Transportation Burdens and Emissions in Massachusetts

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Contents

1 Analysis of transportation-related emissions in Massachusetts

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

1.1 $PM_{2.5}$ in Massachusetts

$PM_{2.5}$ 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 (SO_2), 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 $12\mu g/m^3$ (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 $10\mu g/m^3$ to $8\mu g/m^3$. 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 Massachusetts, with highest concentrations in southwest Massachusetts centered between I-95 and I-90, and inside of I-495, as well as around Springfield (see Figure 1 below).

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

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

[3] An 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

[4] See Liuhua Shi, Antonella Zanobetti, Itai Kloog, Brent A. Coull, Petros Koutrakis, Steven J. Melly, and Joel D. Schwartz. 2016. Low-Concentration PM2.5 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

[5] See 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

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

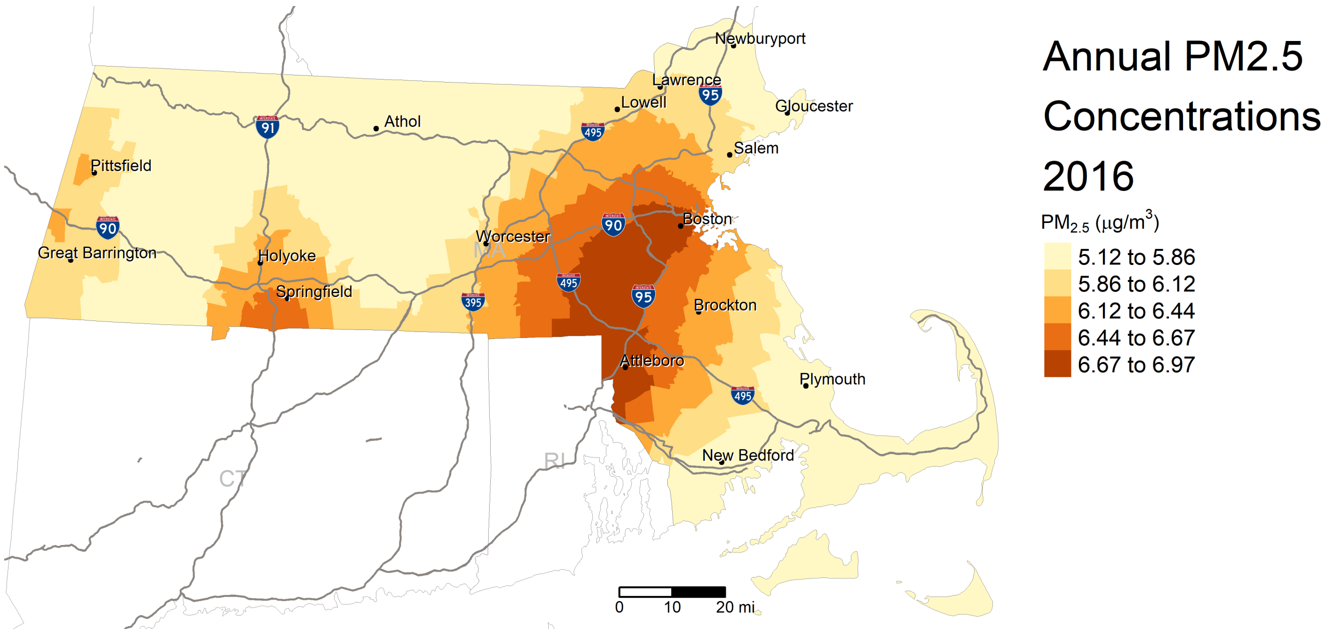

Figure 1: Map of 2016 annual PM2.5 concentrations across Massachusetts at Census Block Group level.

$PM_{2.5}$ 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. Hotspots are concentrated along I-95 and centered around I-495 to I-90 in the Boston area.

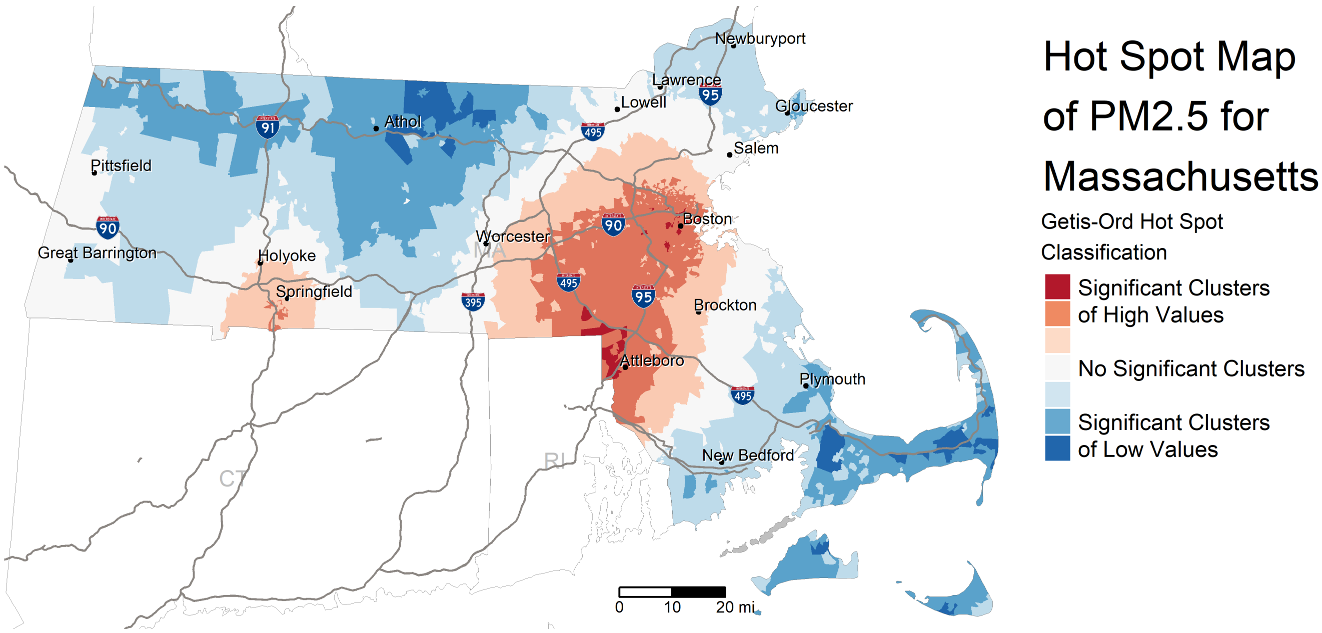

Figure 2: Hot spot map of 2016 annual PM2.5 concentrations at Census Block Group level.

There is a statistically significant hot spot of $PM_{2.5}$ around Springfield and also from Wrentham to Boston.

These $PM_{2.5}$ levels vary significantly across the state, although the clusters of Block Groups with high $PM_{2.5}$ values remains apparent (see Table 1 and Figure 3). See Table 13 in Appendix B for concentrations by municipality.

Table 1: Annual 2016 PM2.5 concentrations (micrograms per cubic meter) by Census block group for the state.

Mean	Median	Min	Max
6.23	6.29	5.12	6.97

The Block Group with highest $PM_{2.5}$ concentration value in the state is found in Attleboro and the lowest is found in Nantucket.

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 6.29. 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 run southwest from Boston to the Rhode Island border.

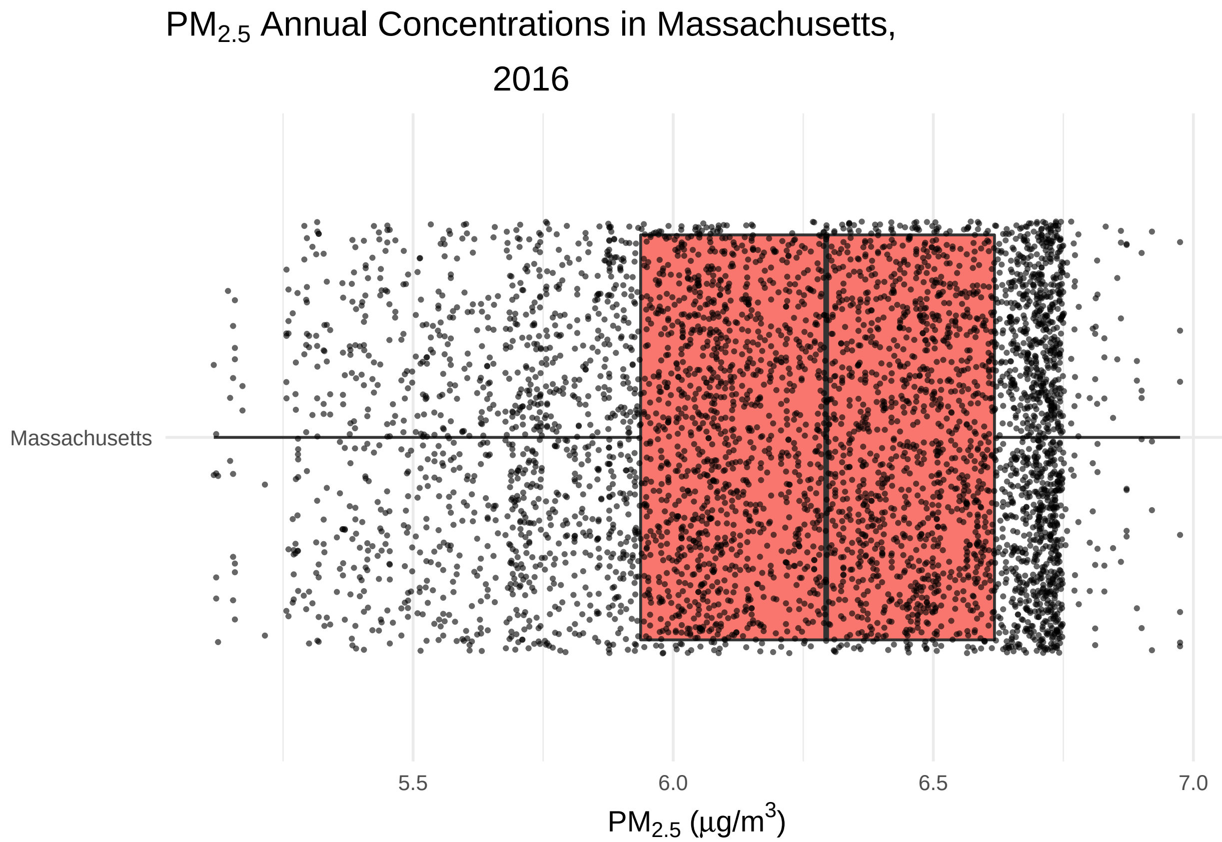

Figure 3: Boxplot of 2016 annual PM2.5 concentrations at Census Block Group level. 1 dot = 1 Block Group.

Since 2011, $PM_{2.5}$ levels have declined across the state, on average by -31.8%. Unsurprisingly, this decline has not been uniform (see Figure 4 below). The greatest declines, 38.2%, have been in western Massachusetts north of Springfield, and in the northeast north of Boston.

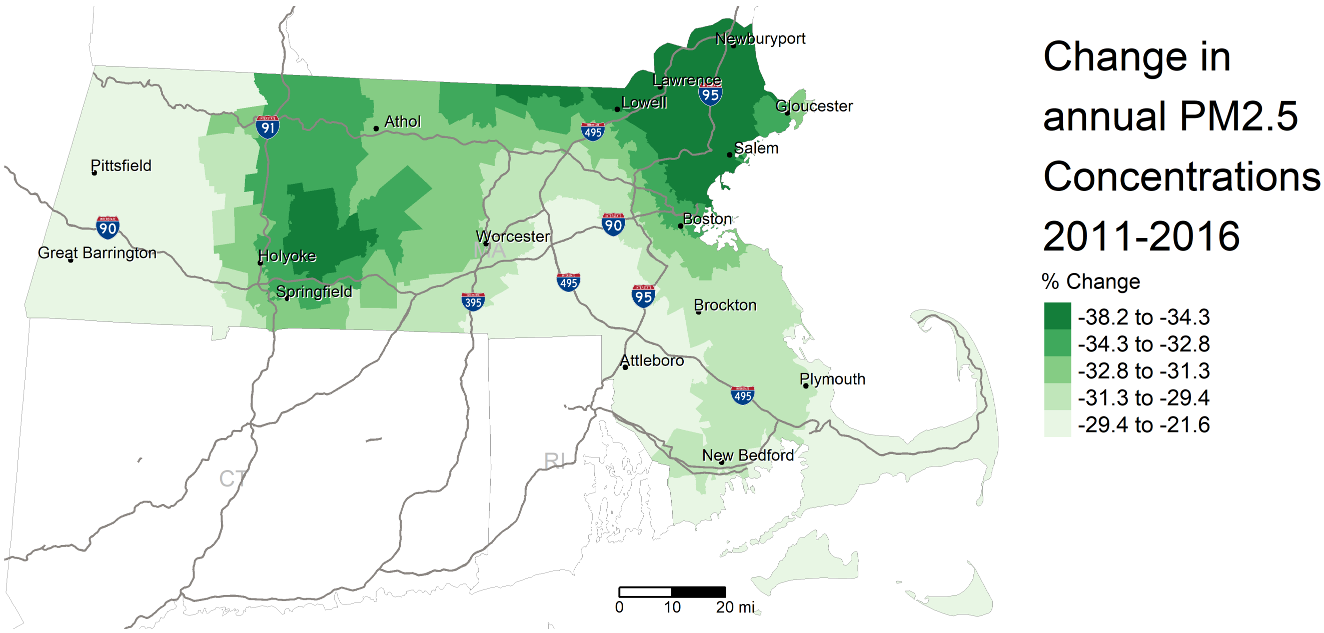

Figure 4: Map of percent change in annual PM2.5 concentrations across Massachusetts between 2011 and 2016 at Census Block Group level.

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. Massachusetts is now slightly below the rest of the region.

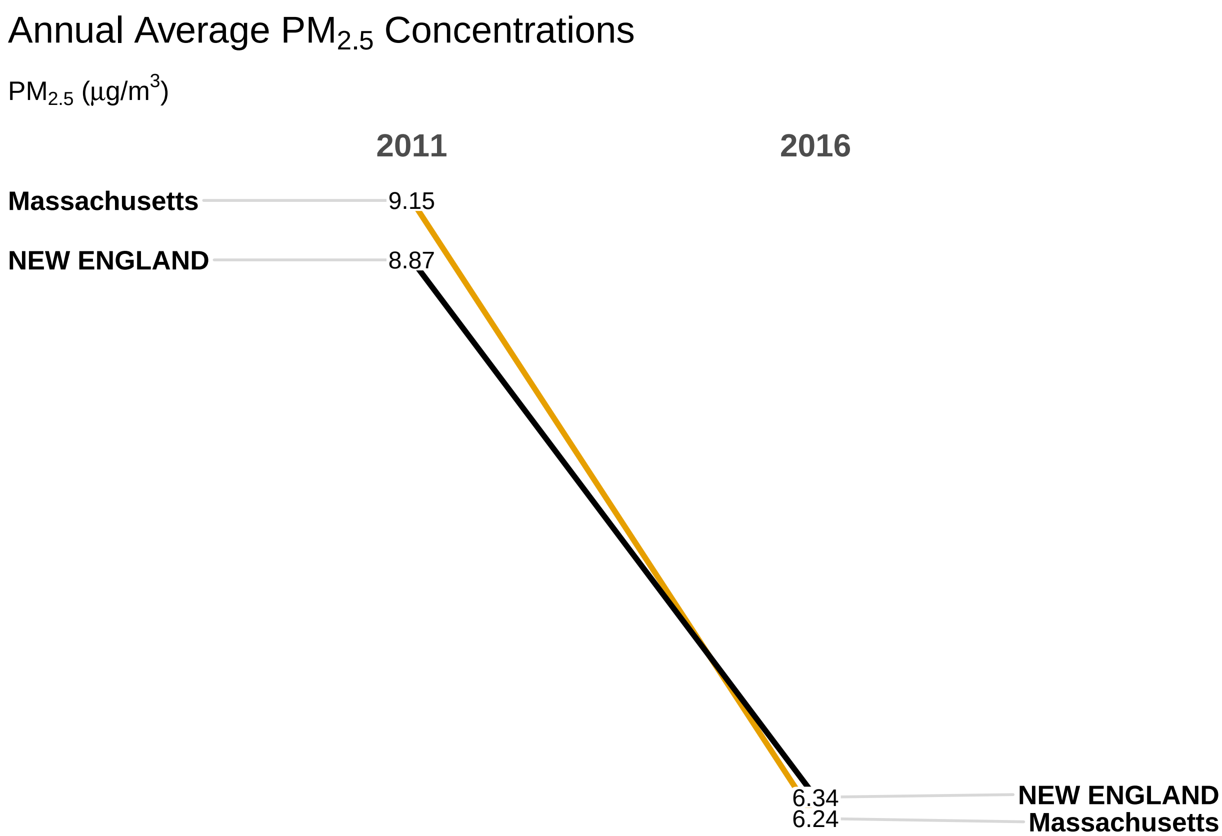

Figure 5: Change in population-weighted concentration of PM2.5 between 2011 and 2016 for Massachusetts and New England.

1.1.1 $PM_{2.5}$ in Massachusetts 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, limited English speaking households in Massachusetts, as defined by state environmental justice policy, are exposed to $PM_{2.5}$ concentrations that are approximately 2.3% above concentrations for the state as a whole. Similarly, People of Color, as defined by state environmental justice policy, are exposed to concentrations over 2% above the state average. By contrast, persons over age 64 are, on average, exposed to concentrations of $PM_{2.5}$ almost 1% below the state average.

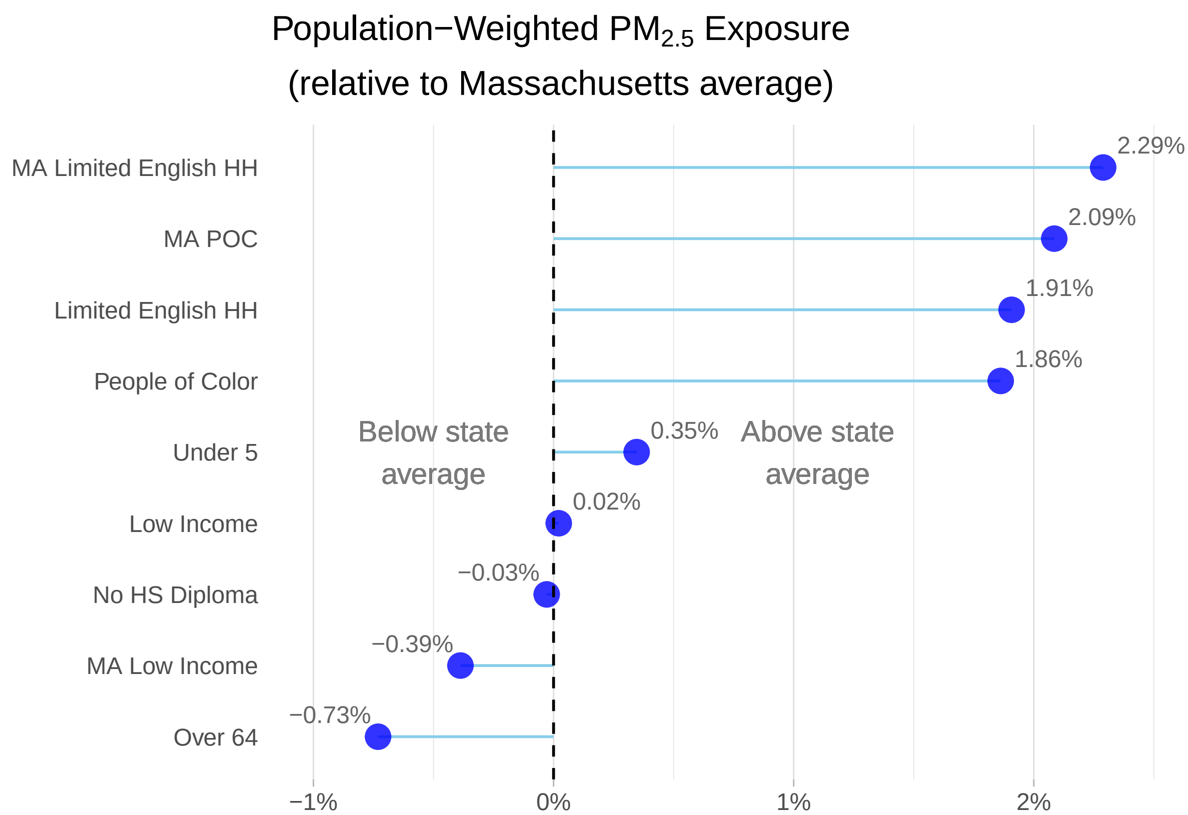

Figure 6: Population-weighted average exposures to PM2.5 for priority populations in Massachusetts relative to the state average.

Like the state 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
average, with limited English speaking households and People of Color leading on this measure.

