ASSESSING OPPORTUNITIES FOR AIR POLLUTION MITIGATION IN CHELSEA, MA

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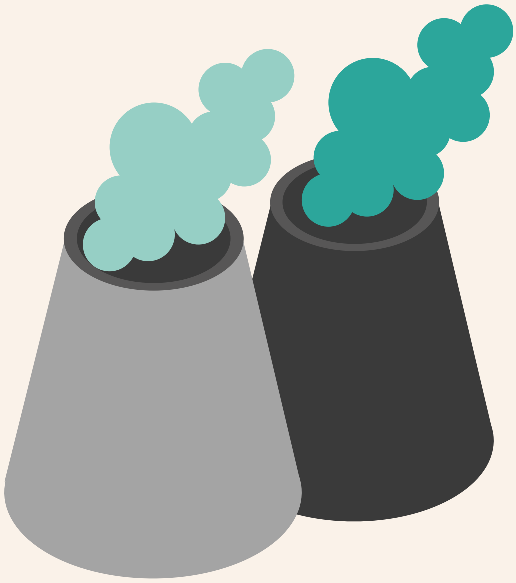
ABSTRACT

Air pollution is a pressing concern for many residents in Chelsea, MA, a city with a very high population density. Chelsea is uniquely impacted by the effects of poor air quality. There are many factors contributing to the air quality concerns in Chelsea, including high truck traffic, airport traffic, as well as parts of the city being used as warehouses and contribution centers. Air pollution has long been linked with many health effects, most notable of which being respiratory conditions such as asthma. We have selected areas within the city to focus on, by identifying areas and population groups most heavily impacted by air pollution, in order to recommend mitigation strategies most appropriate for these areas. We first aimed to analyze existing air quality data in order to understand the trends of air pollution in the city. We analyzed those data and created visuals to illustrate the severity of air pollution in Chelsea. Second, we surveyed community members to gain an understanding of the community's perception of air quality in Chelsea. Lastly, we recommended air pollution mitigation strategies for implementation based on our air quality data analysis, insight into the community, as well as secondary research on existing mitigation strategies. To mitigate the levels and effects of air pollution in Chelsea we considered the feasibility and effectiveness of various strategies specifically applicable to Chelsea. We've made various conclusions and findings throughout the project that ultimately led to our final recommendations.

INTRODUCTION



Poor air quality threatens various communities in Chelsea, MA, a densely populated city in the greater Boston area that is home to many vulnerable groups, including those that are unemployed, below the poverty line, lack access to health care, or don't speak English as their primary language. There are many reasons Chelsea faces worse air quality than many of the surrounding areas, but undoubtedly, the main factor is that Chelsea serves as a "transportation hub" for the rest of Massachusetts. Chelsea has had to face the adverse side effects that come with sustaining a modern industrial society while more wealthy cities see only the benefits and never these same consequences. The city is a mere 2.46 square miles yet it operates as a massive storage facility for jet fuel for the nearby Logan Airport. It acts as a holding ground for massive salt piles that the entire state makes use of to remove ice from roads during the winter. The New England Produce Center, which provides fruits and vegetables for the entire state, is located in the city as well. All of these factors and more result in countless trucks coming and going on a daily basis to make shipments and pick up/drop off equipment. These trucks emit harmful chemicals that harm roughly 40,000+ residents of Chelsea that live in a tiny one-square-mile area.

Air pollution has long been linked with a number of adverse health effects on the human body, and on society at large. Exposure to certain pollutants has been shown to result in increases in mortality and hospital admissions due to respiratory and cardiovascular disease (Brunekreef & Holgate, 2002). The danger is only elevated for the citizens of Chelsea when the normal dangers of pollutants are combined with COVID-19, a virus that spreads at a higher rate in more densely packed cities and has a higher mortality rate among those with pre-existing cardiovascular diseases like asthma. In Chelsea, a staggering 16.93% of residents have asthma (Massachusetts Department of Public Health, 2017). Ultimately, our project will set out to identify the parts of Chelsea that are most impacted by poor air quality and make recommendations for potential strategies to mitigate the effects of pollution based on a number of factors, including community input, the historical success of similar methods, and economic analysis.

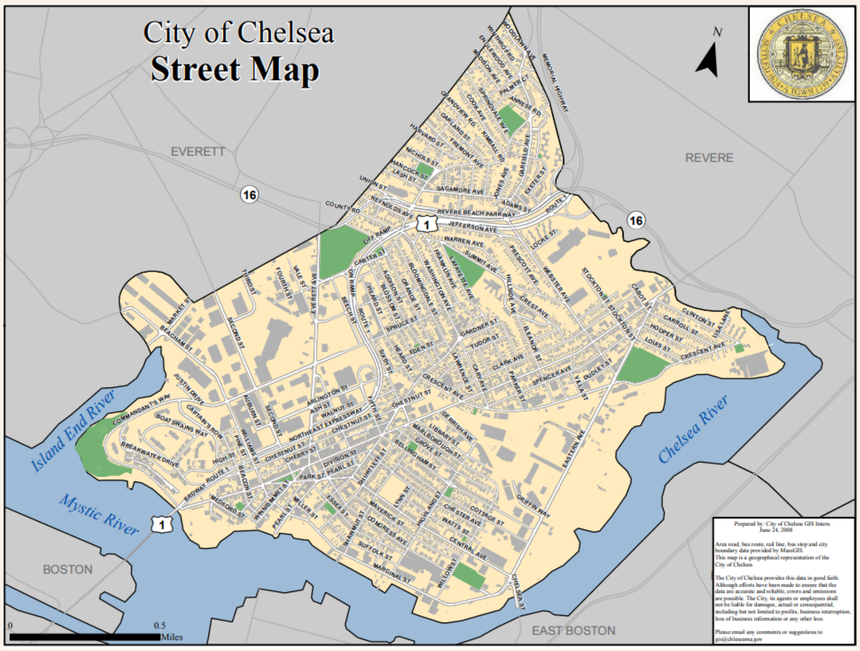


Figure 1: A Street Map of the City of Chelsea

Our project identified the areas that would benefit the most from pollution mitigation projects. We will accomplish this by analyzing raw data collected by twelve different air quality sensors that have been set up around Chelsea and have been uploading data every two minutes for a number of months. Furthermore, any proposed mitigation strategies we identify would require sufficient secondary research in order to determine the given feasibility and effectiveness before we could recommend these strategies.

Our first objective is to analyze current air quality data around Chelsea and construct several visuals demonstrating the different levels of air pollution in the area. The second objective is to survey the community in order to understand and illustrate the severity of poor air quality in Chelsea and the personal stakes people have in the issue. We aim to understand how different people, groups, and communities perceive pollution and their thoughts on air pollution mitigation approaches. Finally, we plan to make recommendations for the implementation of air pollution mitigation strategies based on our analysis of air quality in Chelsea, our insight into the community, and previous mitigation strategies in Chelsea and cities with similar circumstances to Chelsea's.

BACKGROUND

This chapter presents information about the harmful effects of air pollution on society, specifically on Chelsea, MA. Chelsea is home to many vulnerable communities: ethnic and racial minorities, people below the poverty line, those without health insurance and more. The vulnerable nature of these communities causes them to face disproportionate effects of air pollution and its consequences. Poor air quality in Chelsea comes from many sources, ranging from the Logan International Airport and New England Produce Center, to storage for New England's road salt and traffic congestion. To help in the solution of these problems, we will examine these sources of air pollution and existing air pollution mitigation strategies in general. We will also examine relevant publications and assess two case studies related to air quality.

OVERVIEW OF HARMFUL EFFECTS OF AIR POLLUTION

Air pollution is one of the prominent issues in our society that causes harm to the human body and its environment. It is caused by the release of harmful chemicals into the atmosphere by human activities, originating from motor vehicles, industry, housing, and commercial sources (Brunekreef & Holgate, 2002). These harmful substances in the air, known as Particulate Matter are complex mixtures of solid particles and liquid droplets that are present in the air. Some forms of particulate matter are large enough to be seen, but a lot of them are so small they can only be seen in a lab using electron microscopes. There are three main classification of particulate matters based on size: PM 1.0, PM 2.5, and PM 10. They are measured in micrometers with PM 10 being 10 micrometers or smaller in diameter, PM 2.5 being 2.5 micrometers or smaller in diameter, and PM 1.0 being 1 micrometer or smaller. For context, a single strand of hair is around 30 times larger than a PM 2.5 particle.(US EPA, 2016). The particles are extremely dangerous for people who have prolonged exposures. All three classifications of particulate matters can be inhaled and cause numerous harmful impacts to the human body. Most of our research is focused around PM 2.5 for several reasons. Long term exposure to PM 2.5 has shown correlation to premature death, mostly in people who have chronic diseases, while the impacts of PM 10 are less clear.(California Air Resources Board). Particles smaller than PM 10 can get deep into an individual's lungs and even bloodstreams. We are not focusing our research on PM 1.0 as it covers such a small range of pollutants. Exposure to these pollutants has been associated with increases in mortality and hospital admissions due to respiratory and cardiovascular disease (Brunekreef & Holgate, 2002). Many of these hospital admissions consist of members of vulnerable populations, such as children, the elderly, and patients with underlying health conditions. Per year the deaths of children due to acute respiratory infections as a result from exposure to air pollutants are estimated to be over 2 million. (Brunekreef & Holgate, 2002).

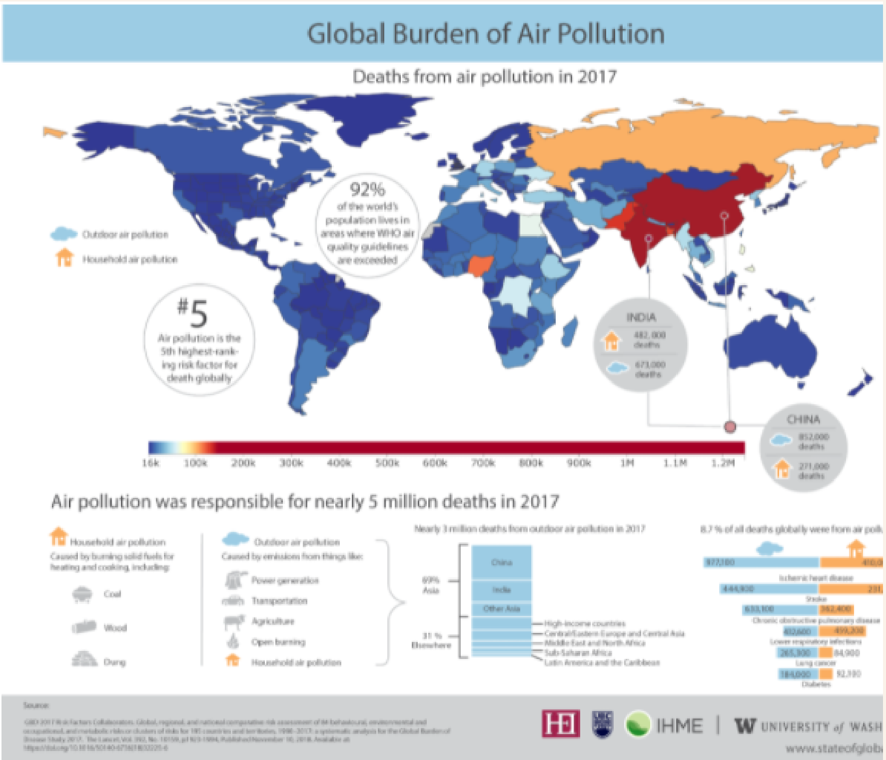


Figure 2: Map of Death Caused by Air Pollution Globally in 2017 (State of global air.n.d.)

Air pollution can also lead to psychological disorders like depression and anxiety. Not only does air pollution affect a person's physical health but also studies have shown a relationship between poor air quality and neurological illnesses such as depression and anxiety. Numerous studies have documented that exposure to particulate matter may be associated with more frequent incidences of depression. (Gładka, Rymaszewska, & Zatoński, 2018). This is possible because particulate matter can be transported through the bloodstream and to the olfactory pathway, due to its small size, which allows it to penetrate through the lungs and blood-brain barrier to reach neurons, resulting in alteration and impairment of cognitive abilities (Gładka, Rymaszewska, & Zatoński, 2018). As devastating as the effects of air pollution are, they vary from society to society.

Vulnerable and environmental justice communities, which mostly include minorities, are more prone to the risk of air pollution than people in wealthier communities (Gładka, Rymaszewska, & Zatoński, 2018). According to research conducted in Massachusetts, Urban areas contain greater densities of low-income, non-white and low-educational attainment populations and PM2.5 and NO2 pollution sources, contributing to some exposure heterogeneity and potential inequalities (Rosofsky, et al., 2018). In this research, there were "greater inequalities in urban areas, where there is often substantial segregation, which reinforces the importance of targeted exposure reduction strategies within vulnerable populations and neighborhoods. Ultimately, there is a complex dynamic wherein changing socio-demographics over time may impact land-use decisions, enforcement policy measures, and other factors influencing emissions." (Rosofsky, et al., 2018).

Studies have shown increased rates of poor health cases relating to high pollution exposure in urban areas. This is because the effects of air pollution causes a dysregulated immune system. Someone living in an area of high-particulate pollution is actually 8% more likely to die from COVID than others living in an area with less pollution when compared. (Costello et al., 2020). Considering some people who live in urban areas do not have reliable insurance to afford health care, they are more vulnerable to COVID-19 as a result of long-term exposure to air pollution, hence they tend to have more chronic diseases, such as asthma and hypertension. These disparities, in addition to health care barriers such as lack of health insurance and access to care, culminate in making people of color especially vulnerable to COVID-19 (Costello et al., 2020).

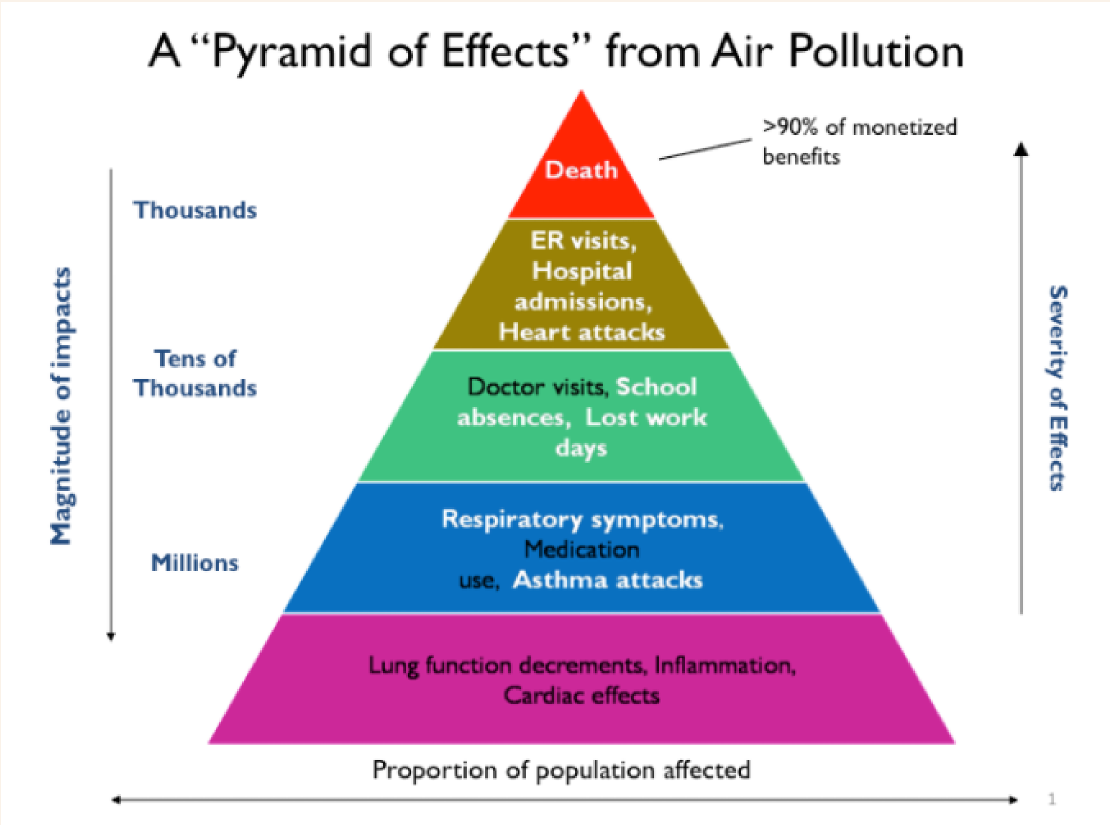


Figure 3: Shows the various health impacts of air pollution

AIR POLLUTION SOURCES

According to the EPA, the transportation sector makes up the largest portion of greenhouse gas emissions in the U.S., at 29%. The second and third most contributing sectors are electricity production at 25% and Industry at 23% (US EPA 2015). The particles considered to be greenhouse gasses are additionally considered air pollutants, and a higher amount of greenhouse gasses even contributes to the formation of more PM(Air quality and climate change, 2020). The significant contributions these sectors make to greenhouse gas emissions make them a pressing concern for air pollution as well as a prime target for strategies seeking to mitigate air pollution.

As previously stated, transportation emissions account for large contributions to air pollution levels. Traffic emissions are a major component within this sector, with 95% of the world's transportation energy coming from petroleum-based fuels, largely gasoline and diesel. Passenger cars, medium- and heavy-duty trucks, and light-duty trucks account for over half of the emissions from the transportation sector (US EPA 2015). More specifically, diesel engines emit mainly PM2.5, NOx, CO2, and older engines generally produce more of these pollutants (US EPA 2017). Gasoline engines mainly emit CO2. They also emit methane (CH4) and nitrous oxide (N2O) in smaller quantities, however, there are more impactful pollutants that have a larger potential for contributing to global warming. Hydrofluorocarbon emissions from leaking air conditioners are another source of emissions from passenger cars that shouldn't be overlooked (US EPA 2015). On city streets, the main characteristics of traffic that increase emissions are delay, stop-and-go, deceleration, idling, and acceleration (Pandian et al., as cited in Mahmod et al., 2013). More sustainable transportation options include public transportation, and active transportation (walking, biking, etc.), and incentivizing these has been shown to not only also reduce emissions and traffic, but to have positive effects on individual health(Sofia et al., 2020).

