.74	47.67	0.380	12,037.3	25.5	0.319	380.1
Oxford	7.65	46.56	0.236	5,052.0	23.2	0.277	28.5
Plainfield	5.83	43.28	0.203	7,837.2	22.3	0.264	83.9
Plainville	7.13	45.65	0.294	15,873.7	25.4	0.311	875.9
Plymouth	7.00	45.65	0.202	1,475.4	22.9	0.269	114.5
Pomfret	5.96	42.94	0.157	3,668.0	20.5	0.237	4.1
Portland	6.91	45.93	0.232	3,126.3	23.9	0.282	55.9
Preston	5.81	44.13	0.187	4,276.3	20.8	0.243	73.2
Prospect	7.49	46.23	0.262	3,569.9	23.8	0.285	34.4
Putnam	6.06	42.62	0.198	7,708.2	21.7	0.253	112.8
Redding	7.92	47.27	0.261	3,455.9	23.7	0.286	23.2
Ridgefield	7.87	46.81	0.257	2,631.9	23.5	0.287	99.6
Rocky Hill	7.10	45.73	0.342	7,628.5	27.9	0.337	575.9
Roxbury	7.20	45.72	0.182	2,564.3	21.5	0.253	0.8
Salem	6.17	45.35	0.172	4,592.5	20.3	0.237	32.5
Salisbury	6.05	43.58	0.141	2,903.5	19.5	0.223	31.2
Scotland	5.96	43.73	0.159	3,424.6	20.7	0.239	0.0
Seymour	7.73	46.86	0.292	5,304.5	24.1	0.291	351.0
Sharon	6.15	44.23	0.143	4,060.1	19.7	0.228	0.1
Shelton	7.90	47.53	0.316	3,417.4	25.8	0.310	156.3

Table 13: Average Pollutant and Transportation Burden Values by Municipality in Connecticut (*continued*)

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Sherman	7.14	44.94	0.199	3,951.8	22.5	0.267	3.3
Simsbury	6.55	44.66	0.181	2,574.0	22.8	0.273	46.7
Somers	6.44	43.85	0.200	3,207.5	23.9	0.281	65.1
South Windsor	6.82	44.72	0.288	8,095.4	26.8	0.321	136.2
Southbury	7.51	46.27	0.229	26,147.9	22.7	0.269	160.6
Southington	7.27	45.89	0.271	20,163.8	25.1	0.302	243.0
Sprague	5.93	43.93	0.177	2,844.4	20.6	0.243	0.3
Stafford	6.11	43.49	0.158	3,831.6	21.4	0.246	17.9
Stamford	8.09	48.33	0.423	3,804.0	26.7	0.340	604.5
Sterling	5.77	43.11	0.165	2,353.1	20.5	0.238	0.4
Stonington	5.69	44.88	0.243	5,557.9	20.4	0.246	107.7
Stratford	7.98	48.55	0.455	8,069.7	26.6	0.336	786.9
Suffield	6.53	43.96	0.219	3,063.0	25.1	0.303	37.7
Thomaston	6.90	45.60	0.231	11,386.8	22.7	0.268	267.8
Thompson	6.09	42.42	0.178	4,513.1	21.6	0.243	43.5
Tolland	6.36	44.08	0.215	15,106.1	22.8	0.267	117.5
Torrington	6.24	45.02	0.173	6,588.5	21.6	0.247	134.4
Trumbull	8.02	47.97	0.354	7,750.0	25.6	0.313	497.1
Union	5.95	43.23	0.157	53,675.1	20.7	0.238	163.8
Vernon	6.65	44.51	0.284	12,299.8	26.0	0.310	357.9
Voluntown	5.59	43.38	0.161	3,617.0	19.9	0.230	0.1
Wallingford	7.32	46.49	0.312	8,965.6	25.3	0.303	338.2
Warren	6.36	45.05	0.142	4,838.5	19.9	0.230	0.6
Washington	6.75	45.30	0.169	2,498.9	20.5	0.240	25.0
Waterbury	7.37	45.99	0.325	7,403.3	24.3	0.301	817.9
Waterford	6.03	46.11	0.251	17,168.7	21.0	0.250	255.2
Watertown	7.09	45.74	0.221	6,068.1	22.8	0.270	74.8
West Hartford	6.96	45.21	0.325	2,852.9	26.8	0.324	562.9
West Haven	7.59	47.68	0.399	5,336.3	25.3	0.316	771.1
Westbrook	6.52	47.70	0.250	35,103.1	23.0	0.277	146.1
Weston	8.01	47.97	0.262	3,036.1	23.8	0.287	17.1
Westport	8.05	48.83	0.363	15,324.7	25.3	0.318	721.3
Wethersfield	7.07	45.50	0.380	15,081.1	28.2	0.345	845.8
Willington	6.13	43.72	0.187	15,621.0	21.6	0.253	66.3
Wilton	8.00	47.91	0.311	3,761.7	24.5	0.301	125.2
Winchester	6.04	44.56	0.151	2,715.9	20.2	0.229	103.2
Windham	6.06	43.99	0.186	2,273.8	21.8	0.255	136.8
Windsor	6.77	44.62	0.333	10,350.0	27.2	0.339	595.7
Windsor Locks	6.67	44.31	0.323	14,068.2	28.1	0.371	276.7
Wolcott	7.27	45.87	0.250	2,085.7	23.9	0.285	65.9
Woodbridge	7.66	46.99	0.294	4,586.3	24.8	0.297	275.6
Woodbury	7.21	45.85	0.175	1,797.4	21.7	0.254	17.1

Table 13: Average Pollutant and Transportation Burden Values by Municipality in Connecticut (*continued*)

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Woodstock	5.94	42.73	0.142	4,510.3	20.4	0.237	0.7

Note:

Pollutant values by municipality are a geographically weighted average of intersecting Block Groups. See Appendix A for definitions of pollutants and units of measure.