Mapping Environmental Injustice in Chelsea, Massachusetts

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Abstract

Working with the Department of Housing and Community Development in Chelsea, MA, our team developed a more comprehensive understanding of environmental hazards within the municipality. Environmental hazards can be damaging to the health of residents and often disproportionately affect minority and disadvantaged communities. Using data primarily from the City of Chelsea, the United States Census Bureau, and the United States Environmental Protection Agency, we geospatially charted the locations of environmental hazards alongside the locations of selected demographics in order to determine whether any patterns emerged. The primary concerns of our research were determining which demographics and locations within Chelsea were most affected by certain categories of hazards, and additionally how environmental hazards impacted the health of these at-risk demographic groups. We developed a theoretical ranking method in order to highlight for our sponsor which areas need the most assistance in mitigating the effects of environmental hazards via environmental policy. Our team also developed easily-translatable community outreach materials in order to garner interest in our findings, such as social media materials and a two page summary of our project and findings. Our method of developing recommendations to combat environmental hazards in Chelsea consisted of researching short term, immediately effective reactive policy to address the symptoms of environmental hazards, along with long term preventative policies which would work to mitigate the environmental and health effects of hazards. Specific recommendations were made for the most affected locations in Chelsea, and more general city or state level recommendations were made to address the state of certain hazards in the city. These recommendations were also considered loosely by feasibility (cost, time to implement, side effects of the policy on the city, etc.), as well as priority (whether the solution addresses multiple populations or locations, is an immediate solution versus a long term one, etc.). Additionally, we interviewed the senior public health and regional planner for the Metropolitan Area Planning Council to gain insight on the intricacies of community planning, solutions to environmental issues that have been used in similar municipalities, and advice on our recommendations from the perspective of a policymaker.

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Exploring environmental inequity

Many philosophies revolve around restoring equity to those who have continuously been underrepresented, marginalized, and/or repressed, such as upholding environmental equity. Environmental equity is the concept that all people should share a fair distribution of environmental hazards such that no community is responsible for more burdens than they can handle. Certain populations, however, suffer disproportionately from these environmental burdens and often face negative health outcomes as a result.

As climate change amplifies social and ecological stressors in urban environments, immediate action with lasting effects must be taken to aid at-risk communities that have been unable to receive assistance in creating adaptable and resilient environmental infrastructure and policy. The most direct way to aid these affected populations is by successfully restoring environmental equity to those communities, and ensuring that these communities maintain an active and informed voice in local environmental policymaking.

This mindset is best described as environmental justice—the fair treatment and meaningful involvement of all people in the development, implementation, and enforcement of environmental law, zoning, and policy (Massachusetts Department of Environmental Protection, n.d.). Policymaking that is mindful of environmental justice tends to lead to a series of actions and plans that are used to maintain and further environmental equity so that all communities share an equitably-distributed concentration of environmental burdens and environmental benefits.

While significant advancements in the fight for environmental justice have been made, there are still notable barriers that stand in the way of full environmental equity. One such barrier is that community members are generally underinformed on the status of environmental equity in their municipality, and therefore do not have a sufficient understanding of their situation to take action. This knowledge gap can could be attributed to a lack of prior research highlighting inequitable local distributions of environmental burdens and their effects on community members. Due to this, individuals and organizations who attempt to restore environmental equity do not have the resources needed to accurately gauge the existing burdens and negative health effects associated with environmental inequity. Without a clearly defined problem, proper action cannot be taken to bring about change, which allows the problems caused by environmental inequity to amplify and worsen with time as environmental burdens stem from environmental hazards.

The effects of environmental hazards

An environmental hazard is a hazard that harms or otherwise endangers the health of a person or their environment. Environmental hazards can be clearly visible, such as an industrial plant polluting a nearby river, or, hazards can be nearly invisible, like air pollution or abnormally high heat. Environmental hazards can also be classified into two types: acute hazards and chronic hazards. Acute hazards are hazards that can only pose a threat to one's health under specific conditions, such as living within an area with frequent flooding or traveling through a location concentrated with air pollutants. Chronic hazards are hazards that continually affect the environment and communities they are a part of, such as urban areas experiencing higher temperatures than surrounding suburban or rural areas. While these examples may seem to more directly affect the environment, hazardous effects can have disastrous effects on public health, as well. For example, prior research has shown that occasional extreme heat in urban areas alone can lead to increased rates of heat exhaustion and heat stroke, heart and kidney failure, and numerous complications for those with pre-existing respiratory conditions (Ebi, Kristie L, et al. August 2021).

The environmental justice movement

The environmental justice movement works to ensure the wellbeing of communities that experience targeted environmental inequity under current environmental regulations. Over the past three decades, the White House, Congress, and several federal offices have begun to pass legislation and environmental policy to battle environmental injustices. One such piece of legislation was Executive Order 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, passed by President Clinton in 1994. This order mandated the creation of an interagency working group to "provide guidance to federal agencies on criteria for identifying disproportionately high and adverse human health or environmental effects on minority populations and low-income populations." This order was the first federal-level response to the environmental justice movement and paved the way for different organizations at both the state and federal levels to actively pursue and uphold environmental justice (Exec. Order No. 12898, 1994).

As a result of the executive order and the continuation of environmental injustice, the Massachusetts Office of Energy and Environmental Affairs (EEA) established criteria that mark areas in Massachusetts as "environmental justice populations" that are in need of support to resolve environmental inequities. In Massachusetts, a region is defined as an environmental justice population if it meets any of the following three requirements (Massachusetts Office of Energy and Environmental Affairs, n.d.):

- Income: The annual median household income is equal to or less than 65% of the statewide annual median household income.
- Minority (may be fulfilled by either of the following):
    - Minorities comprise 40% or more of the population
    - Minorities comprise 25% or more of the population and the annual median household income of the municipality in which the neighborhood is located does not exceed 150% of the statewide annual median household income
- English isolation: 25% or more of households lack English language proficiency

Environmental inequity stems from underlying discrimination

To best understand the challenges environmental justice communities face, it is important to consider the legislation, zoning, and policy that has enabled environmental inequity to appear in the first place. The Massachusetts EEA criteria for environmental justice communities specify racial minorities, low-income populations, and English isolated populations; these groups are typically those that suffer the harshest effects of environmental racism. According to the nonprofit organization Greenaction:

"Environmental racism refers to the institutional rules, regulations, policies or government and/or corporate decisions that deliberately target certain communities for locally undesirable land uses and lax enforcement of zoning and environmental laws, resulting in communities being disproportionately exposed to toxic and hazardous waste based upon race," (Greenaction, n.d.).

Environmental racism is an umbrella term that encompasses many forms of environmental discrimination that at-risk communities face.

Our team's role in restoring environmental equity

Our team was tasked by our sponsor organization, the Department of Housing and Community Development (H+CD) in Chelsea, Massachusetts to perform an analysis of Chelsea's residents and local environmental hazards and to determine which demographic groups and locations face the greatest hazard and health-related risk. Our team opted for a location-based approach, where the determined severity of exposure to these hazards is dependent on individuals' relative proximity to an environmental hazard as well as the number of unique hazardous effects present in the area. This analysis required our team to consolidate data on the demographics of Chelsea, local hazards, and the health conditions that these hazards exacerbate. Our results indicate regions within Chelsea that experience the most severe effects from selected hazards, as well as demographic groups that are most at-risk of negative health impacts due to these hazards. While it is acknowledged that

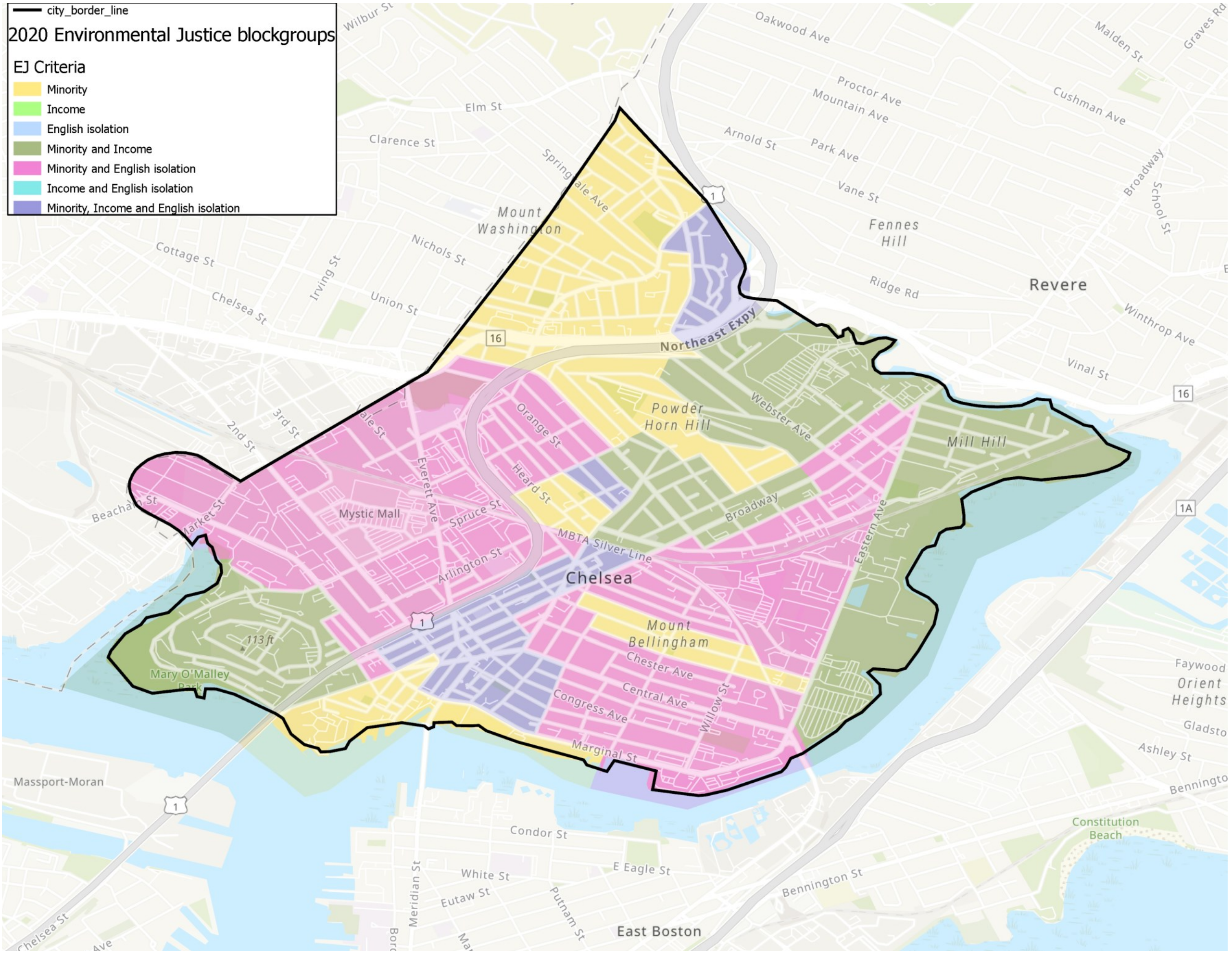


Figure 1: Environmental justice blockgroups in Chelsea, MA, as established by the Massachusetts EEA.

Chelsea is suffering the effects of environmental racism, very little research has been done into which populations or locations within Chelsea are experiencing the brunt of the hazardous conditions. Our results are intended to provide our sponsor and the community of Chelsea as a whole information on the current state of environmental inequity, as well as specific recommendations to promote environmental justice.