Ships and other vehicles within ports are another large component of transportation emissions. Within ports like this one, there are many contributing factors to the pollution, such as marine vessels, cargo handling equipment, and trucks (US EPA, 2017) (Baily & Solomon, 2004). Requiring lower sulfur fuel to be used for trucks, vessels, and cargo handling equipment, or using biodiesel in these diesel engines has been used to reduce emissions. Additionally, switching from diesel to electric power where possible, implementing restrictions on truck idling, and adding shore-side power for docked ships have all been shown to reduce these emissions as well(US EPA, 2017) (Baily & Solomon, 2004).

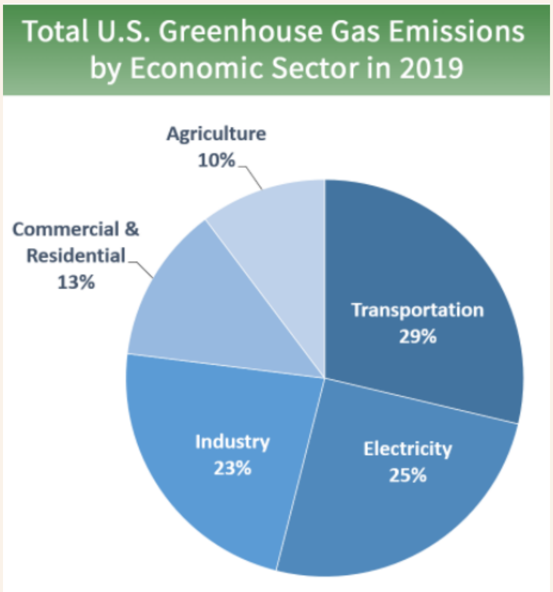


Figure 4: GHG Emissions (US EPA 2015)

Finally, planes and other vehicles used in airports contribute to transportation emissions. Relation between exposure to airport emissions and health risks has been shown by a study from the Massachusetts Department of Public Health. It found children in areas with high exposure to the airport's emissions were three to 4 times more likely to suffer "respiratory effects indicative of undiagnosed asthma". The study provides some recommendations for action, including "providing infrastructure for compressed natural gas (CNG) fuels and electricity charging stations, Alternative Fuel Vehicle Program)", and working "with communities within the high exposure area (in whole or in part) on initiatives that would serve to further reduce exacerbation of preexisting respiratory diseases (e.g., asthma and COPD) among residents" and more (Logan Airport Health Study, 2014).

Within the industrial sector, the main contributions to emissions include "emissions come from the consumption of fossil fuels for energy", "leaks from natural gas and petroleum systems, the use of fuels in production (e.g., petroleum products used to make plastics), and chemical reactions during the production of chemicals, iron, and steel, and cement." (US EPA 2015). An additional contributor is burning fuel to generate electricity used to power these industrial buildings and machinery (US EPA 2015).

This ties into the final previously mentioned sector of emissions, the electricity sector. Generation, transmission and distribution of electricity are all contributing areas within this sector. When generating electricity, the combustion of coal, oil, and natural gas release pollutants. Reducing demand for electricity as well as investing in renewable energy would reduce emissions (US EPA 2015).

CITY OF CHELSEA OVERVIEW

Chelsea, MA is a city in the Greater Boston area and is home to nearly 40,000 residents based on Census data. Chelsea is only 2.21 square miles, which gives the city a population per square mile of nearly 16,000 (U. S. Census bureau: Chelsea city, 2019). This ranks Chelsea as the 29th most dense city in the nation, and the third most dense city in all of Massachusetts (U. S. Census bureau: Chelsea city, 2019). However, many locals speculate that there are thousands or even tens of thousands more residents than has been reported by the census (The Boston Globe, 2020). Around half of the city is also considered industrial zones with no residential buildings, so over 40,000 residents are condensed into an area of roughly one square mile.

Chelsea's demographic makeup shows that the city is home to many vulnerable groups, and the effects of air pollution are exacerbated because these groups often do not have the resources or material wealth to deal with the consequences of poor air quality. Some examples of vulnerable groups include those in poverty, people with limited or no access to health care, those who do not speak English as their first language, and racial, ethnic, or religious minorities. About half of the residents in the city have some form of chronic illness. According to US Census estimates from July 1, 2019, Chelsea is 20.6% non-Hispanic white, 67.0% Hispanic or Latino, 32.8% two or more races, 4.0% Asian, and 6.4% African American. 69.8% of residents speak a language other than English at home, and given that 45.4% of residents are foreign born, for many of Chelsea's residents, English is not their first language. Of those older than 25, 68.9% of Chelsea have a high school diploma, and 18.5% have a bachelor's degree or higher. Furthermore, those under 65 with a disability makeup 9.3% of the city's population, and 7.9% of residents have no health insurance (U. S. Census bureau: Chelsea city, 2019).

In terms of Chelsea's economy, the median annual household income amounted to $56,802, and the per capita income was $25,284 (in 2019 dollars). 18.1% of the population is below the poverty line. Of the 351 towns and cities in Massachusetts, Chelsea ranks as the 6th lowest in terms of per capita income, the 7th lowest in terms of median family income, and 24th lowest in terms of median household income (U. S. Census bureau: Chelsea city, 2019).

Due to the harsh environmental conditions the city faces and the vulnerable groups that live there, there are a number of organizations that aim to reduce the environmental burden that Chelsea's residents face. One of the main government organizations in the city trying to improve general conditions for residents of Chelsea is the City of Chelsea's Department of Housing and Community Development. This department is the sponsor of this very project, and in the past they have sponsored and overseen many successful environmental projects, including projects to renovate parks to be more climate resilient, implementing flood protection systems, mapping urban heat islands around the city, and much more. (Environment and Climate Resilience, n.d). Their work, and the work that other similar groups do, has and will continue to improve and potentially even save lives. Another important environmental justice organization in the city of Chelsea is GreenRoots. They work with the community to solve pressing environmental and community concerns in the city. They have completed projects that have mitigated air pollution emissions, stopped fossil fuel plants and the transportation of dangerous fuels, and more.

COVID-19, a virus that has fundamentally changed our world, has not affected everyone equally; residents of the most vulnerable cities and populations have been harder hit than anyone else. It has been shown that residents of areas with more pollution are more likely to die of COVID than those in areas with better air quality (Costello et al., 2020). Additionally, high population density has been known to predict higher COVID infection spread and cumulative cases (Wong et al. 2020). As stated above, Chelsea is very densely populated, with a population per square mile of nearly 16,000. Many workers in Chelsea are below or near the poverty line, live paycheck-to-paycheck, and work jobs defined as "essential", resulting in many working in person throughout the pandemic. Actually around 80% of the city's residents are considered essential workers (Bongiovanni 2020) Additionally racial-ethnic minority groups are known to experience disproportionate burdens due to COVID-19, and as stated above, Chelsea contains large populations of racial-ethnic minorities (Wong et al. 2020).The combination of all of these factors resulted in many more reported COVID-19 cases in Chelsea than in other cities in the area that do not have as many vulnerable communities as Chelsea. Comparing Chelsea to the nearby Boston for example, Boston had a total case count from January 1, 2020 to March 30, 2020 of about 10% of its population. Chelsea had a case count of 20% of its population for the same timeframe. (Massachusetts Department of Public Health, 2021). Chelsea's poor air quality and vulnerable population resulted in a disproportionately high number of COVID cases and deaths throughout the pandemic.

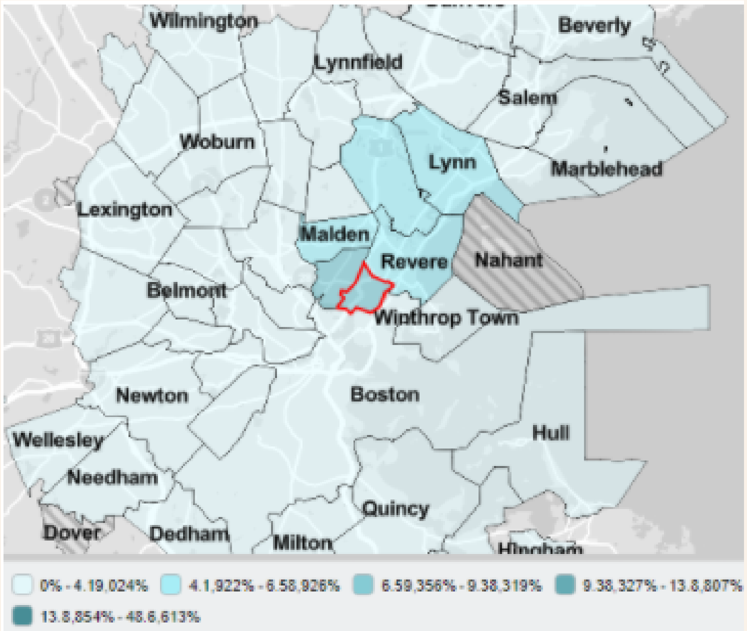


Figure 5: Persons Without Health Insurance, Under Age 65 Years, Percent. Chelsea Outlined in Red

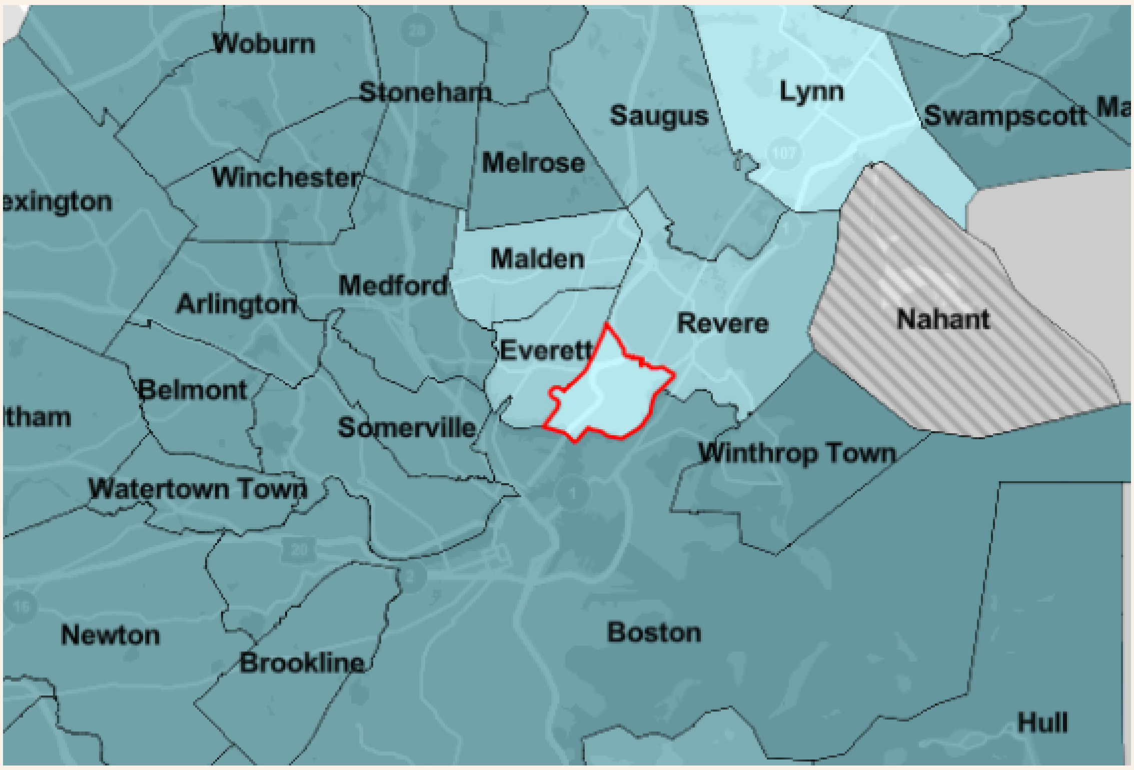


Figure 6: Per Capita Income in the Past 12 Months, 2015-2019. Chelsea is Outlined in Red

AIR QUALITY IN CHELSEA, MA

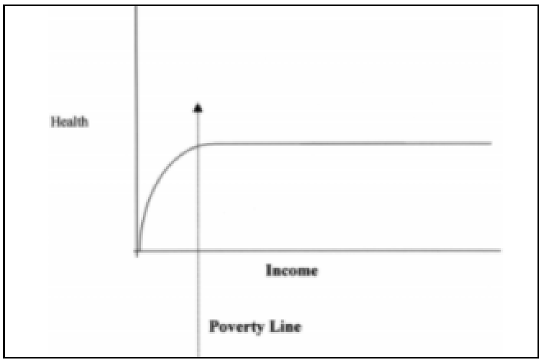
Chelsea is a city located in Suffolk county extremely close to Boston with poor air quality. Chelsea's poor air quality cannot be attributed to any one cause, as there are many sources that are responsible for the pollution, as well as other leading factors that act as amplifiers for the poor air quality. Less than 2 miles away from the heart of the city is the Boston Logan International Airport, with flights flying directly over Chelsea on a daily basis (Logan Airport Health Study, 2014). Additionally, it contains large parking lots for the airport. In an article published in the Boston Globe, it is stated that Chelsea is considered to be the boiler room for the entire state of Massachusetts (Abraham, 2020). It is the spot where all the most toxic wastes that the state requires in order to function are being dumped into (Abraham, 2020). This includes but is not limited to fuel tanks, tons of road salt for the winter, industrial and commercial properties.

High levels of traffic and congestion is another large factor that plays into its current conditions. Chelsea and the general Boston area's industry relies heavily on Chelsea's roads and an average of 90% of the freight movements are done by trucks (Blonde, 2014). These trucks come through the city for the purpose of transporting fuel, carrying goods from the produce center, and other trade, utility and manufacturing freight transportation. It also has the largest road salt pile in the northeast, and also has one of the largest produce distribution centers in the country (Rodriguez, 2020). The New England Produce center which is located in the city supplies fresh fruits and vegetables as well as other goods for more than 8 million people in the region. The international airport and produce center serves almost the entirety of New England but Chelsea is one of the worst affected areas by its air and noise pollution. Chelsea supplies road salt for all of Massachusetts and other nearby states. Air quality is already a large enough

Figure 7: Logan International Airport relative to Chelsea, MA

Figure 8: Road Salt Storage in Chelsea

Figure 9: New England Produce Center



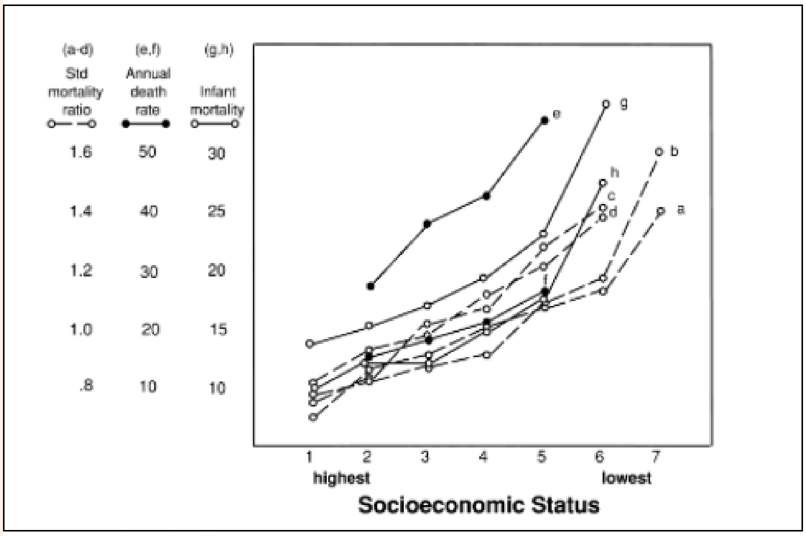


Figure 10 (Top): Shows a Relation Between Income and Health (Alder, 1999)
Figure 11 (Bottom): Shows Relation Between Socioeconomic Status and Multiple Significant Data (Alder, 1999)

All the conditions that lead to the pollution in the city in addition to the socioeconomic factors that compromise the health of residents leads to higher rates of cardiovascular disease and respiratory problems (Abraham, 2020). A study called "Socioeconomic Status and Health: What We Know and What We Don't" shows a graph of income vs health. Figure 7 illustrates that people below the poverty line have significantly lower health. On figure 8 of socioeconomic status vs annual death rate, it is almost a linear trend. As you climb higher on the socioeconomic ladder, the annual death rate decreases. Lower socioeconomic status is equal to higher death rates. (Alder, 1999). This uniquely impacts a city like Chelsea where more than a fifth of the entire population sits below the poverty line.

The Environmental Protection Agency (EPA) has taken direct actions in order to help with the ongoing problems . They have teamed up with the Massachusetts Department of Environmental Protection to install air monitors to track pollution and quality in the city and to permanently put up an air quality monitoring station (Rodriguez, 2020). The EPA also agreed to work with the state to watch and study the pollution more closely (Moran, 2020).

RELEVANT CASE STUDIES

We assessed two case studies on mitigation strategies suggested to the public and personal exposure to air pollution. We did so to learn from existing mitigation strategies as well as methods for measuring individual exposure to air pollutants in an area we are interested in analyzing.

Case 1: Mitigation Strategies for Reducing Air Pollution

In this non-location-specific study, Daniele Sofia et al. aimed to contribute to existing mitigation strategies for air pollution by focusing their study on how individuals, companies, and government agencies can contribute to reducing the harmful effects of air pollution. (Sofia et al., 2020)

In order to mitigate the issue of air pollution, the team identifies that efforts have to be made with all sectors of pollutant emissions, such as individuals, companies, and committees. For each of the three groups, specific recommendations were provided in various sectors. For example, for individuals, the team focused on areas such as public and active transport, aeration, and the household sector. While for companies, specific recommendations were made to companies in different sectors such as agricultural, industrial, and shipping. Furthermore in the agricultural sector, one of the specific mitigation strategies recommended is to improve livestock farming efficiency through actions such as buying from local growers to reduce the travel distance needed for goods. As doing so can slow the rate of deforestation and thus the rate of increasing atmospheric CO2 being produced. (Sofia et al., 2020) Additionally, the team also identified both short and long term goals and efforts that can be adopted by each group and analyzed their potential effects on the environment.

As this study dealt heavily with mitigation strategies in general, we identified many suggestions made and methods for research to be relevant to our project. Since we are working with a local government agency, many suggestions in the study which were made to public authorities may be appropriate to be adapted in Chelsea, MA. We also identified the different focuses of this research to be potentially appropriate to be used in our research.

