Diesel particulate matter, lung cancer, and asthma incidences along major traffic corridors in MA, USA: A GIS analysis

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Abstract

By examining the census tracts and towns that are intersected by Massachusetts’ major highway corridors, Diesel and Health along Massachusetts' Highway Corridors ascertains whether these areas contain significantly higher rates of diesel particulate matter (DPM), lung cancer, and asthma. DPM was significantly higher for corridor towns than non-corridor towns. Hot spot analysis revealed statistically significant clustering of elevated DPM concentrations and asthma incidence in certain towns. The location of these towns was compared to the location of environmental justice neighborhoods. The authors recommend a series of steps that can be taken by policy makers and planners to curb DPM emissions.

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Introduction

Proximity to major traffic corridors may be an indicator of diesel particulate matter (DPM) levels as well as risk of developing asthma and/or lung cancer. The objective of this study is to determine whether areas in Massachusetts containing major highway corridors have higher rates of DPM exposure, lung cancer, and asthma incidence than those that do not and to perform hot spot analysis to locate areas with high concentrations of DPM, lung cancer, and asthma to determine whether these areas overlap with environmental justice (EJ) neighborhoods as defined by the Massachusetts Executive Office of Environmental Affairs (EOEA).\textsuperscript{2} The EOEA has defined an EJ population as a census block group whose residents annual median household income is equal to or less than 65\% of the statewide median or whose population is made up of 25\% minority, foreign born, or lacking English language proficiency (i.e., only one of these criteria must be met to qualify) (Massachusetts Executive Office of Environmental Affairs, 2003).

Diesel engines are known for their longevity and reliability, which make them a desirable and valuable asset to transportation networks around

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\textsuperscript{2}Technically, the EOEA EJ neighborhoods are census block groups, but the EOEA refers to them as “neighborhoods.”
the world (Clean Air Task Force, 2005). In the USA, diesel engines are integrated into every aspect of society; from delivery trucks to school buses to ship engines. Multiple studies have shown that proximity to diesel exhaust causes a variety of respiratory and cardiovascular problems (Dockery et al., 1993; Houston et al., 2004; Pope III et al., 2002; Steenland et al., 1998). Both large (10–2.5 μm diameter [PM_{10}]) and small (2.5 μm and smaller in diameter [PM_{2.5}]) particulate matter diesel exhaust particles have damaging health effects (Donaldson et al., 2000; Hesterberg et al., 2006; McClellan et al., 1985; McClellan, 1987; Peterson and Saxon, 1996). While the large particles are visible, the small particles may result in more damaging effects due to a larger surface area and because they are more easily absorbed into the blood stream (Nemmar et al., 2002).

Using the Environmental Protection Agency’s 1999 National Air Toxics Assessment (NATA) (for DPM data) and the Massachusetts Department of Public Health (DPH) (2005) data (for lung cancer and asthma data), this study examines whether areas that are intersected by major highway corridors have higher rates of DPM, lung cancer, and asthma than those that are not. Major highway corridors were selected based on the MA Executive of Office of Transportation traffic volume counts. Major corridors included in this study include Interstates 91, 90, 95, 495, and 93. Interstates 395, 290, and 190, though they could be considered major highway corridors, were excluded from this analysis. For Interstate 190 and 395, average daily traffic volume counts were far below those included in this analysis (I-190: 77,368; I-395: 51,500; I-90: 119,400; I-90: 122,735; I-95: 180,605; I-495: 124,600; I-93: 219,598). We excluded Interstate 290 because of its exceptionally short length compared to the other interstates included here (I-290: 39,160 m; I-90: 220,994 m; I-91: 99,409 m; I-93: 80,841 m; I-495: 239,060 m; I-95: 159,685 m), the traffic of which we assumed is accounted for in nearby Interstates 90 and 495 average daily traffic counts (Massachusetts Executive Office of Transportation, 2006).

Efforts to curb diesel emissions through engine retrofit filters for existing vehicles are gaining ground in Massachusetts, and this study could provide justification for these efforts and highlight other areas of concern. This study will show locations of the highest concentrations of DPM, and whether there is a spatial correlation between major highway corridor locales, DPM concentration, and lung cancer and asthma rates. This analysis also identifies whether these locales overlap with EJ neighborhoods, which is important because it draws attention to neighborhoods and communities that may experience a disproportionate burden of negative environmental consequences. Studies such as this are valuable to the state of Massachusetts because they identify spatial trends that may be placing humans at an increased risk to the negative effects of air pollution. Other states that have identified EJ neighborhoods can adopt our methodology because we utilize a nation-wide publicly available DPM data source. The results of these analyses can serve as an impetus for reform in state air quality standards and encourage changes in other policy areas.