Background

The city of Chelsea

Chelsea is a small city located across the Mystic River from Boston, MA. With a population of about 40,000 and a land area of 2.21 square miles, the population density of Chelsea is about 18,000 people per square mile, making Chelsea one of the most densely populated places in Massachusetts (United States Census Bureau, 2019). Considering that at least one-third of Chelsea's land area is zoned for commercial and industrial use, the population density within residential zones alone would be higher than this value. (City of Chelsea, Massachusetts, 2018). Chelsea is home to a large population of minorities, with over 70% of the community identified as racial or ethnic minorities (Power, 2021). A history of discrimination in zoning and policymaking, including historical redlining leading to low land value, low property value, insufficient access to healthcare, little availability of healthy food, and a lack of political power or voice held by community members in the majority of Chelsea have amplified environmental racism. (Greenaction, n.d.).

In such a densely populated area, environmental and health hazards are especially dangerous to the community. A higher population density implies that a greater number of people are living closer together, especially within areas affected by a given hazard than in other communities, which puts more people at risk of negative health effects. Additionally, due to Chelsea's limited land area, residents are more likely to live in close proximity to more hazards and are subsequently more likely to experience adverse health outcomes (Brender et.al., 2011).

Environmental hazards of concern in Chelsea

As Chelsea is such a densely populated area, environmental hazards, especially ones that create or amplify negative health effects, are dangerous to the community. Many types of hazards affect the city of Chelsea, but as Chelsea is an urban environment, the primary problems are extreme temperatures caused by the urban heat island effect, air pollution, and flooding. The decision to focus on these three hazard categories was based in part on our research into the severity of urban environmental hazards, and also on the request of the Chelsea H+CD who provided additional insight into Chelsea's hazards and their associated health effects.

Figure 2: Smog rolls over the Tobin Bridge in Chelsea, MA (InvictaHOG, 2007).

Extreme heat

"The "urban heat island effect" describes how a region within a city becomes excessively hot during warm weather as compared to a rural region experiencing the same weather (Bebinger, 2017). Previous research has concluded that the largest contributors to this effect are an excess of heat-retaining construction material and impervious surfaces (bricks, asphalt, and dark-colored materials), as well as a lack of greenery and open space within the affected areas that could effectively absorb heat and sunlight (Beecham et al., 2019). At times, the surface temperatures in urban heat islands can increase to 20–50°F higher than what would be seen in a region with ample vegetation and/or more heat-reflective materials (Bebinger, 2017). Prolonged exposure to the effects of extremely high temperatures can induce several dangerous health conditions, the most serious being heat stroke. High temperatures also cause the air to become more humid, and consequently, its increased density makes it difficult to breathe for children and those suffering from preexisting respiratory conditions (AccessScience, 2019).

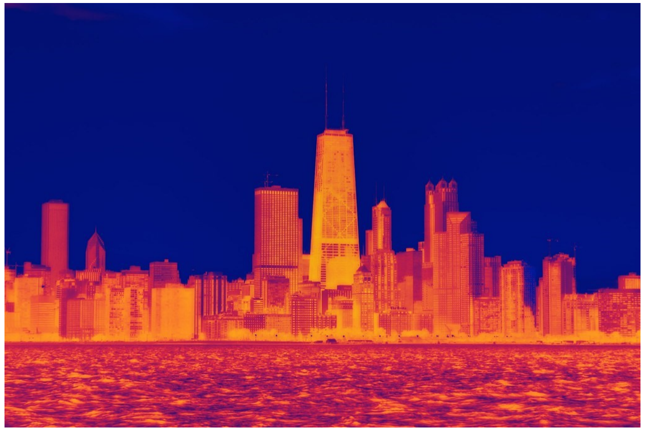


Figure 3: Urban heat displayed through thermal imaging simulation across Chicago, IL (Phillips, 2008).

Poor air quality

Air pollution is caused when emissions from sources like cars, factories, ships, and planes introduce pollutants or particulate matter into the air. A major toxic emission released into the air that is often considered is PM 2.5. PM 2.5 is a form of particulate matter that is 2.5 micrometers or less in diameter and classified by the US EPA as one of the six most common air pollutants. PM 2.5 and other types of particulate matter are toxic to humans, leading to an increase in asthma, respiratory-related hospital visits, and in some cases, respiratory failure (California Office of Environmental Health Hazard Assessment. n.d.). When the respiratory effects caused by pollutants in the air are combined with extremely hot air due to the heat island effect, high-sensitivity and high-risk groups suffer the most. These groups consist of the elderly, young children, those with pre-existing respiratory conditions, and those who are immunocompromised (Bebinger, M., 2017).

Figure 4: Air pollution drifts over a city, reducing visibility significantly (Griffin, n.d.)

Flooding and flood-prone regions

Flood-prone regions, which are expected to flood as the climate changes or as periodic flooding occurs, pose additional risks. Flood maps are a common tool to analyze flood-prone regions. Flood maps highlight areas of land that, in the case of a major flooding event, have a certain chance annually to flood the entire highlighted region. Flooding is especially dangerous in cities located near large bodies of water—which applies to Boston and Chelsea—due to periodic flooding caused by tropical storms or extremely heavy rainfall (Kirshen et al., 2008). The primary damage caused by flooding is to property, but the increased mortality risk during a flood should not be overlooked. Drowning, either in a vehicle or on foot during flash floods or storm surges, is the primary health risk associated with flooding, but water damage to property can lead to mold growth and may pose an unseen and chronic threat to householder respiratory health.

Figure 5: The MBTA places dams at the Fenway portal in Boston, MA due flooding of over 15 feet from the nearby Muddy River (MassDOT, 2010).

Overview

While it has been determined that Chelsea suffers from environmental inequity, it is important to clearly trace the current state of the city to the specific social and economic policies or legislation that helped foster this inequity. Several socioeconomic factors currently contribute to a lack of environmental equity for the residents of Chelsea, with one of the major factors being systemic racism. In the context of our project, systemic racism that affects environmental policy would be considered environmental racism; this environmental racism is a continuous problem in Chelsea that prevents residents from contributing to community discussions about environmental policy.

One practice from the past that has contributed to Chelsea's present crisis was the practice of redlining; this practice was created by the Home Owners' Loan Corporation (HOLC) to control the flow of wealth based on community demographics. Under redlining, residential regions would receive "mortgage security" grades, ranking regions from A-D, best to worst in terms of expected investment return. Areas ranked C or D were considered "poor investments," thereby dissuading banks from issuing mortgages to individuals in those "redlined" zones and reducing the amount of money flowing through those communities. Historically, redlined zones were largely minority communities like Chelsea, and redlined zones today are greatly underdeveloped compared to non-redlined communities. The after-effects of redlining, though not a current practice now, can still be felt especially since nearly half of the entire city of Chelsea was redlined (American Panorama, n.d.).

Another effect that redlining has had on the Chelsea community is on the economic stability of its residents (Pearcy, 2020). The median household income in Chelsea, MA is $53,280 (Datawheel, 2018), far below the state median household income of $81,215 (United States Census Bureau, 2019). Undeveloped areas with high poverty rates are often not adapted to combating environmental hazards so many of these areas are very susceptible to the negative effects of the environmental hazards near them (Substance Abuse and Mental Health Services Administration, 2017).

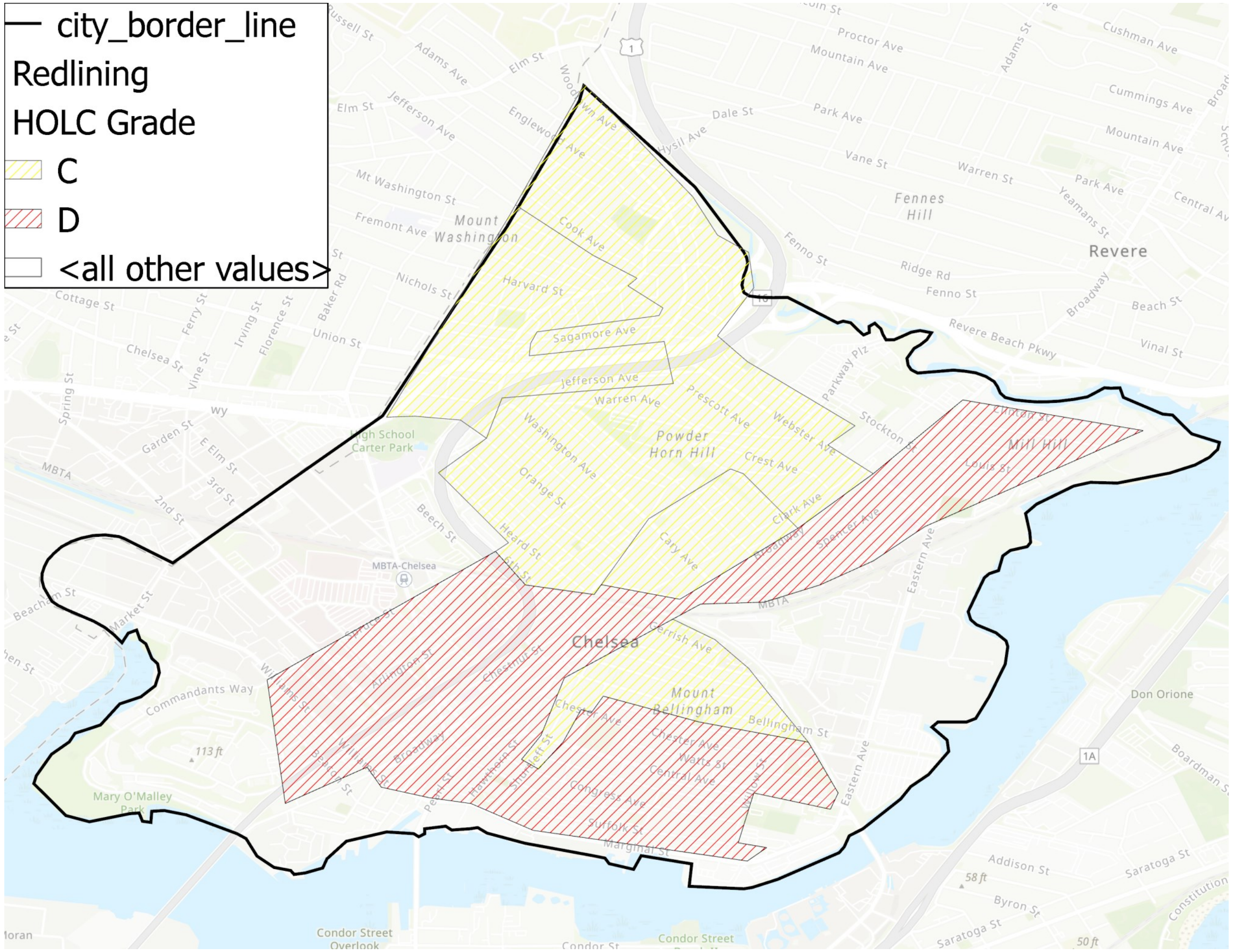


Figure 6: Redlining data for Chelsea, MA. The HOLC grades of "C" and "D" represent areas that were considered "poor investments" and therefore would have received less financial investment and mortgage approvals to individuals living in those areas, the economic consequences of which still resonate today. These "C" and "D" grade areas are represented by yellow and red respectively.

