Boston University

Clearing the Path: Evaluating Air Quality and Sustainable Transportation in Boston

Air Quality & Transit Team F

Hemanshu Bhojwani (% 2024, hemanshu@bu.edu) , Anulika Nnadi (% 2024, annadi@bu.edu),
Ziliang Wang (% 2025, wang4936@bu.edu), Xinzhu Liang (% 2024, simonxl@bu.edu)

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Introduction: (Anulika)

Air quality in Massachusetts is a matter of serious concern, with far-reaching implications for public health. In 2019, air pollution led to 2,780 deaths in the state. These fatalities encompassed a range of severe health outcomes, with 2,185 linked to lung cancer, 1,677 to heart disease, 343 to chronic lung disease, and 200 to stroke. Air pollution also contributed to 15,386 cases of pediatric asthma and 308 low-birthweight babies born to mothers exposed to pollution (Air Pollution's Deadly Toll in Massachusetts). The nature of this issue is emphasized by research linking it to fine particulate matter smaller than 2.5 micrometers in diameter (PM2.5), which has been associated with increased risks of heart and lung diseases. Furthermore, an analysis by the Union of Concerned Scientists (UCS) illuminates distinct disparities in PM2.5 exposure. Asian American residents faced levels 36 percent higher than white residents, African American residents faced levels 34 percent higher, and Latino residents 26 percent higher (Inequitable Exposure to Air Pollution from Vehicles in Mass). These findings highlight the disproportionate impact of vehicle pollution on communities of color. This background accentuates the urgency of addressing air quality issues in Massachusetts, particularly in Boston, through data-driven initiatives, equitable policies, and community engagement efforts to safeguard public health and promote environmental justice.

Problem Statement: (Hemanshu)

Air quality is a critical concern for the wellbeing of Boston residents. Poor air quality could be detrimental to public health, causing respiratory issues such as Asthma. To address the issue of air quality around Boston, we are looking at how public transportation can play a crucial role in reducing emissions and increasing air quality. We aim to look at Boston divided into neighborhoods and see the factors behind the variability in air quality to help make guided decisions on where to focus efforts and policies to enhance air quality.

Goals/Background: (Anulika)

The overarching goal of our project is to enhance air quality in Boston while promoting sustainable urban development and community engagement. For the project, we have established the following goals:

1. *Improve Air Quality in Boston*
    a. Our primary objective is to work towards the improvement of air quality throughout Boston. We aim to achieve measurable reductions in key air pollutants, which contributes to the overall well-being of the city's residents.
2. *Understanding Air Quality Variability*
    a. We aim to recognize the factors influencing air quality fluctuations across Boston's neighborhoods, enabling targeted efforts to address areas with the

greatest need for improvement. This understanding will help us identify targeted strategies for pollution mitigation.

3. *Understanding how public transportation can contribute to reducing emissions*
    a. By studying the role of public transportation in emission reduction, we intend to identify strategies and interventions that can lead to cleaner and more sustainable transit options.
4. *Engage and educate the community in Boston about air quality issues*
    a. We are committed to fostering community engagement and education, empowering Boston residents with the knowledge and tools to advocate for cleaner air and healthier living environments.
5. *Inform and guide decision-making processes with data:*
    a. Our research will provide data-driven insights that can inform policy decisions, urban planning efforts, and transportation initiatives aimed at mitigating air quality concerns in Boston.

In addition to these goals, it is essential to establish a comprehensive background that encompasses various aspects related to air quality and its determinants:

1. *Basics of Air Quality and Pollution*
    a. Our project begins with an exploration of the fundamental concepts underlying air quality and pollution. This involves understanding the components that contribute to air quality, identifying common pollutants such as particulate matter (PM2.5 and PM10), ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2), and carbon monoxide (CO), and comprehending how exposure to these pollutants can have adverse effects on human health.
2. *Understanding the Relationship between Vehicle Emissions, Traffic Congestion, and Air Quality*
    a. We explore interconnection between vehicular emissions, traffic congestion, and their repercussions on air quality. By examining the emissions profiles of different transportation modes, we can recognize how traffic patterns and congestion impact pollutant concentrations in various parts of the city.
3. *Geographical and Demographic Factors in Boston*
    a. Boston is a diverse city characterized by a variety of neighborhoods, each with its unique geographical and demographic attributes. We need to consider how these factors, such as proximity to highways, job availability, and residential density, influence air quality disparities across different areas of Boston.
4. *Understanding Environmental Policy and Urban Planning*
    a. We will explore how policies and planning decisions have historically shaped transportation infrastructure and impacted air quality. Additionally, we will identify potential opportunities for policy interventions to enhance air quality.