	Short - term	Long-term
Citizens	• Change in urban mobility (public and active transport, car sharing) • Hour change in outdoor activity (walking, cycling) • Aeration of indoor environment during the hours of the day with less pollution levels (no morning between 8 and 9) • Use of photocatalytic paints for domestic walls	• Installation of domestic purifiers • Choice in living in less polluted area • Adoption of a diet rich in antioxidants
Enterprises	• Promotion of renewable alternative fuels • Low environmental impact heating/ cooling systems	• On-line work and vertical part-time promotion • Implementation of new innovative technologies • Interventions in agricultural sector (ammonia reduction) • Interventions in shipping sector (dock electrification)
Public authorities	• Urban traffic management • Urban planning • Improvement of public transport and infrastructure • Smart mobility promotion • Promotion of electric vehicles	• New regulations of air quality • Promotion of preventive systems (air quality monitoring systems) • Urban green addition • Incentives on the renewal of heating and energy saving systems • E-mobility incentives

Figure 12: The Mitigation Strategies or Strategic Measures Proposed that Can be Adopted by Different Stakeholders to Obtain Public Health Co-benefits with Air Pollution Reduction (Sofia et al., 2020)

Case 2: Personal Daily Pollutants Exposure in Boston

A second case study was done on a study with a primary focus on expanding limited knowledge on the reliability and accuracy of a particular brand of portable air quality monitors (PAM's). Portable air quality monitors are devices that can be easily placed or be carried by an individual to collect air quality data. This study included comparing data collected by PAM's with professional grade static air quality sensors at urban street level. Additionally, the study also discussed findings about levels of exposure to both indoors and outdoors pollution, as well as how exposure levels differed based on the areas in which a participant is active each day. Lastly, it involved using PAM's to collect data at above street level where there are a significant amount of human activities, such as at the top of a five story building. (Rice et al., 2019)

Due to limitations of the PAM used in the study, regarding the type of pollutant that it can detect, the main pollutants focused on were nitrogen dioxide and fine particulate matter (PM2.5) in both indoor and outdoor settings. (Rice et al., 2019) Selected Boston-area residents were asked to carry the PAM's for up to 15 weeks in order to collect sufficient data.

We've found many aspects of this study to be relevant to our research. For example, utilizing portable air quality sensors rather than only static sensors the city has already installed will contribute to the mapping aspect of our project. PAM's would offer greater flexibility as in cities like Boston where there are many buildings that go higher up than in most suburban or rural areas, where static sensors can not be used effectively, as they lack the mobility PAMs offer. Another aspect is to include consideration for residential and office buildings that are higher up from street level which are likely to have different air quality data from the same spot on the street. As this study shows the reliability of PAM's in measuring relevant data such as temperature, humidity, nitrogen dioxide level, and PM2.5 level, it opens up a new dimension to our research.

SUMMARY

Poor air quality negatively impacts the residents of Chelsea, MA. Poor air quality affects many, especially those who are most vulnerable in society, and can lead to issues such as health concerns. These effects don't impact everyone equally, and the severity of the impact depends heavily on one's socioeconomic status. Many of the highest contributing areas to air pollution are present in Chelsea, but fortunately many mitigation strategies have been researched and documented.

METHODOLOGY

The goal of this project is to assess air quality in Chelsea MA, and also suggest mitigation practices in order to help improve air pollution in the most affected areas in the city. To achieve this goal, first, the team planned to gather and use existing air quality data around Chelsea to construct a map that highlights and visualizes air quality in the city with the goal of identifying hotspots. This allowed us to identify the relative quality of air around the city, to better understand where mitigation strategies may be most urgently needed. Second, to gain an understanding of the local impacts of air pollution, we got insights from the Chelsea community regarding their perception of the city's air quality, its effects, and the pollution mitigation strategies that already exist. Finally, we made recommendations for the implementation of indoor and outdoor air pollution mitigation strategies based on our mapping data, community feedback and insight as well as knowledge gained from researching existing strategies in Chelsea and other cities.

MAPPING AIR QUALITY IN CHELSEA

Our first objective was to combine and analyze the various sources of air quality data from around Chelsea to construct several maps that demonstrate to our audience, a combination of the general public in Chelsea and environmental advocacy groups, where air quality is the most hazardous in Chelsea. Meeting this objective would both illustrate to a viewer where in the city air pollution is worst, and allow us to draw various conclusions about the state of pollution across Chelsea. Completing this objective primarily involved the use of the data accrued from the twelve sensors in Chelsea and displayed on purpleair.com (PurpleAir.com, 2021). These sensors all collect extensive quantitative data of the air in their immediate surroundings, including PM1.0, PM2.5, PM10, temperature, humidity, and atmospheric pressure. The sensors take measurements of all of these metrics roughly every two minutes, and they upload the readings in real-time to be displayed on the site. The twelve sensors are completely stationary and are generally spaced throughout the city, with some sensors in residential areas, some near parks and greenery, and some in industrial districts. This website has been operational since April 10, 2021, and with few exceptions, most sensors in Chelsea have been collecting and publishing data since this date; they are still collecting and uploading data as this research is being conducted (Spring 2021).

Other than the PurpleAir data that has accrued since April 2021, sources for air quality data in Chelsea are scarce. A Northeastern University study (Northeastern Environmental Sensors Lab, 2020), has been collecting data along the traffic-heavy Broadway in Chelsea; however, this data never became publicly available in time to be used in this project. Other studies either have been announced but have yet to generate data (Moran, 2020) or have been discontinued years ago (Commonwealth of Massachusetts 2010 Air Quality Report, 2010). In this report, sensor stations from various cities in Massachusetts tracked information about pollutants from 1985 to 2010, but each chart that included Chelsea, data tracking abruptly stopped in 1999; this is because the air quality station in Chelsea was discontinued that year. Because of all of these factors, by far our best and only source of data for air pollution in Chelsea was the 12 sensors that have been collecting and publishing data to purpleair.com

We used the data amassed by the sensors in Chelsea in two ways. The first is an extensive analysis of the raw data where we will make connections and find correlation between different aspects of the data, such as any connections between temperature or humidity with an increase in PM2.5; additionally, we will explain data anomalies and outliers, and finally we will determine where in Chelsea residents experience the most dangerous air quality. The data was analyzed into weekly medians and converted over to AQI. AQI stands for Air Quality Index and is used to communicate to the public how polluted the air is at a given time. Establishing which parts of the city have the highest levels of pollutants is an essential first step but not sufficient on its own. If an area has a high level of pollution but few people are exposed to that pollution, it could be misleading to say that these are necessarily the areas of highest concern. It is for this reason that we must assess residents' exposure to pollution, and not just the level of pollution itself. This is called exposure assessment, a tool commonly used to quantify and describe the amount of exposure people actually have to pollutants; this is an essential component of health impact assessment (HIA) and is a crucial step we will need to take before considering mitigation strategies (Dias, D., & Tchepel, O., 2018, pg. 1).

Secondly, we will use the GIS mapping software arcGIS in order to create a set of maps that convey to both a general audience and to environmental organizations which areas of Chelsea are most at risk to the adverse health effects of poor air quality. These areas would be good places for groups like GreenRoots and the City of Chelsea Dept. of Housing and Community Development to look into for ideas regarding future projects to mitigate the effects of pollution in these at-risk areas. In order to assist us in our data analysis, we will research how various factors would affect readings, such as how a pollutant reading would go up or down if the temperature was warmer or colder. Additionally, we will go into Chelsea to observe the locations at which each of the eleven sensors is set up. We will take extensive qualitative data, such as noting how much traffic passed nearby the sensor, how close to the street the sensor is, how high above the ground the sensor is, along with anything else that stands out as noteworthy regarding the conditions each sensor faces and how they differ from each other. This will supplement the raw data we have access to in order to explain any outliers in the dataset, of which there are many.

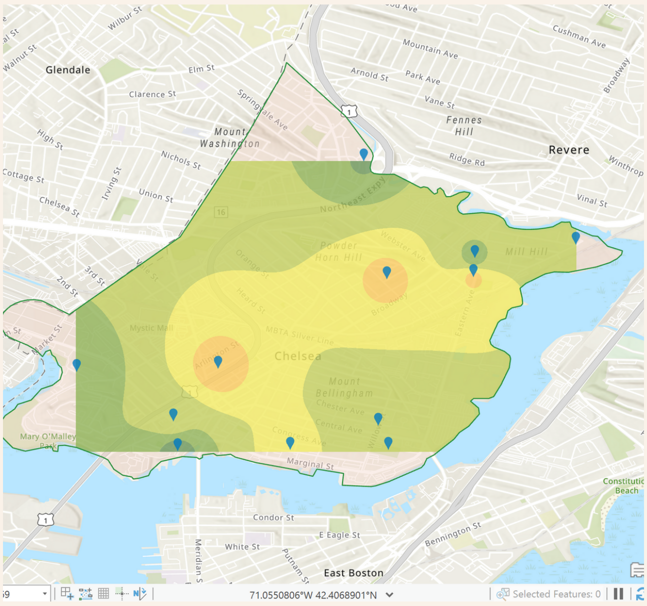


Figure 13: An example of a Heatmap generated for the concentration of pollutants in a given week using ArcGIS

In terms of the visuals planned to create using GIS software, there are two main maps our team intended to develop and use to illustrate the poor air quality in Chelsea. One was a timelapse of all of the data each sensor has collected since most of them were set up in April; in this timelapse, PM2.5 weekly median values are displayed as they overlay a map of Chelsea, growing and shrinking as well as changing color to coordinate to safer levels of air quality to more dangerous levels. This timelapse is available online as a .gif file, but for the sake of being able to print and distribute it, and to access it as a PDF file in the booklet, the still images that comprise the timelapse have been split up and individually placed in order later in the booklet.

The other visual we intended to develop was a "spikemap" of Chelsea, which showed the percentage of days each sensor exceeded a certain threshold for air pollutants. In this visual, sensors with higher percentages are represented by larger circles proportional in radius to their percentages, and a similar color grading scale to the previously mentioned hotspot timelapse is utilized. Furthermore, this spikemap is presented alongside multiple vulnerability maps which display the concentration of different groups that are uniquely at risk to the effects of air pollution, including youth, elderly populations, those without health insurance, and those who are unemployed. The "spikemap" visual will be examined in conjunction with these vulnerability maps in order to identify areas that have a combination of poor air quality and many residents who are vulnerable to this poor air.

In addition to these main two maps, we will create several charts and figures that are supplementary to these maps and display the data used to create these maps more explicitly; these charts and graphs will likely not be as important for a general audience, but an important part of our audience includes environmental organizations like GreenRoots and Chelsea's Department of Housing and Development, so these charts will be crucial to articulate more of the technical side of our research and analysis of the data to these groups.

DEVELOP AN UNDERSTANDING OF HOW THE MOST VULNERABLE COMMUNITIES IN CHELSEA ARE IMPACTED BY AIR POLLUTION.

The second objective was to assess the impacts of air pollution on the most vulnerable communities in the city of Chelsea. It is important to understand the impacts and perception of air pollution among the community, especially vulnerable groups of residents with respect to different age groups, races, and health status in order to most effectively address and suggest ways of mitigating air pollution. Our initial plan was to interview knowledgeable community leaders, who deal with similar environmental justice issues and are also familiar with the residents of Chelsea, in order to understand the ways in which the community struggles with air pollution as well as their thoughts on past and potential air pollution mitigation approaches. Unfortunately, due to unavailability of said community leaders, we were unable to complete any interviews. To fill the void of interviews, we found secondary data that has similar findings as we anticipated our interviews to get. This data focuses on community vulnerability and local environmental justice projects and includes, but is not limited to, census data, health concerns due to air pollution, urban island heat maps of Chelsea and GIS map of demographic vulnerabilities. Locating various groups of vulnerable populations through secondary research and surveys builds our understanding of the community which increases the effectiveness and reception of the mitigation strategies we propose. Surveys in particular help to inform us of the awareness of the community regarding the issue. Knowledge of community awareness, and how it may need to be raised, helped shape our final deliverable. We also supplemented all of this with our own research of challenges imposed by poor air quality on other vulnerable communities similar to Chelsea.

The first method for obtaining insights was to survey the general public. Surveys are beneficial because they allow one to reach a large community directly. The survey was circulated online to residents of the city through social media and was available in both English and Spanish. The survey only consisted of simple, specific, and short questions for multiple reasons. Simple questions ensure that an audience of non-experts can participate and voice their concerns, as the average citizen anywhere wouldn't be able to answer technical questions about air pollution accurately. Simple questions are also often quick questions; this was to ensure participants were more willing to respond than if the questions were long or confusing. Furthermore, this also allowed for easier translations for the large populations of non-native English speakers in the city of Chelsea.

The questions on the surveys were designed to gain the perceptions of residents in the city on the air quality in the city. The survey first consisted of baseline demographics questions asking of their age, race and ethnicity, as well as their primary language. Doing so allowed us to see if there is a correlation between specific demographic groups and their perception of the issue. As a previous study has shown the importance of including such questions and their effectiveness in helping to achieve the goal of this research (Reames & Bravo, 2019). Furthermore, questions were asked to gain further insight into their daily life and whether poor air quality is impacting their everyday well-being and habits. Some of these questions were on precautions they may take such as changing their way of transportation, using air purifiers indoors, or mask usage outdoors (unrelated to COVID). In order to expand the reach of the survey without directly surveying more people, we asked if and how they have observed others in their community, like their neighbors or family members, be impacted by the effects of air pollution. It does not contain questions to obtain unique technical insights about pollution in the city. The questions had multiple formats, including multiple-choice, scaling/rating questions, short answers, and more. We also had a question to pinpoint their relative location to the relative neighborhood to see whether there is a correlation between location and impacts of air quality. Finally, we provided a general short answer question where respondents could share any important insight they wished. All of these questions were optional, so if the individuals did not feel comfortable answering any certain questions, they could just exclude those questions and still complete the rest of the survey.

Another way for obtaining insights and identifying where the most vulnerable populations reside in the city was through analysis of secondary research and GIS maps of vulnerable demographic populations. This secondary research was mainly on scholarly articles that contain data on health concerns and illnesses that stem from effects of air pollution. Studies have shown that prolonged exposure to air pollution can cause an increase in mortality and hospital admissions due to respiratory, cardiovascular, and even neurological and psychological illnesses(Brunekreef & Holgate, 2002)(Gładka, Rymaszewska, & Zatoński, 2018). Analysis of the demographic information over different groups of vulnerability in the city of Chelsea helped us to locate our locations of focus and propose mitigation strategies on those chosen locations. As we had discussed earlier on, Chelsea is home to many people who live below the poverty line, and the median household income is drastically lower than the average of the state (Census 2019). There are also a number of residents of the city who do not have health insurance. These numerous conditions of the residents are what makes Chelsea such a vulnerable community for air pollution. Knowing where the majority of the vulnerable population reside would help us to focus our locations at areas where mostly minorities reside so our proposed strategies can work to reduce pollutants at places that matter. Demographic information maps that were analyzed include the population of elderly people, mainly those of over 85 years of age , the population of youth, unemployed, without health insurance and more.

RECOMMEND STRATEGIES FOR INDOOR AND OUTDOOR POLLUTION MITIGATION

Our final objective was to make recommendations for the implementation of indoor and outdoor air pollution mitigation strategies. Our previous data analysis, mapping, surveys, and interviews were all essential parts of making these recommendations, as they informed us about the air quality concerns we're aiming to address. These previous objectives helped us best understand the levels, locations, and sources of air pollution in Chelsea. Additionally, completion of our previous objectives helped us understand the people it affects, previous mitigation strategies, and the community's perspective. There are a few other necessary components to making these suggestions. We had to analyze previous and ongoing mitigation efforts to make the best recommendations possible. Additionally, we analyzed the effectiveness and feasibility of different strategies to ensure they're as practical and beneficial to the community as possible.

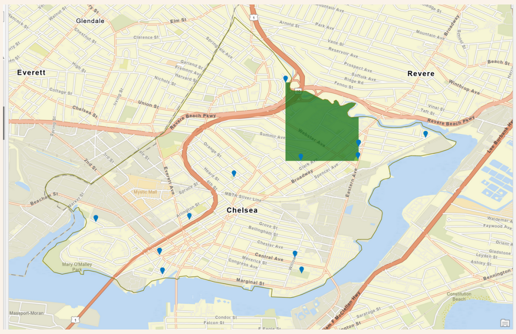
An essential component of recommending pollution mitigation strategies is understanding previous and ongoing strategies, in Chelsea and elsewhere, with a similar goal. Analyzing these previous strategies has the benefit of giving us an understanding of how they were achieved on a logistical and technical level, as well as their effectiveness and general reception. Understanding the logistics of how the various organizations and groups are able to enact environmental change in Chelsea is useful to recommend specific and detailed air pollution mitigation strategies. GreenRoots is an example of an organization we were planning to interview to accomplish these objectives, as they have completed many environmental justice projects in the Chelsea area, such as the reduction of air pollutants by more than 2,000 tons annually at the New England Produce Center and elsewhere in Chelsea and Everett by investing more than $3 million in federal, state, and private funds (Victories, n.d.). Unfortunately, as previously mentioned, this interview was never able to happen, although we did gain some insight in a less official manner, casually speaking with a member of the organization.

Understanding the technical details of other air pollution mitigation strategies also helped us to propose our own strategies. We Researched the implementation of mitigation strategies in other cities will help us to understand if and why they were effective, as well as whether they could be applicable to Chelsea. An example of a useful study for this is one done in Toronto with the purpose of investigating the effect of green roofs and green walls on air pollution in the urban areas of the city. The study concluded that green roofs improved air quality in the area, improving the quality of life of all citizens in the area (Currie & Bass, 2008). We did further research into the methods of this study which served to help us understand how and why it was effective, and what allowed it to succeed that could be applicable to Chelsea. Comparing more similar studies conducted differently and in other places, such as one done in Los Angeles, also added to the depth of our knowledge of what strategies would be most effective and applicable to Chelsea (Akbari et al., 2001). We then combined our analysis of these previous efforts and the insight we gain about the local community to best anticipate the direct impacts our strategies will have on the community, in terms of their exposure to air pollution and general wellbeing and quality of life. Knowing if any strategies had unintended consequences or if the implementation had any other undesirable effects on the community was an important consideration when making our own recommendations.