Spatial analysis and GIS mapping are key tools in restoring environmental justice to communities

Previous attempts have been made at recording and investigating environmental hazards in Chelsea using spatial analysis. Spatial analysis is "the process of examining the locations, attributes, and relationships of features in spatial data through overlay and other analytical techniques," and is the most common method for investigating regional problems (Tulane University Libraries, 2021). Typically, spatial analysis is conducted through the use of Geographic Information System (GIS) mapping, especially for projects that seek to address environmental hazards. GIS mapping allows for spatial visualization of various data sets where individual data points are associated with geographic coordinates, allowing them to be placed on a map. GIS maps allow users to filter data, allowing them to see custom combinations of different data, in one or more separate layers. (MangoMap, 2017). Additionally, GIS software offers spatial analysis programs, allowing for a more data-driven approach. This spatial presentation of data allows users to easily understand how demographics are situated in relation to the locations of environmental hazards. Our team opted to use the industry-standard software ArcGIS Pro to create final maps and perform the analysis needed for our project.

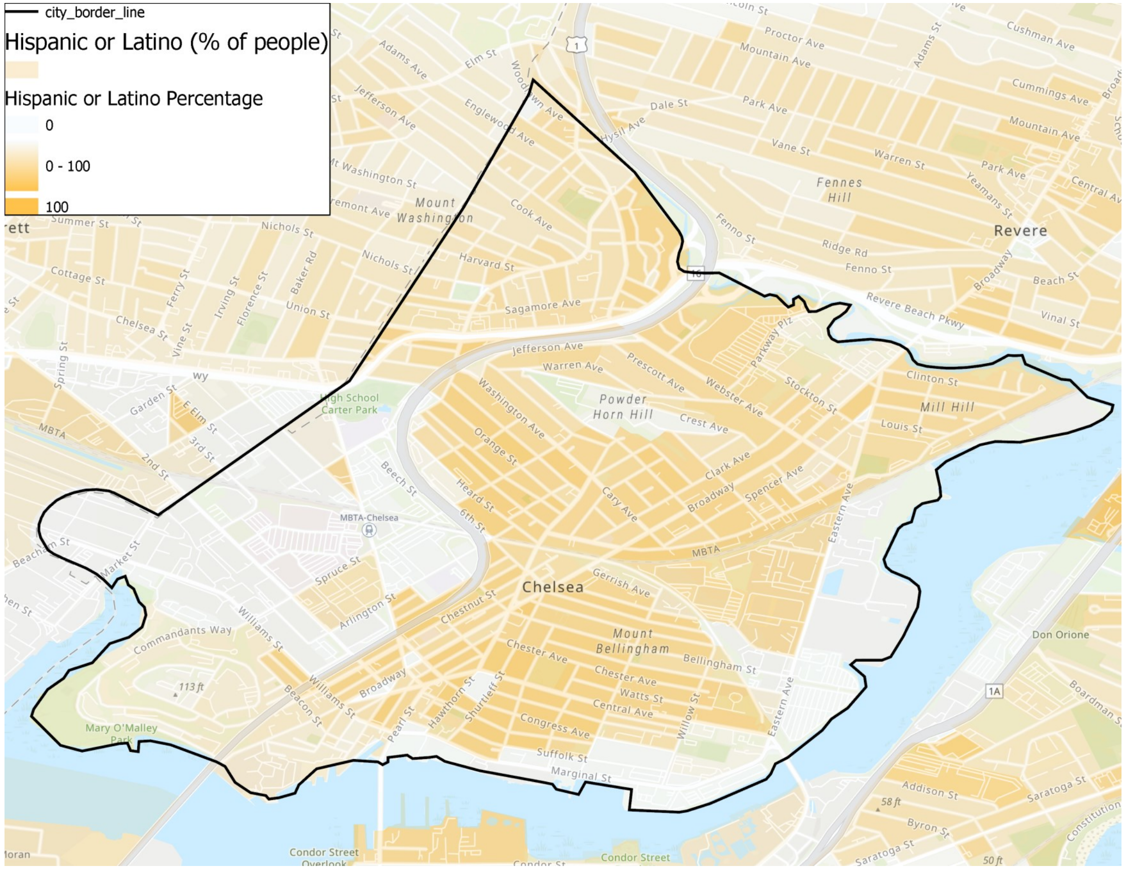


Figure 7: An example GIS map generated in ArcGIS, charting the percentage of a block group's population that is Hispanic or Latino. Darker orange areas have higher ratios of Hispanic/Latino populations.

COVID-19's effects on Chelsea and our project

COVID-19 has had a massive impact on the community of Chelsea. Chelsea has experienced extremely high infection rates throughout the pandemic. As of the start of October 2021, Chelsea had nearly 10,000 documented cases of COVID-19 among its occupants; almost one out of every four people in Chelsea was infected by COVID-19 (City of Chelsea MA., n.d.). The pandemic also amplified problems caused by historical redlining practices, high population density, lack of updated infrastructure, lack of green spaces, and a high poverty rate in Chelsea. Redlining and associated economic consequences have left Chelsea residents without economic opportunity or savings, making it difficult for Chelsea residents to stay home and forcing unsafe contact within their workplaces. COVID-19 also spreads more easily in smaller and indoor spaces than open outdoor ones; Chelsea's lack of public green space (urban space set aside for vegetation), as well as its often extreme heat, causing citizens to condense indoors where it is cooler and there is less available space to socially distance. Due to the pandemic having such a devastating effect on the residents of Chelsea, our team was forced to work on this project remotely, and therefore could not visit Chelsea as frequently as desired.

The planning for our project began in late March 2021, during the COVID-19 pandemic, with the original assumption being that we would work closely and in person with the Chelsea community. When we understood the severity of COVID-19 in Chelsea, many of these plans, such as interviews and on-the-ground investigation, became unfeasible. For a project focused on aiding the residents of Chelsea and community outreach, a remote setting was less than ideal for our team. We hope this situation will be taken into consideration by future readers to understand that this project would have benefitted from an in-person approach.

Research questions

Our methodology was based on a series of research questions, which were in turn influenced by our sponsor's project description. The H+CD wanted our team to complete an analysis by determining correlations between the locations of demographics in Chelsea (such as age, ethnicity, etc.) as compared to the locations of known environmental hazards in Chelsea. In addition to our sponsor's requests, our team wanted to perform additional research and gather data to understand the history and sociological problems that contributed to the current status in Chelsea, and subsequently to make recommendations on how to resolve these issues. In addition to fulfilling the sponsor's requests, our research questions are intended to investigate the connections between the current hazard and health conditions in Chelsea and environmentally racist policy that helped create such an environment. Our team created several research questions which would guide the creation and execution of our methodology.

The following research goals are based on a fusion of our team's objectives and our sponsor's objectives:

Research Question #1:

Where are the most severe environmental hazards in Chelsea, MA, and what are their impacts?

Research Question #2:

What spatial patterns occur when a variety of demographics related to Chelsea are compared against the location of environmental hazards?

Research Question #3:

What sociological factors contributed to the unequal distribution of environmental hazards and resulting health risks in disadvantaged Chelsea, MA communities?

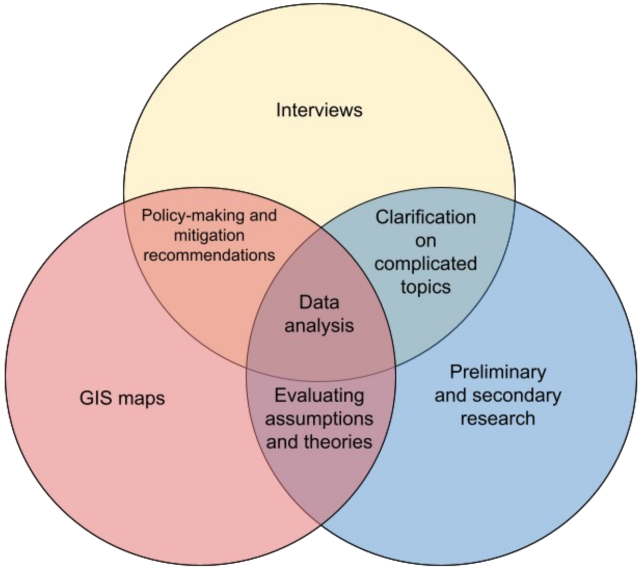


Figure 8: Information assessment model for gathered data and subsequent analysis.

Method 1: Determine the most severe environmental hazards to assess their health impact(s) and area of effect

The first step of our team's research was identifying existing and documented environmental hazards present in Chelsea. Data had to be gathered from various primary (Census, MassDEP, etc.) and secondary sources (MAPC MetroCommon, etc.); most research was done through the internet due to the aforementioned circumstances involving COVID-19. The majority of our data was largely gathered from the city of Chelsea, the U.S. Census, and the U.S. ACS (American Community Survey), supplemented by additional data from sites that document environmental hazards and public health. Our research was conducted using a combination of sponsor-provided sources and resources discovered during preliminary research.

Some of the collected data was determined to be inconclusive or incomplete, and therefore is either not fit for use in drawing conclusions, or only for use with the recognition that the data is not comprehensive. "Inconclusive" data refers to data that does not present a clear conclusion—it neither confirms nor denies a hypothesis (such as in the case of data with no correlation). "Incomplete" data refers to data that has some useful information but is noticeably missing key information, such as data points in a specific region. All included inconclusive and incomplete data that is used is done so with the understanding that any conclusions drawn will be subject to fixed assumptions of the missing data, and noted in our results.

Some collected datasets were not originally in an ArcGIS-compatible format and had to be manually converted into the proper format. This included hazards referenced in the "Potential hazards identified by the Bureau of Waste Site Cleanup, 2005" dataset; data in this set was gathered from "An Investigation to Determine Whether Waste Sites Are Affecting Schools in Chelsea, Massachusetts", prepared by the Massachusetts Department of Environmental Protection's Bureau of Waste Site Cleanup (Bureau of Waste Sites Cleanup, Massachusetts Department of Environmental Protection, 2005). This document contained a list of potentially hazardous sites in Chelsea. The team investigated whether the hazards were still present and harmful by researching what the space was currently being used for and whether it could pose any health threat. However, since the data was from over 15 years ago our team was required to individually confirm the status of these hazards and whether they are still harmful as of recently. The addresses for each hazard site were then converted to geographic coordinates and mapped in ArcGIS alongside their name, address, whether the listing was still accurate in 2020-2021, and its potential health risk to the region and its residents. Other datasets were given additional fields (such as conversions of Census place geographic IDs) in ArcGIS to facilitate joining geographic and numeric data together so that the dataset could be mapped spatially. Adding new fields in the data set allows for additional calculations and inter-dataset analyses, while not modifying the data itself.

Method 2: Evaluate the physical distribution of demographics and identify trends or commonalities between the locations of demographic groups and hazards

Once data was fully imported into ArcGIS, our team set about determining the spatial correlation between demographic groups and hazards. The objective of this method was to determine which demographics were most impacted by each hazard, and which hazards had the widest impact on one or more demographic groups.

The demographics and hazards analyzed were largely determined by what data was available to the team. In some cases, this data was both more and less precise than desired; the most comprehensive data available through the 2020 U.S. Census redistricting data is at the block level (roughly city block size), as opposed to the block group level (a grouping of Census blocks). The data regarding race is broken down by up to six different self-identified races per individual, and the ethnicity data is broken down by "Hispanic/Latino" or "Not Hispanic/Latino," with only the non-Hispanic/Latino ethnicities further broken down by race. As such, the team was unable to determine statistics such as the total population of one race without unintentionally double-counting mixed-race individuals. Additionally, it is not possible with this data to perform an analysis of different race-ethnicity combinations, forcing our analysis to consider race and ethnicity separately. A full list of factors considered by this method, including both hazards and demographics, is included in the Layers for Analysis section of the Supplemental Materials file published alongside this booklet, in the Layers for Analysis section.