State of the field

This project is grounded on three sets of hypotheses. The first is that there are higher rates of DPM along major highway corridors. Along with several other studies, Houston et al.’s (2004) discussion of structural disparities illustrates increased air pollutant concentration near major roadways. Housing located along major roadways is more likely to consist of low-income and minority populations who are living in older housing, which is more susceptible to indoor exposure of outdoor air pollution (Green, 2002; Ruotsalainen et al., 1991; Emenius et al., 2004). These structural disparities embedded in the urban built environment are combined with the fact that higher rates of diesel exhaust exist in these areas in the first place (Hitchins et al., 2000; Houston et al., 2004; Zhu and Hinds, 2002). The second hypothesis is that there is a relationship between proximity to major highway corridors and increased risk of lung cancer and asthma. Multiple studies have illustrated the linkage between these elements (Steenland et al., 1998; Edwards, 1994; Venn et al., 2001). However, debate exists regarding which indicators should be used to identify high rates of diesel exhaust. Some sources, such as the EPA, suggest that DPM is the...
Nitrogen dioxide (NO₂), sulfur dioxide (SO₂), ozone (O₃), and carbon monoxide (CO) (Restrepo and Zimmerman, 2004) and lastly, others argue that the best indicator is elemental carbon (Birch and Cary, 1996). The final hypothesis is that areas identified as having higher rates of DPM, lung cancer, and asthma overlap with the physical locations of EJ neighborhoods.

Geographic information systems

Geographic information system (GIS)-based studies examining DPM, lung cancer, and asthma rates in major highway corridors areas are scarce. However, GIS has become an important tool used in segments of previous studies with related goals. In a study by Houston et al. (2004), researchers utilized GIS to develop estimates of vehicle miles traveled for their study area. Though not integral to the final analysis performed, GIS provided a convenient method to obtain integral information regarding vehicle miles traveled and annual average daily traffic counts (Houston et al., 2004). Increasingly, GIS is being used as the primary tool in spatial statistical analysis studies. Oyana et al.’s (2004) study of geographic clustering enabled the research team to geocode their study area as well as determine spatial associations while Maantay (2007) used GIS to highlight how proximity to noxious land uses was related to asthma hospitalization rates, poverty, and minority status within the Bronx, New York City. Chakraborty et al.’s (1999) GIS-based buffer analysis of air pollution and noise impacts was used as part of a larger model to articulate the effects of potential changes in a Waterloo, Iowa transportation arterial. English et al. (1999) successfully linked proximity to higher traffic areas to an increase in repeated medical visits for asthmatic children by combining statistical methods and the geocoding and buffer capabilities of a GIS.

Like these studies, our analysis contributes to research examining air pollution and vulnerable populations, but is uniquely situated amongst these studies because we operate on a greater (statewide) spatial scale and intend to capture and highlight the effects of mobile sources of air pollution on EJ communities. One other study that has operated at a large geographical scale is Mitchell and Dorling’s (2003) nationwide analysis of British air quality, economic status, and vehicle ownership rates. Kingham et al. (2007) examined similar data elements in their study of environmental justice in Christchurch, New Zealand, concluding that car ownership rates were the lowest in areas of the city with most pollution exposure (also see Jerrett et al., 2001). Unlike these two studies, our analysis relies on an environmental justice definition that is defined by socioeconomic status as well as minority, foreign-born, and English-speaking status.

Our analysis does not rely on moving measurement unit collected data (Weijers et al., 2004) (potentially more accurate than stationary collection points) nor account for influential environmental variables on DPM such as season, wind direction, and wind speed (Begum et al., 2006).