Moreover, cost-benefit analysis is a commonly used method while identifying strategies most appropriate for implementation at a specific location. "Cost" in this context refers to all aspects that need to be considered, including labor and resources. Then, the costs would be compared with the expected results and effectiveness of each of the mitigation strategies being considered to see if the benefits would outweigh the costs involved. We plan to start the analysis with further research on existing cost-benefit analysis conducted on air pollution mitigation strategies, to gain a better understanding of methods used to predict relevant costs. (Malla et al., 2011) Additionally, we plan to focus on studies evaluating implemented low-cost mitigation strategies. (Sa et al., 2017) As we would focus on strategies that are as low-cost and effective as possible, to make our recommendations more feasible and practical. Thereafter, the cost-benefit analysis will be directed onto past air pollution mitigation strategies implemented in other locations worldwide, and identify potential sources where the funding can come from in order for such methods to be implemented. Then, a long term benefits analysis will be conducted to investigate how much the city will benefit from each strategy and predict how effective each strategy will be. From there, a comparison can be done between the predicted costs and benefits in order to provide recommendations.

Finally, we used all our previous research, data analysis and community knowledge to complete our final objective of making recommendations of strategies to mitigate air pollution. We took into account specific criteria, informed by all the previous parts of the project, to determine which ones we recommend. The first thing we considered is effectiveness, and how we anticipate a given strategy may affect the community in terms of reducing air pollutant levels directly, mitigating its effects on people, mitigating contributing factors, and any other ways it would impact lives. The next area of effectiveness we looked at was who is being helped by the strategy and how vulnerable they are to, and affected by air pollution. We also considered a given project's feasibility based on its cost, the timeframe in which it could be completed, any potential available funding, and through whom it would be enacted, whether it be through individuals, organizations, enterprises, or governments. No matter how ambitious and or potentially effective a project may be, if it's not realistic to implement, it's less worth recommending. We then took this insight on effectiveness and feasibility and rated each strategy, relative to each other, to form a list of mitigation strategies to recommend to Chelsea that we determined have the highest potential to be the most beneficial to its residents.

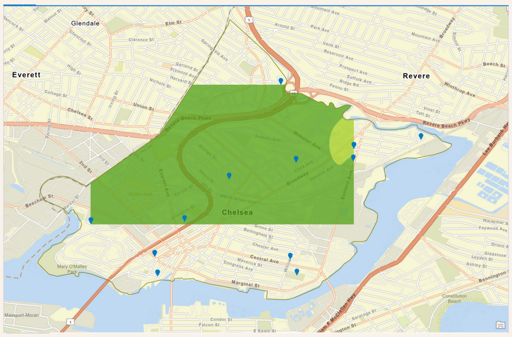
RESULTS AND FINDINGS



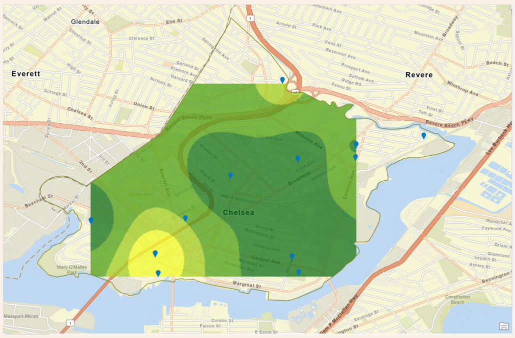
Week Of 4/11/21

VALUE (AQI)

- 0 - 20
- 20.0001 - 30
- 30.0001 - 40
- 40.0001 - 50
- 50.0001 - 60
- 60.0001 - 70
- 70.0001 - 80



Week Of 4/18/21



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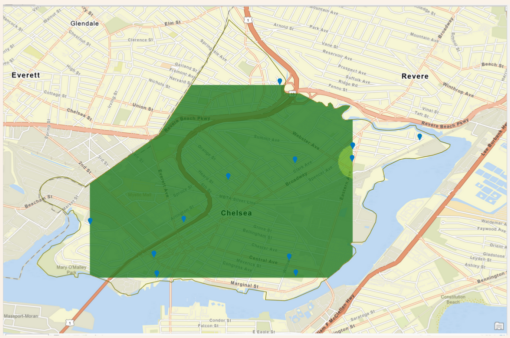
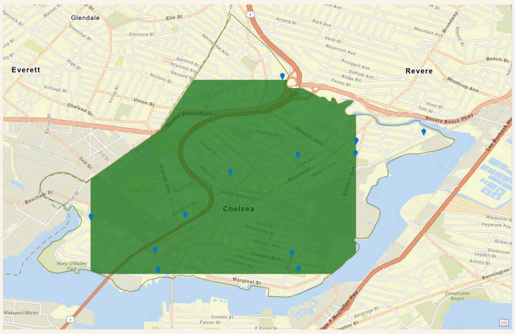
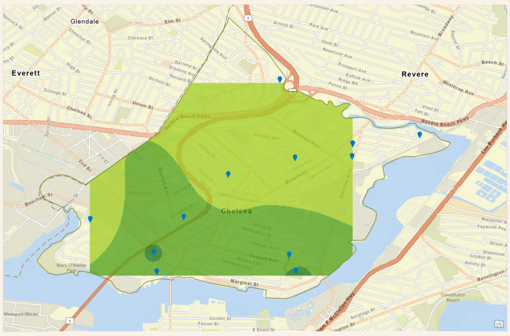


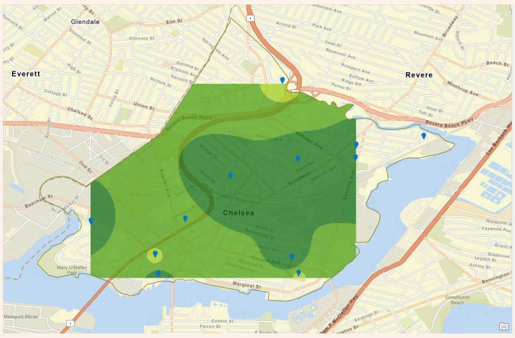
Week Of 5/2/21



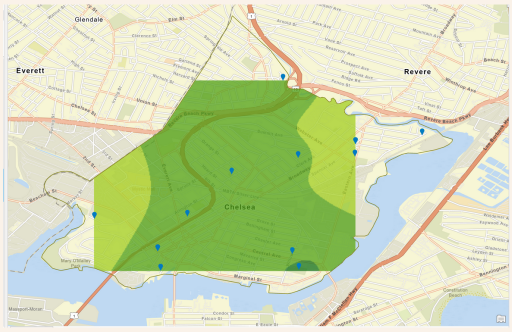
Week Of 5/9/21



Week Of 5/16/21



Week Of 5/23/21



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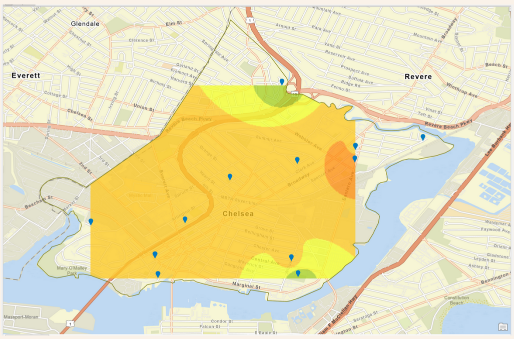
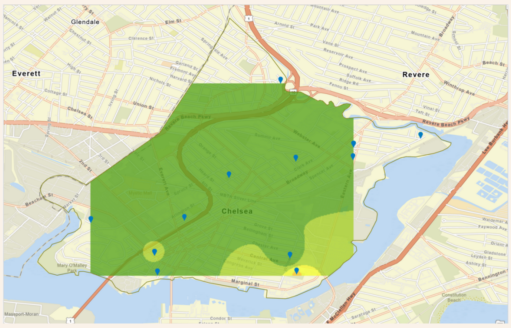
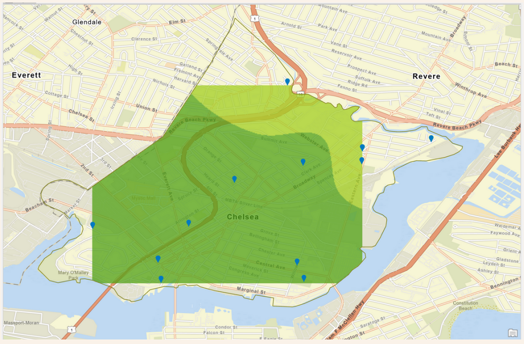


Week Of 6/6/21



Week Of 6/13/21



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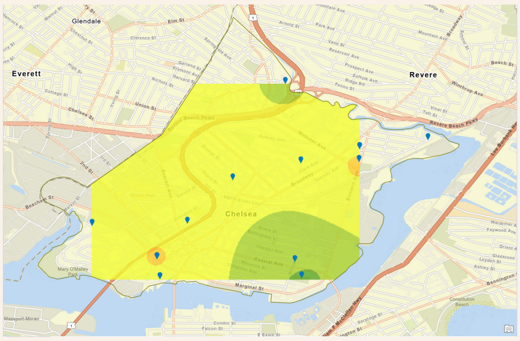
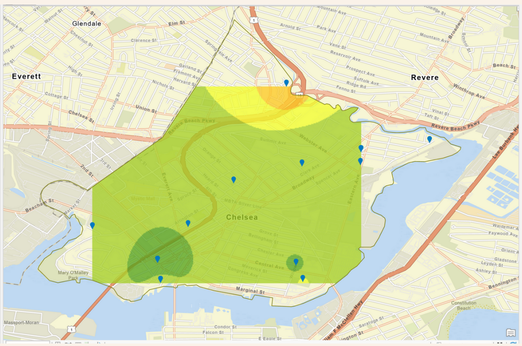
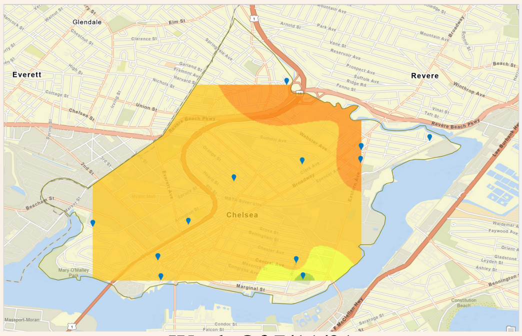


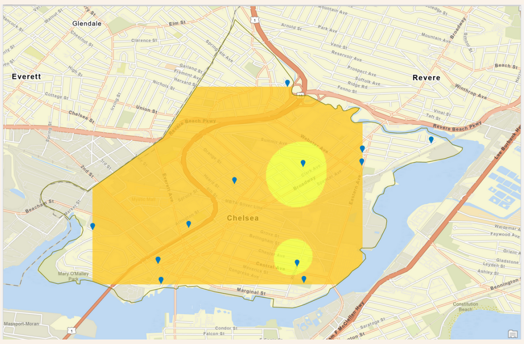
Week Of 6/27/21



Week Of 7/4/21



Week Of 7/11/21



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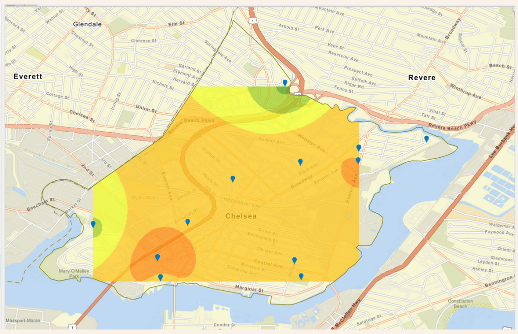
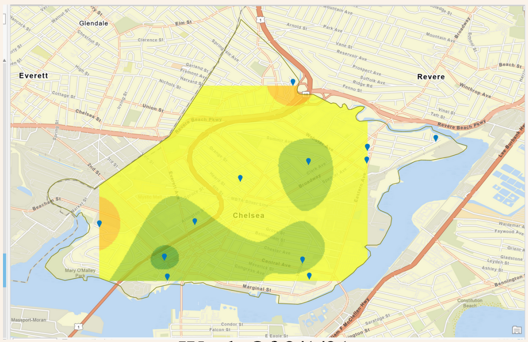
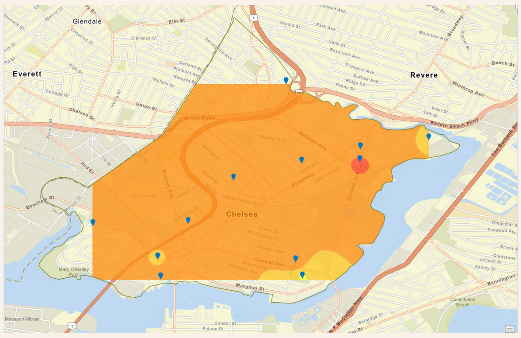


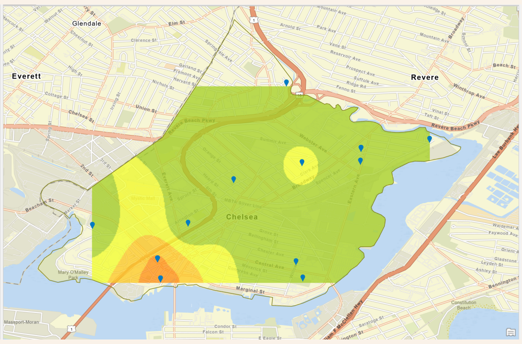
Week Of 7/25/21



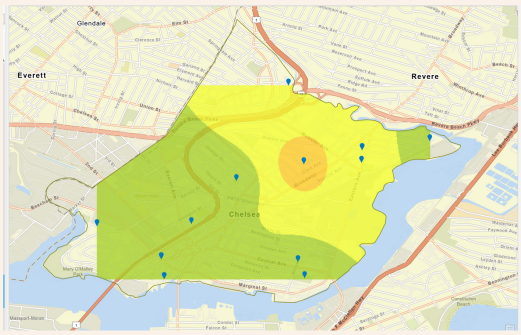
Week Of 8/1/21



Week Of 8/8/21



Week Of 8/15/21



Week Of 8/22/21

Figure 14: Heatmaps of Air Pollution from April to August

Data Analysis & GIS Findings

Time-Lapse Creation

In order to create the visuals needed to illustrate the severity of air pollution in the city of Chelsea, we used ArcGIS. We used a spatial analysis tool in order to make the heat map of where air quality is the most hazardous in a given week. The results are, a stationary heatmap visualizing the median of all the data and a weekly AQI time-lapse from April to August.

In order to create the AQI hotspot timelapse, the first step was to download the lifetime data for all twelve Chelsea sensors. Next, we calculated the weekly median values for PM2.5 for each sensor and converted these values into the standardized and easy to understand AQI. After this, the data needed to be formatted in several .csv files, one for each week since the sensors started recording data in April, in a way such that ArcGIS pro could understand and map the data; it was an important step to include the coordinates associated with each sensor alongside the AQI value, so that the data could be geographically matched with the correct sensor on the map of Chelsea. After importing this data into ArcGIS Pro, we used the IDW (Inverse Distance Weighted) function, which automatically converts the sensor data for a given week into a hotspot map by essentially mathematically “guessing” what values must be likely between sensor locations. This function becomes more accurate at “guessing” the most data points there are in a given area and the proximity of each data point.

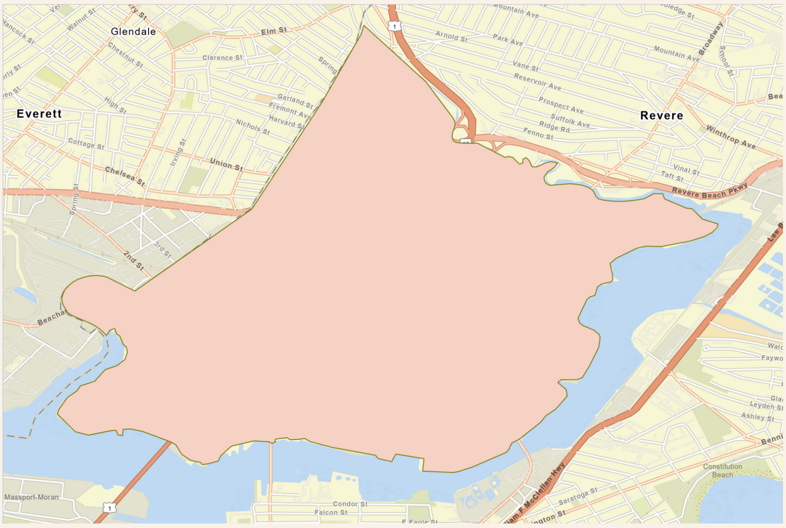


Figure 15: The shape file of Chelsea MA in ArcGIS Pro

With twelve sensors in Chelsea, which is roughly two square miles in total, the IDW function does its job in terms of conveying overall large trends over a span of many weeks, which is perfect for the type of analysis we are doing; however, if this data were used to predict or convey exactly which areas in Chelsea were above a certain threshold, say, above 50 AQI, indicating some risk for populations sensitive to poor air quality, the IDW hotspot map would falter here. This is simply because there are large portions of Chelsea with no air sensor nearby, and the guesswork that comes with the IDW function would not be sufficient as a definitive warning system for areas with high PM2.5 levels. Another note about the nature of the IDW function is how the borders of the function are defined; the function works by creating a rectangle, with the outermost data points acting as guidelines for where the edges of this rectangle are. That is to say, the hotspot map will not be generated outside of any of the farthest reaching sensors in Chelsea, which leads to some of the corners of the city being excluded from the hotspot map. This is a result of a further lack of data- the IDW function cannot “guess” what the air quality is outside of the furthest sensors, so it does not attempt to, and instead cuts off the map at the edges.

After generating an IDW hotspot map for each week, starting on the week of April 11, 2021, and finishing on the week of August 22, 2021, we took screenshots of each week’s hotspot. Two versions of this deliverable are available; one formatted as a .gif file that is an animation, where each week is shown for two seconds, with a total of 20 weeks resulting in a 40-second animation. The second version is simply a collage of all 20 weeks as still images; this version was made in order to be able to view the hotspot time-lapse and understand the implications of it even if it is viewed in a printed or offline setting - either as a PDF file or printed on paper.

Higher Temperatures Correlate to Higher Concentrations of Air Pollutants

While analyzing the raw air quality data, we went through and tried to find correlations between air quality and different potential aspects such as temperature or humidity. We found that there is usually a strong correlation between concentrations of pollutants and temperature. This chart to the right shows a clear correlation for all the sensors and temperature. Despite some outliers in the forms of exceptionally high concentrations of pollutions, there is a strong trendline which indicates that an increase in temperature correlates with an increase in concentration of PM 2.5 levels.