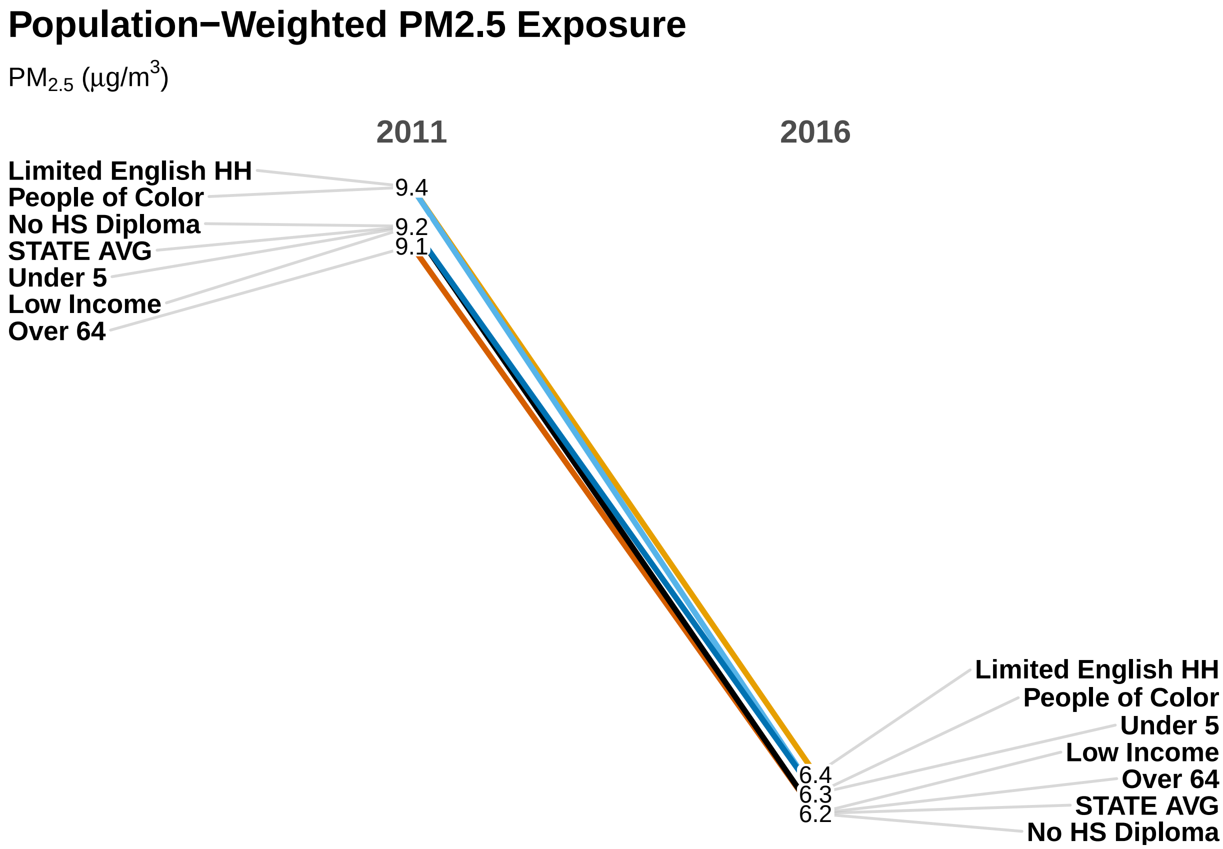

Figure 7: Change in population-weighted exposure to PM2.5 for priority populations between 2011 and 2016.

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 (O_3) in Massachusetts

Ground-level ozone (O_3) 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 (O_3) presented here is based on data from the EPA's EJSCREEN.[12] EJSCREEN data provides ozone (O_3) 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 (O_3) levels vary significantly across Massachusetts, with highest concentrations in the southern and western parts of Massachusetts, and declining toward the north and east (see Figure 8 below).[13]

[7] Tropospheric, 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.

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

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

[10] An 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

[11] See 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.

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

[13] Note 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 Massachusetts 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#MA

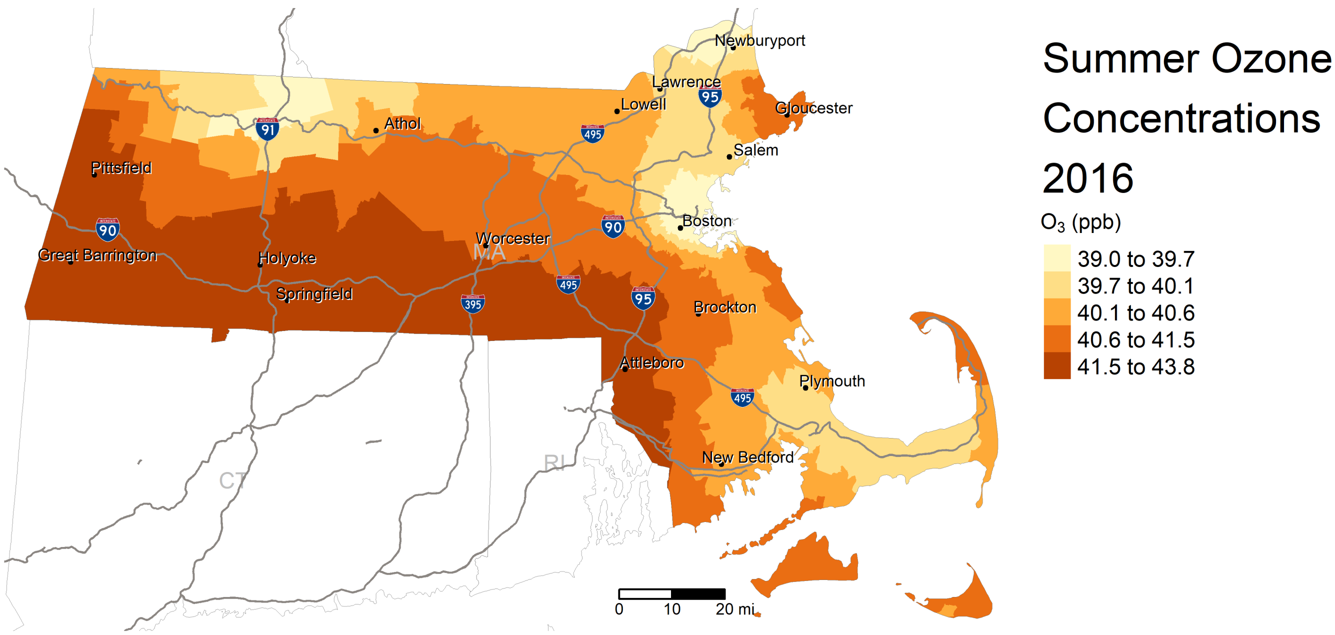

Figure 8: Map of 2016 Ozone summer seasonal average of daily maximum 8-hour concentration in air in parts per billion across Massachusetts at Census Block Group level.

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. These hot spots are concentrated along I-90 west of I-84 and around Springfield and Holyoke.

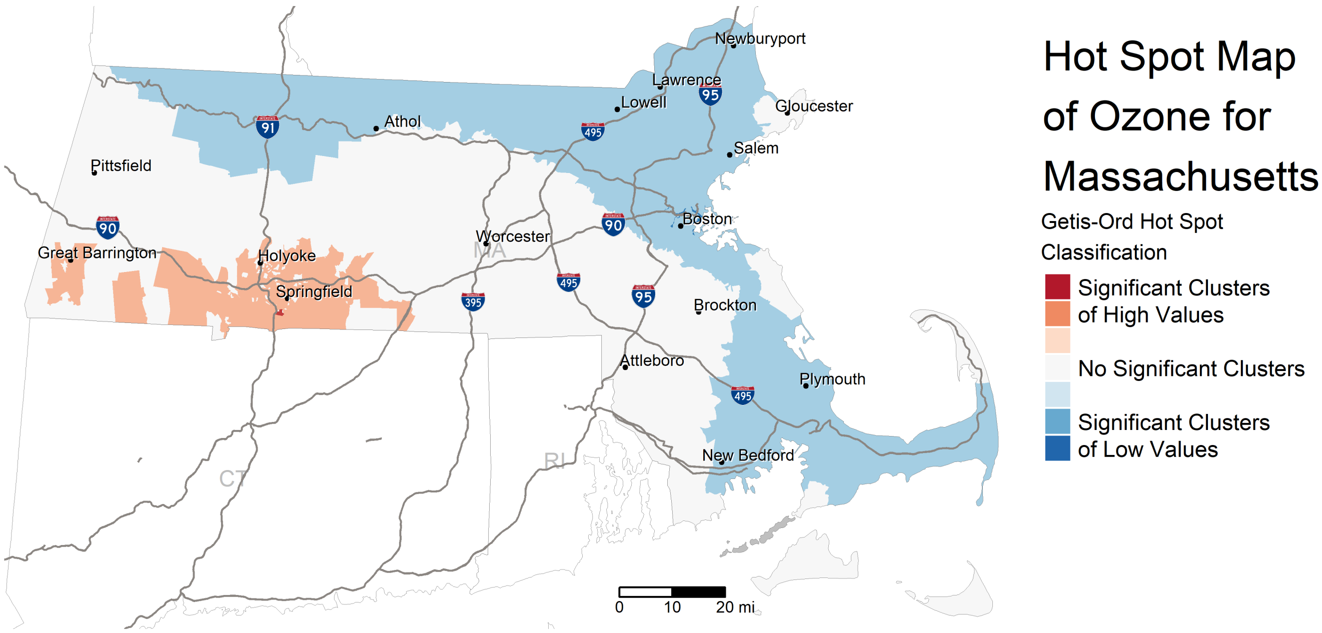

Figure 9: Hot spot map of 2016 Ozone concentrations at Census Block Group level.

There are statistically significant hot spots of Ozone (O_3) south of Springfield. A warm cluster extends from Great Barrington to Sturbridge.

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 (micrograms per cubic meter) by Census block group for the state.

Mean	Median	Min	Max
40.61	40.33	38.99	43.79

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

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 40.33. Half of the state's Block Groups are below the median and half are above the median. Each dot represents an individual Block Group. The large dots on the far right represent outliers or unusually high values. In this case, outliers would be represented by ozone values greater than 43.54035, which occur in Agawam Town, East Longmeadow, Hampden, Longmeadow, Southwick, and Springfield.

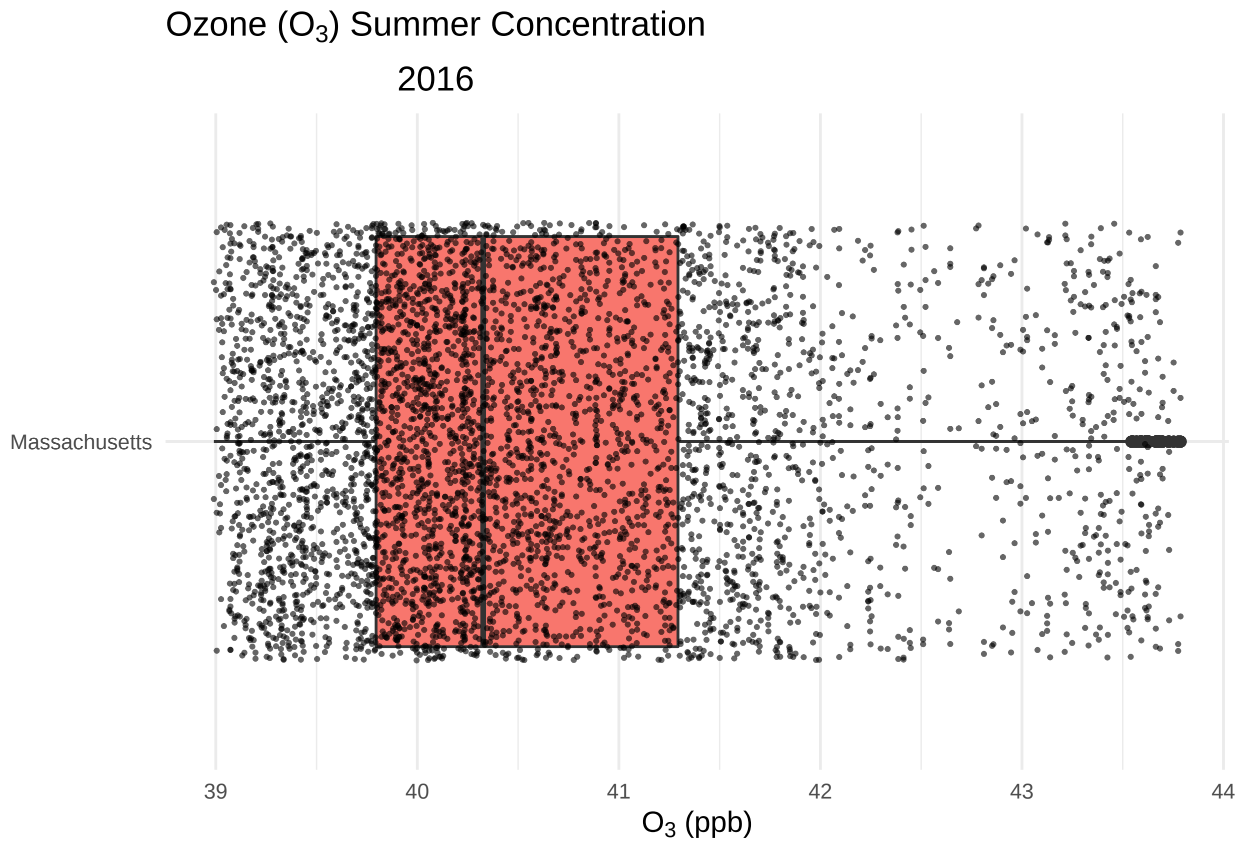

Figure 10: Boxplot of 2016 Ozone summer seasonal average of daily maximum 8-hour concentrations in air in parts per billion by state at Census Block Group level. 1 dot = 1 Block Group.

Since 2011, Ozone (O_3) levels have increased slightly across the state, on average by 0.7%. These have changes not been uniform (see Figure 11 below). The greatest declines, up to -10.5%, have been on Nantucket and Martha's Vineyard. By contrast, increases in summer ozone concentrations of up to 5.9% appear in the center of the state north of Holyoke and around South Hadley.

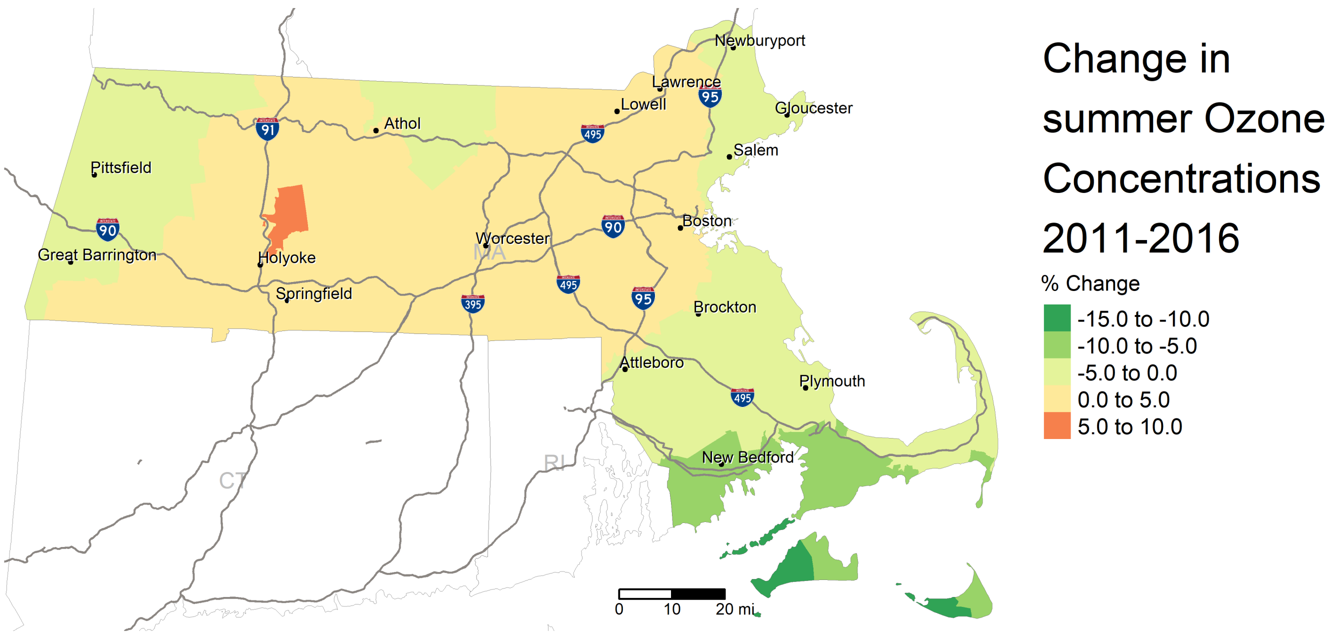

Figure 11: Map of percent change in summer seasonal Ozone concentrations across Massachusetts between 2011 and 2016 at Census Block Group level.

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

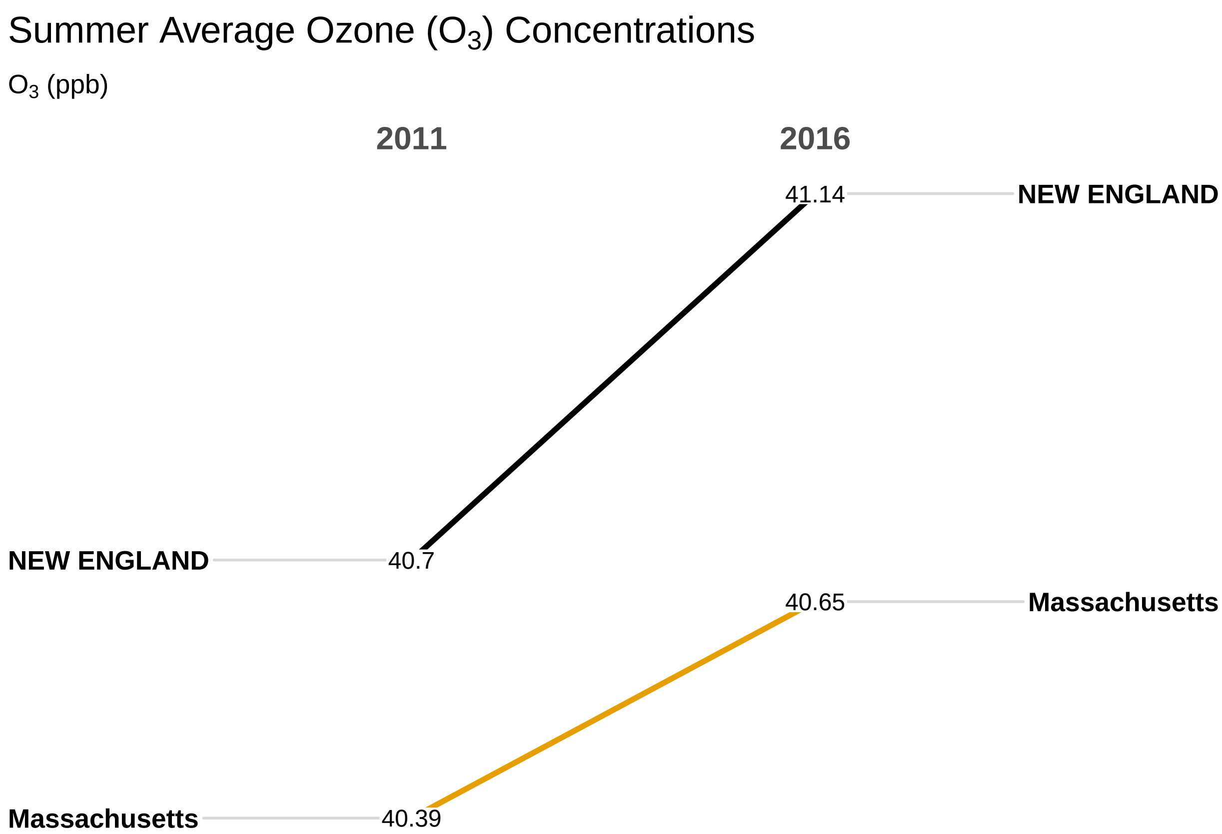

Figure 12: Change in summer average ozone concentrations between 2011 and 2016 for Massachusetts and New England.

1.2.1 Ozone (O_3) in Massachusetts and Priority Populations

In addition to variations in the general geography of Ozone (O_3) 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, low income persons, as identified by Massachusetts Environmental Justice policy, are exposed to summer Ozone concentrations that are 0.5% above concentrations for the region as a whole. Similarly, persons over age 64 are exposed to concentrations 0.2% above the regional average. By contrast, limited English speaking households are, on average, exposed to concentrations of Ozone at or below the regional average.