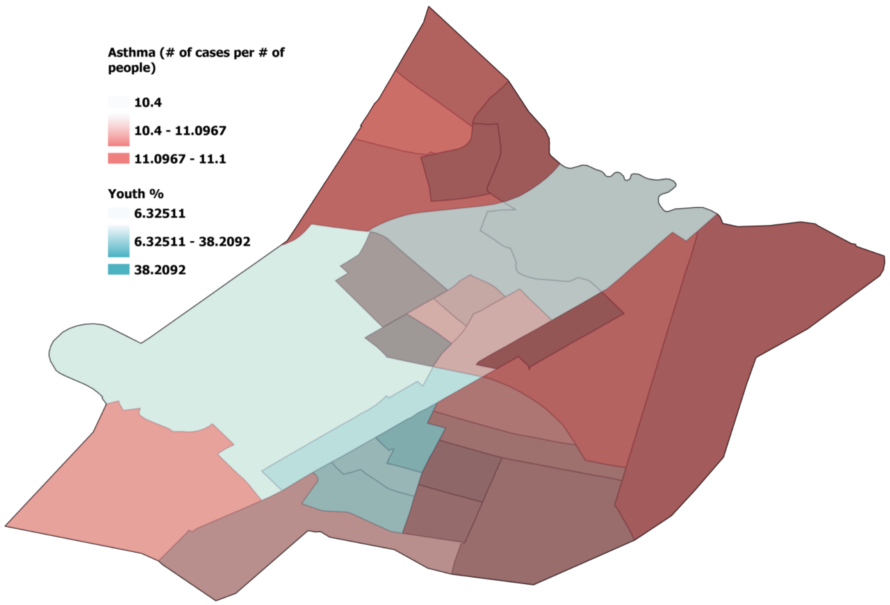


Figure 9: An example of a GIS map used for yes/no visual analysis, with correlation. Deeper reds represent higher numbers of asthma cases, and deeper blues represent higher percentages of youth in each area's total population. Since these maps are partially transparent, the colors overlap. Areas where the combined color is deeper (in this case, salmon-colored) are areas with a high rate of asthma and a high youth population. If many areas are salmon-colored like in this map, this suggests a correlation between asthma rates and youth population.

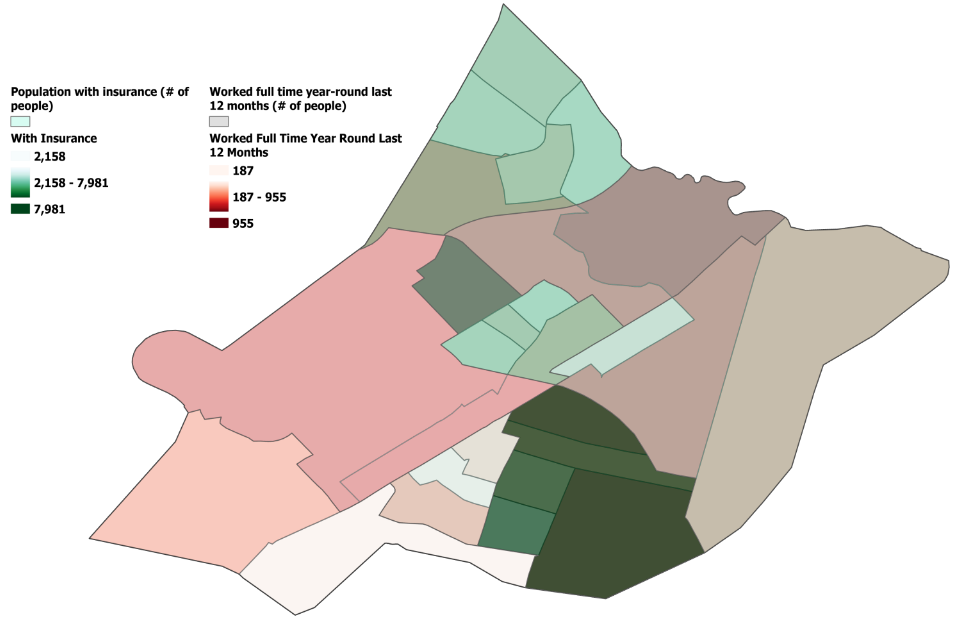


Figure 10: An example of a GIS map used for yes/no visual analysis, with no correlation. Deeper greens represent higher numbers of people with insurance, and and deeper maroons represent higher numbers of people who worked full time year-round in the last 12 months. So many colors manifest on these overlapping maps that there is no clear correlation, unlike in Figure X, which only displays a few colors.

This method was primarily accomplished by overlaying one map layer each of demographic and hazard locations and attempting to determine correlations via a Yes/No visual inspection. For example, when a hazard such as high temperatures consistently overlaps with the presence of a certain health effect, or consistently did *not* overlap with a certain health effect, it could indicate that there is some relationship between the two (positive and negative correlations, respectively). Depending on the interpretation, this correlation may indicate that the hazard has contributed to the presence of the health effect, but also may demonstrate that certain groups are disproportionately affected by the hazard due to proximity. In all cases, our team compared the observed correlations to existing research to determine whether each indicated a causal relationship or just an associative relationship.

The team manually viewed each of these comparisons and determined if any of the maps presented a correlation between the mapped data. Each comparison between a hazard and a demographic was then manually investigated to theorize whether there could be a connection worth investigating between the demographic and the hazard.

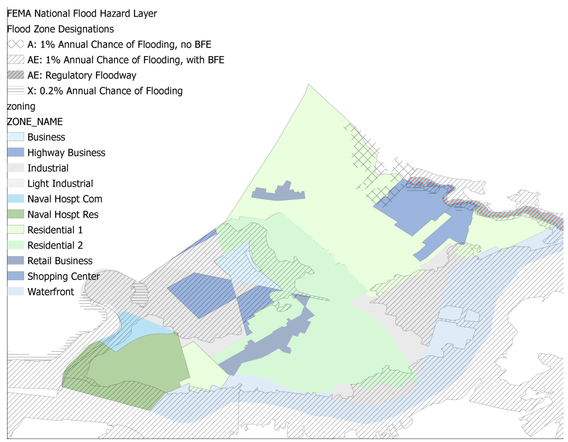
Method 3: Assess sociological factors contributing to the existence of environmental hazards and health risks

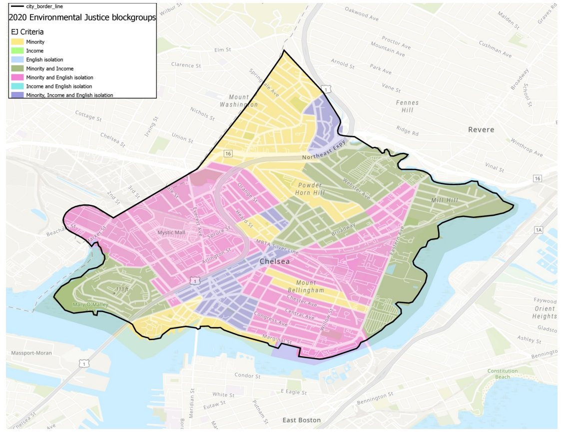
In order to better understand why some hazards are present in Chelsea and better provide recommendations for how to mitigate future hazard impacts, the team also performed some contextual investigation into the history of each hazard. This research was primarily conducted using online sources such as JSTOR and Scopus. Our historical research covered the topics of historical redlining and the effects of climate change on Chelsea, along with the general history of the development of Hispanic/Latino and minority communities in Massachusetts municipalities. Our team also researched past policies, actions, and social pressures that have contributed to the construction or continuance of environmental hazards in Chelsea which disproportionately affect its large minority community.

Multiple organizations were contacted to assist in this investigation, though, due to communication and scheduling complications, most of these meetings did not end up occurring. With consultation from Sharon Ron at the Metropolitan Area Planning Council (MAPC), we were able to learn more about the resources that have been made available in Chelsea in the past, what policy and action may be feasible in Chelsea, and what are considered the biggest health and environmental problems for communities like Chelsea.

Method 4: Using collected data to create public-facing materials

Our team also hoped to distribute our conclusions and the maps in a way that is publicly accessible for use by the community through the use of this booklet, a short two-page summary document of this project, our final presentation which was recorded and live-streamed online, and easily-translated social media posts containing links to our project materials and results. This booklet is publicly available through WPI to provide a full understanding of the project. The GIS layers used to come to our conclusions have been made publicly available through a Google Drive folder, published at https://drive.google.com/drive/folders/1ll3eF1_1jVdlZgU2mAeKwWXidY21Y4F2?usp=sharing, alongside these project files, allowing the community and community leaders to view individual correlations themselves. Advertisement about these public materials was spread through Facebook and Twitter in partnership with the H+CD in order to garner interest in the project.





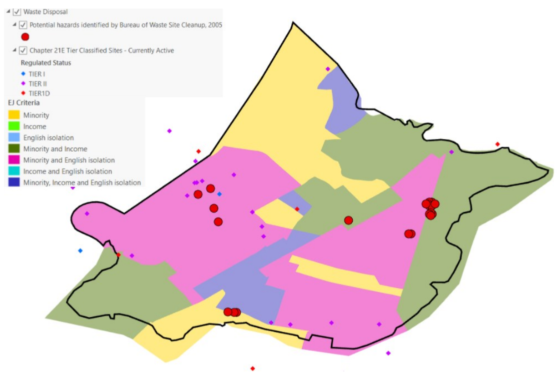


Figure 11: Images included in social media posts, alongside the following text (full size included in Supplemental Materials: Social media post):

Live in Chelsea, MA and interested in the environment and how it affects you? A recent research project by WPI students may let you know which environmental hazards are hurting your neighborhoods—and who's at risk.

Overview

Our sponsor requested that our team identify which demographics and which regions are most severely affected by or at risk of experiencing the effects of environmental racism in Chelsea and provide recommendations for policies or projects to mitigate these effects. As the focus of our project was mapping environmental inequity, our analysis focused on identifying specific demographic groups or locations in Chelsea that are at higher risk of exposure to hazards or experiencing higher rates of negative health effects than the rest of the city. To accomplish this, our team created separate GIS map layers for each demographic, environmental hazard factor, and health condition. For instance, a higher risk may be indicated by a greater percentage of individuals in a demographic affected by a health condition, or a concentration of hazards in an area where there is also a high density of a particular demographic group. Our team's analysis consisted of visual inspections of overlaid maps (where each map charts a different factor, such as age, asthma rate, hazard location, etc.) to identify any patterns or trends related to environmental hazards, as well as limited statistical analysis where appropriate and possible.

Our recommendation format will consist of four tables. Our initial table will explain the three subcategories of hazards: hazards that amplify the urban heat island effect, hazards that worsen air pollution, and hazards that will be a threat to the population during a flood. The other three tables will compare two of our three major categories. These three tables are: hazards vs demographics, hazards vs public health, and demographics vs public health.

Compile hazards. *We listed out specific hazards as either heat, air quality, or flooding-related environmental hazards. Each consists of its own separate column in a general hazard table showing all the hazard types and what hazards are part of that type.*

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Compare hazards against demographic groups. *We then compared every hazard in our lists to each demographic group to see if any hazards tend to affect certain demographics more than others.*

↓

Compare hazards against health effects. *Our team determined in which locations are hazards and health effects both common, and recorded whether a specific type of hazard has a substantial connection to specific health effects, analyzing first any health conditions known to be exacerbated by these hazards (from prior research).*

↓

Compare demographics against health effects. *We then compared all considered health effects or health conditions against specific at-risk demographics, (previously identified in our hazards vs demographics step), to determine if a certain health condition poses a greater risk to one demographic or location over another.*

Figure 12: Methodology for creating results.