5. *Data Analysis and Research Methods*
    a. Our project's success depends on data analysis and research methodologies. We will employ data collection and analysis techniques to assess air quality variations across neighborhoods, find trends and patterns, and establish connections between public transportation utilization and air quality improvements. Additionally, we will engage in community outreach and education efforts to foster awareness about air quality issues among Boston's residents.

Significance/Impact: (Anulika)

The significance and potential impact of this project are multifaceted, touching upon various critical aspects of public health, environmental sustainability, equity, and community well-being. The project's primary aim is to enhance the health and quality of life of Boston's residents by improving air quality. By reducing air pollution, particularly the presence of PM2.5 and other harmful pollutants, the project seeks to diminish the incidence of respiratory diseases, cardiovascular issues, and other health complications. This could potentially result in fewer hospitalizations, an elevated overall quality of life, and even a reduction in premature deaths, as demonstrated by the statewide statistics. The project emphasizes the principle of environmental justice by acknowledging and addressing disparities in air quality and pollution exposure among diverse racial and ethnic groups in Boston. By focusing on neighborhoods characterized by higher pollution levels and actively engaging communities that are disproportionately affected, the project seeks to reduce health inequities and promote a fair and inclusive urban environment. This emphasis on equity aligns with broader efforts to create a more just and inclusive society.

Additionally, the project's data analysis and research methods provide policymakers and urban planners with valuable insights. These insights can inform evidence-based decision-making processes related to public transportation, environmental policy, and urban development. Data-driven interventions can lead to more effective and efficient measures to combat air pollution. Examining the role of public transportation in reducing emissions and improving air quality reiterates the importance of sustainable urban planning and transit systems. If successful, the project's insights could serve as a model for other cities facing similar challenges, promoting the adoption of cleaner transportation options and contributing to a reduction in greenhouse gas emissions. The project's potential long-term benefits span improved worker productivity, reduced healthcare costs, and an overall healthier and more attractive city environment, resulting in economic growth and prosperity in cleaner, more livable cities.

Exploratory Data Analysis: (Hemanshu)

Our analysis made use of a variety of datasets (listed below) that helped us gain a comprehensive understanding of the underlying factors behind Air Quality in Boston. We started by looking at data at a census tract level, as this was the starting point for many of these datasets, and cleaned the datasets up by fixing missing values and handling outliers to make sure it's accurate. This included using either the mean, median, or the most occurring value depending on the context. We then filtered the data, dividing them into neighborhoods, to help gain a better understanding of the characteristics of different areas around Boston. This was done by taking the nearest available air quality sensor, making boundaries across neighborhoods, and taking count of the number of stops, docks etc. in a given area. This information was then divided into a resultant CSV file (DataByNeighborhood.csv) for easy access to create graphs and we also created an html map (VisualMap.html) and a dashboard website to help visualize the data across areas (Figure 1).

Datasets:

- **Proximity to Roads:** Examined the correlation between community types and the Proximity to Roads (PPI) Index, assessing how communities relate to road networks.
- **Air Quality data from Google Maps:** Air Quality data including AQI, PM, SO2, NO2, and O3 across various areas in Boston pulled from AirNow and PurpleAir.
- **MBTA Transit:** Geolocation of Trolley (T) stops across Boston
- **Census Data:** ACS census data from U.S. Census Bureau for every census tract and Boston neighborhood in Suffolk County.
- **Social Vulnerability:** Information divided by tracts on groups more likely vulnerable to impacts of hazards, including death, injury, loss, or disruption of livelihood.
- **Health Dataset:** CDC Data by Zip Code of prevalence of relevant health conditions such as Asthma and Physical Health.
- **MBTA Bus Stops:** Geolocations of Bus Stops across Boston.
- **Blue Bikes Data:** Number of Blue Bikes stations and docks across Boston.
- **Open Spaces and Green Spaces:** Information on the number of open spaces and parks in each neighborhood.
- **Neighborhoods of Boston Summary:** Population by Age, Labor Force, Payroll Jobs, Vehicle Ownership