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

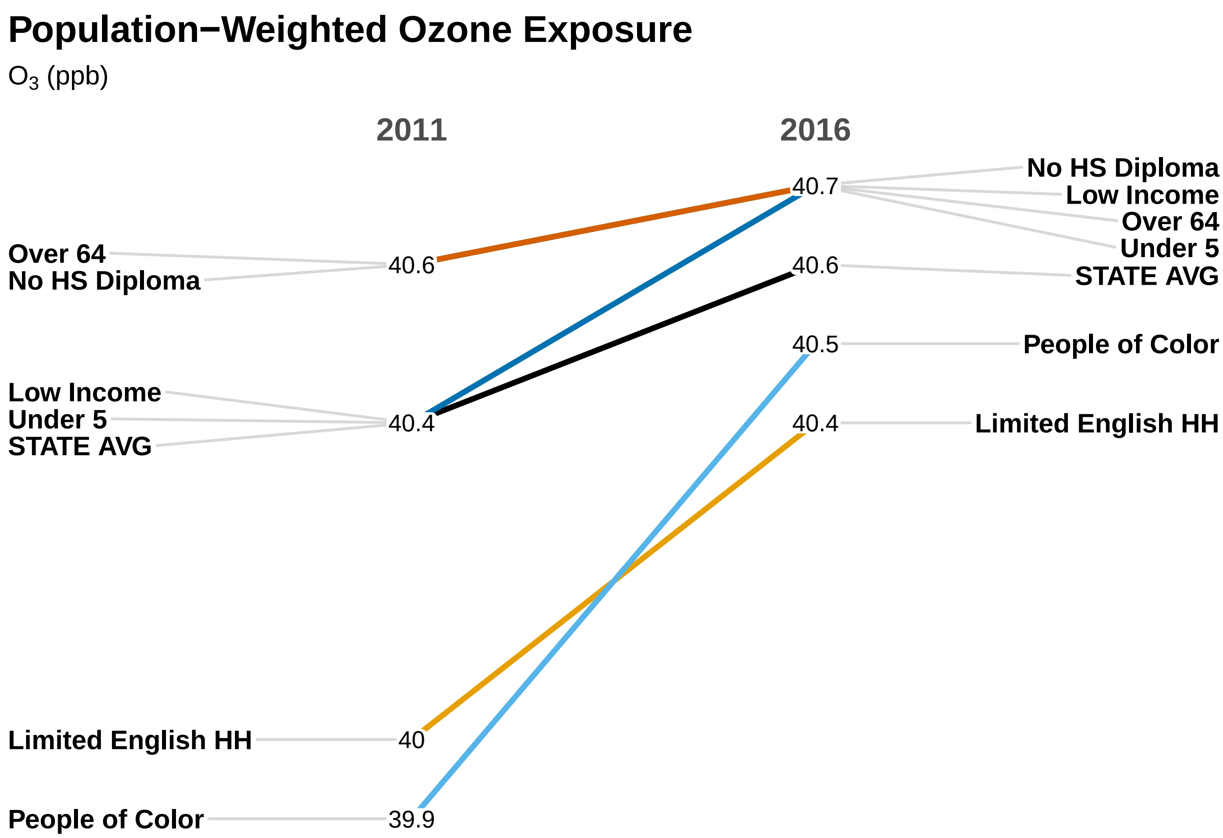

Figure 14: Change in population-weighted exposure to summer ozone for priority populations between 2011 and 2016.

1.3 Carbon Dioxide (CO_2) in Massachusetts

Carbon dioxide (CO_2) emissions are the primary driver of human-induced climate change.[14] Direct exposure to CO_2 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 CO_2 emissions is the transportation sector, especially automobiles. Other sources of CO_2 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 CO_2 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 (CO_2) 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 CO_2 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 CO_2 emissions closely follow major roadways across the state (see Figure 15 below).

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

[15] See 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

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

[17] See 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

[18] See 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/

[19] Gately, C., L.R. Hutyra, 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

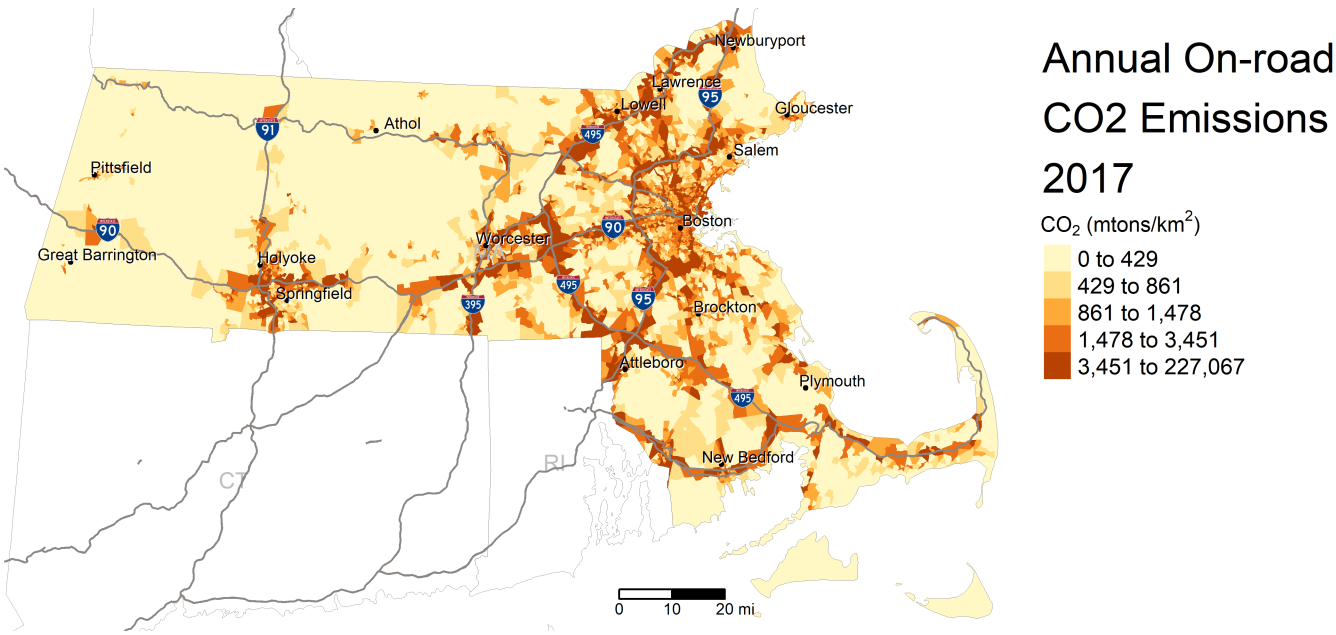

Figure 15: Map of 2017 Carbon Dioxide (CO2) annual on-road emissions in metric tons per square kilometer across Massachusetts at Census Block Group level.

Significant hot spots, or clusters of high CO_2 emissions, appear in downtown Boston (see Figure 16 below).

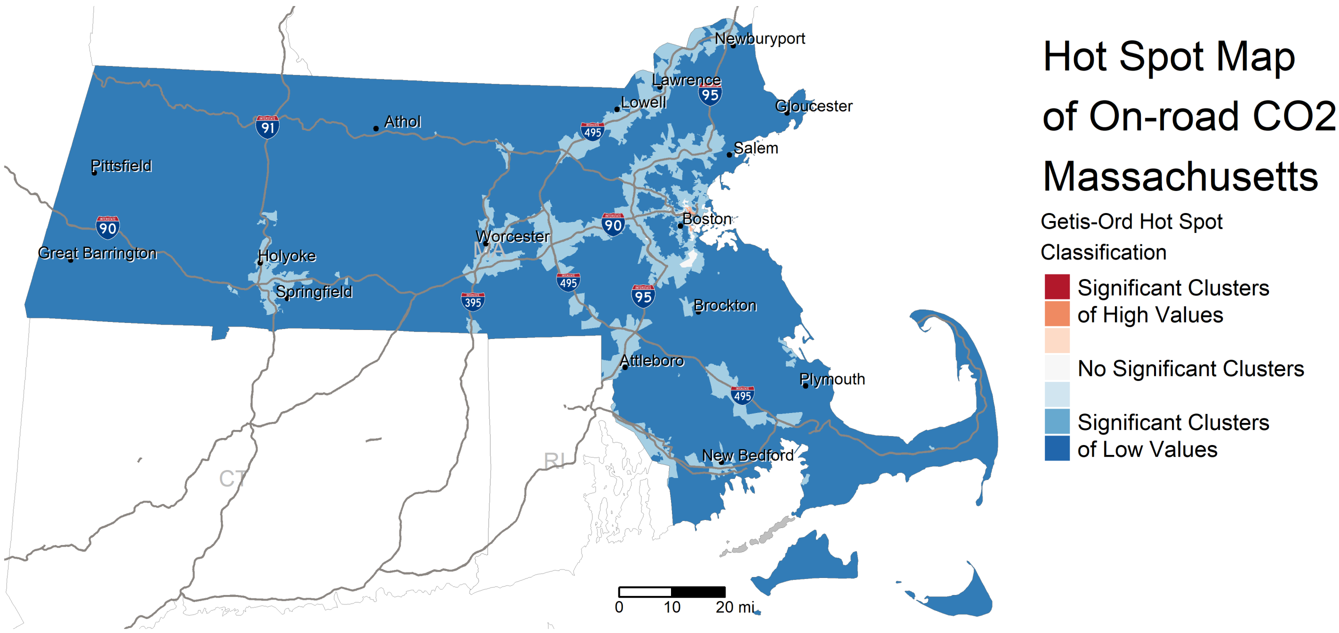

Figure 16: Hot spot map of 2017 CO2 emissions at Census Block Group level.

CO_2 emissions vary across the state with significant outliers (see Table 3.

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

Mean	Median	Min	Max	State Total
5,466	1,032	0	193,358	27,208,279

The Block Group with highest CO_2 emissions value in the state is found in Canton and the lowest is found in Oak Bluffs. See Table 13 in Appendix B for emissions by municipality.

Since 1990, CO_2 emissions increased significantly across the state, on average by 18.9%. These changes have not been uniform (see Figure 17 below). The greatest declines have been in western Massachusetts. By contrast, Cape Code has seen increased emissions.

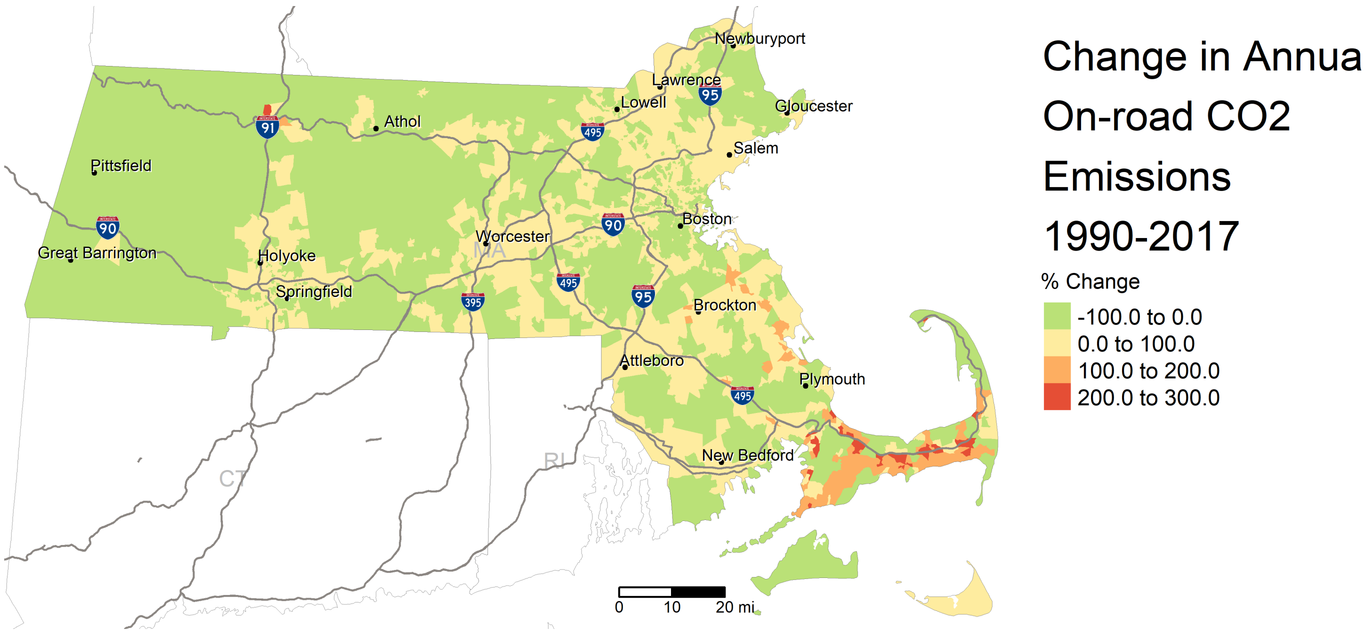

Figure 17: Map of percent change in annual CO2 emissions across Massachusetts between 1990 and 2017 at Census Block Group level.

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 CO_2 emissions for the state as a whole. Figure 18 shows annual CO_2 emissions between 1990 and 2017. Total on-road CO_2 emissions for the state increased dramatically between 1990 and and 2005. Since 2005 emissions have shown a slight downward trend.

Table 4: Annual On-road CO2 Emissions

1990 CO2 (mtons)	2017 CO2 (mtons)	Pct Change	1990 Per Capita (mtons/person)	2017 Per Capita (mtons/person)	Per Capita Pct Change
22,875,230	27,208,279	19%	3.8	3.97	4%

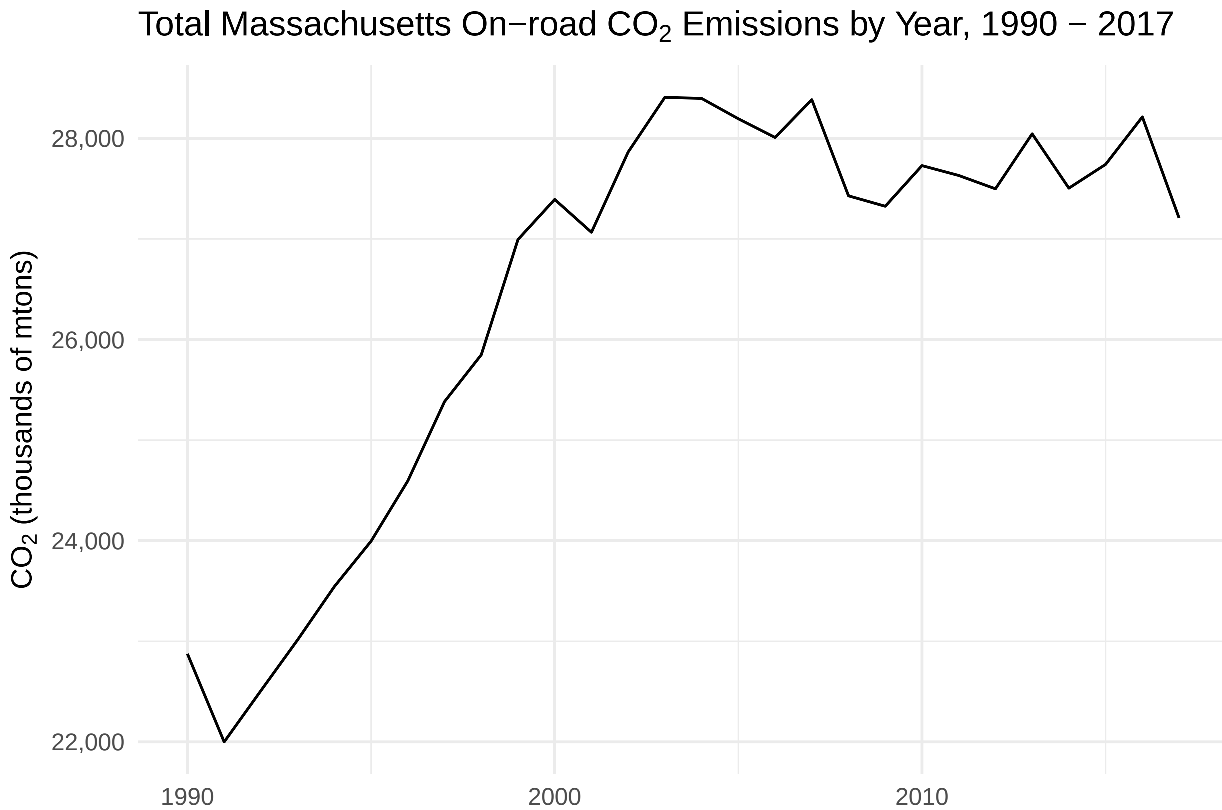

Figure 18: Total CO2 emissions 1990 to 2017 for Massachusetts.

The growth in CO_2 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 Massachusetts

Diesel Particulate Matter (DPM) refers to particulate matter generated from the combustion of diesel fuel. DPM mass (expressed as μgDPM/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 5μg/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 (μg/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 in the Boston area inside of Rt 128, and around New Bedford, Springfield, Gloucester, and Lowell (see Figure 19 below).

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[20] See 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

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

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

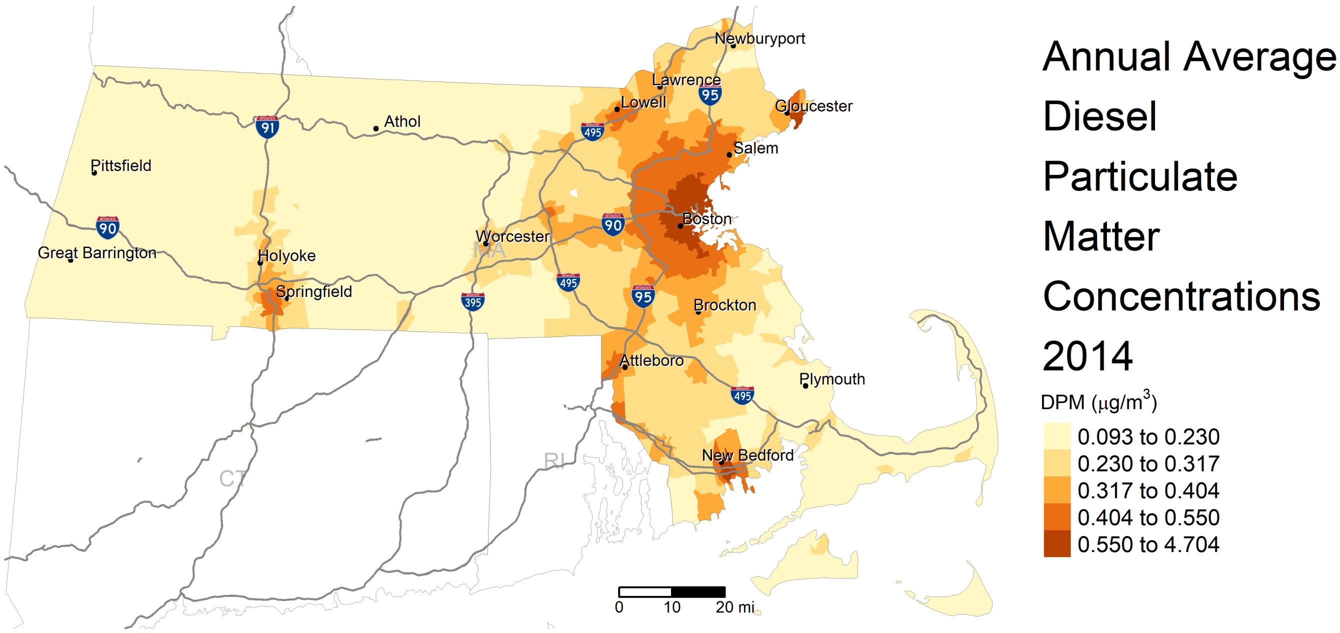

Figure 19: Map of 2014 annual average ambient concentrations of Diesel Particulate Matter in micrograms per cubic meter across Massachusetts at Census Block Group level.

There are significant spatial clusters of high DPM concentrations in New Bedford (see Figure 20 below).

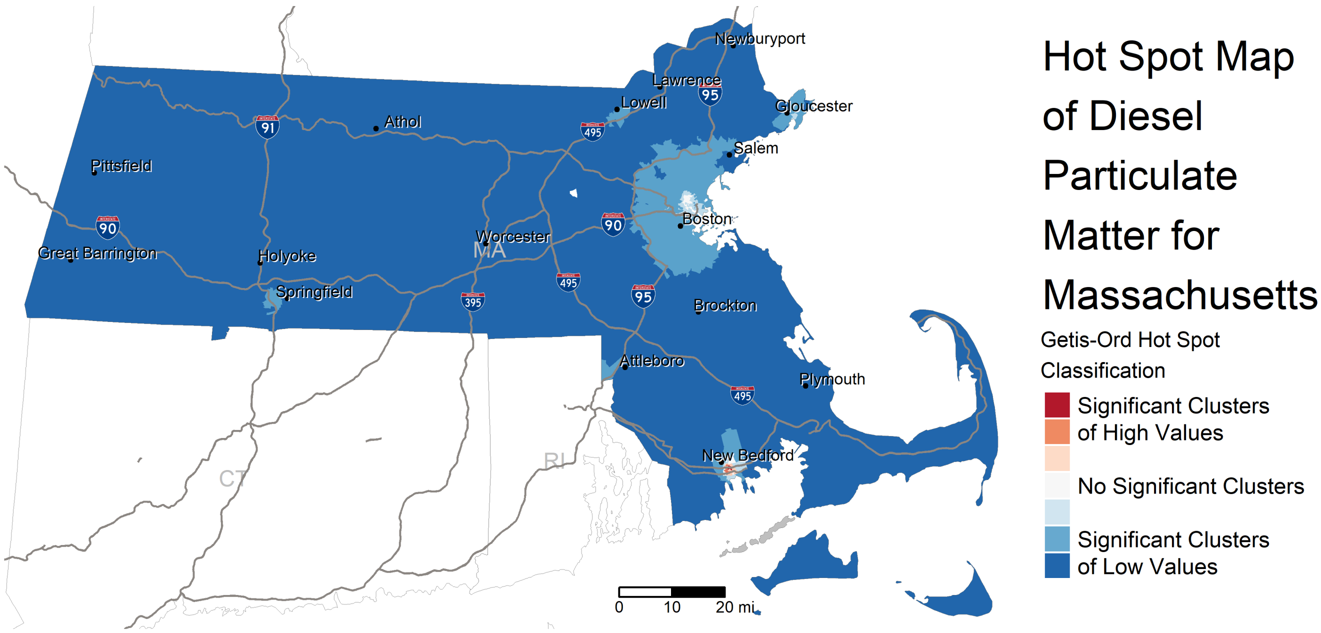

Figure 20: Hot spot map of 2014 Diesel Particulate Matter emissions at Census Block Group level.