Results of air hazard analysis

Analysis of Chelsea's air quality demonstrated that areas bordering highways and areas with many Hispanic/ Latino individuals tend to be exposed to greater concentrations of PM 2.5, a common and harmful air pollutant, and tend to live in areas that report high rates of respiratory conditions. Areas in Chelsea that contain a large proportion of Chelsea's population are located within 500ft of a major roadway, bus route, or train route; the resulting pollution released by the vehicles along roadways, bus routes, and train routes, including highway US-1, contains the PM 2.5 particle. It has been found that individuals who inhale air with more PM 2.5 particles are at a higher risk of having health conditions like asthma and COPD (chronic obstructive pulmonary disease) than those who experience

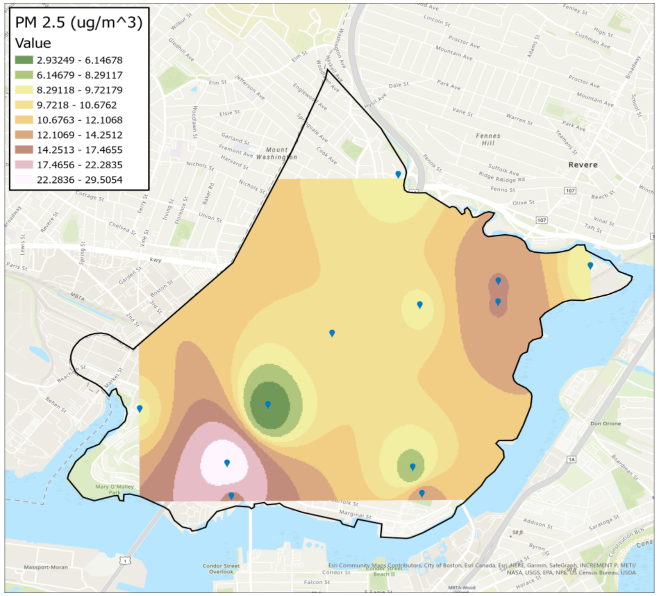

Figure 13: One-year average PM 2.5 levels across Chelsea. Deep greens and whites represent areas with low and high PM 2.5 concentrations respectively.

lower dosages (Environmental Protection Agency., n.d..). This is consistent with correlations of health and PM 2.5 levels across Chelsea. High rates of asthma are common among individuals who live near roadways, bus routes, and subway/train rails. Additionally, areas with individuals who regularly experience poor sleep correlate with the same areas where high PM 2.5 levels are present.

Our analysis also showed poor air quality caused by high levels of PM 2.5 correlated positively with high-population areas, increased poverty status, unemployment, historically redlined areas, a lack of medical insurance, housing vacancy, households of 3–6 people, and poor underage English proficiency.

Results of heat hazard analysis

Analysis of heat hazards demonstrated a clear correlation with impervious surfaces, low vegetation, high air and surface temperatures, little English proficiency, disease, and Hispanic/Latino groups.

Across Chelsea, areas with more impervious surfaces, such as heat-absorbing asphalt and buildings, experience higher air and surface temperatures than those with lower concentrations. In contrast, areas with ample vegetation experience much lower temperatures. In particular, these high-temperature areas are the western and eastern industrial zones, which have a high percentage of their land area covered by heat-absorbing structures like parking lots, roadways, and large dark roofs. By far, the most regularly coolest area of Chelsea is the naval hospital district, which is dense in vegetation and low in impervious surfaces.

Minorities and Hispanic/Latino groups disproportionately experience high temperatures. Additionally, these demographics tend to live in areas that were historically redlined, which tends to indicate current areas that are low-income and lacking in economic development (Pearcy, M., 2020). Those who speak proficient English tend to live in cooler areas than those households which are English isolated. The age groups that appear to live in high-temperature areas correlated with youth and portions of the elderly populations of Chelsea. Family households also tend to live in hotter areas than non-family households. Individuals who use the commuter rail as their primary method of transportation tend to live in areas suffering from heat islands, as well as those not in poverty but are insured correlate with these areas. Additionally, these areas are marked as populations with "high sensitivity to heat" by the MAPC; this metric measures how much pre-existing social conditions contribute to access to resources or exposure to hazards. These conditions include age, occupation, health, and housing features (Metropolitan Area Planning Council, n.d.).

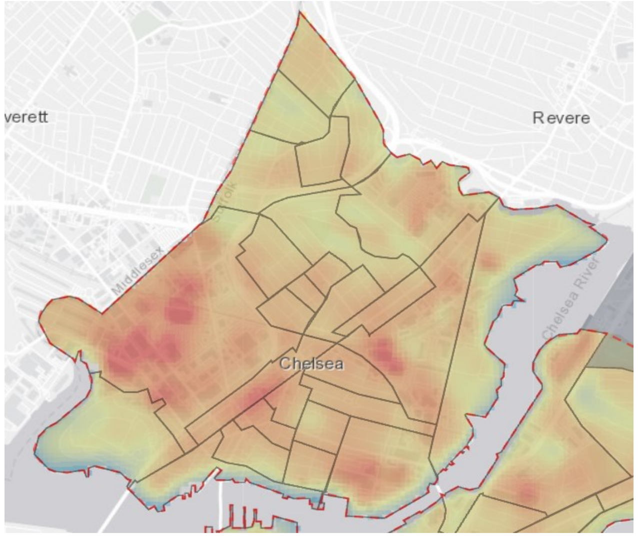

Figure 14: Land surface temperature across Chelsea, MA. Red represents 34 degrees Celsius, while blue represents 18 degrees Celsius (Boston University & GreenRoots, n.d.).

Areas that experience high air temperatures also have increased rates of cardiovascular disease, chronic kidney disease, diabetes, asthma, and COPD. Across Chelsea, those who live within areas that have high air temperatures have increased rates of obesity, poor physical health, poor mental health, and poor sleep.

Results of flood hazard analysis

Analysis of flooding data demonstrates correlations between flood zones, storm surge inundation areas— areas that will be flooded in the event of rising tidal waves caused by a major storm, areas vulnerable to sea level rise, high population, poor English proficiency, impervious surfaces, poor vegetation, and incomplete secondary schooling.

Areas that are inundated via a storm surge are the same that are vulnerable to sea level rise and general flooding. Primarily, these areas are the industrial districts of Chelsea as well as the area near its highway ramps and the southeastern coast. Industrial areas are most vulnerable; Federal Emergency Management Agency (FEMA) flood layers mark Chelsea's industrial districts and its southeastern coast as having a 1% annual chance of flooding with base flood elevation. Base flood elevation is the difference in altitude between the water level under normal conditions and the highest flood point during a 1% chance annual flood. Additionally, the area surrounding the highway ramps is marked as having a 1% annual chance of flooding with no base flood elevation and is near a regulatory floodway. These areas are the same areas that are vulnerable to storm surge inundation for a category 1 storm, though for a category 3 or 4 storm, this inundation area extends to the center of Chelsea. Additionally, sea-level rise maps from the National Oceanic and Atmospheric Organization (NOAA) put portions of the western industrial district underwater at 0 ft of sea rise, nearly covering 50% of the western industrial district at 1 ft, and nearly covering all of the industrial districts and the southeastern coast from 1–4 ft. By current estimations and at the current rate of sea-level rise, these portions of Chelsea will be endangered solely by sea-level rise after 2070 (Analyze Boston., 2017).

These same areas also correlate strongly with low vegetation and high levels of impervious surfaces. Areas vulnerable to flooding contain high populations, low English proficiency, those who have not completed secondary school, low income, high housing vacancy, and adult populations. Hispanic/Latino and environmental justice communities tend to correlate with flood zones. Interestingly, conditions like COPD, high blood pressure, poor mental/physical/sleep health, and cardiovascular disease negatively correlate with flood zones. Some flood areas along the east coast have high asthma rates.

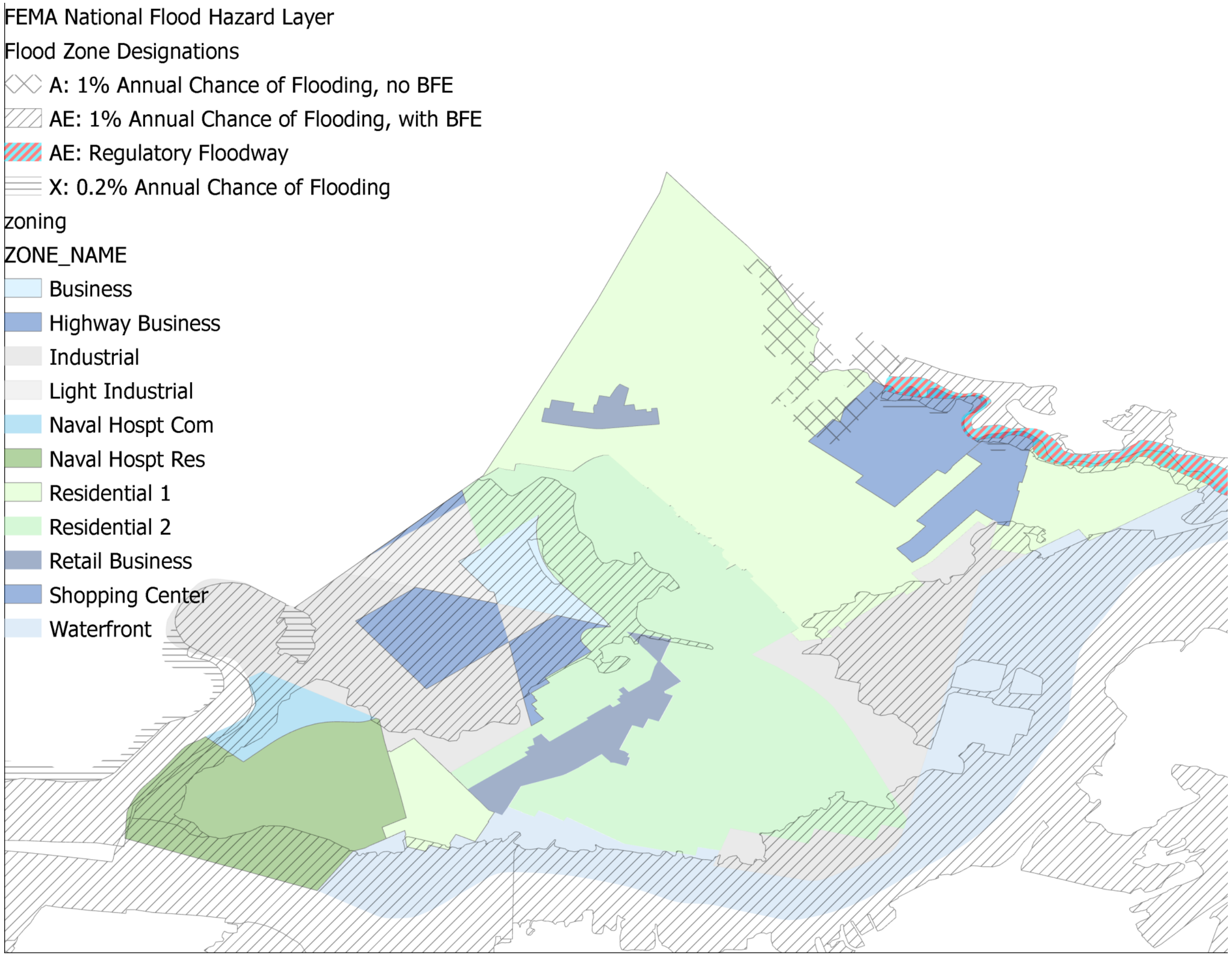

Figure 15: Flood areas (crosshatched) across Chelsea, MA. Flood areas largely correlate with coastal and industrial zones.