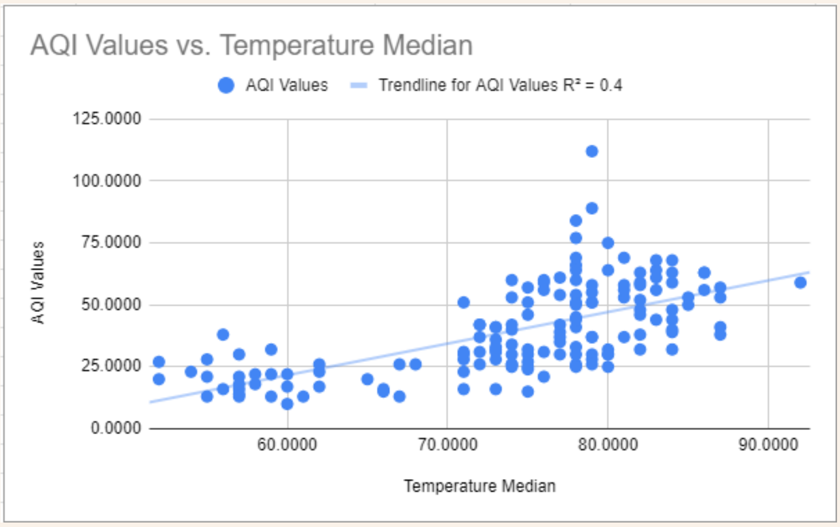


Figure 16: Chart of all 12 sensors readings vs temperature at that time

Now, take a look at the two photos below, the correlation can be further shown and explained. The one on the left is a heatmap of hazardous air qualities in the month of May and the one on the right is for a week in August. Green means better air quality and orange/red means that the air is more polluted and more dangerous. The correlation is clear here, as in May where the temperature is generally lower than August, the air quality is better, while as we get in the summer in August the air quality gets worse and the readings are considerably higher. You can see more of the correlation between temperature and concentration of pollutants in the the previous pages of the heat for each week from April to August. A study that was done during a heatwave in the UK, also shows that correlation between temperature and air pollution as significant and a positive relation. (Kalisa 2018)

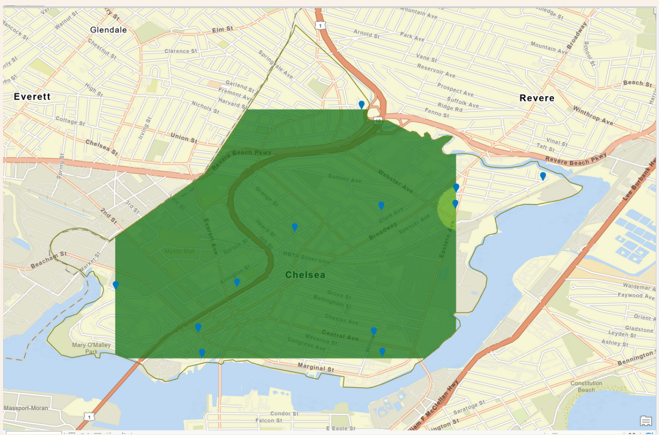


Figure 17: Heatmap of A Week In May

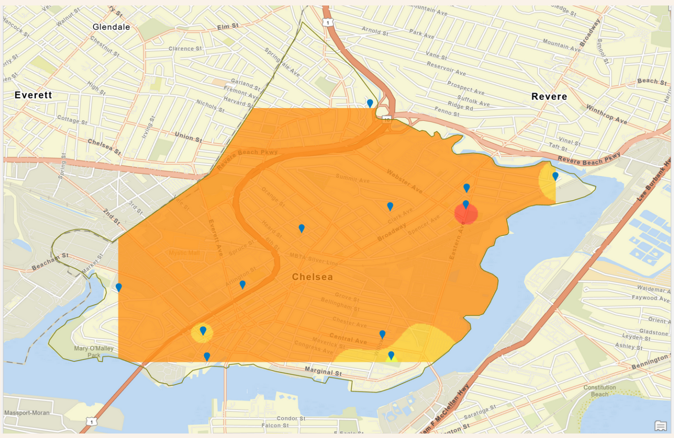


Figure 18: Heatmap of A Week In August

Outliers

A common theme seen in all PM2.5 data for every sensor across Chelsea is the prevalence of extreme outliers. Before being adjusted to the AQI scale, the typical PM2.5 range for a normal day in Chelsea is anywhere between 1 and 20 µg/m3; however, these outliers, which occur irregularly every few days or so, often exceed 200 µg/m3 and even get above 1000 µg/m3, which is more than 50 times larger than the higher PM2.5 values you'd see on a normal day.

What causes spikes this drastic? The question is simple but the answer is much more complex. These spikes all have some commonalities but many more differences; they are all brief, lasting no longer than an hour at the absolute most. Some of them only last for one measurement (two minutes), while others have a sustained high PM2.5 value for half an hour. Some are preceded by a buildup period for a few minutes where the PM2.5 level gradually climbs before reaching the peak, while others have no precedent at all, going from a normal level of PM2.5 to a spike within a single measurement. Similarly, some are followed by a gradual decrease in PM2.5 after the peak of the spike has occurred, returning to normal PM2.5 levels slowly over the course of up to an hour; others rapidly return to normal with no gradual decline.

Speculating on the possible different sources that cause these various outliers is interesting, but actually being able to go outlier by outlier and determine what caused each one is nearly impossible.

One technique we used to inspect the range of these spikes was by cross-referencing them with two nearby sensors. For example, the sensor on Eastern Ave. is very close to the one on Spencer Ave, only a block or so away. First, we identified all of the outliers above a certain threshold and took note of the exact date and time at which they occurred; next, we cross-referenced this with the other sensor of the two to see if a spike similarly occurred at the exact time it did for the first sensor. Again, here there were mixed results. Most of the time there was no correlation between the two, but occasionally large spikes for one sensor lined up with smaller increases in PM2.5 for the other. There are so many of these spikes that checking each one or running a complex statistical analysis on them was not something we were able to spend time doing given the 7 weeks we had to complete the project, but this may be an interesting opportunity for future research. Once more, this is just speculation, but we believe that spikes which register on two nearby sensors are caused by larger sources of pollution, like a plane flying particularly low overhead or a ship idling close by for a long period of time. Spikes that are isolated to one sensor are likely smaller, more localized sources of pollution, and these are far more common. This includes things like cars and trucks idling near a sensor, or someone smoking near a sensor.

Regardless of the direct causes of each of these spikes, the fact of the matter is that they exist, and aren't errors or false data; they may be misleading if the data is analyzed incorrectly, but the data itself is not false.

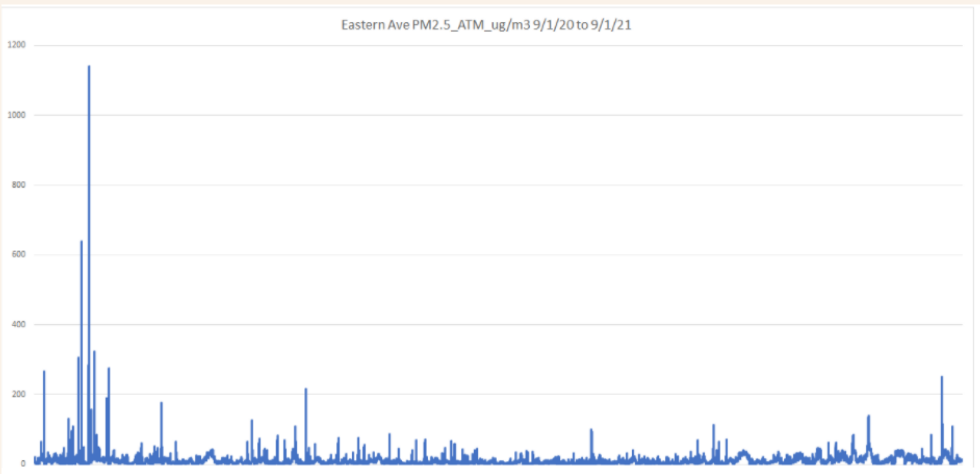


Figure 19: The chart of median vs average of one sensor

Medians Vs Averages

When analyzing the air quality data, we went through the mass amount of raw data from each sensor and calculated both the averages as well as medians of each week. This was done for PM 2.5 readings, temperature, and humidity of each and every sensor. Then, both the averages and medians of the data was plotted on the same graph and compared. We analyzed the graphs and came to the conclusion that median is overall a much better representation of the data for each week as opposed to averages. For example, if there is a small period of time in that given week that the readings are significantly higher than the rest of that week, it would severity increase the average of that week while leaving the median little to unchanged. This is mainly due to extreme outliers in the data set, regardless of whether or not that data is real legitimate or not. As you can see on the graph below, in a week between the month of July and August, the median is average is drastically different. Overall, median is a much better representation of our data for GIS and the time-lapse and is generally much better at showing long term trend and patterns as it is less impacted by the existence of outlier in the data.

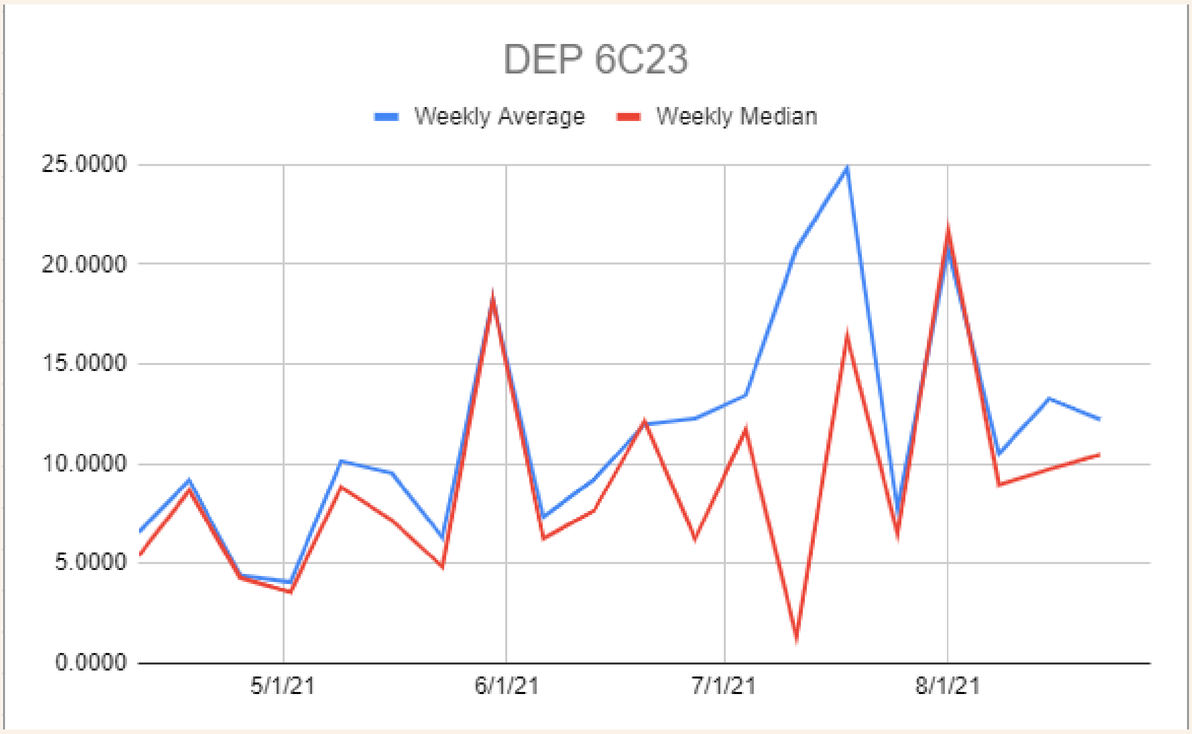


Figure 20: The chart of median vs average of one sensor

Variability:

Looking at the hotspot time-lapse we created in figure 13, it is clear to see the high week-to-week variability of air quality in Chelsea. There are a couple of sensors that just by visually inspecting the time-lapse can be seen to generally have a higher number of weeks with poor air quality, namely the sensors on Eastern Ave and Mills Ct. Still, even these sensors occasionally have good air quality while the other sensors in the city have poor quality, for example as seen on the week of August 15, 2021. The simple fact that there are no sensors within Chelsea with considerably worse pollution than the rest, at least using the weekly median PM2.5 values as we did for this time-lapse, indicates high week-to-week variability within the city.

Comparing our study with a similar one done in the city of Richmond, Virginia, which similarly made use of the exact website and sensors we did (PurpleAir), the similarities and differences between our own research and analysis and the research done in this study illuminate why this high variability exists in our study but is not as prevalent in theirs.

The 2020 study, Assessing Inequitable Urban Heat Islands and Air Pollution Disparities with Low-Cost Sensors in Richmond, Virginia, made use of eight PurpleAir sensors across Richmond, the exact same types of sensors we made use of, keeping track of and uploading the same data types. The study analyzed both air quality trends and temporal trends to a great depth.

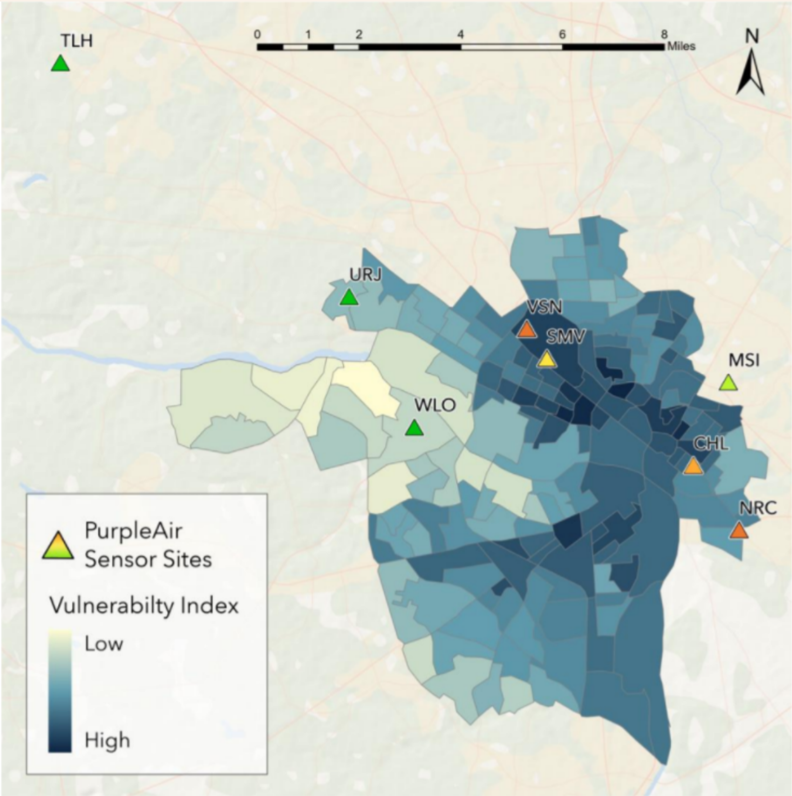


Figure 21 Variance among hourly average PM2.5 values recorded by all eight PurpleAir sensors on the ten hottest days of 2019. (a) Distributions of PM2.5 values by site are ordered left to right by mean and fall into five distinct categories of significant difference as indicated by colors. Green corresponds to lower average PM2.5 concentrations, while higher average PM2.5 concentrations are shown in orange. (b) These colors are projected onto each site with an underlying vulnerability index. (Eanes et al., 2020)

The map in figure 21 shows the map of Richmond and some of the sensors analyzed in the study. Throughout the study, the variance of both pollution and temperature are discussed at length, but generally, the variance is low enough to identify permanently "better" and "worse" areas, as indicated in the figure (Eanes et al., 2020). What's important to note here is the size of Richmond; the city is over sixty square miles, roughly thirty times more total area than Chelsea's measly two square miles. This is important to note because the sensor locations analyzed during this study were far enough apart that the locations many sensors were in are considerably different in terms of population density, total greenspace, number of impervious surfaces, and many more. Within Chelsea, distinctions like this are rare given the small size of the city; much of the city is similar in nature to the rest of the city, with only minute differences here and there in terms of greenspace, population density, and so on. The only exception to this is perhaps Admirals Hill, which is more wealthy than much of the rest of Chelsea and has significantly more greenspace. The reason it's important to point out this discrepancy between our own study and the one done in Richmond is that the primary difference between the two studies is the size of the area we are inspecting, while the number of sensors is roughly the same. That is to say, much of the high variability we observed in the timelapse makes sense given how small Chelsea is and how uniform much of the city is in terms of the common lack of green space and the high number of impervious surfaces.

All of this is not to say there are no areas in Chelsea with significantly poorer air quality in comparison to the rest of the city, but rather that it will take more analysis to identify these areas. This will be examined further in the Selection and Justification of Mitigation Locations section.

Selection and Justification of Mitigation Locations

The time-lapse, seen in figure 14, which shows weekly median AQI values since April 2021, serves as an important visualization of the air quality data collected across Chelsea over a long stretch of time; however, due to the high variability of air pollution data we observed in time-lapse, we decided it would not be possible to pick locations for immediate implementation strategies based solely on this.

Ideally, the locations we select for specific pollution mitigation strategy implementation should be based on the vulnerability of the groups that live and spend time in those areas combined with the overall state of air quality in those areas. Even with a comprehensive analysis of both of these factors, it is not guaranteed that any single place in the city has both the worst quality of air pollution and the highest population of vulnerable groups; this process cannot be perfectly objective. However, in this section, we will weigh and compare the daily air pollution spikes across Chelsea and various groups considered "vulnerable" to the impacts of poor air quality in order to select three locations where we can focus our mitigation strategies. These locations are by no means the only places in Chelsea that would benefit from cleaner air, but we hope to articulate through this section that these areas would benefit the most from immediate relief.