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

Table 5: Annual 2014 DPM concentrations by Census block group

Mean	Median	Min	Max
0.426	0.351	0.093	4.704

The Block Group with highest DPM emissions value in the state is found in Fairhaven and the lowest is found in Westhampton. 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 0.35. 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 on the right represent outliers, or unusually high values. In this case, outliers would be represented by DPM values greater than 0.8622334, which occur in Acushnet, Boston, Cambridge, Chelsea, Everett, Fairhaven, Gloucester, Medford, New Bedford, Somerville, and Winthrop Town.

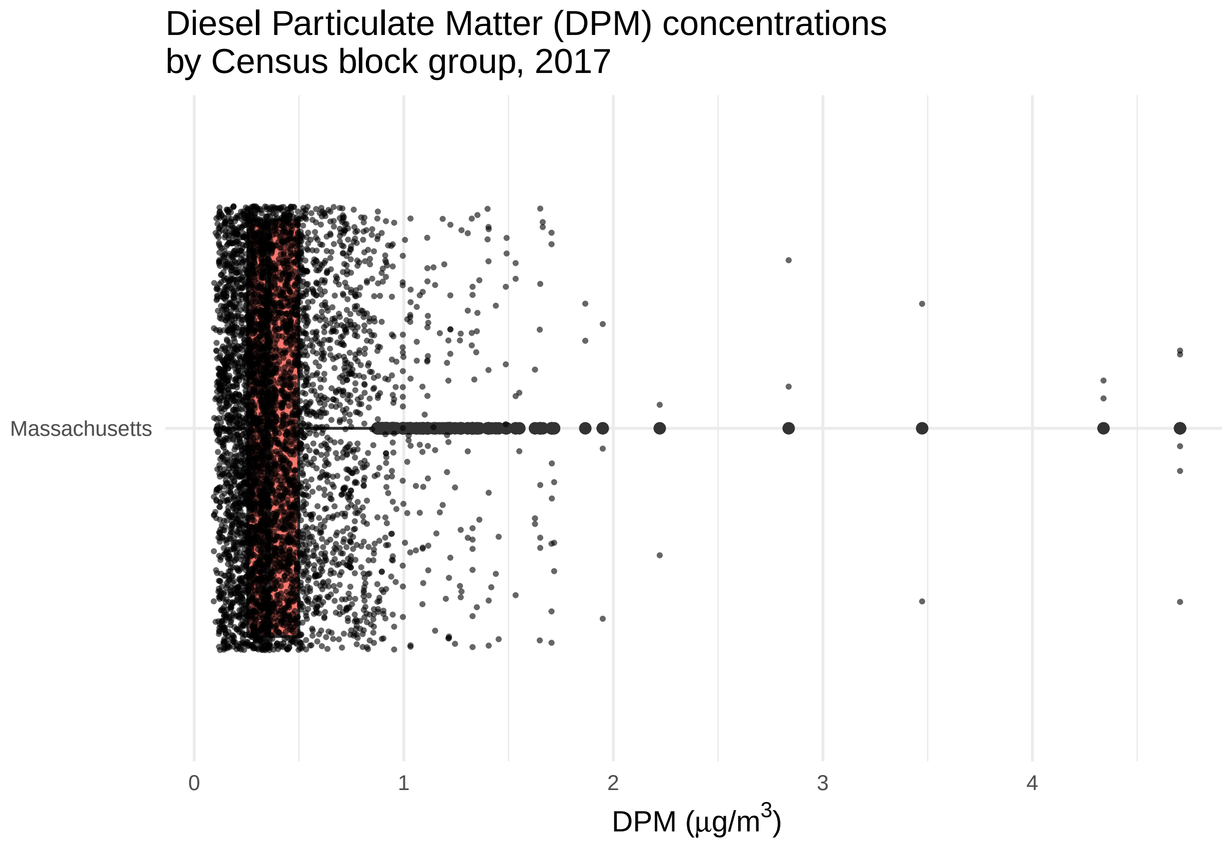

Figure 21: Boxplot of 2017 Carbon Dioxoide on-road emissions in metric tons per square kilometer by state at Census Block Group level. 1 dot = 1 Block Group.

1.4.1 Diesel Particulate Matter in Massachusetts and Priority Populations

In addition to variations in the general geography of DPM concentrations, exposure to these concentrations also varies demographically. Figure 22 below shows population-weighted exposures for priority populations relative to average DPM concentrations for the state. For example, limited English speaking households in Massachusetts, as defined by state environmental justice policy, are exposed to DPM concentrations that are more than 54% above concentrations for the region as a whole. Similarly, People of Color, as identified by Massachusetts Environmental Justice policy, are exposed to concentrations more than 24% above the state average. By contrast, persons over age 64 are, on average, exposed to concentrations of DPM 10% below the state average.

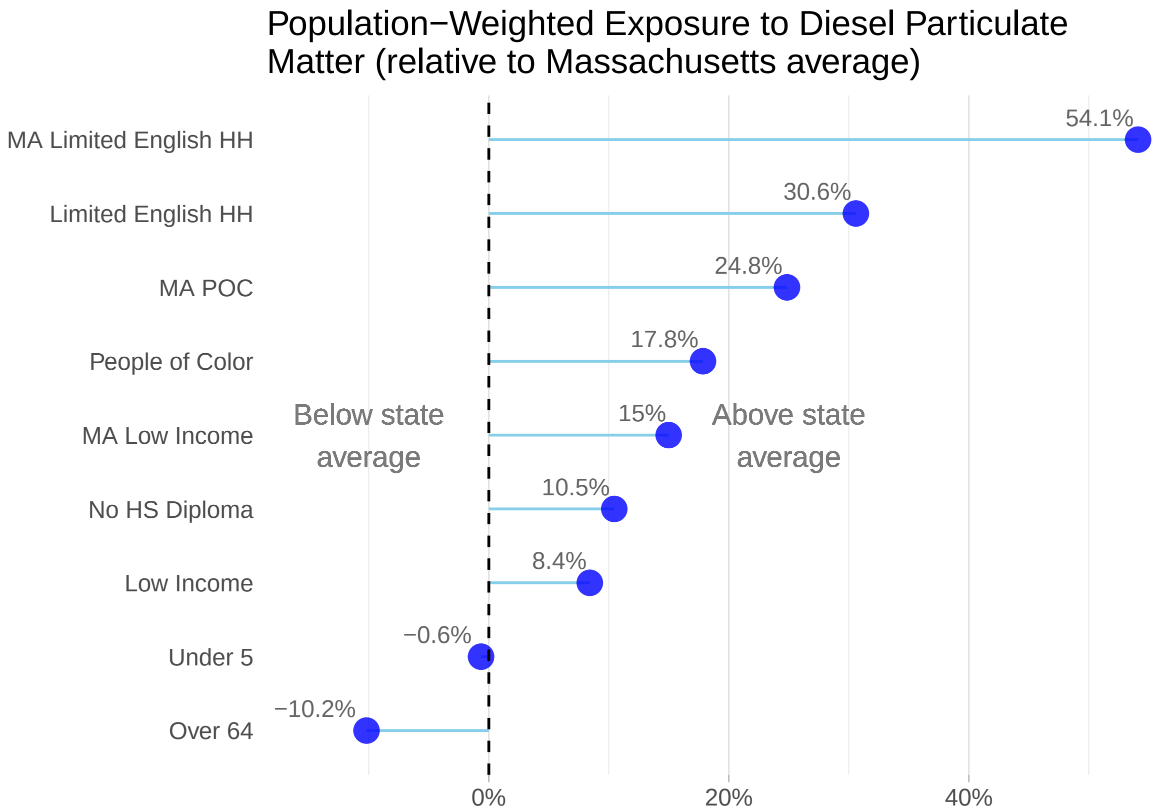

Figure 22: Population-weighted average exposures to annual average ambient concentrations of Diesel Particulate Matter across Massachusetts relative to the state average.

There is a moderate 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 Massachusetts

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.

Lifetime cancer risks are concentrated around Springfield, northeast of Worcester, and inside of Rt 128 in the Boston area, extending north to Lowell (see Figure 23 below).

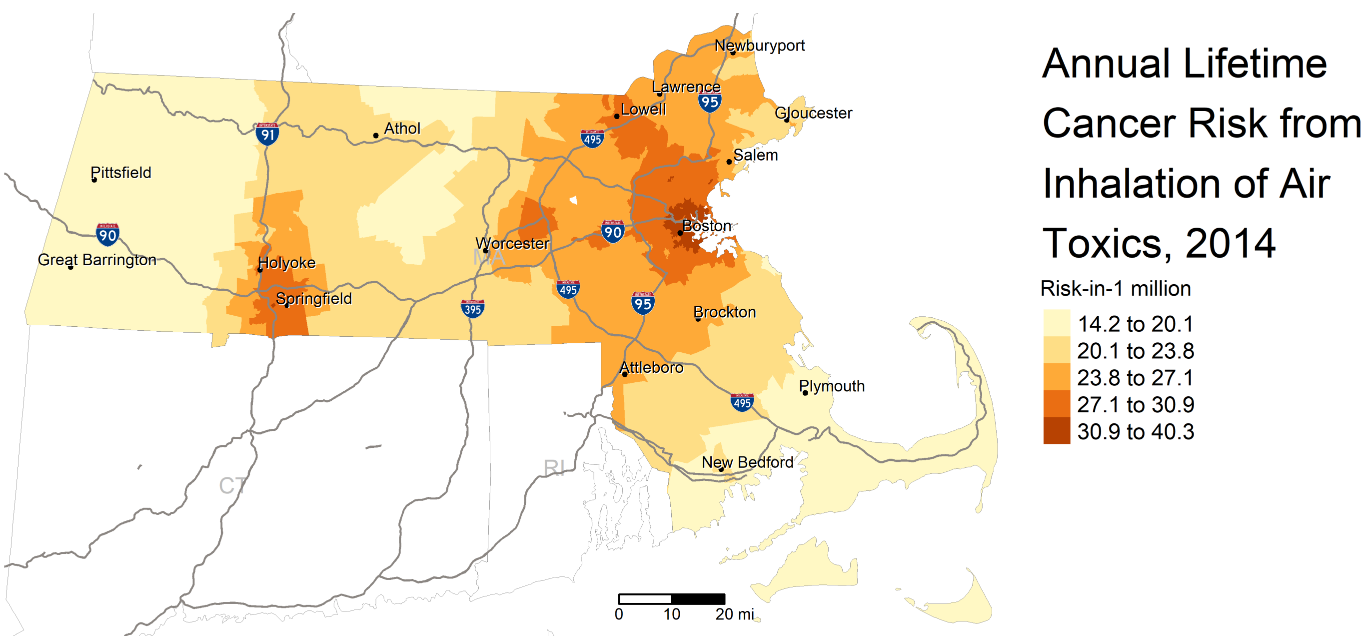

Figure 23: Map of 2014 lifetime cancer risk from inhalation of air toxics (expressed as risk in-1 million) across Massachusetts at Census Block Group level.

There appear to be significant spatial clusters of high lifetime cancer risk from inhalation of air toxics primarily in Boston, with warm clusters extending north to Lowell and Lawrence, and also out west around Springfield and Holyoke (see Figure 24 below).

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

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

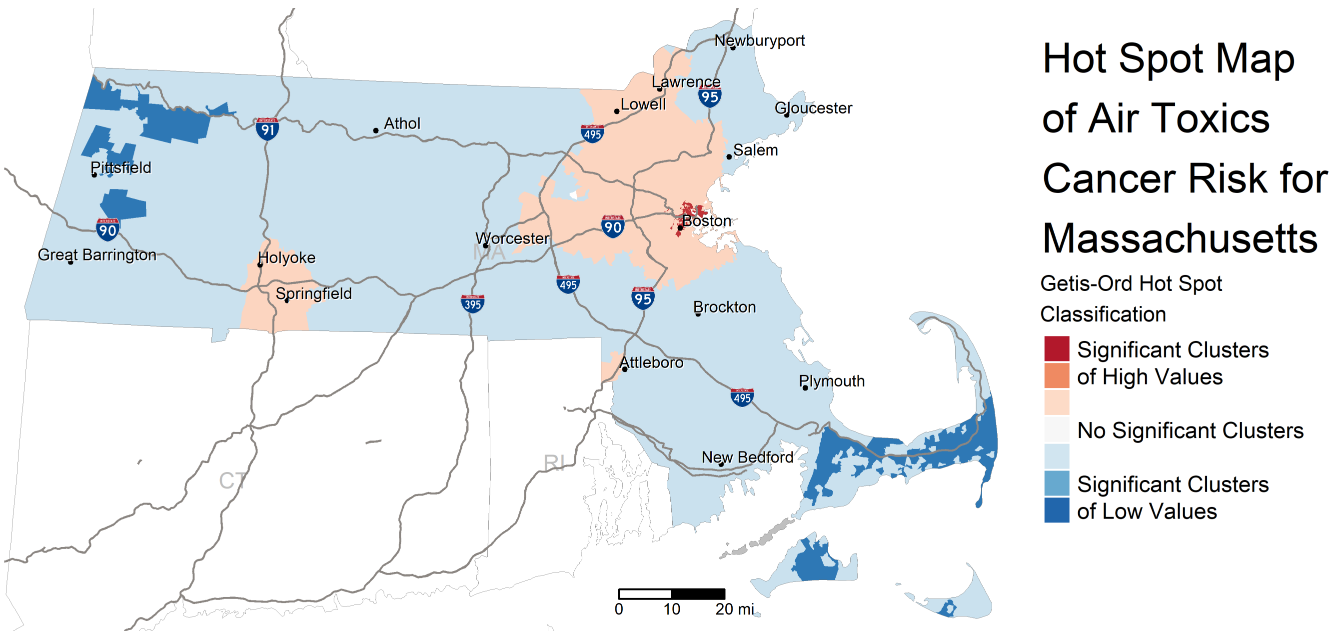

Figure 24: Hot spot map of 2014 lifetime cancer risk from inhalation of air toxics at Census Block Group level.

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
25.8	26.1	14.2	40.3

The Block Group with highest cancer risk value in the state is found in Boston and the lowest is found in Nantucket. See Table 13 in Appendix B for concentrations by municipality.

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 two parts represents the median lifetime cancer risk value for all Block Groups, which in this case is 26.12. 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 37.8833872, which all occur in Boston.

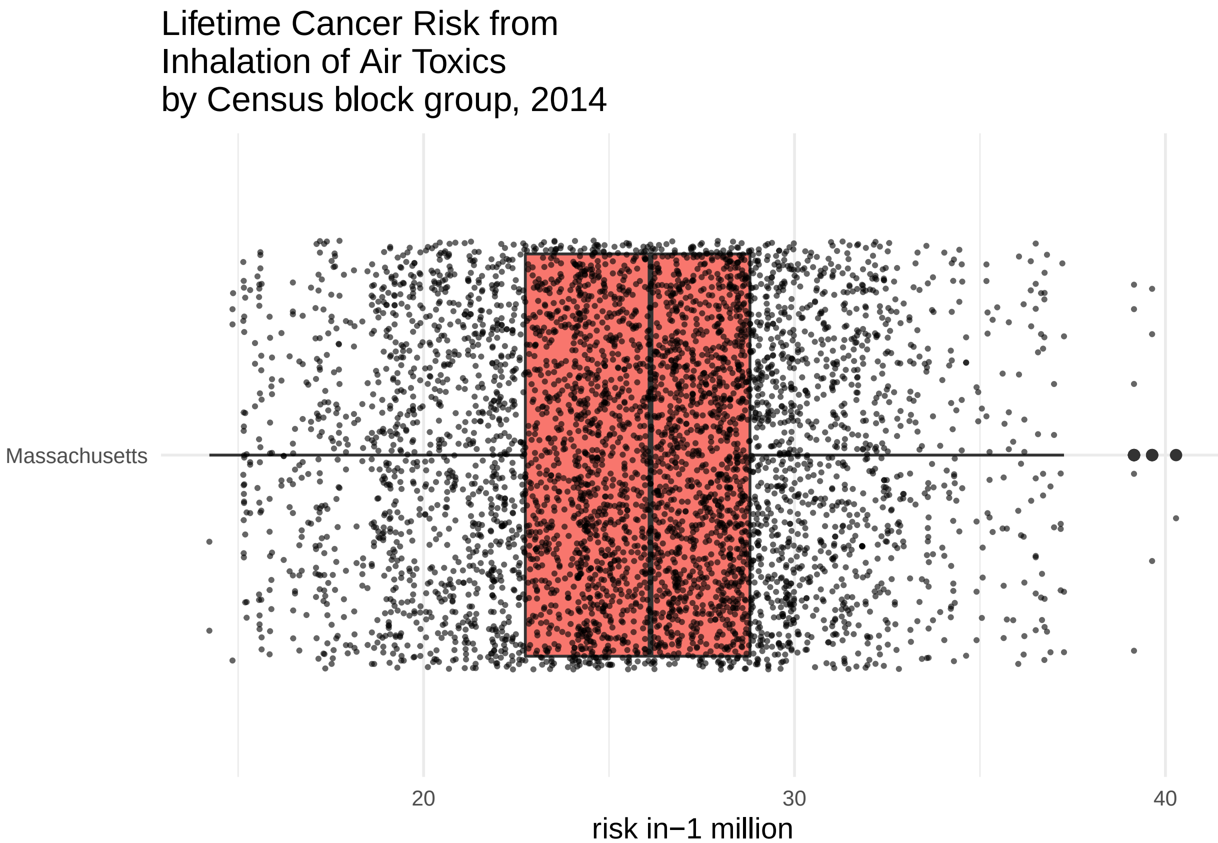

Figure 25: Boxplot of lifetime cancer risk from inhalation of air toxics (expressed as risk in-1 million) across Massachusetts by state at Census Block Group level. 1 dot = 1 Block Group.

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

In addition to variations in the general geography of cancer risk, exposure to these risks also varies demographically. Figure 26 below shows population-weighted exposures for priority populations relative to the average cancer risk for the state. For example, limited English speaking households in Massachusetts, as defined by state environmental justice policy, experience lifetime cancer risks from inhalation of air toxics that are 12.5% above the state as a whole. Similarly, People of Color, as identified by Massachusetts Environmental Justice policy, experience lifetime cancer risks of 8.3% above the state average. By contrast, persons over age 64 are, on average, exposed to cancer risk 2.7% below the state average.

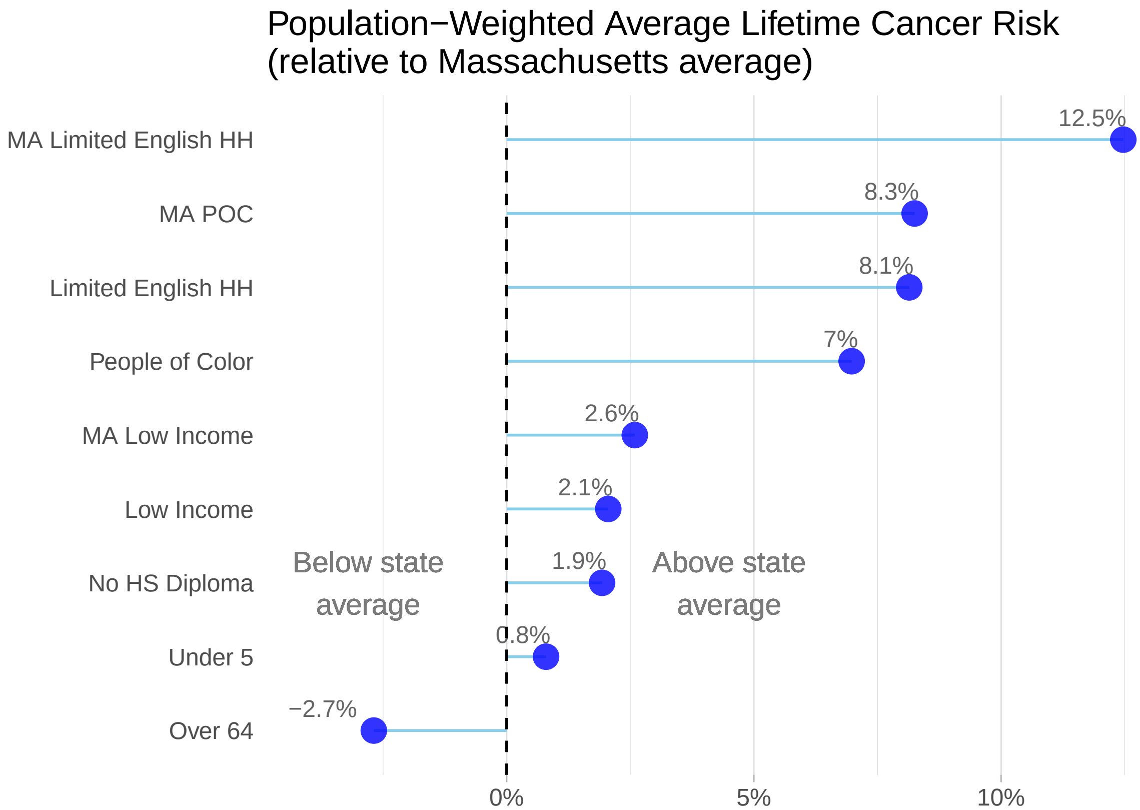

Figure 26: Population-weighted average lifetime cancer risk from inhalation of air toxics (expressed as risk in-1 million) across Massachusetts at Census Block Group level relative to the state average.