Environmental justice paradigm

The environmental justice paradigm has emerged over the past two decades as a framework for integrating class, race, gender, environment, and social justice concerns. Emerging from the debate surrounding the inequity of waste facility siting in the United States during the 1980s, EJ has become a rallying cry for poor people and communities of color that have borne a disproportionate burden of environmental ‘bads,’ and have had restricted access to environmental ‘goods,’ such as parks and open spaces. When the state of North Carolina attempted to site a PCB landfill in a predominantly African-American community, the opposition forced acknowledgment of racial environmental injustice, recognizing it as strongly influenced by civil rights issues. The environmental justice paradigm posits “… certain minority populations are forced, through their lack of access to decision-making and policy-making processes, to live with a disproportionate share of environmental ‘bads’—and suffer the related public health problems and quality of life burdens” (Agyeman et al., 2003, p. 6). Today, many federal and state agencies, including the EPA and the EOEA, have EJ programs. Only eight states do not have any formal EJ-related policy, law, or program (Bonorris, 2007). The Massachusetts EOEA has even developed a set of EJ neighborhood

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4 For more information, see Toxic Wastes and Race in the United States (Chavis, 1987).
6 Iowa, Kansas, Nebraska, Nevada, North Dakota, Oklahoma, South Dakota, and Wyoming.
GIS layers using 2000 census data. These layers are utilized as part of this study.

GIS technology has come to serve as a powerful tool in advocacy efforts for EJ communities (Levy et al., 2001; Pastor et al., 2005). In response, some GIS EJ literature has begun to critique the methodologies involved in analyzing these areas and populations, suggesting that more attention should be paid to factors of risk and that there should be a focus on mobile sources in addition to stationary sources of pollution (Maantay, 2002, 2007; Pastor et al., 2005).

Data collection and management

The data utilized in this analysis originated from the US Environmental Protection Agency, Massachusetts Department of Public Health, Massachusetts Geographic Information System (MassGIS) (Massachusetts Executive Office of Environmental Affairs, 2006), and US Census Bureau (2006). In February 2006, the EPA released the 1999 NATA. As outlined on EPA’s NATA website, the purpose of the assessment was to “identify and prioritize air toxics, emission source types and locations which of greatest potential concern in terms of contributing to population risk” (Environmental Protection Agency, 2006a). DPM is included in the NATA, along with 176 other air pollutants that the assessment provided data for at both county and census tract levels. The 1999 NATA is currently the most up-to-date and comprehensive source of publicly available DPM data.7 The Hazardous Air Pollutant Exposure Model (HAPEM) (which is part of the NATA) predicts inhalation exposure of specified population groups and toxics, calculated through a number of factors including ambient air quality levels, climate data, and census data at the county and census tract levels (Environmental Protection Agency, 2006b). HAPEM data were used in this study because it models human exposure rates and risk.8 The HAPEM data enable comparison between the geographic scales of the model (census tracts, counties, states, etc.). Though the 1999 NATA accounts for non-point sources of pollution including mobile sources, it does not take into account proximity of these sources to highway corridors. HAPEM inputs include 1999 national emissions inventory data (stationary and mobile sources), estimates of ambient air levels (using the Aspen model), screening level inhalation exposure (for population exposure estimates), and approximations of cancer health effects (as well as other public health risks) as a result of inhalation of toxics (Environmental Protection Agency, 2006c). DPM exposure concentrations are reported in micrograms per cubic meter (µg/m³) and we used values at the census tract spatial scale. The HAPEM data used in this analysis were downloaded in Microsoft Access format from the EPA 1999 NATA webpage (http://www.epa.gov/ttn/atw/nata1999/tables.html). Massachusetts was selected from the “Pollutant--Specific Database” section.

The Massachusetts Department of Public Health developed the Massachusetts Community Health Information Profile (MassCHIP) to provide health-related information to parties interested in health planning. This study utilized the MassCHIP client to generate two reports: one for 2002 lung cancer incidence (includes raw incidence count, adjusted rate per 100,000, and age-adjusted rate confidence interval), and the other for asthma-related hospitalizations (includes raw incidence count, adjusted rate per 100,000, and age-adjusted rate confidence interval). MassCHIP lung cancer and asthma data are reported by town, while NATA DPM data are reported by census tract, requiring aggregation of DPM data to the town level for comparison of these three factors to be possible.

The MassGIS was the source of cartographic boundary files for year 2000 census blocks, towns, and roads.