In order to make use of the PurpleAir sensor data to figure out hotspots of air pollution in the city, we created a "spikemap" as seen in figure 22. This figure was created from sensor data from Chelsea, starting in April 2021 when most of the sensors started uploading air quality data. Each sensor's daily average AQI was calculated, and using simple excel formulas, we counted the number of instances the average daily AQI was 50 or greater. 50 AQI was selected as the threshold because it is defined by the EPA as the point at which "there may be a risk for some people, particularly those who are unusually sensitive to air pollution" (AirNow). The number of instances this threshold was met or exceeded was divided by the total number of days in the sample. This was not the exact same for every sensor, as many sensors in Chelsea started uploading data between April 4, 2021 and April 23, 2021, but on various different days during that span. Furthermore, one sensor has been recording data since September 2020, but all data prior to April 4, 2021 was not considered for this visual in order to most closely match up with the timeframe of the other sensors. This was a priority because of the known connection between temperature and other weather with pollution, as discussed on page 22; matching time frames between sensors would help ensure that the percentage "spikemap" would be accurate, instead of comparing pollution from winter months and summer months for two given sensors, for example. On this note, two sensors- those on Walnut St. and Mills Ct., the sensors with the highest percentage of days above 50 AQI (48% and 47% respectively), only began recording data since in August 2021. This is likely why these percentages are significantly higher than any other sensor, as the sample size is both smaller than the other locations and these sensors have only recorded data during a hot month, between August and September 2021, while other sensors have been recording since April 2021. We thought these two sensors should still be included in the visual, although further analysis and larger sample size would be required before making any definitive claims about the overall level of air pollution in these areas. The table that the map in figure 22 was created from is available in the appendix.

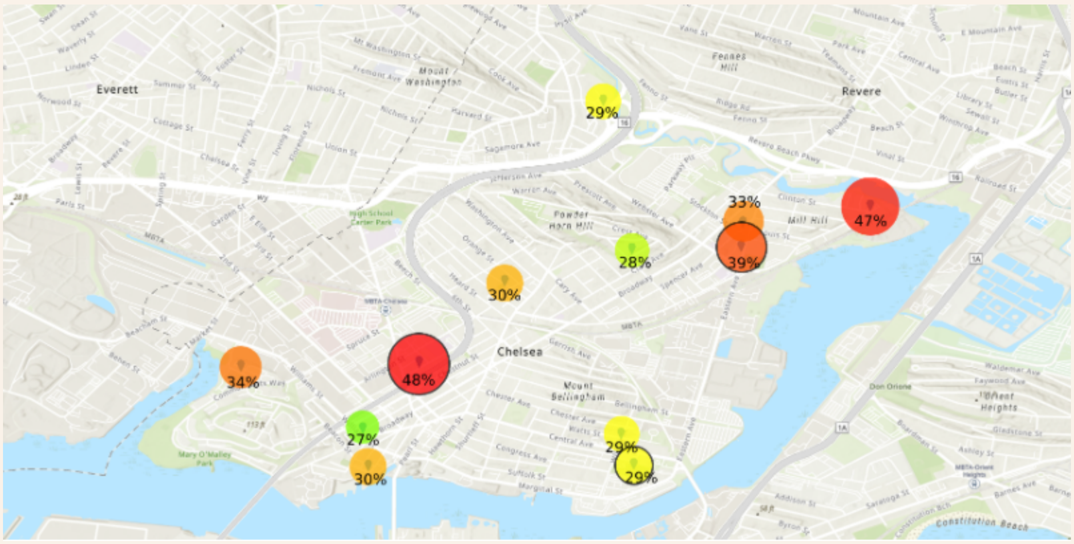


Figure 22: Map of percentage of days a sensor's daily AQI value equalled or exceeded 50

Excluding the sensors on Mills Ct. and Walnut St., the sensor on Eastern Ave. had the highest percentage of days above 50 AQI at 39%. The other sensors in Chelsea range between 27% and 33%, so 39% is considerably higher than the next closest percentage. Because of this reason, this sensor location quickly became one of our areas of focus. This sensor is located right across the street from two large elementary schools and is close by to Eastern Ave, one of the busiest streets in Chelsea.

Furthermore, even if the sensor on Walnut St. had a small sample size with selection bias, 48% of the days exceeded 50 AQI; the sensor is located in a residential area with many homes, but these homes are closely surrounded by a highway business district, a normal business district, and is directly beside the Tobin bridge. For these reasons, we began considering this sensor location, despite the smaller sample size.

Finally, the remaining sensors in Chelsea all saw their daily AQI average go above 50 somewhere between 27% and 33% of the time. The final sensor location we selected is in Highland Park. On the surface, this sensor had just 29% of its days above 50 AQI, seemingly in the middle of the pack and not too bad; however, the unique location of this sensor may explain the reason for this statistic. In a picture we took while visiting Chelsea seen in figures 23 and 24, the sensor is completely gated off and is surrounded by greenery. Furthermore, the sensor itself is all the way in the back of the park, past a parking lot and an entire soccer field; this is to say, the sensor is not very close to the road, whereas most other sensors are right on the sidewalk of a busy street. All of this is to say, it is highly likely that because of these reasons, the fact that 29% of days exceeded 50 AQI may not be a fully representative view of how bad the pollution in this area is. Because of this reason, we will consider this location as one of our locations for mitigation implementation.

There are various groups that are more impacted by poor air quality than others. These can be considered vulnerable groups. Some of the groups most at risk of the health issues relating to pollution include people with lung diseases, infants and young children, the elderly, people in poverty or who lack access to healthcare, and people who spend a lot of time near busy roadways (Minnesota Pollution Control Agency, 2019). In terms of children and elderly groups, they are more likely to develop asthma and other respiratory diseases from poor air quality. As for those in poverty and without access to healthcare, they are less likely to seek and therefore receive treatment for any ailments developed because of pollution. They would be less likely to afford things like indoor air filters to mitigate pollution on their own, within their own homes.

Figure 23: Highland park monitor Signage

Figure 24a: Highland park monitor

Figure 24b: Highland Park monitor, in the yellow box

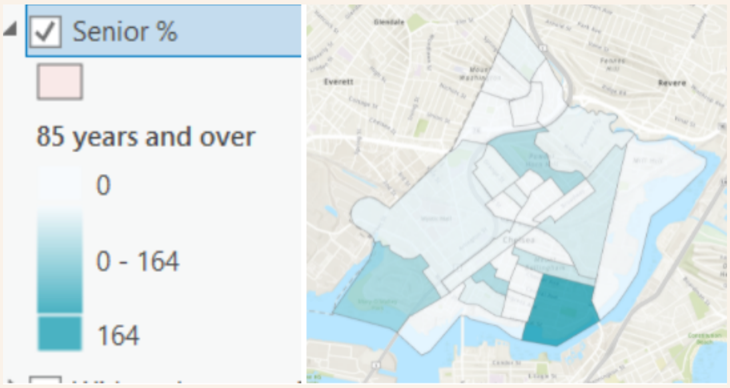


Figure 25: Age 85 and over population in Chelsea by block group

Figure 25 shows the population of residents over 85 in Chelsea by block group; the area surrounding Highland park has by far the highest concentration of residents over 85 living there. The next highest area is in the southwest of Chelsea, which has a considerable senior population living there; however, this area is much wealthier than much of the rest of Chelsea, including the three sensor locations mentioned earlier: Highland park, Eastern Ave, and Walnut St. The buildings here are newer, more expensive, and there is considerably more green space to reduce the pollution. This can be seen in figure 26. It is because of these reasons that despite having a considerable senior population and an air quality sensor on Justin St. that exceeded 50 AQI 34% of the days since April 2021, we didn't select this as one of our locations to focus mitigation strategies on.

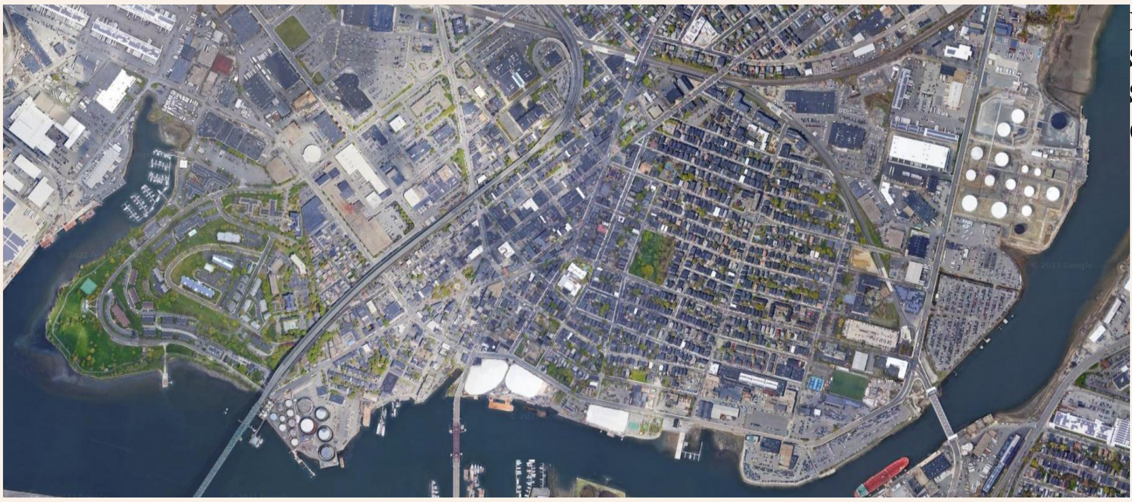


Figure 26: Satellite view of Southern Chelsea (Google Maps)

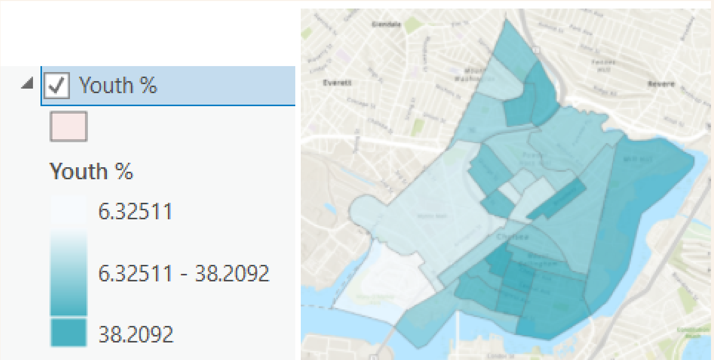


Figure 27: Youth percentage in Chelsea by block group

In figure 27, a similar situation is seen by observing the block group data for youth percentage in Chelsea by block group. It is worth noting that all three sensors we are considering for mitigation strategy implementation are seen to have a high youth percentage on this map - Highland Park, Walnut Street, and Eastern Avenue. Furthermore, this demographic data just covers actual residents that live in these areas but neglects people who spend time in them. Highland Park and Eastern Ave in particular have a high number of children who spend time outdoors. Highland Park is a recreational area with a soccer field and playground and is directly across the street from a daycare and an elementary school. Eastern Ave is right across the street from two large elementary schools. For these reasons, children spend considerable time outdoors in these areas in particular, making it even more important to mitigate pollution in these areas because of the unique vulnerability children have to respiratory diseases like asthma.

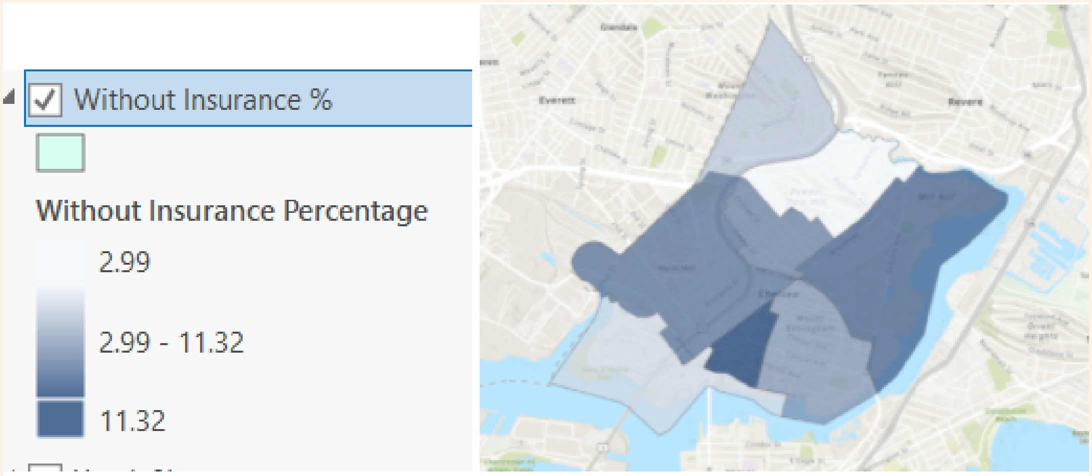


Figure 28: Percentage of people without Health Insurance by Block Group in Chelsea

Figure 28 shows the percentage of people who lack health insurance in Chelsea by block group. The area with the highest percentage is directly next to the Walnut street sensor, on the Eastern side of the Tobin bridge. The second highest is the group that includes Eastern Ave.

As explained throughout this section, several locations were considered for mitigation strategy implementation and three were selected. These locations were selected after examining a combination of the analyzed air sensor data from the twelve sensors across Chelsea and the various demographic data which revealed where different groups uniquely vulnerable to air pollution reside within the city. As seen in figure 29, these will be the areas we will focus our mitigation strategies on. The three locations each span a few blocks away from where their respective sensor is located, but for the sake of consistency and naming clarity, we will refer to the larger areas they encompass as "Highland Park", "Eastern Ave", and "Walnut St".

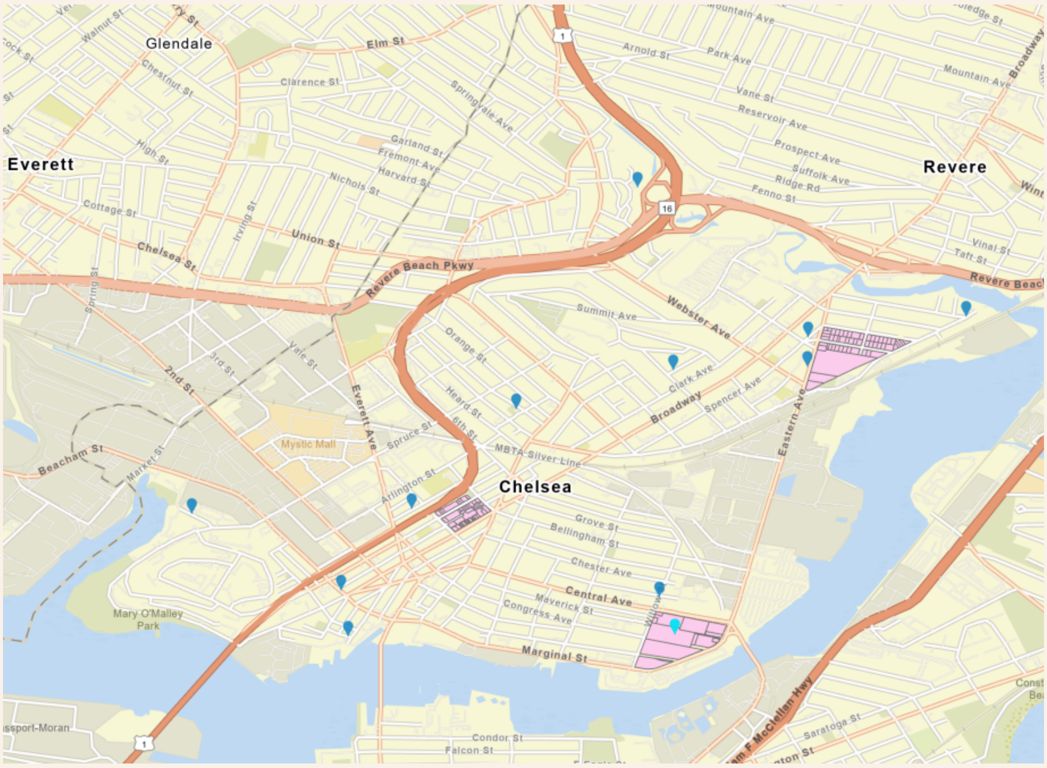


Figure 29: Location Selections for Pollution Mitigation Strategy Implementation

Surveys

After the survey that we created to assess community insights has been sent out, we realized that we got a good amount of responses in a rather short amount of time. There were actually 10 responses after the first couple hours of it being released to the public. That does go on to see the urgency of the issue in the eyes of the residents in Chelsea. However, we only ended up getting a little over 20 responses. The responses were extremely helpful and insightful. In the responses, all of them live in the city, which is the point of the survey, to collect insights on residents in the city. Of all the surveyed, the youngest is 19 years old and the oldest is 60 years old. About 38% of people who responded are of Hispanic, Latino, or Spanish origins and about half are of White origins. Two thirds of all people are very concerned with the health concerns that are associated with air pollution. Over 90% were at least somewhat concerned with the pollution. Two thirds of the respondents also know someone who lives in the city and has a respiratory or breathing problems like asthma.

Over 70% of them either have an air filter or would like one. That shows the importance for the residents to take action against the poor air quality in the city. A majority of the people use cars as their primary method of transportation to get around the city. We also had an optional section for open responses in case people would like to share their thoughts. We had 5 of those responses from people. One of them wanted us to make the map of their locations larger for them to see since it could not have been blown up in size. The other responses think that it is tough living in the city. They think that the main reasons are the airport and traffic. "It’s tough living in Chelsea because of air quality… airport, major highways/bridges, ship and boat traffic, train traffic, oil tankers transporting fuel, oil fuel refineries…so many pollutants, we have it all here in Chelsea." This was one of the points mentioned by one of the respondents. Of those that are surveyed, they also say that they would like to know about the life expectancy of residents that live in areas of poor air quality like Chelsea and would love to know more for their future generations. One person also would like air filters but they think that the good ones are much too expensive for them. Air filters are important in order to help with indoor pollutants but funding should be provided by the government or environmental organizations especially in a city where the residents are making less than the state average.