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

1.6 Respiratory Hazard Index in Massachusetts

Respiratory hazard from air toxics refers to non-cancer 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 around Springfield, and Holyoke, and Lowell, as well as within Rt 128 in the Boston area (see Figure 27 below).

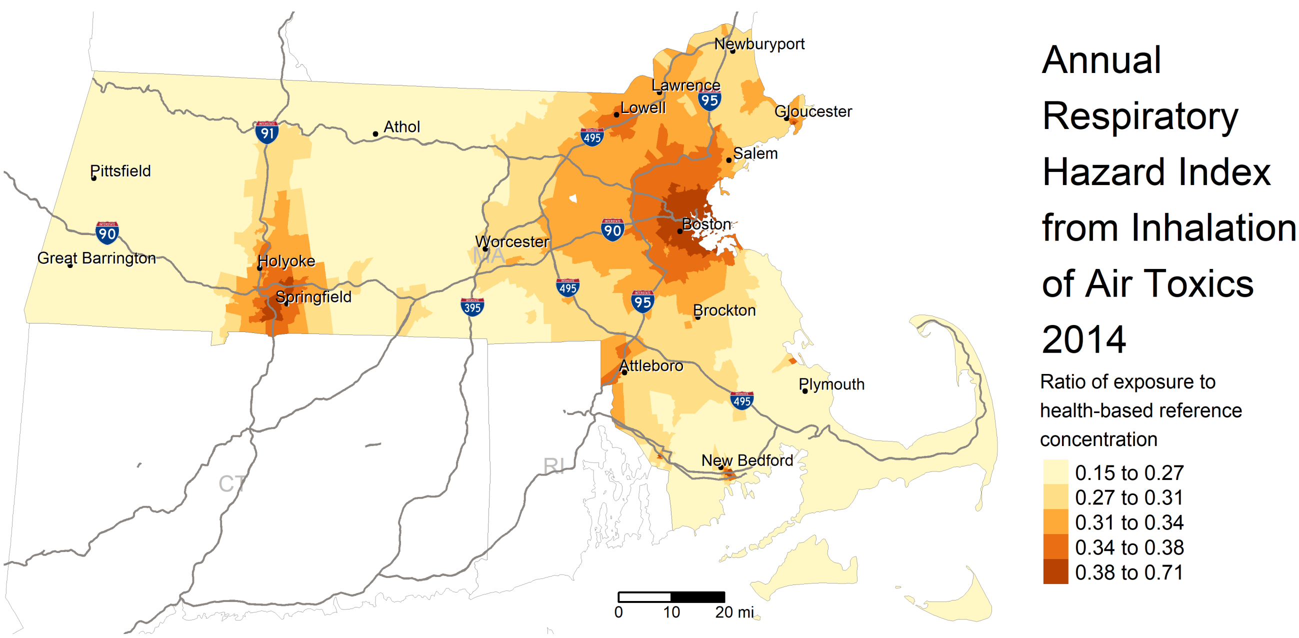

Figure 27: Map of 2014 respiratory hazard index from inhalation of air toxics (expressed as ratio of exposure concentration to health-based reference concentration) across Massachusetts at Census Block Group level.

There appear to be significant spatial clusters of high indices of respiratory hazard index from inhalation of air toxics in Boston (see Figure 28 below).

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

[26] See "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

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

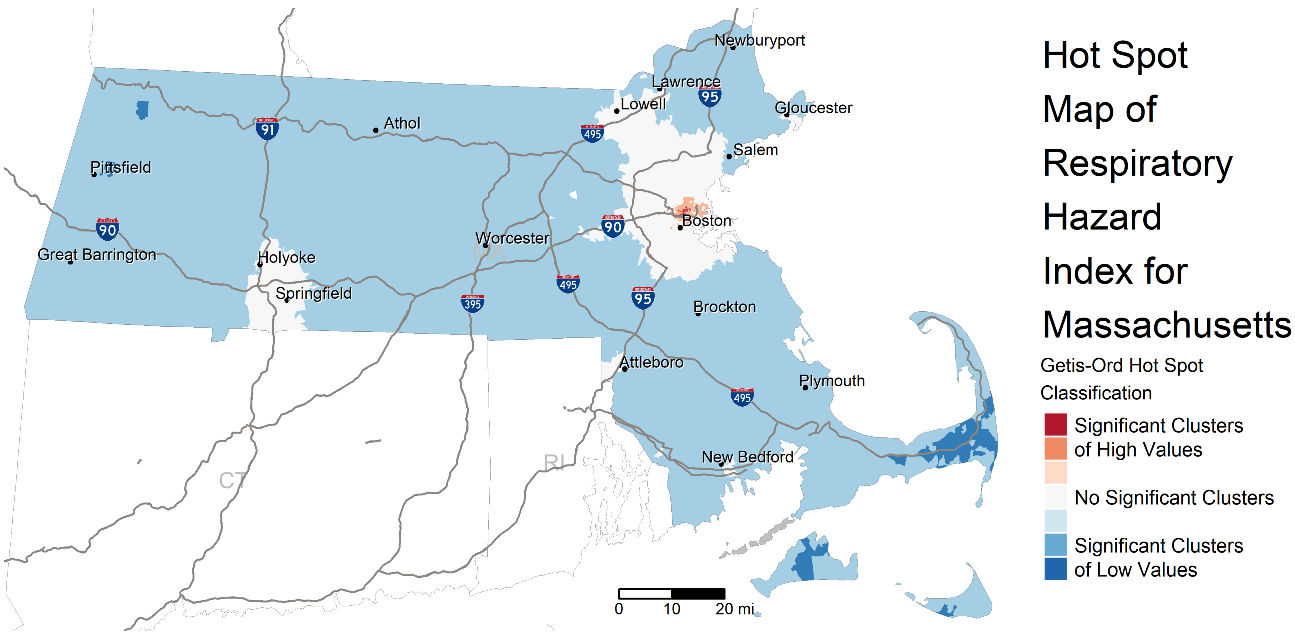

Figure 28: Hot spot map of 2014 respiratory hazard index from inhalation of air toxics at Census Block Group level.

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
0.33	0.32	0.15	0.71

The Block Group with highest respiratory hazard index value in the state is found in Cambridge and the lowest is found in Nantucket. 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 0.32. Half of the state's Block Groups are below the median and half are above the median. Each dot represents an individual Block Group. Large black dots represent outliers or unusually high values. In this case, outliers would be represented by respiratory hazard values greater than 0.5026368, which occur in Boston, Cambridge, Fairhaven, Fall River, and Winthrop Town.

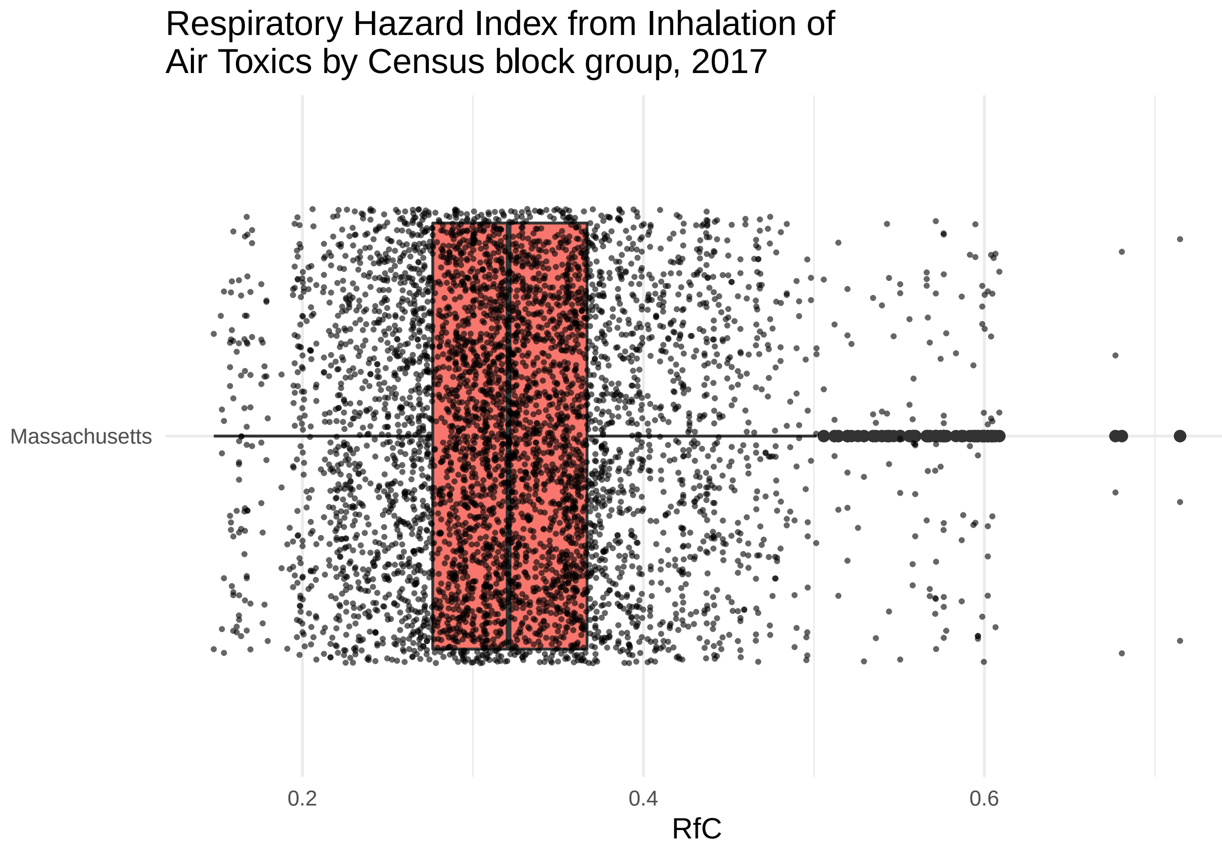

Figure 29: Boxplot of respiratory hazard index from inhalation of air toxics (expressed as ratio of exposure concentration to health-based reference concentration) across Massachusetts by state at Census Block Group level. 1 dot = 1 Block Group.

1.6.1 Respiratory Hazard Index from Inhalation of Air Toxics in Massachusetts 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 the average hazard index for the state. For example, limited English speaking households in Massachusetts, as identified by Massachusetts Environmental Justice policy, experience respiratory hazard indices from inhalation of air toxics that are 19% above the state as a whole. Similarly, People of Color, as identified by Massachusetts Environmental Justice policy, experience lifetime hazard index values more than 11.8% above the state average. By contrast, persons over age 64 are, on average, exposed to respiratory hazard indices over 3.9% below the state average.

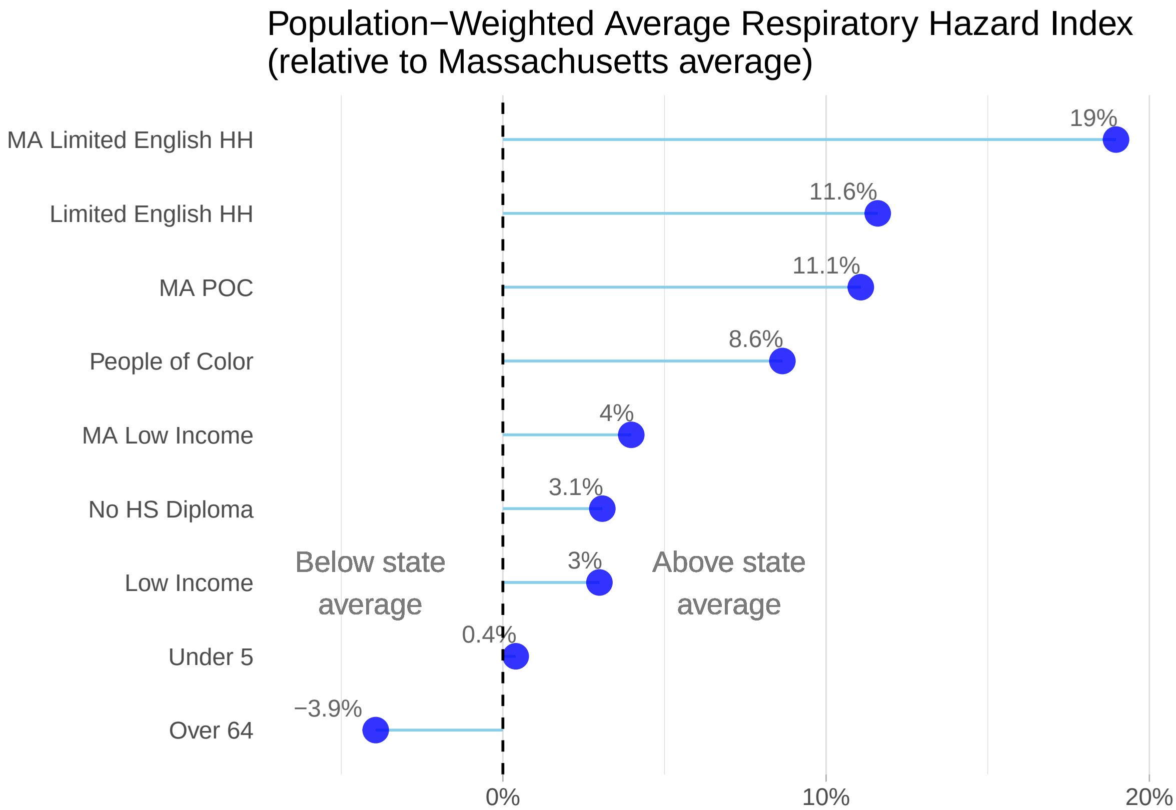

Figure 30: Population-weighted average respiratory hazard index from inhalation of air toxics (expressed as ratio of exposure concentration to health-based reference concentration) across Massachusetts at Census Block Group level relative to the state average.

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 Massachusetts

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 (O_3) 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 all major roadways, especially around Springfield and the eastern half of the state (see Figure 31 below).

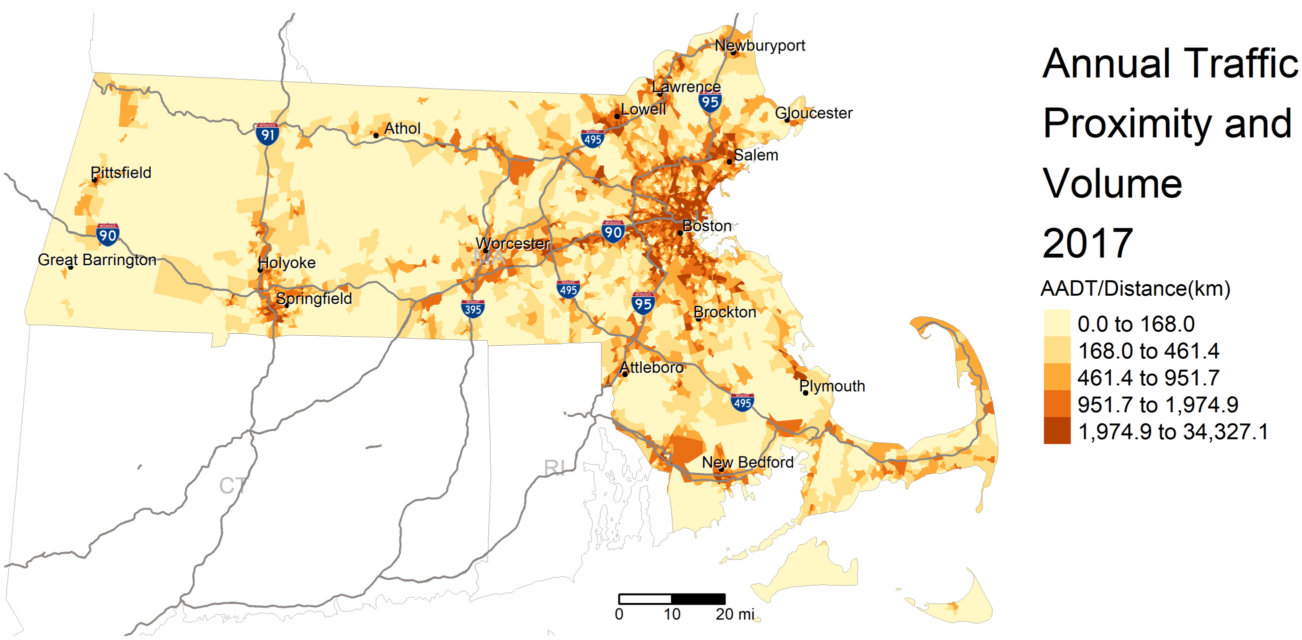

Figure 31: Map of 2017 traffic proximity and volume (calculated as a count of vehicles (average annual daily traffic) at major roads within 500 meters, divided by distance in kilometers (km)) across Massachusetts at Census Block Group level.

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

[29] Measures 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 Boston (see Figure 32 below).

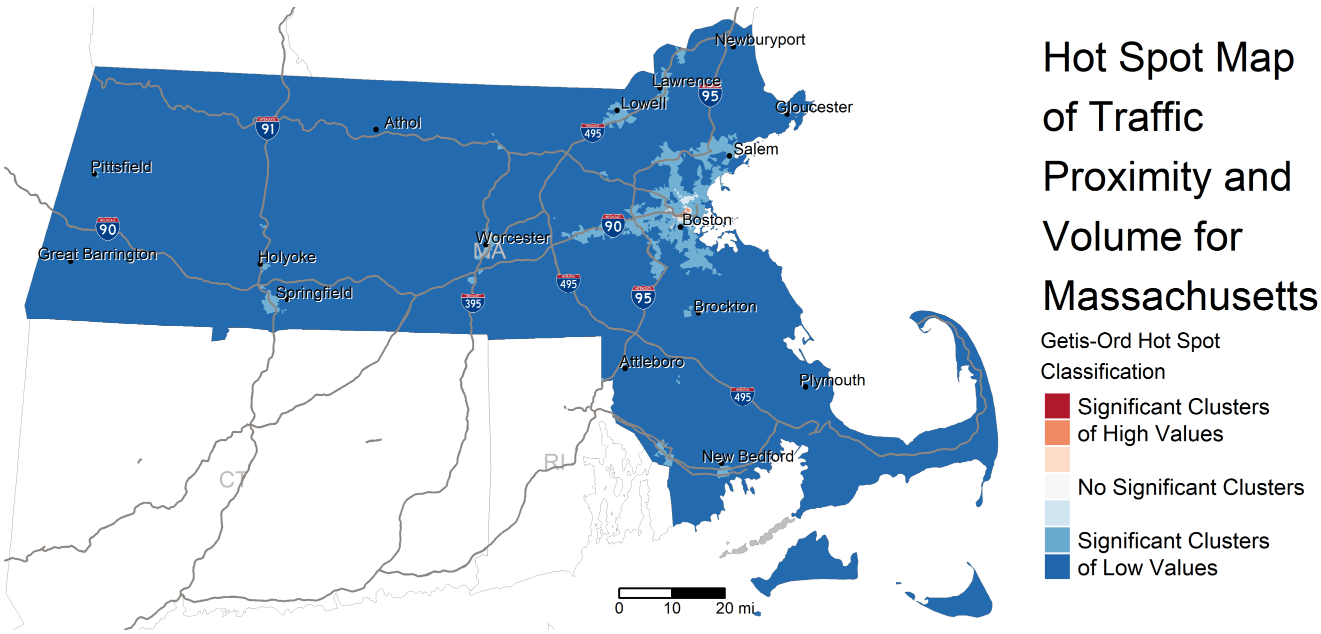

Figure 32: Hot spot map of 2017 traffic proximity and volume at Census Block Group level.

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
1,535	657	0	34,327

The Block Group with highest Traffic Proximity and Volume value in the state is found in Boston and the lowest is found in Stow. 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 657.44. 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. These outliers are concentrated in Boston, and along major highways radiating out to I-95.