Other results

Health conditions appear more frequently in areas with high proportions of racial and ethnic minorities than in areas with comparatively lower proportions. They also tend to appear in places where there is a higher proportion of family housing than non-family housing and where people did not work for the full previous year (12 months). Health conditions tend to be positively correlated with individuals who have insurance, and negatively with individuals who do not; this appears to be less attributable to, say, the insured population being more at risk of these conditions, and more attributable to how insured individuals are more likely to get diagnosed with these conditions more often than uninsured individuals do.

Air quality outcomes and recommendations were investigated in further detail by another project team working with our sponsor. To access their full report, see "Assessing Opportunities for Air Pollution Mitigation in Chelsea, MA" through WPI.

Summary of results

Correlations between flood-vulnerable areas, hot areas, impervious surfaces, lacking vegetation, and industrial areas indicate that impervious surfaces and lack of green space are of primary concern in Chelsea. By far, the most endangered areas of Chelsea are its two industrial districts and the residential zones surrounding them.

Impervious surfaces and sparse vegetation tend to create higher temperatures, resulting in worsening health conditions. Particularly of note is how a significant portion of Chelsea is dedicated to parking spaces for businesses and industrial storage and is therefore largely covered in dark, impermeable surfaces such as concrete and asphalt.

Additionally, the problem of lacking vegetation and canopy covers is widespread and self-perpetuating. As trees are few in industrial areas, it is harder for new trees to grow due to poor air quality. Additionally, industrial sites often contaminate soil or release toxins that hamper plant growth. Poor vegetation not only results in higher temperatures but poorer air quality and worsened soil resistance to flooding erosion.

The groups most exposed to each of these hazards vary by block group, but across Chelsea, the most vulnerable populations are Hispanic/Latino and low-income groups. These groups experience higher rates of cardiovascular disease, chronic kidney disease, diabetes, asthma, COPD, obesity, poor physical health, poor mental health, and poor sleep. Areas like the naval hospital district still experience the highest rates of these health issues despite heavy green space and low impervious surfaces, but this is likely due to the area's significant elderly population.

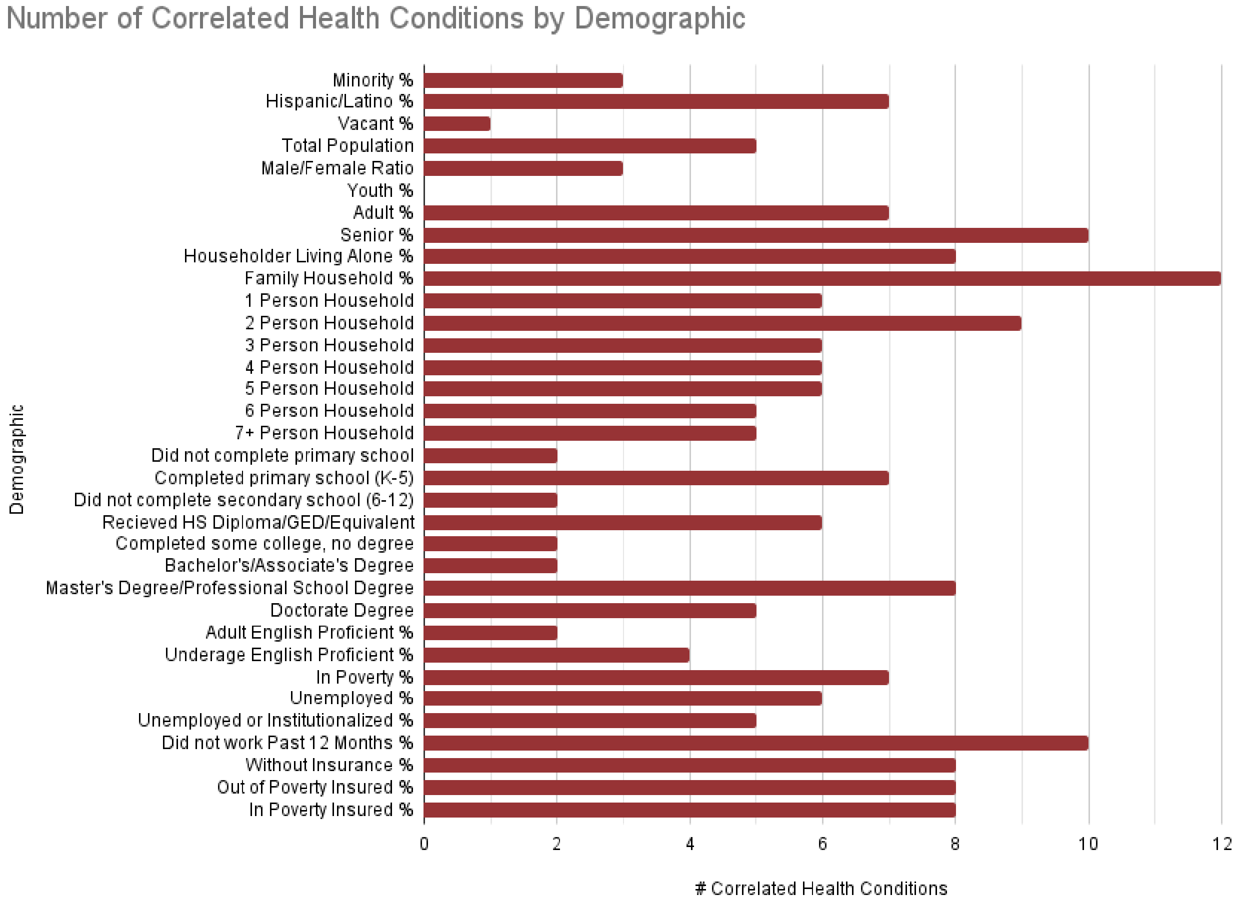

Figure 16: Health conditions by demographic. Health conditions tend to appear more frequently across elderly, low-income, and minority communities.

Challenges involved in data analysis

Throughout the project, there were some challenges of note involving data gathering, processing, and interpretation. Most notably, challenges arose from different data resolutions and the lack of available data.

A particular fault across our analysis arose from how different data sets have different levels of granularity. While race/ethnicity data is as specific as block level, other datasets range from the census tract level to the city-wide level. When making comparisons between different data resolutions, the results and conclusions are always less accurate than those using comparisons between datasets of the same resolution. In these cases, assumptions must be made and data at one resolution will not map perfectly to data at another. The team did its best to assure those correlations involving data at a lower resolution were consistent across data at a higher resolution.

Additionally, some data was simply not available in an ideal format. Datasets of documented hazardous sites are rare. Health data, in particular, is sparsely available due to restrictions on the disclosure of this information, and what is publicly available is at a low resolution. Other data, such as PM2.5 levels in areas not covered by sensors, were not available. It was also noted by our contact at the MAPC that little data is available that covers other forms of harmful particulate matter.

Local organizations were also reached out to by the team for guidance, datasets, and an experienced perspective, but were unavailable for comment.

Much of the project was also spent struggling with software, attempting to learn ArcGIS and GIS mapping, as well as data management in SQL and Microsoft Access. For this reason, we advise future teams, especially student teams, to reach out to relevant departments (such as IT for installation) early, to have someone experienced with GIS mapping at hand, and to reach out to users more experienced with the software. We also encourage student teams to take some time actively working with the program prior to the project to understand basic GIS setup and programming to reduce time spent learning about the program during their project terms.

Due to the sheer quantity of data being processed and the number of comparisons between maps to be made, the aforementioned theoretical ranking system was used, but it does have some flaws. For one, the weighting of each factor within the table is, while informed, partially subjective, as it is difficult to accurately measure the relative impacts of each factor. Additionally, determining which factors should be included within the ranking was also an informed subjective decision, driven by what data was available and how much data could feasibly be processed, as comparisons between maps had to be made manually due to data granularity issues.

Overview

While the majority of our analysis was performed utilizing ArcGIS, the primary analysis method used was yes/no visual correlation. Identifying a suitable spatial analysis tool in GIS was difficult, as no member of our team had any experience using ArcGIS or anything similar before this project. Due to a lack of remaining time in the project and data restrictions, our team opted to use solely the visual analysis method in our analysis.

This is primarily because the map layers we created in ArcGIS used four different feature classes: polygons of census blocks, census block groups, census tracts, and raster images. While we were able to identify spatial analysis tools that would calculate the correlation between two data sets, these tools all required that the two data sets be in the same layer. Our data was linked to a specific census area with different areas using distinct geographic shapefiles, and therefore requiring that much of our data be on different levels. Specifically, our demographic data was at the block group or block level, health data was at the census tract level, and our hazard data was a mix of raster and uniquely shaped polygon features. To join data from different sources (hazard, demographic, health) required linking both sets to the same polygon feature class (geographic area), which was not possible with our data in its current format. While converting rasters to polygons and blocks/block groups to Census tracts was possible, the time necessary would have far exceeded the time remaining for the project and would have also reduced the geographic specificity of our data and analysis.

After performing our visual analysis, our team needed a system to take this data and use it to generate results and recommendations. Specifically, our team intended to find a ranking system that would allow us to combine our analysis steps and determine the most affected areas and demographics. Unfortunately, our team was unable to find a ranking system that fit our needs. Instead, our team developed a custom ranking system specific to this project and data.

Our team decided that when ranking locations within Chelsea, we would do so at the block group level. Ranking at the block level is not only not possible with the specificity of our data, but not as useful as the locations are too small. The census tract level is also not desirable as we would only be considering eight different large areas within Chelsea and could miss correlations that only appear at smaller geographic scales. The block group level is the most suitable, as it has 27 areas—enough to be specific, but not too many to rank.

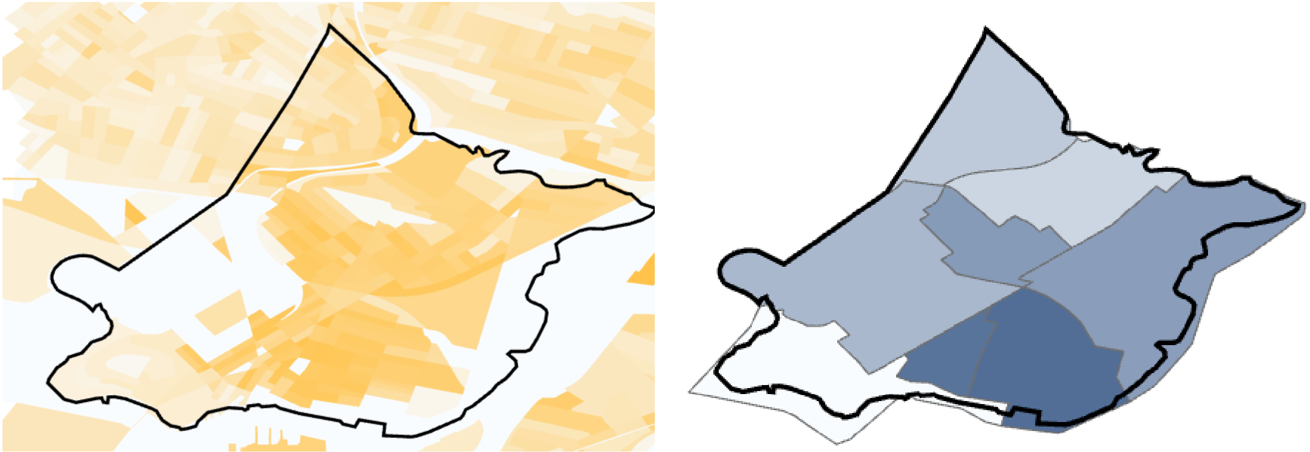

Figure 17: Data at multiple difference granularities, or resolutions. While "Hispanic or Latino Percentage" (left) is available at the more-specific block level resolution, "Obesity" data is only available at the less-specific census tract level resolution, complicating comparisons between the two levels.