(footnote continued)

reflect all pathways of exposure; The assessment results reflect only compounds released into the outdoor air; The assessment does not fully reflect variation in background ambient air concentrations; The assessment might systematically underestimate ambient air concentration for some compounds; The assessment used default, or simplifying, assumptions where data were missing or of poor quality; The assessment may not accurately capture sources that have episodic emissions (e.g., wildfires and prescribed burning or facilities with short-term deviations such as startups, shutdowns, malfunctions, and upsets); Estimates of risk are uncertain” (http://www.epa.gov/ttn/atw/nata1999/limitations.html).
Methodology

Town and census tract polygons were created from census block data. A census block is the smallest geographic unit used by the United States Census Bureau. A cluster of census blocks forms a census block group, and a cluster of these forms a census tract. Towns can have one or more census tracts (typically containing between 1500 and 8000 people each) within them, depending on population. This, in turn, dictates physical area, which can vary according to population (Massachusetts has an average census tract population of 4660 people). In Massachusetts, for instance, there are 1361 census tracts, with a minimum area of 0.075 km\(^2\), a maximum area of 516 km\(^2\), and an average area of 15 km\(^2\) (Fig. 1).

Tabular data on DPM, lung cancer, and asthma rates were joined to the corresponding spatial layers and maps showing their spatial distributions were produced (Fig. 2). All GIS analysis was completed in ArcMap 9.1 (ESRI, 2005). Each was divided into two groups—those intersected by major highway corridors (“corridor towns”) and those not intersected by major corridors (“non-corridor towns”). The difference in mean values between these two groups was analyzed for significance using an independent samples \( t \)-test.

Weighting algorithm was used to assign DPM census tract level values to the town level values. Using census tract population data as a weight, new town level DPM values were aggregated based on the following formulas:

When multiple towns fell within a single census tract:

\[
\text{Weighted HAPEM} = \left( \frac{\text{town population}}{\text{census tract population}} \right) \times \text{census tract HAPEM}
\]

When single tracts fell between multiple towns:

\[
\text{Weighted HAPEM} = \left( \frac{\text{census tract population}}{\text{town population}} \right) \times \text{census tract HAPEM}
\]

Using these two equations, the DPM by town map was produced (Fig. 2b).

Hot spot analysis

A hot spot analysis was performed for DPM at the town level and for lung cancer and asthma incidence to determine whether hot spots for these data elements coincided with major highway corridors and environmental justice communities identified by the MA EOEA. Hot spots are calculated...
using the $Gi^*$ statistic developed by Getis and Ord (1992) to measure clustering of values in a sub-region of a study area (Getis, 2004). $Gi^*$ statistics, when used in conjunction with Moran’s $I$ statistics, can “measure the degree of association that results from the concentration of weighted points” included in a predefined radius distance (Getis and Ord, 1992, p. 190); in this case the distance band identified through spatial autocorrelation. By summing the values of neighbors in the sub-region and dividing by the sum of the values of all features, the $Gi^*$ statistic is calculated (Mitchell, 2005, p. 176). After standardizing these values to obtain a $z$-score, the resulting values identify the magnitude of hot and cold spots; areas where high and low concentrations of values exist. In this analysis, we used a 95% confidence interval, meaning $z$-scores above 1.96 and below $-1.96$ correspond to hot and cold spots, respectively (a $z$-score of 0 indicates no concentration of high or low values). Spatial autocorrelation coefficient (Moran’s $I$) was used to determine the proper distance bands for the hot spot analysis (Anselin, 1994). The distance at which spatial autocorrelation was the strongest was used. For town DPM concentration, this distance was 1750 m; lung cancer rate: 10,000 m; and asthma rate: 5000 m. Hot spot analysis was performed to produce the maps found in Fig. 3.

**Results**

Lung cancer incidence was not significantly higher in corridor towns (data were unavailable for nearly one third of Massachusetts, which certainly affected dispersal of hot spot patterns), though a trend in this direction exists in the data. Hot spot analysis revealed statistically significant clustering of elevated DPM concentrations in the Boston metro area and clustering of increased lung cancer rates east of Interstate 495. From visual
inspection of the hot spot maps, it was apparent that town DPM and asthma incidence maps had common hot spot locations, while no lung cancer values overlaid with these two elements. Some hot spots for each data element coincided with major highway corridors. One potential reason that lung cancer hot spots did not overlap with asthma hot spots may be due to the fact that asthma is typically earlier onset than lung cancer (Boffetta et al., 2002; Brown et al., 2005; Santillan et al., 2003). Therefore, when considering the transient nature of people over a lifetime, asthma rates may be more accurately tied with the local population than lung cancer. An overlay of town DPM and asthma incidence hot spot maps showed a significant clustering of increased rates of all three elements in the greater Boston metro area, specifically, Revere, Chelsea, and Everett. This analysis supports claims that proximity to major highway corridors increases DPM exposure since higher rates appear to occur near clusters of major highway corridors (i.e., Eastern Massachusetts) (Hitchins et al., 2000).