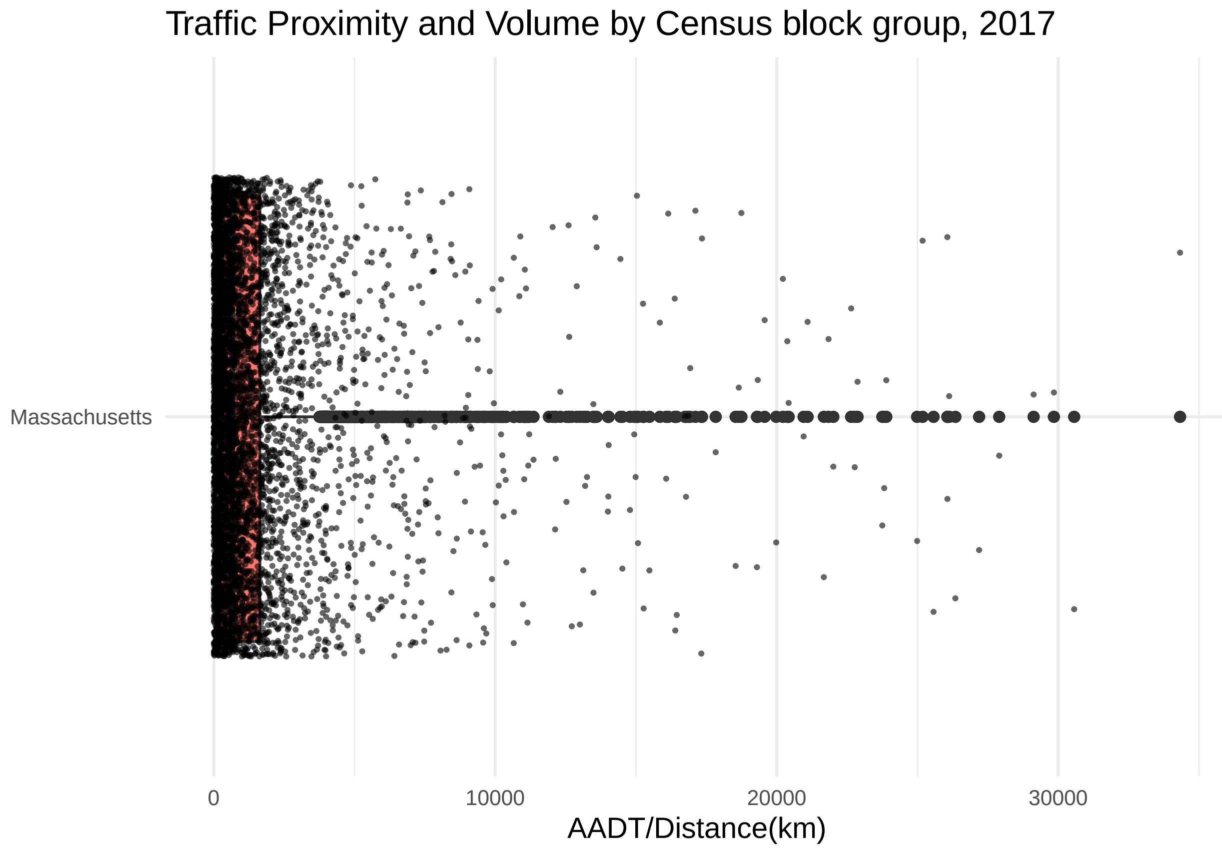

Figure 33: Boxplot of 2017 traffic proximity and volume (calculated as a count of vehicles (average annual daily traffic) at major roads within 500 meters, divided by distance in kilometers (km)) across Massachusetts at Census Block Group level.

1.7.1 Traffic Proximity and Volume Exposure in Massachusetts 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, limited English speaking households, as identified by Massachusetts Environmental Justice policy, are exposed to traffic proximity and volume more than 118% above the state as a whole. Similarly, People of Color, as identified by Massachusetts Environmental Justice policy, are exposed to traffic proximity and volume approximately 55% above the state average. By contrast, persons over age 64 are, on average, are exposed to Traffic Proximity and Volume of more than 20% below the state average.

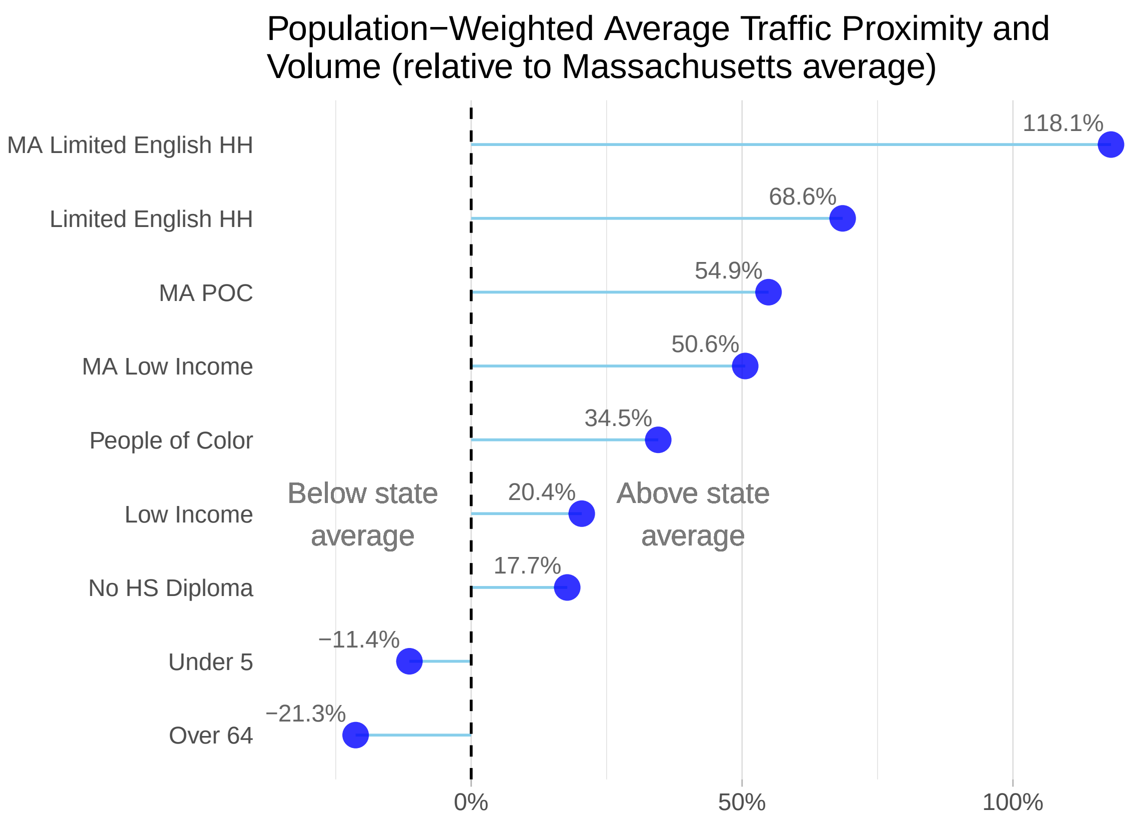

Figure 34: Population-weighted average Traffic Proximity and Volume (calculated as a count of vehicles (average annual daily traffic) at major roads within 500 meters, divided by distance in kilometers (km)) across Massachusetts at Census Block Group level relative to the state average.

There is a moderate positive correlation between the proportions of People of Color and traffic proximity and volume, and a moderate positive correlation with low income persons (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 (O_3)
  - 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 (CO_2) 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 paticulate 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 ($\mu g/m^3$). 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 (O_3)

Ozone (O_3) 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 ($\mu g/m^3$). 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 CO_2 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 (CO_2) Emissions

DARTE CO_2 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 CO_2 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
Under 18	Persons under 18 years of age	B01001: Sex by Age	Block Group
Over 64	Persons over 64 years of age	B01001: Sex by Age	Block Group
Disabled	Persons 18 years+ with a disability	B18101: Sex by Age by Disability Status	Tract
No Car Household	Households with no vehicle available	B08201: Household Size by Vehicles Available	Tract
RI Income	Maine Low Income threshold: 30% or more 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

Table 9: Demographic Variables *(continued)*

Variable	Description	ACS Table ID	Geography
MA Income	Massachusetts Low Income threshold: 25% or more of households with median household incomes below 65% statewide median	B19001: Household Income	Block Group
MA Limited English Household	Massachusetts Language Isolation threshold: 25% or more people in households where all adults speak English less than "very well"	C16002: Household Language by Household Limited English Speaking Status	Block Group
MA POC	Massachusetts POC threshold: 40% or more are persons of Hispanic or Latino origin or persons who are not White OR 25% or more are persons of Hispanic or Latino origin or persons who are not White AND the median household income of the municipality is less than 150% of the statewide median household income	B03002: Hispanic or Latino Origin by Race	Block Group
RI Income	Maine Low Income threshold: highest 15% of block groups with 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
RI POC	Maine POC threshold: highest 15% of block groups with persons of Hispanic or Latino origin or persons who are not White	B03002: Hispanic or Latino Origin by Race	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 PM2.5

BG	PM25	People of Color	Non-POC	TotalPop
BG1	2.5	5	20	25
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, which means that each $PM_{2.5}$ concentration value is associated with a different number 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 $PM_{2.5}$ concentraions 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 Minority populations.

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., Minority pop x $PM_{2.5}$ concentrations) is then divided by the sum of the weights (i.e., total Minority), 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**

Table 12: Block Group Populations and PM2.5 *(continued)*

BG	PM25	People of Color	Non-POC	TotalPop	PM25xTotalPop
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

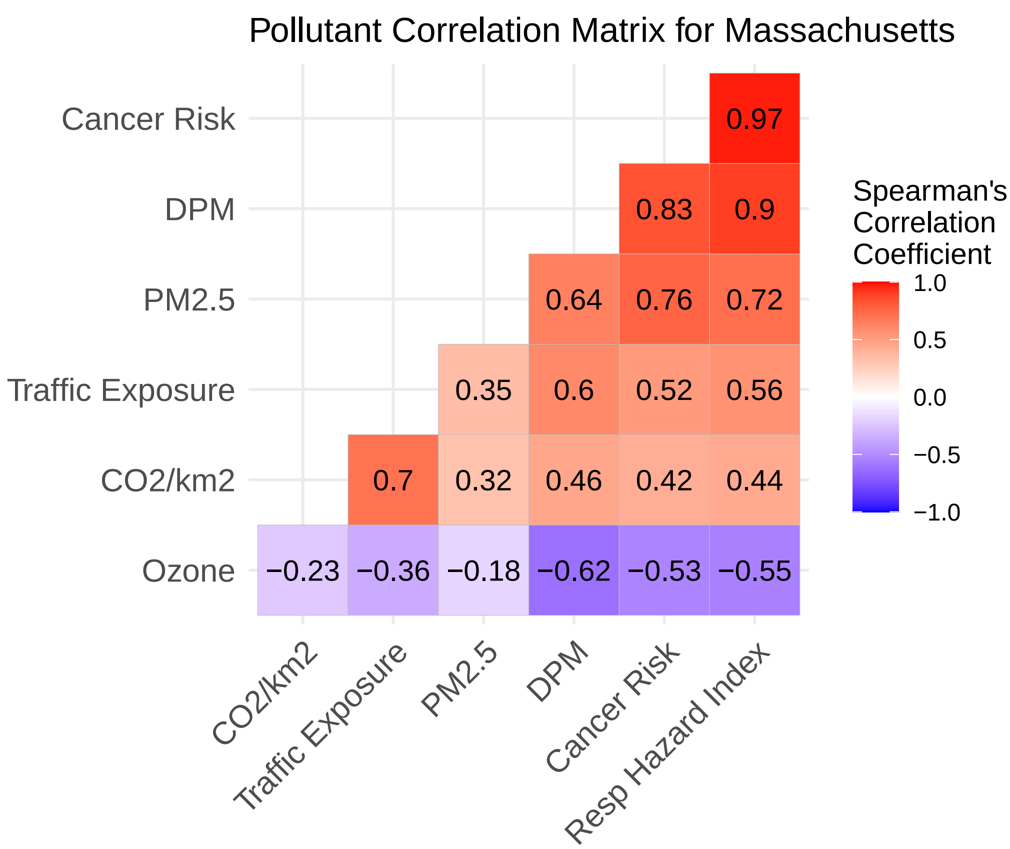

Figure 35: Spearman's correlation matrix of pollutants by Census Block Group.

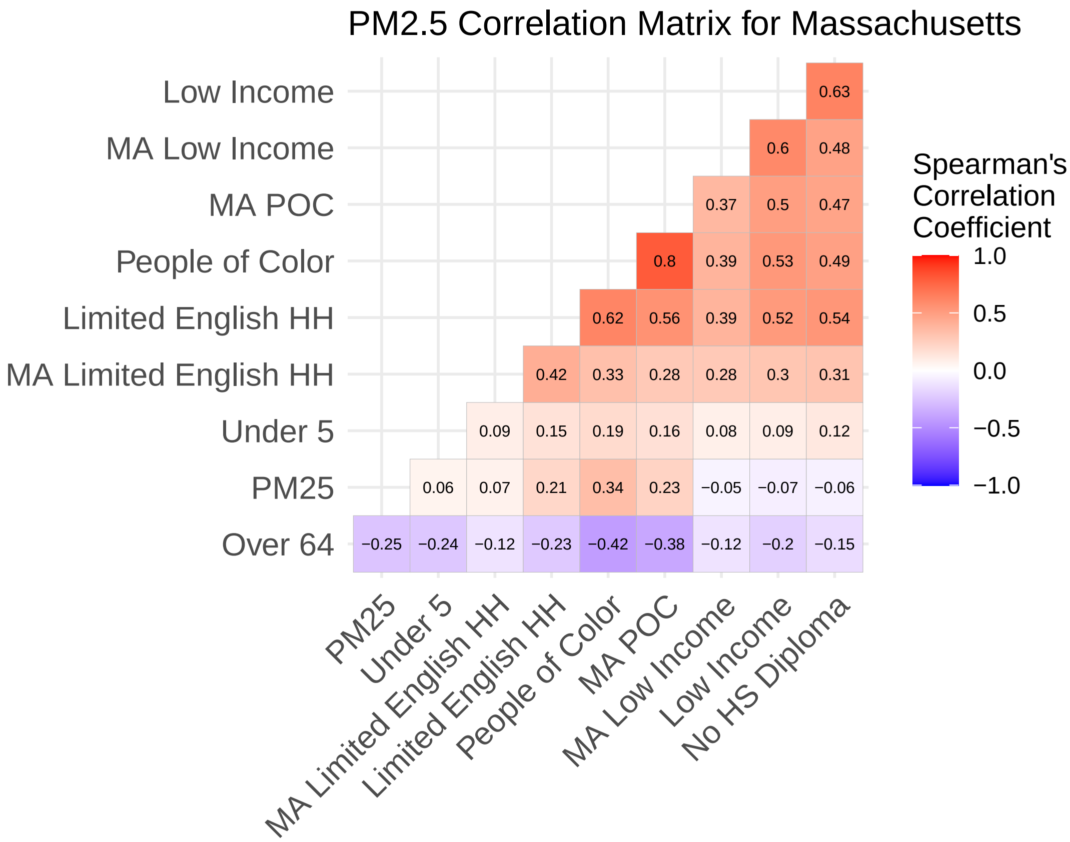

Figure 36: Spearman's correlation matrix of annual PM2.5 concentrations and the proportions of priority populations by Census Block Group.

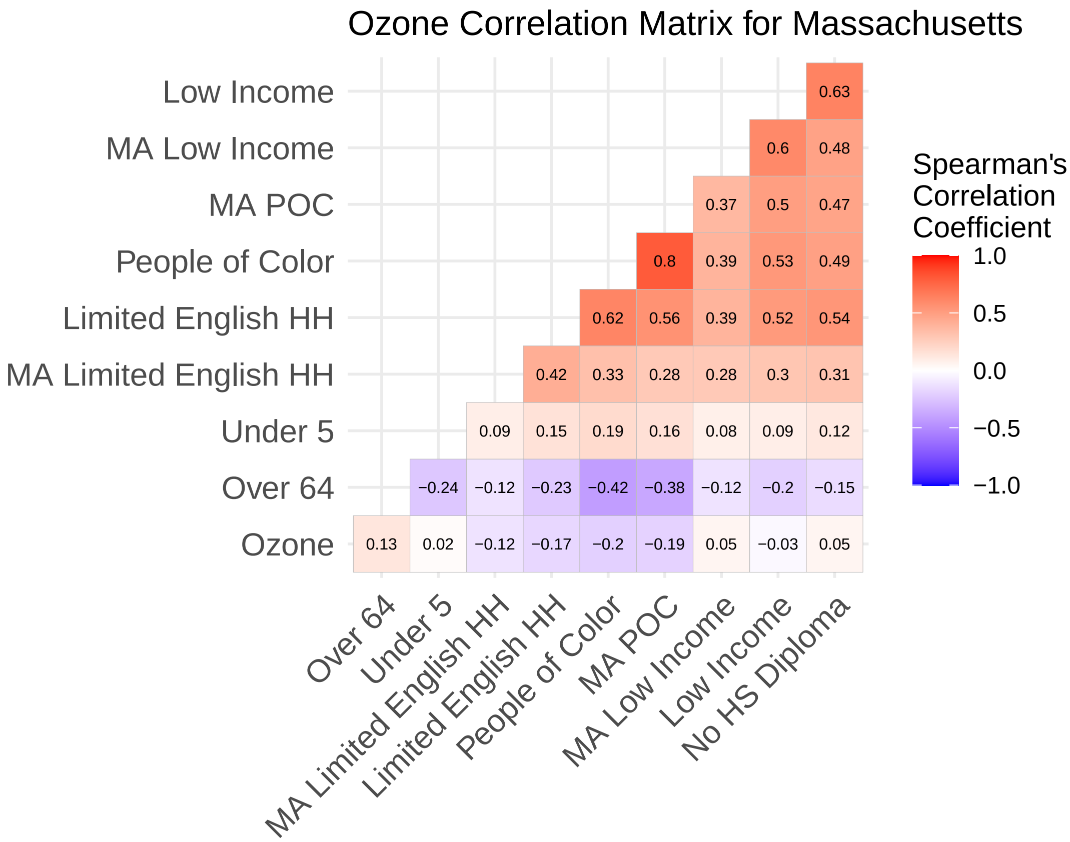

Figure 37: Spearman's correlation matrix of summer Ozone concentrations and the proportions of priority populations by Census Block Group.

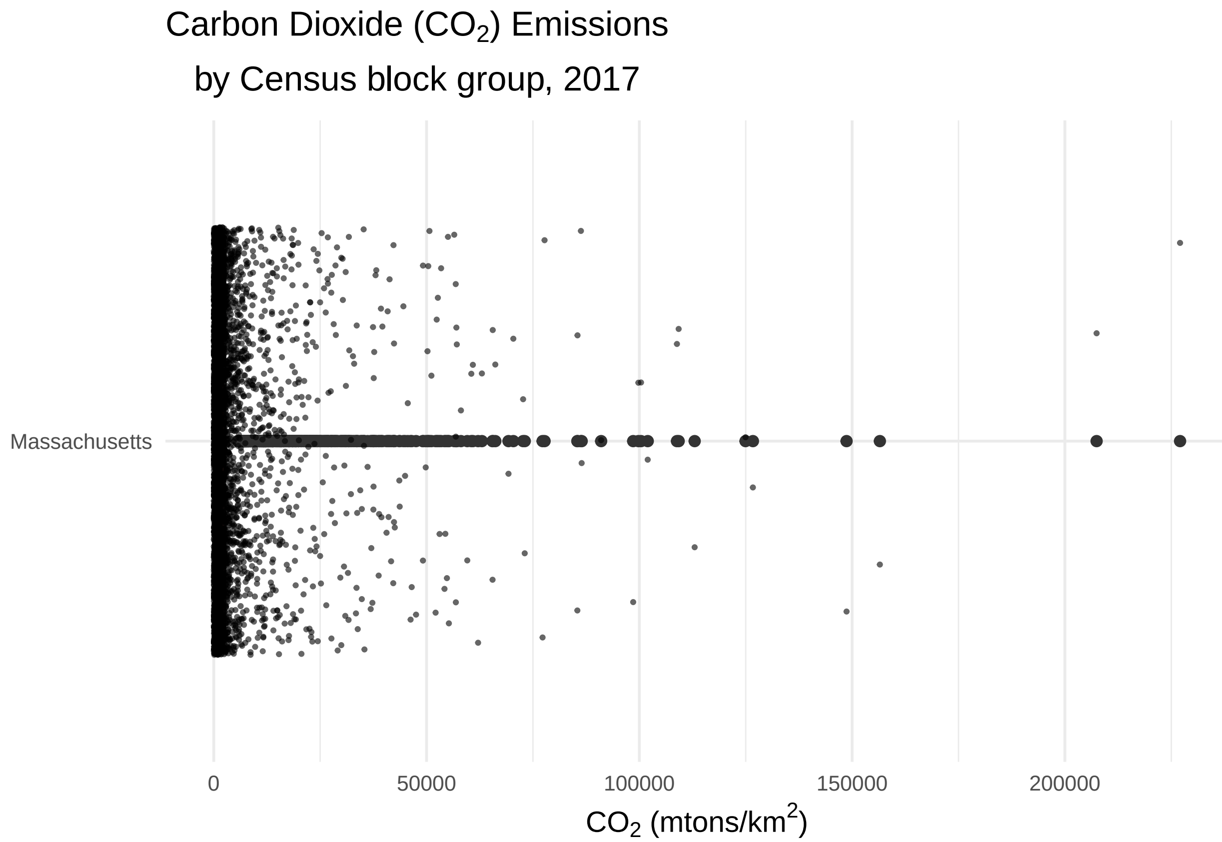

Figure 38: Boxplot of Carbon Dioxoide on-road emissions in metric tons per square kilometer by state at Census Block Group level. 1 dot = 1 Block Group.