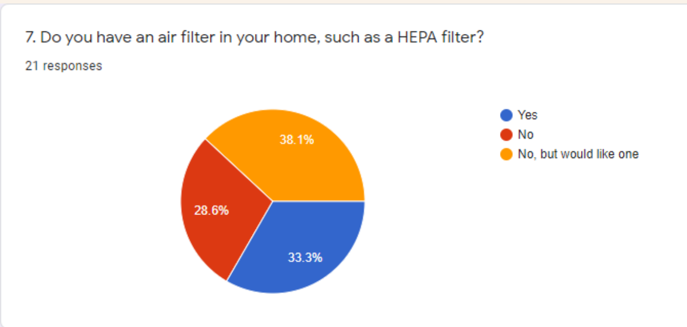


Figure 30: Survey Responses on whether they have air filters

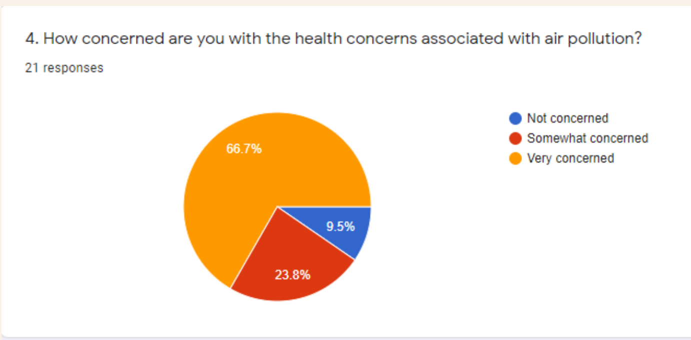


Figure 31: Survey Responses of Health concerns associated with air pollution

"I grew up on Essex Street, behind the former Boston Hides and Furs and the Eastern Mineral salt piles, and under all of the lowest (really low) flying plans headed to Logan Airport. It's astounding to me, now as a traveling adult, just how bad the air was where I grew up and how bad it still is. I recall just how thick and smoggy my breaths taken as a kid always were, a normalcy that is far from normal -- or healthy. When I leave Chelsea for more rural areas now, It's even more glaring how bad our air here truly is. I can breath outside of Chelsea, the air is not thick, I do not smell it, I do not feel it going down, it does not cause me headaches or nausea. The quality of air the people of Chelsea are subjected to, should be a crime. I've had to watch nieces, nephews, siblings and friends grow up with adverse breathing conditions and knew all along it's predominately caused by the terrible air quality here. It's tough to see it happen, from generation to generation (my family has lived in Chelsea for over 30+ years). I sincerely believe, just as Massport did years ago with window installations due to the noise pollution in segments of the city, the state should step in and provide healthier upgrades/accommodations to the most effected areas in the city, possibly through a system that provides better filtration for homes. Everyone across the country, and the world, is deserving and entitled to fresh air, which we do not have in Chelsea. Our children and most vulnerable suffer the most, while city money-makers (Logan/Eastern Mineral/Etc.) make profits off our plight."

-Anonymous Survey Respondant

Mitigation Strategies

Based on all our findings and research, we have compiled indoor and outdoor air pollution mitigation strategies to specifically recommend to Chelsea. The Objective of these strategies is to not only improve the air quality in the previously mentioned areas- Highland Park, Eastern Ave, and Walnut Street- that are most affected by and vulnerable to air pollution but to improve their quality of life and general well being. These strategies can be generally divided into two categories. The first category is mitigating air pollution emissions from local sources, mainly traffic emissions, industrial emissions, water treatment plant emissions, and ports/airport emissions. The second category of strategies consists of strategies that reduce the impacts and existing levels of air pollution. These include investing in urban greenery, indoor air filters, urban heat reduction, and raising awareness. In order to recommend the best of these strategies, we researched and ranked the potential feasibility and effectiveness of each strategy, relative to each other, with the most feasible, most effective ones being the best. The effectiveness ratings were generated by analyzing how effective these strategies were in previous applications. This involved researching the amount of air pollution they can filter out of the air, or reduce from being put into the air, at various scales and time intervals, as well as other impacts they have on stakeholders and the circumstances under which they had these effects. This research was then combined with knowledge of Chelsea, and its circumstances, to ensure they would be applicable. Feasibility ratings were generated by analyzing the likelihood and capability of implementation of a given strategy. Cost and time of implementation were significant factors in this category as well as the means through which a strategy would need to be implemented, whether it be through individuals, institutions, enterprises, or governments.

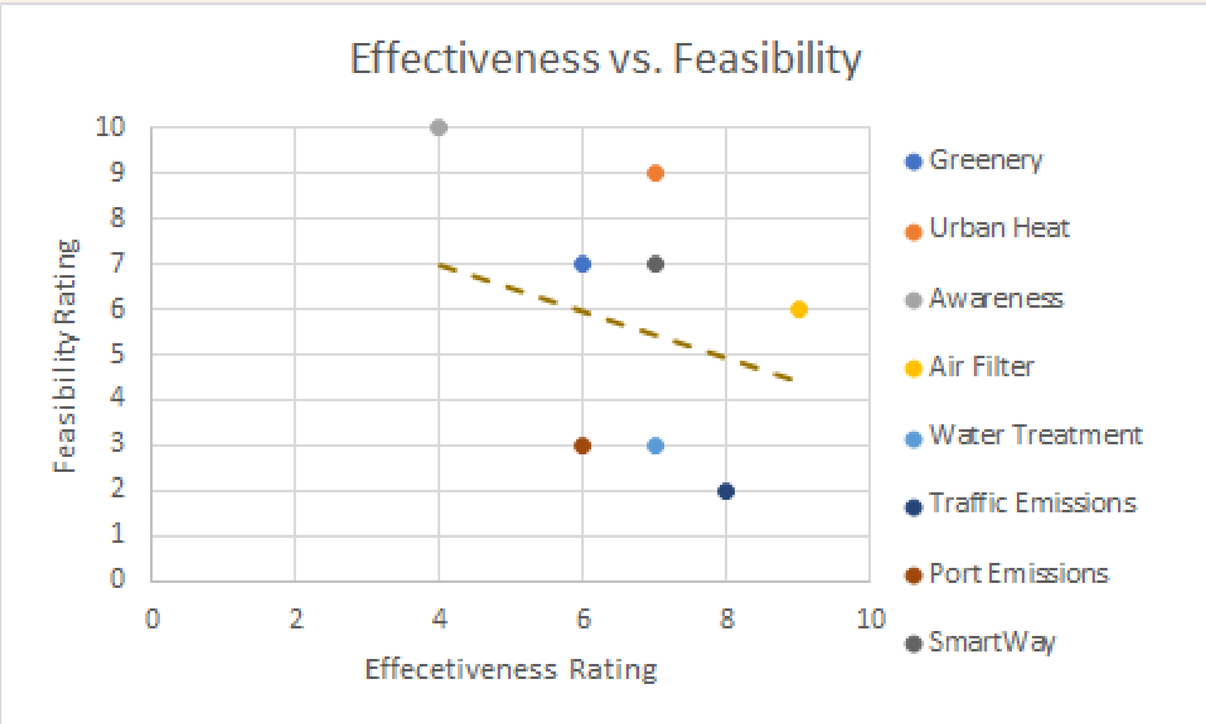


Figure 32: Feasibility vs. Effectiveness Plot

Mitigating Water Treatment Plant Emissions

One area of industry in which emissions can be reduced is in water treatment plants. These plants contribute to levels of local air pollution by emitting greenhouse gases, volatile organic compounds, nitrogen oxides, and sulfur oxides (Alyasi et al. 2018). This is an area of emissions reduction we specifically chose for Chelsea due to the location of Chelsea Creek Headworks, a sewage treatment facility, right behind Highland Park and in close proximity to The Boys and Girls Club. The facility directly borders the soccer field in Highland Park, so the players breathing heavily on the field couldn't possibly be any closer, this close proximity is illustrated in figure 33. The Boys and Girls Club, filled with young children, isn't much further away, situated just across the street from Highland Park. Mitigating the emission of air pollutants from this facility would increase the quality of air the people in these locations breathe, and thankfully there are proven methods of accomplishing this Duan et al. (2020) outlines the process through which N2O emissions can be reduced. The first step would be developing a comprehensive understanding of operational conditions and baseline N2O emission status of the plant to identify the main contributing factors. The second would be to use a multi-pathway N2O mathematical model to evaluate the effectiveness of the mitigation strategies that have previously been shown to be successful, such as low DO control strategy, intermittent aeration strategy, and more. This model additionally assesses the consequences of proposed strategies on plant nutrient removal performance. The study also found implementing strategies like this led to a "35% reduction in N2O emissions", reduced operational costs due to "20% savings in aeration energy consumption" and no decrease in the performance of the plant(Duan et al. 2020). From this we can conclude that this strategy would benefit the areas around the plant as well as the people owing and operating it.

Feasibility Rating - 3
Effectiveness Rating - 7

.With regards to feasibility, the savings in energy costs, and therefore operating cost add to the score, however, the score still remains relatively low due to required cost and time commitment. In the process outlined by Duan et al. (2020), an intensive long-term monitoring program was undergone, consisting of two 4 week N20 monitoring campaigns, a three-day intensive monitoring period, and a year and a half of monitoring influent and effluent quality, before they can even begin to mitigate emissions. Due to this, we rated this strategy a 3 for feasibility, relative to our other strategies, as it could take the longest to start benefiting the community. The effectiveness score is on the higher side largely due to the location of the plant near the community and some of its vulnerable populations. The effectiveness score was also influenced by the fact that in previous projects like this, not only was the plant's effectiveness not reduced but operational and energy costs were reduced and it resulted in a 35% reduction in N2O emissions, which was equivalent to an annual reduction of 2.35 tonne of N2O in the studied plant (Duan et al. 2020). While the annual emissions reduction may differ in the plant in Chelsea, due to difference in size, this impressive performance led us to rate it a 7 for effectiveness.

Figure 33: View of Chelsea Creek Headworks from Highland Park

Mitigating Freight Transportation Emissions

An additional source of emission to target within the industrial sector is freight transportation emissions. Chelsea is home to many different trucking companies as well as companies that utilize trucking to transport goods and freight, as shipping in the greater Boston area relies on trucks for more than 90% of freight movement, compared to 78% nationally(Blonde et al., 2014). If you look closely in figure 34, many of these companies with fleets of trucks are located right nearby residential areas. HDVs(Heavy-Duty Vehicles, such as large trucks) emit as much as ten times more pollution than passenger cars per kilometer and are also known to be a significant source of particulate matter emissions (Mahmod et al., 2013). Additionally, it is projected that globally by 2050, freight transport emissions will surpass passenger vehicle emissions (US EPA Smartway 2016). For these reasons, mitigating these emissions is essential. To do so, we recommend local companies who are involved in freight transportation, particularly if they utilize trucks, to participate in the EPA's SmartWay program (US EPA Smartway 2016). This is a trusted program that is "supported by major transportation industry associations, environmental groups, state and local governments, international agencies, and the corporate community." The program benefits the participating companies by providing "a comprehensive and well-recognized system for tracking, documenting and sharing information about fuel use and freight emissions across supply chains", help "helps companies identify and select more efficient freight carriers, transport modes, equipment, and operational strategies to improve supply chain sustainability and lower costs from goods movement."

It additionally "supports global energy security and offsets environmental risk for companies and countries" and finally, most beneficial to local communities, "reduces freight transportation-related emissions by accelerating the use of advanced fuel-saving technologies." The program has even seen great success in reducing emissions throughout its history as since its creation in 2004 it has "helped partners avoid emitting 143 million metric tons of CO_2, 2.7 million short tons of NO_x, and 112,000 short tons of PM" (US EPA Smartway 2016). The local Chelsea community could greatly benefit from these reductions in emissions and in addition to that, the companies would also benefit from operating more efficiently and at a lower cost.

Feasibility Rating - 7
Effectiveness Rating - 7

This strategy received a high score in feasibility from us, due to the incentives for companies to participate. The program provides these companies with the resources to achieve their freight supply chain sustainability and to improve their environmental performance, at no cost. Additionally, $44.8 billion in fuel costs have been saved by U.S. trucking companies working with SmartWay (US EPA Smartway 2016). For these reasons we gave it a 7 in feasibility. For effectiveness, the program's track record of helping companies reduce emissions, and use less fuel give it a rating of a 7.

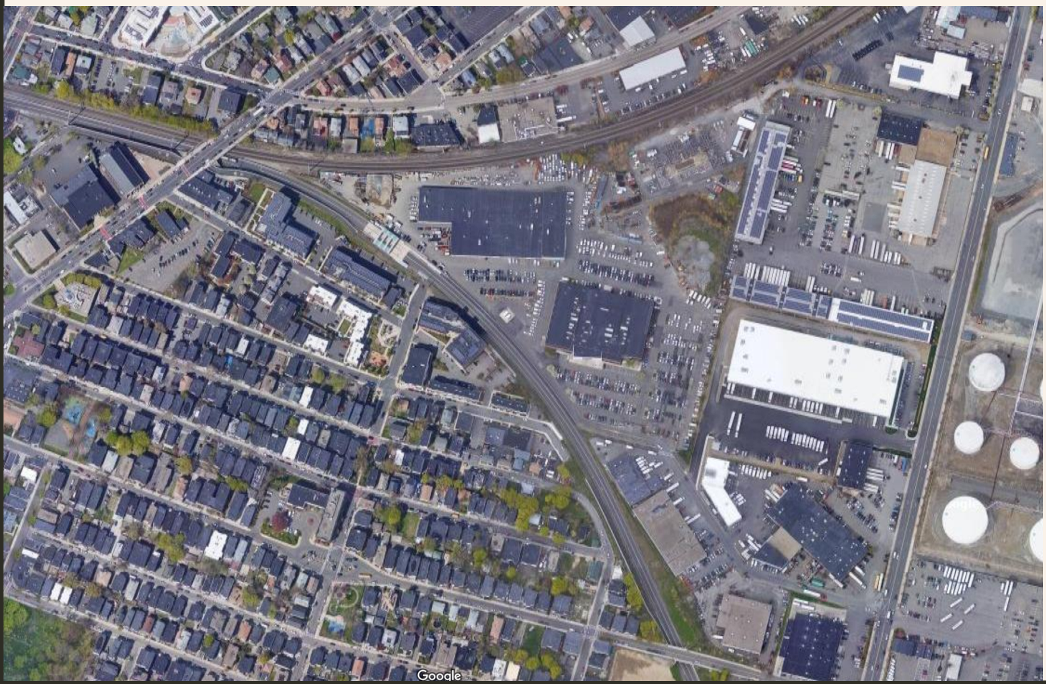


Figure 34:
Satellite Image of trucking facilities near resedential areas in Chelsea (Google Maps)

Mitigating Traffic Emissions:

Chelsea experiences heavy traffic on a daily basis, with large amounts of passenger cars and heavy-duty trucks passing through the city. US-1, the road that goes over the Maurice J. Tobin Memorial Bridge averaged 72,743 vehicles per day, at the point where it comes onto land in Chelsea, for the year 2020. The Revere Beach Parkway averaged 44,038 vehicles per day in 2020 at the point where it intersects with Garden Street. Many smaller local streets experience heavy traffic too with Webster Avenue averaging 16,026 per day and Washington Ave averaging 7,692 (Traffic volume and classification | mass. Gov. 2021). While these traffic counts are largely made up of passenger cars, Chelsea also contains large amounts of industry that heavily relies on shipping freight. In the Boston metropolitan area, shipping relies on trucks for more than 90% of freight movement, compared to 78% nationally (Blonde et al., 2014). Large amounts of heavy-duty trucks with diesel engines on the road shipping freight is a significant air pollution concern due to the emissions they give off. This is in addition to all the car traffic and associated emissions, making vehicle emissions a good target for air pollution mitigation in Chelsea. Reducing the number of heavy-duty trucks in city centers has been shown to be an effective way of reducing the amount of air pollution people in that area are exposed to. This can be done by replacing them with smaller, lighter vehicles ideally without diesel engines. While this would result in more traffic on the roads, emissions of pollutants such as PM2.5 in the city center would actually be reduced. Additionally, Routing heavy-duty trucks away from the city center could also benefit the community, as the emissions would be further from residential and retail areas and fewer people would breathe them.

These strategies would especially be relevant to Chelsea, as Washington Ave is right in the middle of the city's dear retail and residential areas and saw the largest percentage of its traffic numbers made up vehicles FHWA Class 4 and above, meaning largely heavy-duty trucks. Reducing emissions from passenger vehicles in the city could be done by reducing speed limits and modifying intersections to reduce the amount of deceleration, stops, idling, and acceleration done by cars (Mahmod et al., 2013). Finally, measures that reduce traffic demand reduce emissions. Better, more reliable, higher-quality public transportation, would incentivize more widespread use, which has been shown to result in lowered traffic and emissions. Incentivizing other alternative transportation such as biking or walking has also been shown to not only also reduce emissions and traffic, but to have positive effects on individual health (Sofia et al., 2020). Reducing the number of heavy-duty trucks in the center of the city could have been shown to be an effective way of reducing the amount of air pollution people in that area are exposed to. This can be done by replacing them with smaller, lighter vehicles ideally without diesel engines. While this would result in more traffic on the roads, emissions of pollutants such as PM2.5 in the city center would actually be reduced. Additionally, Routing heavy-duty trucks away from the city center could also benefit the community, as the emissions would be further from residential and retail areas and fewer people would breathe them. These strategies would especially be relevant to Chelsea, as Washington Ave is right in the middle of the city's dear retail and residential areas and saw the largest percentage of its traffic numbers made up vehicles FHWA Class 4 and above, meaning largely heavy-duty trucks.

Figure 35: Traffic in Chelsea

Reducing emissions from passenger vehicles in the city could be done by reducing speed limits and modifying intersections to reduce the amount of deceleration, stops, idling, and acceleration done by cars (Mahmod et al., 2013). Finally, measures that reduce traffic demand reduce emissions. Better, more reliable, higher-quality public transportation, would incentivize more widespread use, which has been shown to result in lowered traffic and emissions. Incentivizing other alternative transportation such as biking or walking has also been shown to not only also reduce emissions and traffic, but to have positive effects on individual health (Sofia et al., 2020).

Feasibility Rating - 2
Effectiveness Rating - 8

For feasibility, we gave targeting traffic emissions a comparatively low score. Our method of reducing speed limits to reduce emissions is unfeasible due to the process through which this would likely need to be accomplished. Speed limits are set using a safety standard, which relates to accidents, not air pollution. The standard method involves setting the limit at the speed that 85% of traffic already on the road drives under, and this is usually only changed if excessive accidents occur (Traffic Safety Coordinating Committee, 2009). Emissions reduction is a non-standard reason to lower a speed limit and is, therefore, less likely to convince local governing bodies, such as the Chelsea Traffic & Parking Commission to change them. The method modifying intersections to reduce amounts of accelerating, decelerating, stopping, and idling also is not very feasible, for the same reason that the justification of the change to local authorities, would not be based on safety concerns regarding accidents. The improvement in traffic flow this strategy entails is a more standard and accepted reason for changes to be made, however, the feasibility still remains low as it would likely need to be justified by a study done by traffic engineers and typically “design and installation costs routinely exceed $250,000 for intersections where signals are installed” (Needham Traffic Management Advisory Committee, 2003). Reducing the reliance on cars in the city would require large investments into public transportation and infrastructure, as even just installing a crosswalk can cost a town around $10,000 (Needham Traffic Management Advisory Committee, 2003). This all results in a feasibility rating of 2. Mitigating traffic emissions receives a high effectiveness score at an 8. This high score was based on a combination of two main factors; the tens of thousands of cars seen on individual Chelsea streets daily and the number of various pollutants these cars emit.