There are two sets of results in this study. The first is the results of the independent samples’ t-tests between corridor and non-corridor values for DPM rates, lung cancer, and asthma incidence. The second set is the results from the hot spot analyses and inclusion of EJ neighborhood locations.

Regarding the first set of results, an independent samples’ t-test was executed with an alpha level at 0.05 on the mean values for corridor and non-corridor towns.

As shown in Table 1, DPM at the town level was the only element that contained statistically significant results. DPM was significantly higher for corridor towns ($M = 0.53; \text{S.D.} = 0.33; t(\text{d.f.}) = 5.29; p = <0.0005$) than non-corridor towns ($M = 0.33, \text{S.D.} = 0.34$). On the census tract level, the mean DPM was higher in corridor tracts but not significantly so. This is perhaps due to the fact that
many census tracts in the Boston metro area have elevated DPM levels due to heavy local traffic, but are not intersected by a major highway corridor. This resulted in the inflation of the mean DPM for non-corridor census tracts.

The mean lung cancer incidence was higher in corridor towns than non-corridor towns, while the opposite was true for asthma, although neither were significantly so. Both lung cancer and asthma data were incomplete, with 105 (lung cancer) and 43 (asthma) missing values. This influenced the statistical power of the analyses performed.

Hot spots for town level DPM occurred primarily to the east of the Interstate 95 corridor, while hot spots for lung cancer and asthma incidence occurred throughout the state.

Town DPM hot spots were overlaid with asthma hot spots to highlight common hot spots to show that the towns of Revere, Chelsea, and Everett overlapped. Finally, these areas were then overlaid with the EOEA’s EJ neighborhood layer (Fig. 4).

Of the 120,400 residents living in Revere, Chelsea, and Everett, 83,565 (69%) people live in EJ neighborhoods and town DPM and asthma incidence hot spots (Table 2). These figures demonstrate the fact that many residents live within the borders of EJ neighborhoods as well as areas of spatially clustered high values of town DPM exposure and asthma incidence.

**Discussion**

The results of this study support existing claims that higher rates of DPM at the town level exist along major highway corridors than elsewhere and that proximity to diesel exhaust could cause respiratory problems (Houston et al., 2004; Hitchins et al., 2000; Zhu and Hinds, 2002). The findings presented here suggest that further study examining corridor DPM rates is warranted. Though some debate exists on what are the most accurate indicators of the presence of DPM, our results suggest that higher rates of DPM provided in the HAPEM data exist in corridor towns. The Boston metro region is an area of particular concern because it contained such high DPM values (Boston’s DPM mean is 3.18 μg/m³ versus 0.38 μg/m³ for all other Massachusetts towns) and also contains 388 of 1551, or 25%, of the EJ neighborhoods in Massachusetts. Of the 388 EJ neighborhoods located within Boston, all lie within town DPM hot spots.

GIS was an integral tool used in this study, and we hope that it contributes to the ongoing

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**Table 1**

Independent samples’ *t*-tests

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Corridor</th>
<th>Non-corridor</th>
<th><em>t</em>(d.f.)</th>
<th><em>p</em></th>
<th>Significant (<em>z</em> = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (M)</td>
<td>0.97</td>
<td>0.85</td>
<td>1.76</td>
<td>0.078</td>
<td>No</td>
</tr>
<tr>
<td>Standard deviation (S.D.)</td>
<td>1.26</td>
<td>0.95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>267</td>
<td>1094</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (M)</td>
<td>0.53</td>
<td>0.33</td>
<td>5.29</td>
<td>&lt;0.0005</td>
<td>Yes</td>
</tr>
<tr>
<td>Standard deviation (S.D.)</td>
<td>0.33</td>
<td>0.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>113</td>
<td>238</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (M)</td>
<td>72.53</td>
<td>66.7</td>
<td>1.13</td>
<td>0.205</td>
<td>No</td>
</tr>
<tr>
<td>Standard deviation (S.D.)</td>
<td>26.8</td>
<td>44.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>92</td>
<td>154</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (M)</td>
<td>654.06</td>
<td>663.83</td>
<td>-0.321</td>
<td>0.749</td>
<td>No</td>
</tr>
<tr>
<td>Standard deviation (S.D.)</td>
<td>246.13</td>
<td>258.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>107</td>
<td>201</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
discussion of both cleaner air quality standards and GIS methodology. Similar to Oyana et al.’s (2004) study of geographic clustering, this analysis depended on GIS technologies to analyze and present complicated data and relationships. In addition, it is hoped that this study bolsters the call for an increased focus on mobile sources of pollution presented by Pastor et al. (2005).