To determine a final ranking, we summed the impact scores for each location from the heat, air quality, and flood tables. Additionally, the number of health conditions for which each block group was within the two most affected census tracts was also added to this sum. This total sum impact score was then sorted, allowing our team to easily identify the three most affected block groups. The tables of these scores is available in Supplemental Materials: Point-sum table.

The Census-defined block groups with the highest scores, indicating the greatest cause for concern, were block groups 160101-3, 160101-4, and 160101-5. These numbers correspond to a combination of the TRACTCE field (160101) and the BLKGRPCE field (3), which correspond to the Census tract identifier and Census block group identifier for 160101-3 respectively. For this reason, we recommend focusing on these block groups and tailoring recommendations to each of the hazards they were most impacted by. 160101-3 was most impacted by flooding concerns; 160101-4 was most impacted by heat concerns; 1605.01-5 was most impacted by flooding concerns. All three groups have high scores for all three primary hazard types.

Restoring environmental equity in the three highest-scoring block groups

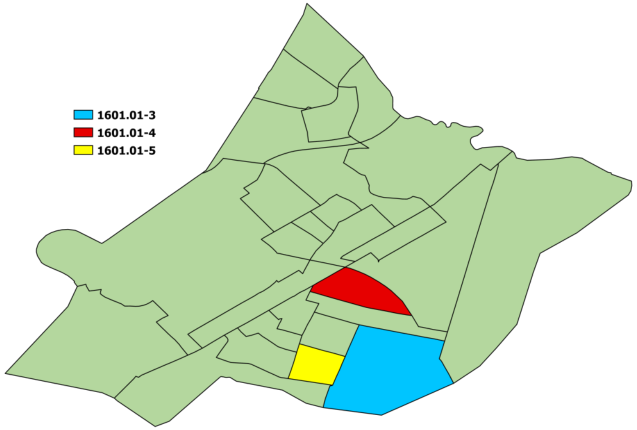

Figure 18: The three highest-scoring block groups in Chelsea, MA.

Block group 160101-3

While block group 160101-3 is noticeably vulnerable to all three major types of hazards, it is most vulnerable to flooding. This area has notable heat issues, is almost entirely covered by NOAA and FEMA-identified flood zones, and suffers from poor air quality. This block group is located along the southeastern shore of Chelsea, bordered by Highland Street, Bellingham Street, and Chelsea Creek.

The coastal portion of this area is almost entirely occupied by parking spaces that serve as parking for the Logan Airport and car rental services. This results in an overwhelming presence of impervious surfaces, which prevents water from soaking through the ground, leading to reduced flood resistance and higher rates of heat retention (John, W., Kim, J.-H., Li, M.-H., Brown, R. D., & Jaber, F. H., 2020). This also results in a high quantity of vehicle emissions due to cars idling in and frequently driving through the area (such as PM 2.5) which increases temperatures and decreases air quality (Union of Concerned Scientists, 2019). Reduction of impervious surfaces could reduce the urban heat island effect (Yang, J., Wang, Z.-H., & Kaloush, K. E., 2015). The reduction of parking spaces would likely prove helpful to the area environmentally on multiple levels.

Figure 19: Block group 160101-3 in Chelsea, MA from overhead (Google Earth, 2021).

Additionally, as much of the area is occupied by asphalt, there is very little green space in block groups 160101-3; only 1.47% of the total land area is green space. Greenery has been shown to reduce flood risk, air pollution, and heat, and the lack of green space contributes to an area's susceptibility to these hazards. (Zhang, Murray, A. T., & Turner, 2017; Mandych, n.d.). While this area is home to Highland Park, the park also uses a turf field, which does not provide any environmental benefits, such as reducing air pollution or heat. Inland residential blocks are relatively well-greened, but approaching the coast, greenery is lacking (or, in the case of some parking spaces, nearly nonexistent).

The block group is also home to several industrial and processing facilities. This may increase emissions and heat both due to processing and a large number of incoming and outgoing vehicles. These facilities may also pose a hazard in the event of a flood, potentially freeing dangerous materials and chemicals from the soil and pavement, and carrying these into residential areas.

Block group 160101-3 also contains three Tier-II Chapter 21E Tier Classified Sites, as well as underground storage tanks, which could be of environmental concern and pose a threat during a flood event. Chapter 21E describes the responsibilities of businesses for reporting and cleanup of hazardous waste disposal sites to the Massachusetts Department of Environmental Protection (Massachusetts Department of Environmental Protection, n.d.). The Tier-II sites include one coastal site at 467/580 Chelsea Street and two inland sites at 22 Willow Street and 340 Marginal Street. Additionally, underground storage tanks belonging to the Chelsea Creek Headworks and MWRA Caruso Pumping Station could pose a risk in the event of a flood. We recommend further research to determine if these sites have had their risk to the population minimized.

In order to mitigate the potential effects of flooding in the region and to reduce the extreme heat this region faces, a push for the creation of green space would be extremely helpful in reducing heat, air pollution, and flood risk, especially along the coast. Parking lots often have significant unused space along with parking dividers, which could be an opportunity for the addition of plants. green space within this area will strengthen the soil and reduce erosion, creating soil that is more resistant to floods and reducing potential flood damage (Mandych, n.d.*.)*.

While green space is likely the most useful tool and mitigates multiple hazards at once, additional measures could include heat-reflective white roofs (many of the buildings have roofs dark in color) and additional circulation using AC units to reduce the extreme heat individuals will experience within their homes. This could be accomplished by implementing a policy to subsidize resident AC unit purchases or distribute free units to at-risk residents. Since this block group is coastal and within a flood zone, preparations could be made to strengthen the coastline with flood barriers, and emergency evacuation plans and related procedures should be made and provided to these residential areas for the event of a flood (Metropolitan Area Planning Council, 2018). Finally, the city should consider investigations into coastal erosion in

Chelsea and plan to mitigate this risk as sea levels continue to rise.

This block group contains a large proportion of the youth (0-17) and senior (65+) age groups as compared to the rest of Chelsea, as well as a large proportion of high-density households (6+ people per household). The area is also home to a youth Boys & Girls Club, a rehabilitation center, and a daycare that is affected by the current environmental hazards present in this region.

Block group 160101-4

Block group 160101-4 is also impacted by all three major hazard types but is particularly vulnerable to extreme heat. It is inland and largely residential, bordered by Broadway, Grove Street, and the Silver Line 3 bus road. Additionally, the western edge of the area is alongside Broadway, a frequently used main road, increasing pollution and heat due to passing vehicles. The area is home to the Chelsea Public Library.

Like much of Chelsea, impervious surfaces cover most of the block group, covering 92.23% of the area. This includes roofs, which are almost entirely heat-absorbing dark colors in this area. The block group is also partially affected by flood zones in the northwestern section of the block group.

Figure 20: Block group 160101-4 in Chelsea, MA from overhead (Google Earth, 2021).

No significant industrial or waste hazards appear to be documented within the area, though there are a few select industrial businesses.

Greenspace continues to be an issue in this region (though less so than in 160101-3), covering only about 4.97%, leading to higher temperatures, worse air, and reduced flood resistance. The block group is also home to green space worth preserving: the Box District Park, the Marlborough Street Community Garden, and the Bosson Playground (though the Bosson playground is largely paved).

The area begins to be at risk of flood during sea-level rise at about 3 feet of additional sea level height. Hurricane storm surge information shows that Category 1-4 storms would impact the northeastern segments of this block group.

The team recommends increasing green space, through green roofs and additional vegetation, especially in western residential neighborhoods. Community gardens could provide additional vegetation, avoid soil erosion through raised garden plots or planter boxes, and provide sources of recreation, food, and income.

Further recommendations include HEPA filters and AC units for the reduction of poor air quality and heat risk as well as white roofs to reflect heat, and the assessment of public transportation access in the area to encourage a reduction in the use of personal vehicles.

This block group contains a large proportion of ethnic minorities (Hispanic / Latino population), adults with little to no English proficiency, and medium density households (3-5 individuals per household), as compared to the rest of Chelsea.

Block group 160101-5

Block group 160101-5 is along the southern coast of Chelsea. It is directly adjacent to the west side of block group 160101-3 and bordered by the coast, Highland Street, Shawmut Street, and Maverick Street. This block group is most vulnerable to flooding and heat concerns, as well as some industrial sites.

There is a fair bit of green space in the central-western block of housing, including the TND Community Garden, but green space is lacking as a whole across the block group, covering only about 2.5% of the block group;

Figure 21: Block group 160101-5 in Chelsea, MA from overhead (Google Earth, 2021).

including the narrow area between this block group and the coast, the green space average coverage drops to 0.73%.

Impervious surfaces are also a concern, as much of the area is dedicated to industrial space and roadways. These surfaces cover up to 92.23% of the block group. This impervious space also includes vacant commercial land, indicated by massive (relative to the block group) unused paved lots, at 110 Marginal Street and 182 Marginal Street. Housing covers much of the remaining surface area of this block group, and the vast majority of houses have dark roofs.

Heavily-trafficked routes like Marginal Street and the Chelsea Creek may increase the prevalence of emissions in the area, especially near industrial facilities that often have both maritime and land vehicles idling, loading, and offloading materials.

The area would also be inundated in the event of flooding, especially near the coast. Additionally, the area along the coast is vulnerable to storms; for a Category 1 storm, about half of the block group stretching upwards from the coast would likely be inundated. NOAA sea level rise mapping data shows parts of the coast already underwater with less than 1 foot of sea-level rise, but inundation worsens along the coast as sea-level rise increases. No flood barriers of any sort appear to be present currently.

By far the most noticeable features nearby this block group are the massive salt piles stored along the coast, which stretch into other block groups, located at 99 Marginal Street. These salt piles are the primary source for the city of Boston's deicing trucks (Cook, 2015). Salt piles like this pose a significant environmental risk (including emissions related to the transport of said salt), especially in the event of a flood and wind carrying salt as an airborne hazard.

There are also hazardous sites. This includes two Chapter 21E Tier Classified Sites that could pose a risk to the population in the event of a flood, located at 100-110 Marginal Street (Tier II) and 150 marginal Street (Tier II). Also present is the Chelsea Marginal Street Dump, which appears to be an unpermitted land dump, documented in the City of Chelsea's GIS dataset. Additional risk mitigation measures could be warranted and worth investigating. Measures like green roofs, additional vegetation, and gardens are recommended to increase green space in order to reduce the impacts of all three major hazard types.
To address the flood risk to the region, the construction of flood barriers along the coast may help reduce the risk posed by salt storage to residents, as well as mitigating damage caused by sea level rise and storm surge inundation. As industrial salt storage is of major risk, we recommend working with the owners of these materials to manage or minimize the risk of outdoor salt storage.
White roofs and the reduction of unused impervious surfaces could also prove effective in mitigating heat. Fewer impervious surfaces would open room for additional grounded green space and therefore reduce flood risk.
While PORT park is not located within this block group, 160101-5 is the closest residential block group to it, and therefore it is an important source of green space and recreation for the residents of this block group.

It may also be worth evaluating traffic laws and maritime regulations to determine if policies could be implemented to reduce idling times for road and maritime vehicles along the coast.

This block group contains the largest proportion of unemployed individuals, adults that lack English proficiency, and family households compared to the rest of Chelsea.