Mitigating Port/Airport Emissions

With many ports and harbors located close by, reducing their associated emissions could be a potential way to reduce overall air pollution in Chelsea. Within ports, there are many contributing factors to the pollution, such as marine vessels, cargo handling equipment, and trucks (US EPA, 2017) (Baily & Solomon, 2004). This means there is a variety of strategies that have been used, ranging in ease of implementation and effectiveness. Requiring lower sulfur fuel to be used for trucks, vessels, and cargo handling equipment, or using biodiesel in these diesel engines has been used to reduce emissions. Additional techniques include switching from diesel to electric power where possible, implementing restrictions on truck idling, and adding shore-side power for docked ships(US EPA, 2017) (Baily & Solomon, 2004). Figure 36 shows a docked ship right by Chelsea emitting black smoke. Reducing and regulating emissions from the nearby Logan Airport would also help to reduce the effects of poor air quality on Chelsea residents, as a relation between exposure to airport emissions and health risks has been shown by a study from the Massachusetts Department of Public Health. It found children in areas with high exposure to the airport's emissions were three to 4 times more likely to suffer “respiratory effects indicative of undiagnosed asthma”. The study provides some recommendations for action, including “providing infrastructure for compressed natural gas (CNG) fuels and electric charging stations, Alternative Fuel Vehicle Program”, and working “with communities within the high exposure area (in whole or in part) on initiatives that would serve to further reduce exacerbation of preexisting respiratory diseases (e.g., asthma and COPD) among residents” and more (Logan Airport Health Study, 2014). Previously, a nitrogen dioxide monitoring program by Massport ran between 1982 and 2012. This program monitored NO2 concentration data at the airport and in neighboring residential communities, which did not include Chelsea, but did include sites less than a mile away (Air Quality at Boston Logan International Airport, n.d.). A program like this could still be applicable today to ensure that NO2 levels continue to decrease and to help identify what more could be done for these communities, such as possibly implementing harsher restrictions.

Effectiveness: 6
Feasibility: 3

This strategy of targeting port emissions receives a feasibility rating of 3, as the majority of these methods would come at an expense to the facilities. For example, purchasing new service vehicles that use different fuels would likely cost thousands of dollars per vehicle. For effectiveness, we rated this strategy a 6, due to the potential of reducing its pm emissions by investing in cleaner energy and phasing out diesel engines that emit this pm.

Figure 36: View from Chelsea of a docked ship

Air Filter and Ventilation Systems:

Air Ventilations systems are systems put in place that allows fresh airflow in and out of a building. This can be in the form of either natural methods such as open windows or mechanical systems like Air conditioning.

Mechanical Ventilation Systems are systems that improve air quality indoors by supplying fresh air or extracting stale air. There are two types of Mechanical Ventilation Systems that could be used. The most popular one is the Single Unit System Ventilation, these are mostly used in individual rooms or confined spaces. The Central heating, Ventilation, and Cooling System Unit (HVAC) is another type that is used for larger indoor spaces such as schools. Central HVAC is recommended by The U.S. Environmental Protection Agency (EPA) as the preferred unit for use when possible because they are often quieter than alternative units, and therefore less likely to be turned off, easier to maintain because of the reduced number of individual components per unit, and also compatible with higher efficiency filtration, this means it is compatible with filters that theoretically remove at least 99.97% of dust, pollen, bacteria and any airborne particles with a size of 0.3 microns. (citation EPA).

Air filters are devices that act as an absorbent of air pollutants and are designed for domestic use. The effectiveness of improving indoor air quality by air filters depends on the filter's Minimum Efficiency Reporting Value (MERV) rating. MERV ratings indicate the ability of an air filter to remove air pollutants; the metric to determine these ratings was developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers(ASHRAE). The higher the MERV rating of an air filter the higher the performance.

In relating to Chelsea specifically, our team chose these air filtration mitigation strategies with sensor locations at Highland Park and Eastern Ave in mind. These locations were chosen because they accommodate most of the younger population in Chelsea. In the vicinity of Highland Park are the Boys and Girls club and a school, since 80% of Chelsea's population are essential workers, a lot of children spend most of their time in school and after-school in the Boys and Girls Club. For this reason, we think the Central HVAC system will benefit children in schools and also large buildings such as the boys and girls club since if maintained properly would provide breathable air for the children participating in programs at the boys and girls club.

Furthermore, there are several residential buildings near Highland Park and Eastern Ave; to improve indoor air pollution in homes, we suggest the use of air filters. For the most part of the location of sensors chosen, there is no Air Conditioning which means in the summertime they are forced to open their windows letting in unsafe air. (Chelsea and East Boston Heat Study. (n.d.)). Fortunately, the GreenRoots organization in Chelsea is about to embark on a project which will include providing air filters to Chelsea residents for free. We would advise GreenRoots to make sure they purchase air filters with a MERV rating of 12 and above. According to a study done by ASHRAE in comparing high MERV rating air filters, MERV 12, 13, and 14 to lower MERV rating air filters, MERV 5, it was concluded that higher MERV rating air filters were 40 - 50% effective than lower MERV rating filters(Zhang, 2020). Both Air filters and HVAC systems need to be maintained properly and regularly in order to achieve maximum performance.

Feasibility Rating - 6
Effectiveness Rating - 9

This strategy compared to the others we chose, as the rating shows, is very effective considering the impact of air pollution reduction that could be achieved using air filters in these locations we focused on as a group. But in terms of feasibility, good air cleaners with HEPA air filters are very costly and may be a problem for financially challenged homes to buy and maintain. Mostly at times, these air filters are provided by funding from government and environmental justice organizations.

Figure 37: Example of a HEPA filter from trusens.com

Usage of Greenery:

The utilization of greenery has been a proven mitigation strategy for indoor air pollution. In a community like Chelsea, where many homes are overcrowded and are in need of renovation, indoor air quality is even more of an issue. Multiple characteristics specific to old buildings, which are very common in various parts of Chelsea, contribute to poor indoor air quality, including aging plumbing and mold formation. As one of the anonymous survey respondents said, "Spending most of my time indoors can also start to affect me due to their growths on the wall from the old building walls. The same walls within homes are not equally checked on especially when dependent on variously different landlords. I've lived in eight different homes most of the time it's all the same with lead, black mold, or mold in general." This phenomenon can be clearly seen in our selected locations, especially near Highland Park and Walnut Ave, as we've observed on-site visits. Even for newer houses, synthetic furnishing, which is frequently seen today, contains hundreds of volatile organic compounds (VOCs) (Wolverton, 2020). Many other common household objects also emit gases such as ammonia, carbon monoxide, and methane, all negatively impacting air quality. Many construction materials that houses are built with, even human beings who occupy the homes, naturally emit volatile substances such acetone and ethyl alcohol (Fenyvesi, 1998). For such reasons, the EPA has ranked indoor air pollution as one of the top threats to human health (Franchini & Mannucci, 2018). Plants such as peace lily, parlor palm, lady palm, and Florist's chrysanthemum have been proven as some of the most effective plants to improve indoor air quality. Depending on the size of the plants, prices can vary, but on average, they are around 50 dollars per pot. Out of the plants listed above, they can live up to around 5 years while maintaining the same effect against air pollutants through their life span. According to the NASA Clean Air Study, these plants are very effective in lowering the level of indoor air pollutants, especially harmful gases such as ammonia, benzene, and formaldehyde, at rates up to 3000 micrograms per hour (Wolverton et al., 1989).

Figure 38: View of the outside of the Boys and Girls Club in Chelsea

Greenery can not only mitigate indoor air pollution but also outdoors. One of the most commonly used methods worldwide for outdoor air pollution mitigation is increasing the number of trees planted and the area of green space. However, not all species of trees lower air pollutant levels the same amount. According to a study that analyzed and ranked 3602 tree species in terms of effectiveness in lowering air pollutant concentration. Out of all species analyzed, Juniperus virginiana, Cupressus sempervirens, Juniperus Chinensis, thuja occidentalis, and Pinus strobus were some of the most highly ranked species for indoor air pollution mitigation (Yang et al., 2015). As the study analyzed tree species under all kinds of conditions and climates in many urban areas across the world, the results were with all factors taken into consideration. Thus, we believe that it is a strategy likely to be effective in Chelsea, under the specific climates of New England.

Additionally, green roofs, which are a relatively new method developed, have also proven to be viable in lowering air pollutants. A study done in urban Toronto found a 10–20% increase in the surface area for green roofs on downtown buildings would contribute significantly to the social, financial, and environmental health of all citizens. Additional benefits and usage of a green roof include serving as a rainwater buffer, reducing ambient temperature, reducing heat islands, as well as regulating the indoor temperature. (Currie & Bass, 2008). In Chelsea, there is a significant lack of space covered by trees, at only 2% of all spaces (S. Arman, personal communication, October 1, 2021). In locations such as Eastern Ave (right in front of the Mary C. Burke Elementary Complex) and on streets near Highland Park, we've seen a shortage of trees planted nearby. For example, during our visits, we observed that trees are scarce at these locations, in particular, on Congress Ave, Maverick St, and Willow St, which all border the Boys and Girls Club in Chelsea as can be seen with Figure 38, and are right next to Highland Park. These locations are frequently occupied by the city's youth population, who are more likely to be impacted by air pollutants than adults, particularly reflected by the city's high asthma rates among children. Thus, it is important to prioritize these locations for efforts aiming to improve air quality.

Feasibility Rating - 7
Effectiveness Rating - 6

As the feasibility rating takes all factors and potential conditions of implementation into account, a score of 7 was given. While indoor greenery use is relatively cheap and easy to maintain, it presents itself as one of the most feasible options for individuals, outdoor implementation is not so simple. Outdoor implementation such as increasing tree canopy and green space can be more complicated, implying the involvement of city planning and public work departments, which would increase the amount of time needed to accomplish so. Other factors can also reduce the feasibility of such, one of which is the fact that it takes way longer for saplings or younger trees to grow into a size where it becomes effective in air pollution reduction than indoor plants do. Although transplanting already grown trees is also an option, it is very expensive to do so (Tattar, 1998). Thus, a score of 7 is given having all factors around indoor and outdoor implementation taken into consideration. In terms of effectiveness, while it proves to be effective, it is not the most effective as many air filter systems are able to reduce air pollutants concentration more efficiently, as discussed above and in the Air Filter and Ventilations section. Thus, a score of 6 was decided for effectiveness.

Raising Community Awareness:

Local grassroots movements are crucial to continued environmental action; the more aware of the environmental issues a given community is, the more likely it is for the community to stand up and take action. Community campaigns to raise awareness about air quality and the effect it has on an individual and the city as a whole is a very effective low-cost approach to help mitigate air pollution. Campaigns should focus on topics about various aspects of air quality covering both indoor and outdoor air quality including the importance of the Air Quality Index. The community should also be educated on preventive measures such as good ventilation, cleaning, hygiene practices, and characteristics of certain cleaning practices, to improve their city's air quality. Even though there is little research on community engagement benefits, there is substantial evidence that community participation is associated with improved health outcomes. (J;, B. J. W. (n.d.))

Not only should the education of air quality be taken to communities, educational materials about air quality should be provided to students and educators since children are more affected and are also most susceptible to experience health-related diseases associated with poor air quality. Educating about the importance and influence of Indoor Air Quality in schools and children, and behavioral changes in schools like opening the windows to the outdoor and the door to the inner corridor before the school starts have been proving to reduce CO_2 concentration levels in schools (Sá, Juliana P, 2017).

Figure 39: Chelsea resident demanding clean air for the city

Schools and environmental Justice groups should take the initiative of starting air quality programs or participate in already existing programs such as the Air Quality Flag Program. The Air Quality Flag Program is an environmental education program organized by the US Environmental Protection Agency(EPA) that encourages schools and communities to spread awareness about outdoor air quality. To participate in this program, the first step is to purchase 5 flags, green, yellow, orange, red, and purple which cost about $100. These colors match the EPA's Air Quality Index, which is the standard metric for how clean the air is. The AQI explicitly designates a level of danger to different concentrations of pollutant concentration, with lower levels being safe or only dangers to at-risk groups, and higher levels indicating high danger to just about everyone. Next, sign up for daily email or download the program widget to get flags you are supposed to fly on a flag pole or even post on the city's website every day to help residents adjust their daily activities based on the air quality status of the day. (AirNow.gov, U.S. EPA. (n.d.))The program has participants from all over the country because of how easy it is to implement and maintain. It also helps protect children, those who have asthma, and other lung diseases, from periods when air pollution is greatest.

Feasibility Rating - 10
Effectiveness Rating - 4

Community awareness about Air Quality is simple to implement and maintain. There are various resources available such as the Environmental Protection Agency website to help properly educate the community and others, therefore the feasibility ranking of 10. The effectiveness of community awareness on the other hand is hard to prove, there is very minimal research on the impact of these campaigns on either the individual or the community as a whole. It is hard to predict the effectiveness of this strategy because it is subjective and also may vary based on the topic we are raising awareness for. Nonetheless, the few existing research shows positive effects between community awareness and health benefits. In addition, in our research, we found that the effectiveness of community awareness can not be quantified and usually does not have immediate effects but has gradual positive outcomes in the community therefore we gave a ranking of 4.

Urban Heat Mitigation:

Chelsea also experiences extreme urban heat effect, where the temperature is significantly higher due to high population density and concentrated usage of surfaces that absorb and retain heat, such as pavement and buildings. As air quality is dependent on many variables, one of the most impactful of them all is temperature. As studies have shown, there is a strong positive correlation between temperature and the concentration of air pollutants. This is due to the process of formation of particles which we define as PM being favored by higher temperatures (Wang & Ogawa, 2015). Essentially, the higher the temperature gets, the more PM particles are formed. As a result, the higher the surrounding temperature gets, the worse air quality gets. In Chelsea, since the percentages of the area covered by trees and green space are so low, at only 2% and 4% respectively (S. Arman, personal communication, October 1, 2021), another solution would have to be found. Due to the high concentration of buildings in Chelsea, and many buildings today have black roofs, which absorb and retain a large amount of heat. Something as simple as painting the roofs white can help alleviate the effect that black roofs have on increasing temperature and thus worsening air quality. Green roofs, another mitigation strategy discussed above, have also been proven to be effective against the urban heat effect (Currie & Bass, 2008). To combat the issue of urban heat islands, we would recommend both green and white roofs as effective mitigation strategies, depending on budget and specific situations. Specifically recommended for the Boys and Girls Club right across the street from one of our selected locations, Highland Park. The building currently has a black roof, and on hot days, that contributes to worsening the air quality in nearby areas. Given that it's an area with frequent visits by a large portion of the city's youth population, who already have an abnormally high rate of asthma as discussed above, painting the roofs white can be a way to reduce the effect of many issues.

Another source that contributes to the urban heat effect in the city is the usage of artificial turf on the soccer field in Highland Park. As studies have shown, using artificial turf in place of natural grass can cause an increase of up to 2.3 kWh per square meter, per day, of heat to the atmosphere, which could result in urban air temperature increases of up to 4°C (Yaghoobian et al., 2010). As discussed above, the area already suffers from the urban heat effect, we would recommend replacing the turf with natural grass, as that can eliminate a contributor to such an effect in the area. Although there will be more time and cost involved once implemented for maintenance, but for an area where a lot of the city's youth population often visits and spends a lot of time, we believe it is essential to minimize the effects of extreme heat and its effect on air quality.

Feasibility Rating - 9
Effectiveness Rating - 7

In terms of feasibility to carry out the urban heat mitigation, it has a relatively low cost and little time needed. This is why it has been given a high rating of 9 for feasibility, although not the highest as that goes to raising awareness, which involves little to no costs. Though the installation costs of a white roof would be slightly more expensive than a regular black roof, the long-term benefits of lower energy bills and improved health outweigh the initial cost. (US EPA, 2021) From past studies, we can see the correlation between temperature and air quality, which is also backed up by our data. Through analysis, we've concluded that the worst air quality in Chelsea came on extremely hot days, the effects of which are amplified due to the urban heat effect. Thus, minimizing the effects of urban heat, through the utilization of white roofs, which would lower the interior and surrounding temperatures, can significantly improve air quality, especially on hot days. Although not as effective or as immediate as an air filter and filtration system, in the context of immediate implementation, it is relatively effective, resulting in a score of 7.

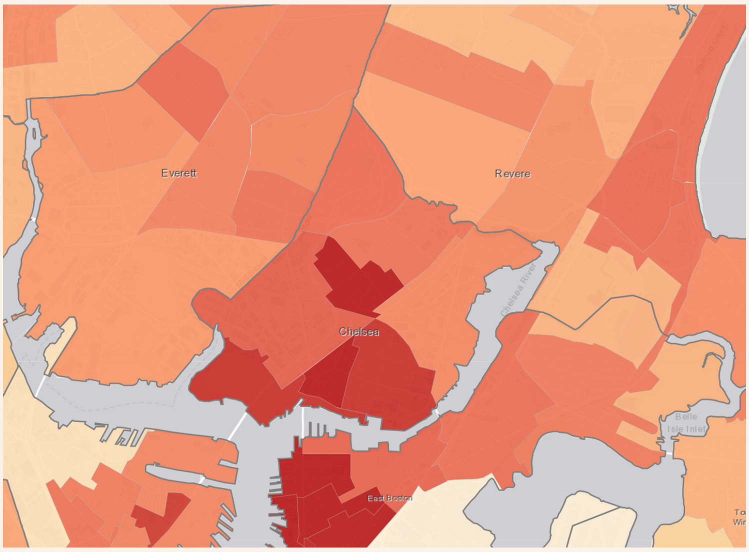


Figure 40: Heat Vulnerability Map of Chelsea and Surrounding Areas (ArcGIS, 2020)

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