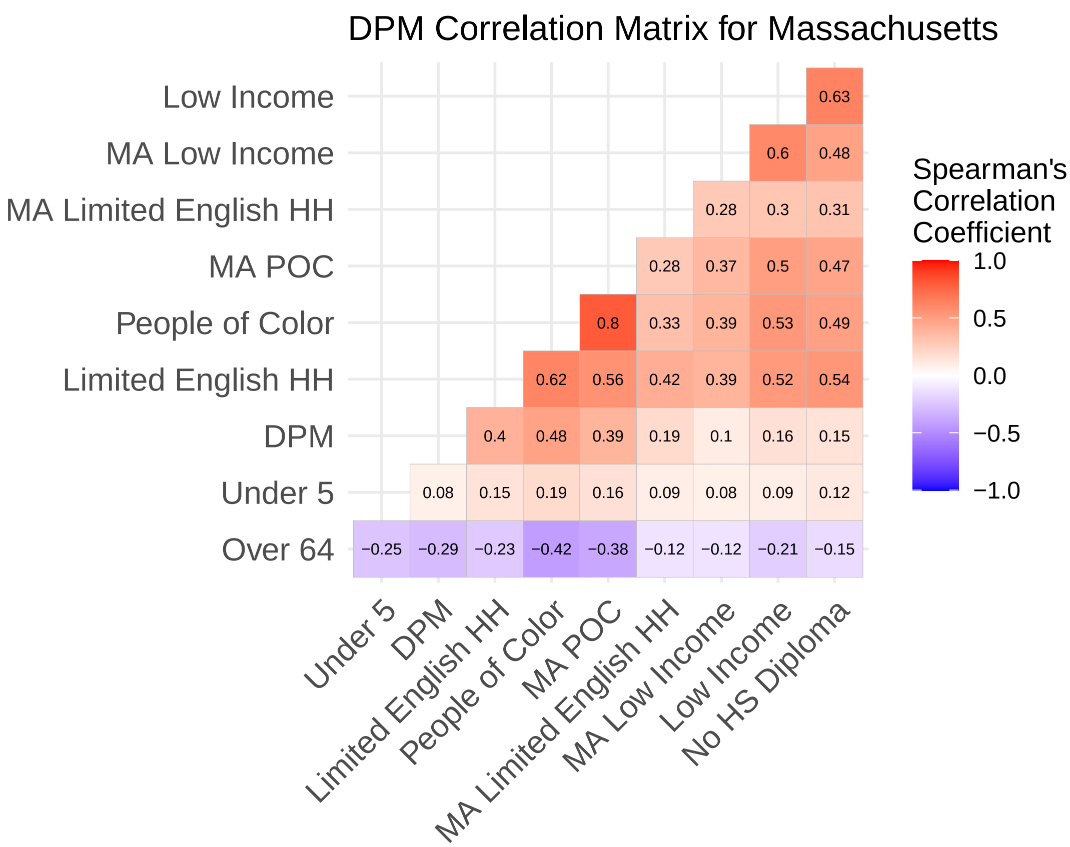

Figure 39: Spearman's correlation matrix of annual average Diesel Particulate Matter concentrations and the proportions of priority populations by Census Block Group.

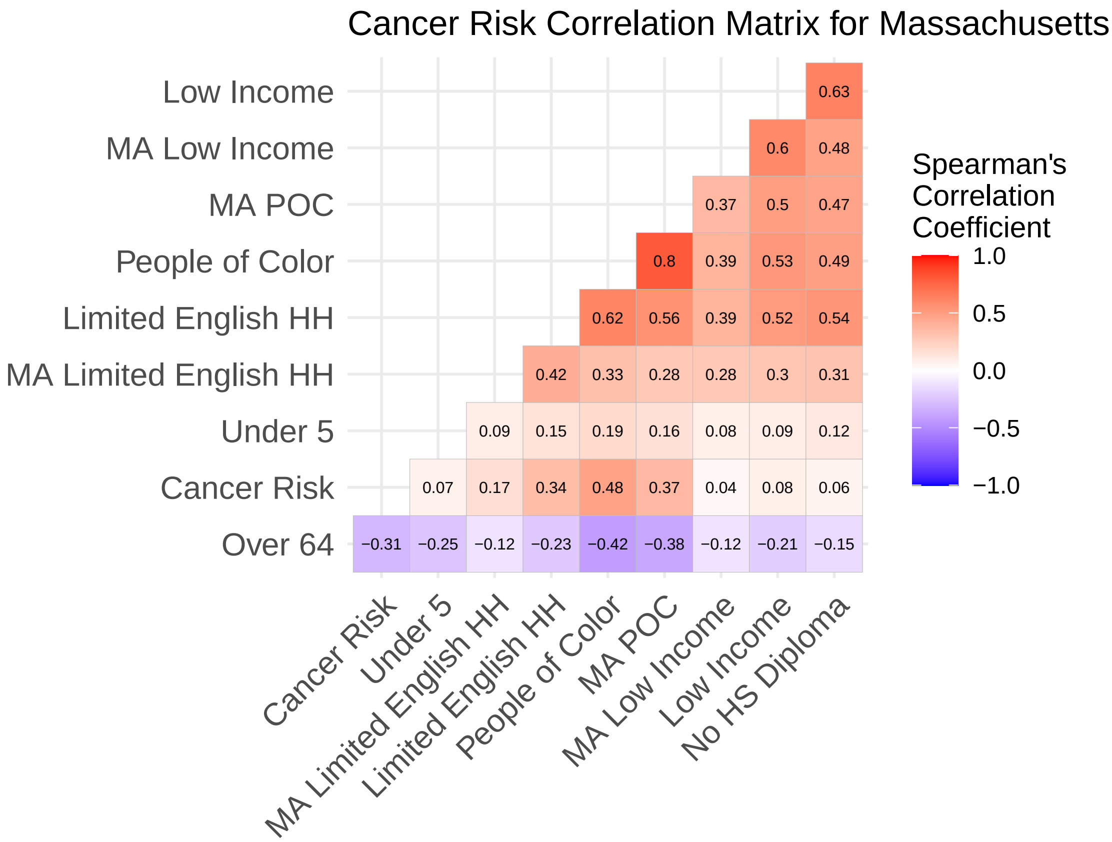

Figure 40: Spearman's correlation matrix of lifetime cancer risk and the proportions of priority populations by Census Block Group.

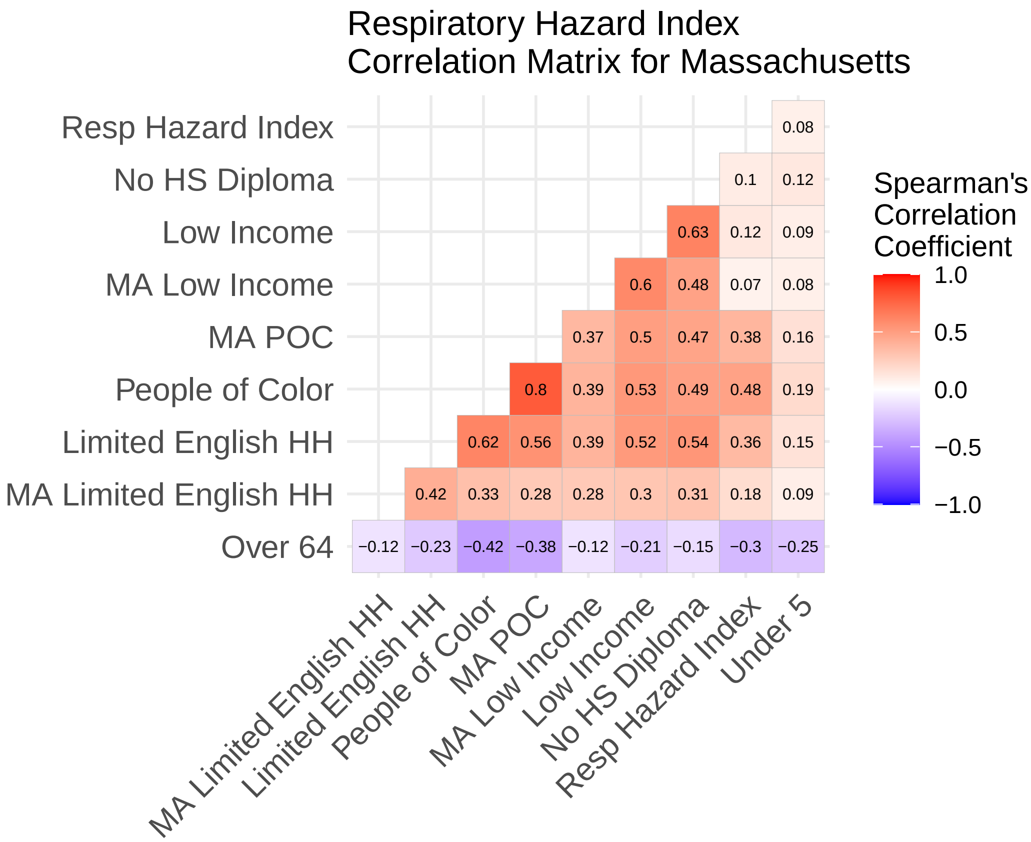

Figure 41: Spearman's correlation matrix of respiratory hazard risk and the proportions of priority populations by Census Block Group.

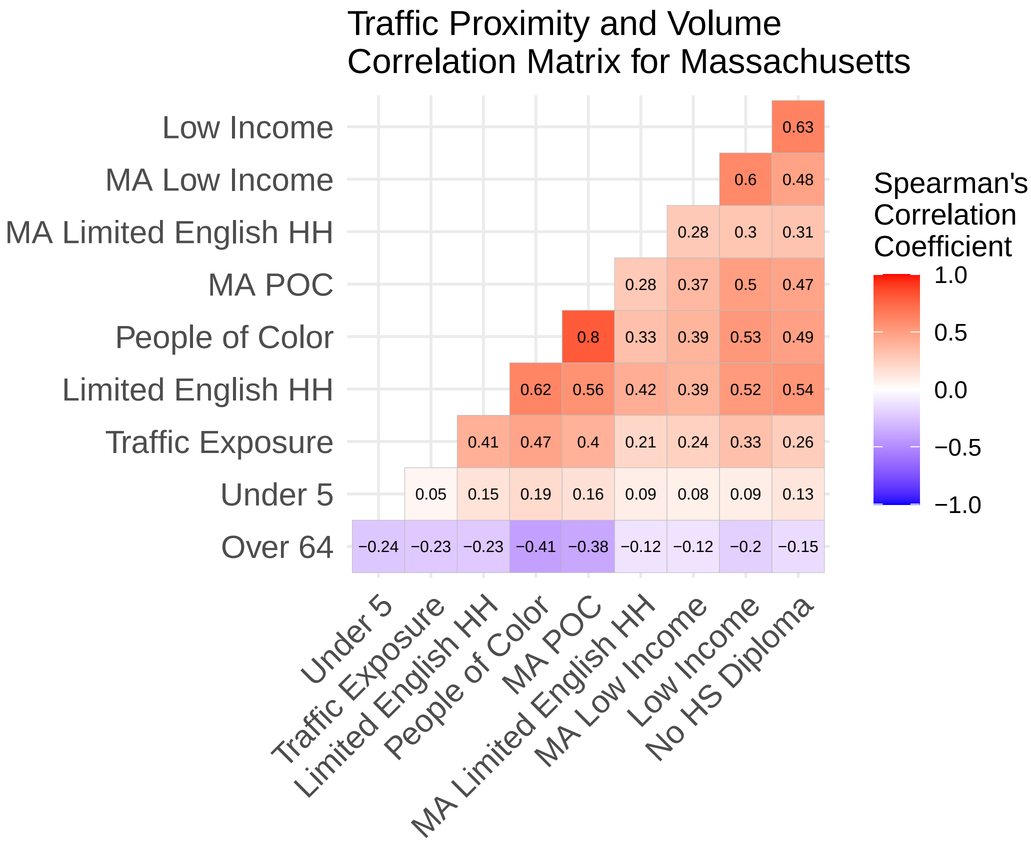

Figure 42: Spearman's correlation matrix of traffic proximity and volume and the proportions of priority populations by Census Block Group.

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Abington	6.25	40.77	0.309	2,058.0	24.3	0.295	581.2
Acton	6.26	40.47	0.283	4,351.1	26.3	0.317	445.7
Acushnet	5.79	40.22	0.385	1,181.5	20.0	0.254	94.7
Adams	5.57	40.86	0.121	1,206.5	17.7	0.199	456.8
Agawam Town	6.51	43.63	0.278	5,763.0	27.6	0.343	301.1
Alford	6.11	42.69	0.143	1,028.5	19.7	0.228	0.2
Amesbury Town	5.70	39.32	0.264	17,684.9	24.4	0.295	561.2
Amherst	5.87	41.71	0.193	2,389.7	23.9	0.290	330.3
Andover	6.03	40.11	0.357	28,736.0	26.8	0.327	622.4
Aquinnah	5.32	41.03	0.192	499.6	15.2	0.166	0.0
Arlington	6.58	39.72	0.484	1,738.1	28.8	0.364	2,275.6
Ashburnham	5.15	40.48	0.119	1,838.2	19.9	0.228	27.6
Ashby	5.17	40.46	0.130	1,155.9	19.7	0.224	25.0
Ashfield	5.53	40.29	0.106	3,987.1	19.1	0.220	0.0
Ashland	6.66	41.23	0.297	9,888.3	25.8	0.312	196.5
Athol	5.36	40.41	0.135	4,453.6	20.9	0.241	221.7
Attleboro	6.84	42.00	0.378	12,354.0	25.4	0.317	642.0
Auburn	6.10	41.63	0.270	24,263.3	22.6	0.269	1,002.0
Avon	6.42	41.09	0.387	12,273.2	24.8	0.307	754.3
Ayer	5.88	40.46	0.247	3,635.1	24.5	0.297	482.3
Barnstable Town	5.46	39.83	0.179	14,483.2	17.2	0.210	408.2
Barre	5.41	41.23	0.123	3,072.7	19.6	0.228	0.0
Becket	5.82	42.30	0.122	21,092.0	18.1	0.205	70.3
Bedford	6.37	40.20	0.338	7,317.5	26.7	0.333	377.3
Belchertown	5.82	42.57	0.147	3,590.9	22.2	0.261	102.7
Bellingham	6.75	41.89	0.272	12,856.8	24.4	0.291	407.3
Belmont	6.63	39.77	0.455	1,909.8	28.8	0.364	1,208.3
Berkley	6.23	41.07	0.278	4,529.4	22.3	0.269	196.6
Berlin	6.24	40.94	0.247	6,226.2	30.9	0.296	223.0
Bernardston	5.55	39.03	0.131	2,922.8	22.0	0.257	117.6
Beverly	5.89	40.18	0.344	4,959.2	23.7	0.296	761.9
Billerica	6.24	40.19	0.371	4,712.9	27.4	0.337	567.2
Blackstone	6.70	42.02	0.261	2,013.0	24.4	0.290	115.9
Blandford	5.81	43.03	0.116	29,569.2	18.9	0.216	240.4
Bolton	6.15	40.74	0.247	5,881.1	25.1	0.299	180.9
Boston	6.67	39.57	0.755	11,501.7	31.4	0.435	3,808.7
Bourne	5.58	40.00	0.214	8,094.2	18.9	0.235	240.8
Boxborough	6.15	40.56	0.273	39,282.6	25.4	0.308	366.7
Boxford	5.88	39.98	0.284	12,687.8	25.4	0.317	254.4
Boylston	6.15	41.08	0.200	6,125.5	24.2	0.285	146.5
Braintree Town	6.45	40.53	0.440	24,730.4	26.1	0.330	1,269.2

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Brewster	5.32	39.95	0.130	3,303.0	15.7	0.167	104.2
Brimfield	5.82	42.83	0.151	9,693.6	20.3	0.236	57.3
Brockton	6.31	41.01	0.349	4,105.0	24.5	0.301	860.1
Brookfield	5.74	42.22	0.157	1,759.7	20.5	0.237	175.9
Brookline	6.74	39.65	0.634	1,721.6	30.6	0.407	2,011.6
Buckland	5.45	39.65	0.109	2,655.5	19.2	0.216	11.4
Burlington	6.37	40.03	0.424	46,149.9	27.5	0.343	1,096.5
Cambridge	6.66	39.37	0.767	2,419.4	31.7	0.480	2,921.5
Canton	6.61	41.29	0.397	57,185.7	26.3	0.327	565.7
Carlisle	6.24	40.30	0.272	1,306.1	26.2	0.315	44.1
Carver	5.80	40.10	0.211	3,425.1	19.8	0.235	46.3
Charlemont	NA	NA	NA	NA	NA	NA	NA
Charlton	5.95	42.06	0.182	28,449.3	21.5	0.254	288.2
Chatham	5.27	40.27	0.148	1,962.0	15.3	0.158	394.1
Chelmsford	6.09	40.26	0.377	23,294.5	27.1	0.336	1,158.6
Chelsea	6.50	39.25	1.044	3,452.0	31.0	0.445	5,463.5
Cheshire	5.71	41.22	0.110	1,916.3	17.9	0.201	100.6
Chester	5.81	43.03	0.116	3,746.1	18.9	0.216	0.1
Chesterfield	5.62	41.42	0.104	3,590.6	18.2	0.205	0.2
Chicopee	6.34	43.18	0.319	19,482.8	28.4	0.367	548.1
Chilmark	5.32	41.03	0.192	881.1	15.2	0.166	0.0
Clarksburg	5.41	40.44	0.112	830.4	17.2	0.193	10.8
Clinton	6.07	40.88	0.191	1,773.0	24.1	0.287	264.3
Cohasset	6.05	40.67	0.239	2,777.5	20.6	0.251	111.2
Colrain	5.33	39.77	0.094	3,117.5	17.9	0.200	0.0
Concord	6.38	40.41	0.286	3,541.7	26.2	0.316	787.0
Conway	5.53	40.29	0.106	4,039.7	19.1	0.220	0.5
Cummington	5.60	41.43	0.095	7,058.6	17.4	0.195	78.6
Dalton	5.86	41.59	0.118	905.0	18.6	0.208	112.0
Danvers	5.98	40.00	0.402	19,870.7	26.6	0.336	1,391.6
Dartmouth	5.69	40.70	0.306	7,547.3	18.8	0.232	100.2
Dedham	6.72	40.81	0.475	63,688.0	28.1	0.363	2,369.0
Deerfield	5.64	40.03	0.180	19,381.8	22.4	0.271	223.6
Dennis	5.37	39.81	0.147	8,065.4	16.2	0.191	319.7
Dighton	6.41	41.53	0.267	1,646.8	22.1	0.266	107.1
Douglas	6.28	42.06	0.164	2,520.6	21.3	0.242	48.3
Dover	6.73	41.12	0.297	937.1	25.4	0.308	49.6
Dracut	5.97	40.24	0.299	2,345.5	27.0	0.324	239.9
Dudley	6.03	42.25	0.180	3,114.4	21.9	0.255	134.1
Dunstable	5.76	40.30	0.225	664.4	24.6	0.292	92.2
Duxbury	5.81	40.53	0.213	11,303.0	20.7	0.244	341.3
East Bridgewater	6.14	40.72	0.266	2,302.7	23.1	0.276	216.4
East Brookfield	5.76	42.00	0.160	2,006.3	20.4	0.238	212.4

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
East Longmeadow	6.49	43.71	0.239	4,727.9	27.9	0.333	199.2
Eastham	5.28	40.47	0.131	2,964.4	15.3	0.161	478.2
Easthampton Town	6.09	42.34	0.210	5,325.1	24.6	0.296	246.9
Easton	6.47	41.30	0.291	4,348.6	24.0	0.290	214.2
Edgartown	5.29	40.75	0.148	727.6	15.2	0.159	47.4
Egremont	NA	NA	NA	NA	NA	NA	NA
Erving	5.52	39.83	0.122	7,927.9	21.7	0.254	370.6
Essex	5.73	40.71	0.270	1,891.2	22.6	0.273	171.7
Everett	6.51	39.31	1.280	3,787.4	30.6	0.455	4,649.3
Fairhaven	5.69	40.28	0.978	16,156.3	19.6	0.293	786.4
Fall River	5.95	41.27	0.282	24,612.4	21.4	0.271	1,207.9
Falmouth	5.53	40.64	0.188	5,633.3	17.4	0.211	294.9
Fitchburg	5.41	40.58	0.175	3,800.6	21.6	0.256	394.1
Florida	5.45	40.58	0.106	2,662.5	17.2	0.191	26.1
Foxborough	6.70	41.71	0.332	28,968.9	24.9	0.304	723.0
Framingham	6.62	40.99	0.359	11,259.4	27.0	0.326	1,190.9
Franklin Town	6.78	41.85	0.273	18,884.8	24.3	0.290	221.0
Freetown	6.00	40.74	0.225	6,553.3	20.5	0.244	301.8
Gardner	5.28	40.63	0.152	4,796.6	20.2	0.235	372.5
Georgetown	5.80	39.92	0.279	21,076.6	25.0	0.303	376.2
Gill	5.55	39.03	0.131	3,590.5	22.0	0.257	135.9
Gloucester	5.61	41.16	0.487	6,169.8	22.9	0.305	261.6
Goshen	5.64	41.04	0.107	4,488.2	19.0	0.219	34.2
Gosnold	5.32	41.03	0.192	948.6	15.2	0.166	0.0
Grafton	6.42	41.51	0.238	37,070.1	24.7	0.289	537.0
Granby	6.09	42.64	0.199	2,977.7	25.2	0.311	110.1
Granville	5.81	43.03	0.116	6,724.6	18.9	0.216	0.1
Great Barrington	6.02	42.64	0.131	5,111.5	19.4	0.226	113.2
Greenfield Town	5.54	39.25	0.177	16,235.9	21.6	0.257	355.4
Groton	5.77	40.39	0.216	6,042.7	23.9	0.283	236.4
Groveland	5.78	39.79	0.258	2,836.0	25.5	0.303	142.9
Hadley	5.96	41.67	0.229	13,043.4	25.4	0.308	156.0
Halifax	6.01	40.47	0.230	3,550.6	21.6	0.257	90.9
Hamilton	5.82	40.32	0.248	2,122.3	23.2	0.283	136.9
Hampden	6.27	43.59	0.180	719.5	23.0	0.271	10.6
Hancock	6.05	41.67	0.128	2,951.5	19.1	0.216	5.0
Hanover	6.07	40.59	0.260	9,807.9	22.7	0.271	228.3
Hanson	6.06	40.58	0.243	2,866.1	22.3	0.264	124.2
Hardwick	5.49	41.78	0.128	5,280.2	20.0	0.230	16.6
Harvard	6.02	40.57	0.259	3,600.3	24.7	0.301	164.5