Recommendations for policy advocacy based on this analysis focus on the reduction of DPM levels, especially along major corridors, and particularly in the Boston metro area and the towns of Revere, Chelsea, and Everett. Possible actions include treatment of both the effects and sources of the problem:

- Adopt legislation mandating usage of DPM filters in conjunction with ultra low sulfur diesel fuel.
- Employ diesel cleanup measures for stricter particle air quality standards, such as federally enforceable State Implementation Plans.
- Establish a state fund to aid diesel equipment owners in replacing older equipment with cleaner technologies.
- Institute an enforceable anti-idling campaign and install electrification programs at truck stops to eliminate need to run truck engines overnight.
- Implement strategies outlined in the Massachusetts’s EAOA’s Environmental Justice Policy to enhance participatory options for those residing in EJ neighborhoods. Also, follow the EAOA’s guidelines to ensure all industrial facilities within EJ neighborhoods comply with all environmental regulations and rules.

Table 2
Environmental justice neighborhoods and town DPM and asthma incidence hot spot overlap populations

<table>
<thead>
<tr>
<th>Town name</th>
<th>EJ neighborhoods and hot spot overlay population</th>
<th>Total town population</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revere</td>
<td>23,116</td>
<td>47,283</td>
<td>49</td>
</tr>
<tr>
<td>Chelsea</td>
<td>33,697</td>
<td>35,080</td>
<td>96</td>
</tr>
<tr>
<td>Everett</td>
<td>26,752</td>
<td>38,037</td>
<td>70</td>
</tr>
<tr>
<td>Total</td>
<td>83,565</td>
<td>120,400</td>
<td>69</td>
</tr>
</tbody>
</table>

Fig. 4. Environmental justice neighborhoods and DPM and asthma incidence hot spot overlay regions. Source: US EPA 1999 National-Scale Air Toxics Assessment; Massachusetts Department of Public Health: Massachusetts Community Health Information Profile: 2002 Lung Cancer Incidence and 2003 Asthma-related Hospitalizations; MassGIS/2000 US Census.
Municipal planners should employ pollution reduction techniques in EJ neighborhoods, such as barrier walls and community designs that integrate compatible land use types, such as work, school, and recreation in areas with low vehicle trip counts.

Conclusions

Future analysis should include detailed assessment of corridor areas that contain the highest DPM rates and identification of major contributors, which may involve substantial primary data collection. Some variables that affect DPM rates were not accounted for in this analysis, such as non-interstate road corridors and industrial sources. For instance, the town of Revere is a hot spot for town DPM and asthma incidence rates, but it does not contain a major corridor as we have defined it. Yet Revere has a number of roads that experience significant traffic (e.g., Route 1), which may have influenced our results. Though our analysis found significantly higher rates of DPM in corridor towns than non-corridor towns, we do not assert that major corridors cause higher DPM rates. Towns with higher DPM rates might also have greater industrial DPM sources which could influence the DPM data, and it would be beneficial for future research to account for such variables. Collecting the absent lung cancer and asthma data would allow for a more complete statistical assessment of rates in corridor areas. Finally, obtaining current data would make the results more pertinent, instead of including values that are up to 8 years old (1999 NATA data).

Employment of more complex regression modeling programs that incorporate multiple variables, such as distance to roads, geographical features, wind, and season would provide additional insight into DPM exposure. This study presents preliminary information regarding the existence of spatial trends in DPM distribution in Massachusetts. In many GIS-based analyses, obtaining accurate and current data is often a problem and this study is not an exception. However, these findings strongly suggest significantly elevated DPM exposure in the Boston metro area and clustered town DPM and asthma incidence rates in the towns of Revere, Chelsea, and Everett.

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