City-wide recommendations

Many of the major environmental hazards contributing to the problems of flood risks, poor air quality, and extreme heat are present across multiple block groups in Chelsea. Therefore, we have come up with a series of city-wide recommendations which, if applied correctly, would reduce the effects of certain environmental hazards or could potentially remove one or more environmental hazard sites. These recommendations are not ranked.

Recommendation 1: Enhance the reliability of the current transportation system and reevaluate traffic laws

This project could require significant resources, but could reduce emissions. Many air quality problems can be attributed to the use of gas-powered personal vehicles, which release more PM 2.5 into the air than an equivalent capacity of gas, diesel, hybrid or electric buses would. PM 2.5 has been shown to induce or worsen negative health effects related to the respiratory system, leading to various respiratory diseases such as asthma, bronchitis, or COPD (Environmental Protection Agency, n.d.). By increasing the accessibility, capacity, and reliability of existing bus routes, the necessity of using personal vehicles to get around, in, and out of Chelsea would also be reduced. This recommendation could help reduce traffic congestion on roadways that experience constant vehicle use. In addition, this solution is also a quality-of-life improvement for residents of Chelsea and for those wishing to move in and out of the city, offering them affordable transport. Based on our interview with the MAPC, it was apparent that the current transportation system could be improved in some way to increase the reliability and ease of use of the public bus transport system. This is a rather complicated undertaking, and it would largely be preventative, with its effects only seen in the long term. If the residents of Chelsea can take advantage of improved public transportation, the city should expect better air quality and slightly lower temperatures in areas where high PM 2.5 levels are most common (UCSUSA, 2019).

Recommendation 2: Creation of green roofs and white roofs

Figure 22: A green roof atop the 10-story Chicago City Hall. Roofs like these can provide greenery in environments that otherwise have little space for them (TonyTheTiger, 2008).

Buildings in Chelsea occupy roughly 13.6% of its total land area, and based on satellite maps of Chelsea, most of these roofs are of a dark color or use heat-absorbing materials. Such materials greatly contribute to the urban heat island effect within cities (Yang et al., 2015). Several studies have shown that the usage of white roofs (painting the roofs white or using white/light-colored materials) and green roofs (roofs that hold gardens or some form of vegetation on top of them) reduce the effects caused by urban heat islands. (Beecham et al., 2019; AccessScience, 2019). Due to this, we highly encourage programs and/or individual actions which aid in the creation of green roofs and white roofs throughout all areas in Chelsea.
Specifically, white roofs should be created on structures that do not have a flat roof or on structures that do have flat roofs (as they cannot hold a green roof), either permanently or as a temporary measure until a green roof can be applied. Green roofs should be applied as often as possible on flat roof buildings across Chelsea. In an ideal situation, every

Figure 23: A white roof atop a building. White roofs absorb less heat than darker colors (Hagerty, n.d.).

roof that is flat would become a green roof, and all other roof styles would become white roofs. Green roofs are a larger project than white roofs due to the labor involved and the cost of materials for construction. In addition, some green roofs will need to be maintained if these green roofs become rooftop gardens for individuals or become very elaborate. Even white roofs can be expensive, and oftentimes buildings in Chelsea may require repairs or modifications to support green roofs; additional research is recommend. By completing this recommendation, there will be a reduction in poor air quality and a large reduction in extreme heat caused by the urban heat island effect.

Recommendation 3: Repurposing of unused spaces to create green spaces

Impervious surfaces are extremely common across Chelsea, most notably in parking lots and unused lots which have pavement and/or concrete covering them. Impervious surfaces contribute to flooding and heat vulnerability, being poor at water absorption and far too good at heat absorption (Sohn et al., 2020). It would be beneficial to the city of Chelsea if the city was to take another look at current parking and open lots to see if they are not being used or underused and can therefore be repurposed into green spaces. This does not mean tearing up pavement or concrete areas and replacing them with green spaces; during our interview with the MAPC (see Supplemental Materials: Interview with the MAPC), it was noted that ripping up paved areas and trying to plant vegetation in those areas was unwise, as metals and chemicals from the pavement would have seeped into the underlying soil. As such, plants placed in the area would most likely require additional resources and care; it would be better to build above these unused spaces in boxed or raised gardens. This would reduce the amount of work needed to create a green space, and is less costly than tearing up the ground. Green spaces could also be placed upon city-owned property that also serves as a shelter from the sun, such as covered bus stops. Building gardens and green spaces above ground can reduce the extreme heat effects and reduce pollutants in the air (Beecham et al., 2019; AccessScience, 2019). The amount of labor and cost needed to complete this recommendation is minimal for small gardens, but these costs, of course, depend on the size and need for maintenance (TRUiC, 2020). The most challenging part of implementing community gardens would likely be finding space to implement them.

Recommendation 4: City-wide plans in the event of an emergency due to flooding, extreme heat, and/or poor air quality

Many of these recommendations will take time before they are completed and their effects are felt. There are also some environmental hazards that cannot be removed outright, such as sea-level rise. Therefore, it is advisable to have plans in place for potential events on days with bad air quality, extreme heat, and in the event of a flood. These plans should be city-wide policies/plans which consist of information sessions that inform the residents of Chelsea about environmental hazards, extreme heat, poor air quality, and flood zones in Chelsea. In addition, these sessions should talk about what people should do in the event of a flood, extreme heatwave, and or extremely bad air quality within the city. Furthermore, the city, the residents, and/or local organizations should have areas marked out for emergency medical care as well as safe spaces for people to go to in the event of extreme heat, poor air quality, and/or a flood. By preparing the community early and informing residents of possible emergency situations, it will both inform and hopefully encourage action to reduce environmental effects. Most important, though, is making sure that action plans for emergency scenarios are in place and well-documented. This recommendation will be difficult to organize as this recommendation requires more logistical work as well as outreach to the communities of Chelsea.

Recommendation 5: Programs to assist in the purchase and installation of HEPA filters and AC units

Another mitigation recommendation for reducing the effects of heat and air quality on the residences of Chelsea is specifically related to poor air quality and extreme heat. During our meeting with the MAPC, we learned that the organization had helped plan a program that would give out AC units to residents of Chelsea. There were 73 units available, but over 700 people sent in a request for an AC unit, indicating a massive need for them. AC units are expensive, and the electricity they require can cause financial strain on the many (often low-income) residents of Chelsea. This would require a community effort to reach out to individuals about this program, followed by an economic plan for how much of the costs of installing and powering the HEPA filter and AC units will be covered under the program.

Figure 24: Chelsea Public Works staff deliver a window air conditioning unit to a resident at a public development apartment complex in Chelsea. This energy-efficient unit is one of 73 funded by a major grant. Nearly 700 residents applied for these units, indicating a major need for cooling (Bebinger & Costa, 2021).

Recommendation 6: Cooperation with government and community organizations for funding

As funding is often a major hurdle for community projects large and small, it would also be beneficial to apply for any available grants that would enable the execution of other recommendations. Oftentimes, government agencies will offer rounds of funding to applicants who demonstrate a need for financial assistance—as did the MAPC when Chelsea applied for funding for air conditioning units (Bebinger & Costa, 2021). However, agencies distributing grants often have few funds to provide; additional investigation into ways to further cooperate with these agencies would be ideal. Additionally, advocacy on the municipal, state, and federal levels for favorable policy, as well as the fostering of cooperation between multiple agencies, is worth investigating. These organizations may include the OTA, MassDEP, MAPC, etc.

Recommendation 7: Work with companies in the region that produce or house toxic materials which could be washed up in the event of a major flood

The city could also benefit from working alongside companies that produce or house possible toxic materials within Chelsea that are located near or within flood zones. Should these materials get washed up in the event of a flood, it could cause harmful effects to the residents within the flooded regions in which these toxic materials get washed up. This recommendation requires less general labor and costs and is more focused on communication, regulation, and deal-making between the city and local companies with help from local organizations and the residents of Chelsea.

Recommendation 8: Community environmental justice engagement

As noted by various local environmental justice advocates, community support and opinion can be key tools in restoring environmental equity. While action from local governments is welcome and helpful, many local environmental groups, such as GreenRoots, advocate for a "power to the people" approach in tandem (GreenRoots, n.d.). This type of approach focuses on the prioritization of citizen-led enfranchisement and action, providing residents "next steps" or action plans that inform them on the part they can play in the future of their communities. Additional research into ways to encourage community engagement, such as further education on the presence and effects of local environmental hazards, would be worthwhile.

Additional research opportunities

These recommendations are not the only options; it is possible that other methods of environmental hazard mitigation could be effective in Chelsea. Our team recommends that additional research be done into hazard mitigation measures that have been effective in similar communities and the costs of these measures. Some potential solutions could include de-paving, use of porous concrete, replacing of turf fields with natural grass, assessment of zoning laws, assessment of traffic laws, re-zoning, land cleanup, soil strengthening, assessment of flight paths, noise pollution mitigation, erosion mitigation measures, communication standards for medical emergencies, implementing cooling stations (see C-HEAT study by GreenRoots and Boston University (Boston University, & GreenRoots. n.d.)), and reduction of traffic congestion. We highly recommend further research be done into mitigation measures in the highway and industrial districts of Chelsea, which rest almost entirely within flood plains, are covered with impervious surfaces, have little to no green space, see heavy traffic, experience high temperatures, experience poor air quality, serve as the first defense against flooding, and contain the majority of Chapter 21E sites in Chelsea as well as underground storage tanks. Further research could also be done into the locations of TURA-recognized facilities, important community center (like schools) locations in relation to hazards, community engagement and power redistribution, sewer systems, and water pollution.

Conclusion

The city of Chelsea is, as a whole, significantly at risk of three major hazards: extreme heat, flood zones, and air pollution. These hazards can negatively impact the health, livelihoods, and quality-of-life for citizens, especially since Chelsea has such a small land area and therefore hazards can easily impact most of the city. Particularly, however, the primary areas of concern should be block groups 160101-3, 160101-4, and 160101-5, which are most in need of environmental hazard mitigation measures as determined by a theoretical ranking system developed by the team. Furthermore, the two industrial districts, while rarely containing residential space, are hotspots for extreme heat, impervious surfaces, low green space, toxic sites, flood zones, and poor air quality, and pose a risk to nearby neighborhoods.

Chelsea's greatest problem by far appears to be its overwhelming lack of green space and presence of impervious surfaces. It is heavily recommended that further research be done into the feasibility of and opportunities for increasing green space, potentially where impervious surfaces already exist. The replacement of unused impervious surfaces with greenery would be an excellent way to reduce hazard impacts in two ways at once. Areas like the naval hospital district demonstrate the effectiveness of these measures; by far, this area has the best air quality, heat, and flood outcomes (despite being along the coast), likely due to its prevalent green space and relatively smaller presence of impervious surfaces.

As a community entirely marked as an environmental justice community, Chelsea as a whole is uniquely vulnerable to environmental hazards and home to minority groups that are also uniquely vulnerable. While all of Chelsea should be considered for environmental justice measures, the groups most in need across Chelsea are the minority, low-income or unemployed, and low English proficiency populations.

Additionally, further research into other mitigation measures would be beneficial, especially in industrial areas that, while sparsely populated, are very vulnerable to all three major hazard categories.

Environmental equity is a status that must be maintained knowingly and purposefully due to its extreme complexity. While many factors were considered for this project, there is a wealth of data available that may illuminate additional facets of inequity. There is also a need for more comprehensive data documenting many demographics that are not currently well-documented, such as poverty and homelessness. Future analyses would also benefit from an improved understanding of the area surrounding Chelsea and its impacts on the city.

Any further action should be done with additional research and the immense complexities of community planning in mind. Like a complex machine, a community has numerous components that interact in elaborate ways; the community of Chelsea is no different.

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