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Harwich	5.32	39.97	0.173	13,588.1	15.6	0.165	368.7
Hatfield	5.87	41.30	0.256	7,920.8	24.4	0.300	146.1
Haverhill	5.75	39.74	0.289	21,273.8	26.0	0.315	587.6
Hawley	5.33	39.77	0.094	7,212.7	17.9	0.200	19.6
Heath	5.33	39.77	0.094	5,524.8	17.9	0.200	0.1
Hingham	6.20	40.38	0.331	11,222.9	24.9	0.308	301.4
Hinsdale	5.83	41.72	0.107	2,669.5	18.5	0.206	12.2
Holbrook	6.37	40.86	0.337	2,163.4	25.0	0.308	418.4
Holden	5.84	41.14	0.166	4,077.5	21.9	0.254	189.6
Holland	5.90	43.02	0.144	823.2	20.5	0.238	13.4
Holliston	6.71	41.47	0.260	2,424.2	24.9	0.295	233.0
Holyoke	6.27	42.79	0.295	13,829.0	27.3	0.336	891.3
Hopedale	6.65	41.73	0.229	2,849.5	23.6	0.283	282.3
Hopkinton	6.62	41.40	0.279	47,553.4	24.8	0.295	360.4
Hubbardston	5.41	40.92	0.119	2,719.7	19.6	0.224	0.4
Hudson	6.35	40.84	0.285	5,187.6	26.4	0.312	151.1
Hull	6.22	39.97	0.362	2,353.4	26.6	0.338	227.5
Huntington	5.76	42.16	0.113	3,731.2	18.8	0.213	0.3
Ipswich	5.75	40.48	0.248	3,141.0	24.7	0.305	290.7
Kingston	5.83	40.35	0.227	13,552.2	20.7	0.249	348.1
Lakeville	6.02	40.51	0.243	7,625.1	21.0	0.255	239.0
Lancaster	5.92	40.68	0.206	20,862.4	23.6	0.286	903.4
Lanesborough	5.90	41.51	0.111	3,203.4	18.2	0.204	118.5
Lawrence	5.91	40.06	0.360	9,635.8	26.6	0.327	1,457.8
Lee	5.97	42.39	0.163	23,791.8	19.1	0.225	343.0
Leicester	5.93	41.56	0.179	2,575.4	21.6	0.252	235.8
Lenox	6.09	42.09	0.121	2,367.5	19.2	0.217	436.7
Leominster	5.66	40.67	0.200	6,941.9	22.3	0.266	428.0
Leverett	5.56	41.05	0.124	3,892.7	21.4	0.251	1.1
Lexington	6.51	40.03	0.467	29,427.5	28.2	0.357	1,147.0
Leyden	5.55	39.03	0.131	23,207.2	22.0	0.257	38.5
Lincoln	6.50	40.31	0.308	3,785.4	26.1	0.319	374.3
Littleton	6.08	40.44	0.315	47,677.7	25.7	0.315	681.4
Longmeadow	6.58	43.77	0.306	10,671.9	29.4	0.362	511.7
Lowell	6.05	40.24	0.407	4,575.5	27.9	0.348	1,687.7
Ludlow	6.17	43.12	0.205	15,999.4	26.6	0.329	284.1
Lunenburg	5.58	40.51	0.198	2,461.2	22.6	0.268	86.9
Lynn	6.11	39.76	0.457	1,323.4	28.2	0.351	1,287.7
Lynnfield	6.15	39.88	0.416	15,125.8	27.2	0.343	770.2
Malden	6.45	39.43	0.649	907.3	29.0	0.384	1,297.0
Manchester-by-the-Sea	5.76	40.64	0.245	5,192.4	22.5	0.273	321.7
Mansfield	6.68	41.67	0.324	19,959.6	24.7	0.303	431.2
Marblehead	6.00	39.90	0.340	748.4	23.1	0.290	581.2
Marion	5.70	40.24	0.239	12,813.6	17.7	0.216	201.6

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Marlborough	6.44	40.96	0.342	31,960.8	27.7	0.321	624.4
Marshfield	5.81	40.69	0.215	2,195.8	20.7	0.248	161.7
Mashpee	5.50	40.21	0.172	2,568.8	17.4	0.216	181.2
Mattapoisett	5.69	40.27	0.273	13,520.6	18.7	0.224	256.3
Maynard	6.37	40.63	0.272	3,325.1	26.0	0.314	878.2
Medfield	6.73	41.46	0.310	3,359.5	25.2	0.305	224.8
Medford	6.53	39.52	0.627	12,530.5	29.7	0.389	3,389.7
Medway	6.74	41.63	0.261	6,818.4	24.9	0.295	194.1
Melrose	6.37	39.57	0.531	475.3	28.2	0.357	378.8
Mendon	6.65	41.85	0.222	1,645.2	23.3	0.275	141.0
Merrimac	5.70	39.40	0.258	32,411.5	24.7	0.301	413.9
Methuen Town	5.86	40.06	0.325	9,569.0	26.4	0.322	964.7
Middleborough	5.95	40.31	0.246	42,563.3	21.2	0.261	265.3
Middlefield	NA	NA	NA	NA	NA	NA	NA
Middleton	6.01	39.99	0.319	4,655.3	25.8	0.318	292.5
Milford	6.67	41.63	0.258	22,391.7	24.2	0.299	620.1
Millbury	6.24	41.61	0.245	32,936.1	23.4	0.275	707.4
Millis	6.74	41.55	0.285	2,454.9	25.3	0.302	165.0
Millville	6.62	42.02	0.242	1,885.4	22.9	0.265	93.8
Milton	6.65	40.54	0.509	32,522.3	28.6	0.364	1,368.7
Monroe	NA	NA	NA	NA	NA	NA	NA
Monson	6.04	43.29	0.153	2,797.7	21.7	0.254	57.4
Montague	5.63	39.88	0.141	2,026.5	22.3	0.268	143.5
Monterey	5.87	42.77	0.102	4,014.9	18.1	0.205	0.0
Montgomery	5.81	43.03	0.116	1,198.6	18.9	0.216	6.7
Mount Washington	6.11	42.69	0.143	3,962.9	19.7	0.228	0.1
Nahant	6.15	39.54	0.441	513.0	25.5	0.337	310.4
Nantucket	5.13	40.67	0.154	1,561.2	14.6	0.154	92.2
Natick	6.70	40.95	0.360	8,763.7	26.9	0.326	927.5
Needham	6.73	40.66	0.393	12,550.9	26.8	0.331	752.3
New Ashford	6.05	41.67	0.128	1,392.1	19.1	0.216	0.0
New Bedford	5.76	40.37	0.749	9,579.2	20.0	0.273	1,318.9
New Braintree	5.49	41.78	0.128	2,851.6	20.0	0.230	0.8
New Marlborough	5.86	43.34	0.109	2,996.4	18.6	0.211	0.1
New Salem	5.56	41.05	0.124	6,056.4	21.4	0.251	1.4
Newbury	5.71	40.01	0.228	10,418.8	23.3	0.283	219.3
Newburyport	5.70	39.72	0.278	11,012.9	24.4	0.295	913.8
Newton	6.73	40.11	0.478	6,487.7	28.9	0.366	1,956.5
Norfolk	6.75	41.73	0.295	3,929.8	24.6	0.299	66.2
North Adams	5.48	40.61	0.119	1,624.1	17.5	0.198	375.3

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
North Andover	5.94	40.01	0.299	3,139.3	25.9	0.314	326.7
North Attleborough	6.88	42.03	0.377	20,717.8	25.9	0.325	468.1
North Brookfield	5.65	41.84	0.147	2,298.8	19.9	0.231	33.4
North Reading	6.12	40.01	0.345	3,161.1	26.7	0.328	211.5
Northampton	5.94	41.80	0.225	10,277.0	22.8	0.273	442.9
Northborough	6.35	41.13	0.266	23,126.9	28.7	0.296	355.0
Northbridge	6.47	41.74	0.200	2,846.7	22.7	0.265	199.3
Northfield	5.56	39.28	0.120	3,444.8	21.9	0.256	0.2
Norton	6.61	41.58	0.277	9,725.9	24.0	0.291	305.1
Norwell	6.02	40.61	0.257	5,522.9	22.5	0.271	354.5
Norwood	6.69	41.34	0.383	9,916.8	26.0	0.325	1,135.9
Oak Bluffs	5.38	40.90	0.237	314.2	15.6	0.169	36.8
Oakham	5.55	41.44	0.122	3,191.5	19.5	0.225	0.1
Orange	5.42	40.13	0.120	3,558.3	20.9	0.244	178.7
Orleans	5.29	40.29	0.146	6,362.9	15.0	0.155	213.7
Otis	5.78	43.22	0.117	8,809.8	18.1	0.204	7.5
Oxford	6.11	41.90	0.198	14,190.6	21.9	0.254	339.3
Palmer Town	5.86	42.92	0.180	27,389.8	22.2	0.268	303.8
Paxton	5.77	41.34	0.173	5,257.6	21.1	0.242	130.8
Peabody	6.07	39.90	0.442	23,720.4	27.0	0.344	1,699.7
Pelham	5.69	41.73	0.124	3,039.2	21.6	0.255	7.5
Pembroke	5.95	40.53	0.237	5,470.4	21.5	0.255	73.1
Pepperell	5.56	40.33	0.163	1,934.5	22.5	0.262	177.4
Peru	5.66	41.38	0.101	2,160.9	17.6	0.194	0.1
Petersham	5.39	40.99	0.123	8,039.9	20.3	0.233	0.0
Phillipston	5.39	40.99	0.123	5,510.1	20.3	0.233	49.1
Pittsfield	6.08	41.81	0.140	1,260.9	19.5	0.223	254.0
Plainfield	5.60	41.43	0.095	3,603.4	17.4	0.195	0.9
Plainville	6.83	41.94	0.334	18,919.7	25.1	0.311	434.1
Plymouth	5.66	40.13	0.204	7,390.5	19.2	0.234	263.0
Plympton	5.91	40.34	0.216	291.0	20.7	0.244	24.5
Princeton	5.60	40.89	0.133	3,618.4	20.4	0.233	1.3
Provincetown	5.26	41.28	0.159	9,420.1	16.6	0.213	651.9
Quincy	6.54	40.08	0.550	36,987.0	29.6	0.385	1,109.4
Raynham	6.29	40.96	0.322	26,853.9	23.3	0.287	318.5
Reading	6.24	39.93	0.463	9,467.2	28.2	0.356	1,055.8
Rehoboth	6.63	42.02	0.288	3,424.0	23.3	0.281	80.0
Revere	6.37	39.38	0.612	4,599.7	29.6	0.391	3,470.7
Richmond	6.05	41.67	0.128	1,522.7	19.1	0.216	3.4
Rochester	5.79	40.13	0.221	5,603.1	19.8	0.234	29.6
Rockland	6.18	40.64	0.284	4,553.9	23.6	0.280	411.8

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Rockport	5.51	41.45	0.329	2,886.0	21.7	0.267	327.2
Rowe	5.33	39.77	0.094	5,275.9	17.9	0.200	34.3
Rowley	5.76	40.12	0.247	15,788.8	23.8	0.290	154.1
Royalston	5.22	40.07	0.104	6,291.0	19.4	0.223	0.0
Russell	5.81	43.03	0.116	25,308.1	18.9	0.216	224.1
Rutland	5.58	41.18	0.128	5,923.6	19.5	0.222	104.6
Salem	6.01	39.89	0.407	1,638.1	24.6	0.314	1,813.3
Salisbury	5.69	39.55	0.271	24,277.2	24.2	0.297	496.7
Sandisfield	5.78	43.22	0.117	5,817.6	18.1	0.204	0.0
Sandwich	5.52	39.84	0.183	11,417.2	18.0	0.222	238.6
Saugus	6.24	39.65	0.523	5,029.4	28.4	0.361	1,484.3
Savoy	5.45	40.58	0.106	3,879.4	17.2	0.191	0.1
Scituate	5.91	40.84	0.230	1,823.7	20.5	0.250	120.2
Seekonk	6.80	42.35	0.403	13,327.6	25.2	0.318	363.7
Sharon	6.62	41.53	0.319	18,532.1	24.8	0.303	491.1
Sheffield	5.97	43.14	0.134	2,227.4	19.2	0.220	44.1
Shelburne	5.45	39.65	0.109	4,783.8	19.2	0.216	72.4
Sherborn	6.73	41.25	0.303	3,547.6	25.8	0.309	259.8
Shirley	5.74	40.50	0.207	3,486.8	24.0	0.290	69.0
Shrewsbury	6.29	41.29	0.259	16,645.8	25.0	0.295	722.2
Shutesbury	5.56	41.05	0.124	1,899.6	21.4	0.251	0.1
Somerset	6.13	41.65	0.321	23,697.1	21.9	0.272	891.6
Somerville	6.61	39.35	0.879	3,781.7	31.1	0.438	2,852.0
South Hadley	6.17	42.55	0.249	4,426.9	26.9	0.333	261.8
Southampton	6.03	42.52	0.159	952.7	22.6	0.266	156.3
Southborough	6.56	41.11	0.344	27,002.5	26.3	0.319	621.4
Southbridge Town	5.92	42.48	0.185	2,677.3	22.1	0.265	264.0
Southwick	6.26	43.63	0.164	3,990.2	21.9	0.257	92.0
Spencer	5.77	41.70	0.159	1,982.8	20.4	0.236	68.4
Springfield	6.45	43.50	0.355	5,503.6	29.2	0.369	1,321.3
Sterling	5.84	40.85	0.173	20,311.3	22.1	0.257	205.1
Stockbridge	6.08	42.30	0.136	9,674.8	19.3	0.222	118.4
Stoneham	6.37	39.72	0.511	7,495.4	28.7	0.362	2,589.2
Stoughton	6.51	41.29	0.330	6,226.9	24.8	0.302	518.5
Stow	6.30	40.69	0.252	3,143.6	25.3	0.306	108.6
Sturbridge	5.86	42.50	0.220	34,349.2	22.3	0.276	349.2
Sudbury	6.49	40.70	0.262	3,404.2	25.8	0.309	163.2
Sunderland	5.76	40.74	0.175	3,617.7	23.5	0.283	355.0
Sutton	6.30	41.77	0.179	9,961.3	21.9	0.256	128.0
Swampscott	6.05	39.79	0.400	907.8	24.8	0.313	1,005.5
Swansea	6.29	42.03	0.324	17,248.6	22.5	0.280	372.3
Taunton	6.37	41.18	0.277	6,443.0	22.8	0.275	292.3
Templeton	5.30	40.64	0.140	5,498.3	20.2	0.235	197.7

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Tewksbury	6.13	40.16	0.379	23,427.3	27.4	0.337	337.7
Tisbury	5.41	41.06	0.187	217.4	15.9	0.176	48.5
Tolland	5.81	43.03	0.116	3,810.7	18.9	0.216	0.0
Topsfield	5.89	40.08	0.287	10,608.2	24.7	0.303	457.2
Townsend	5.35	40.39	0.147	2,462.7	21.1	0.242	112.2
Truro	5.26	41.08	0.132	7,494.6	16.2	0.177	505.9
Tyngsborough	5.89	40.30	0.272	16,553.0	25.9	0.311	254.7
Tyringham	5.87	42.77	0.102	842.5	18.1	0.205	1.4
Upton	6.55	41.59	0.211	4,806.6	23.7	0.279	100.9
Uxbridge	6.51	41.96	0.204	16,515.4	22.5	0.266	223.5
Wakefield	6.25	39.80	0.510	23,559.4	28.2	0.360	1,465.3
Wales	5.90	43.02	0.144	4,124.3	20.5	0.238	3.2
Walpole	6.71	41.56	0.333	4,655.6	25.2	0.308	365.8
Waltham	6.63	40.10	0.434	24,676.3	28.1	0.354	1,004.5
Ware	5.62	42.45	0.150	4,371.0	21.2	0.251	92.2
Wareham	5.70	40.04	0.238	41,817.5	19.3	0.232	685.1
Warren	5.72	42.51	0.160	10,031.4	20.5	0.239	154.3
Warwick	5.52	39.83	0.122	6,246.0	21.7	0.254	33.2
Washington	5.82	42.30	0.122	2,780.1	18.1	0.205	0.0
Watertown Town	6.68	39.75	0.484	927.6	29.4	0.373	1,887.9
Wayland	6.59	40.64	0.301	7,510.5	26.3	0.316	387.2
Webster	6.13	42.15	0.191	27,144.9	21.2	0.236	259.6
Wellesley	6.71	40.66	0.396	9,292.6	27.1	0.333	1,529.0
Wellfleet	5.27	40.76	0.118	1,120.7	15.1	0.159	497.1
Wendell	5.52	39.83	0.122	1,539.4	21.7	0.254	5.3
Wenham	5.88	40.19	0.289	5,553.6	23.8	0.288	428.2
West Boylston	5.98	41.05	0.205	6,759.8	23.3	0.271	236.1
West Bridgewater	6.28	40.98	0.311	8,845.3	24.1	0.294	528.0
West Brookfield	5.63	42.15	0.155	3,043.9	20.2	0.234	195.8
West Newbury	5.74	39.64	0.254	2,186.4	24.4	0.294	101.9
West Springfield Town	6.43	43.33	0.319	14,942.5	27.8	0.350	749.6
West Stockbridge	6.16	42.22	0.147	11,408.3	19.4	0.225	129.1
West Tisbury	5.32	41.03	0.192	1,199.7	15.2	0.166	2.0
Westborough	6.48	41.28	0.278	32,061.5	25.7	0.302	1,295.1
Westfield	6.19	43.15	0.181	12,651.0	23.2	0.279	244.0
Westford	6.03	40.34	0.268	26,454.3	25.5	0.308	209.0

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

Municipality	PM2.5	Ozone	DPM	CO2	Cancer Risk	Resp Hazard Index	Traffic Exposure
Westhampton	5.81	41.90	0.093	2,435.7	19.0	0.218	3.9
Westminster	5.39	40.69	0.143	14,453.3	20.0	0.231	376.0
Weston	6.64	40.45	0.353	26,817.1	26.6	0.328	647.0
Westport	5.66	41.22	0.220	10,612.4	18.5	0.226	182.0
Westwood	6.72	41.13	0.382	18,236.2	26.5	0.331	698.9
Weymouth Town	6.33	40.42	0.380	2,583.8	25.8	0.323	794.1
Whately	5.76	40.74	0.175	19,017.9	23.5	0.283	83.5
Whitman	6.17	40.73	0.280	1,739.4	23.7	0.283	327.3
Wilbraham	6.23	43.39	0.199	4,403.6	25.1	0.303	192.4
Williamsburg	5.64	41.04	0.107	2,493.7	19.0	0.219	99.4
Williamstown	5.60	40.86	0.106	3,264.2	17.8	0.199	126.6
Wilmington	6.23	40.06	0.396	20,902.3	27.7	0.341	755.8
Winchendon	5.18	40.28	0.117	4,199.6	19.7	0.226	123.8
Winchester	6.49	39.75	0.435	1,459.4	28.8	0.353	544.6
Windsor	5.66	41.38	0.101	4,626.5	17.6	0.194	16.6
Winthrop Town	6.43	39.25	0.695	1,027.2	31.4	0.483	541.5
Woburn	6.40	39.89	0.465	21,389.1	28.2	0.357	1,972.0
Worcester	6.10	41.35	0.283	6,735.8	23.5	0.281	1,225.4
Worthington	5.60	41.43	0.095	7,122.8	17.4	0.195	0.0
Wrentham	6.80	41.90	0.302	54,561.6	24.7	0.298	296.9
Yarmouth	5.39	39.80	0.174	6,318.2	17.0	0.195	345.9

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.