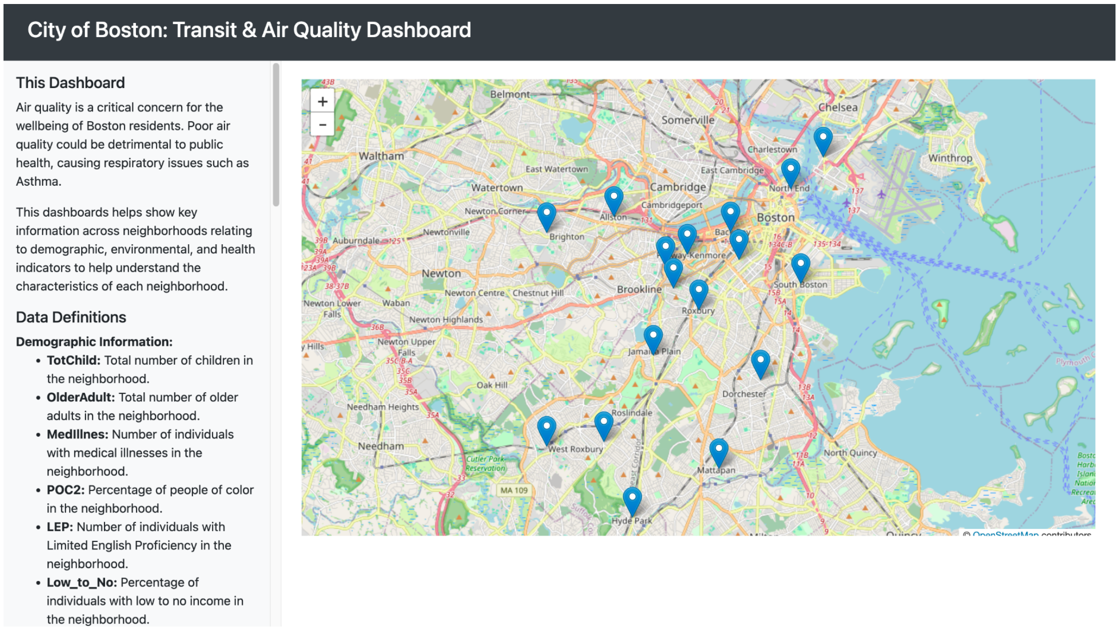

Figure 1: Dashboard Website, Visual Summary of all our Datasets

Base Questions:

Q1: What is the yearly change in air quality for Boston residents based on their proximity to different types of transportation infrastructure, specifically, proximity to public transportation options or proximity to roads?

MBTA Stops (Simon):

In deliverable 1, we performed an analysis between air quality and one popular public transportation in Boston which is the MBTA. We analyzed the AQI_OZONE and AQI_PM2.5 (data from AirNow API) versus the number of stations in that area. However, after we revised it, we found the raw data, but some areas are having the same zip code (e.g, Back Bay and Bay Village are having the same zip code 2116).

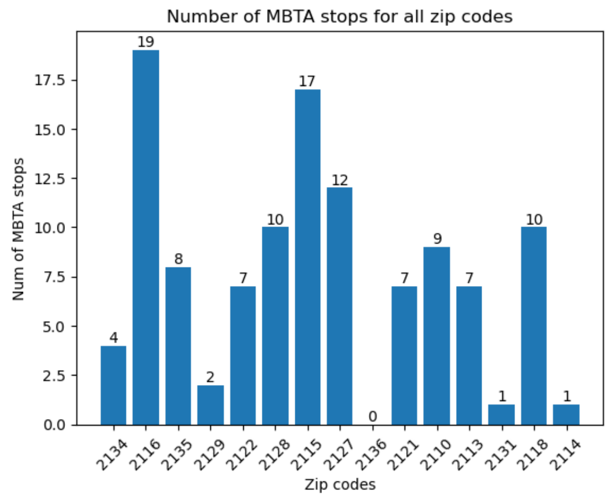

Figure 2: Overview of MBTA Stations in neighborhoods

We gathered the data by the Boston Map and the air quality data from Google Air Quality API. To prevent having multiple points for zip codes that don't have any stops, we truncated the data according to the zip code. Figure 2 shows the result after truncating the data, and the number of stops are grouped by each neighborhood by zip code.

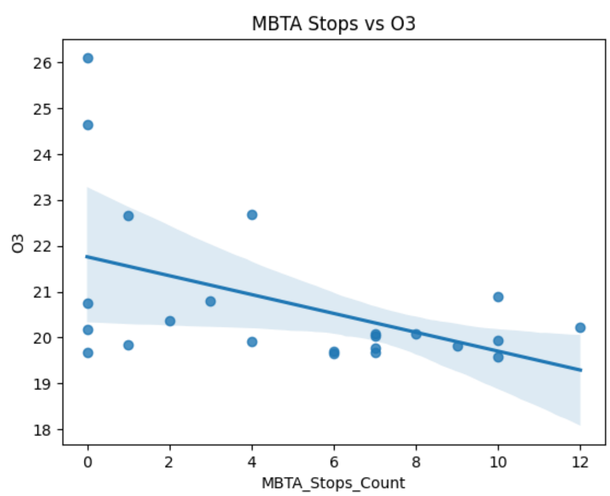

Figure 3: The relationship between MBTA and ozone levels

There are several indexes regarding the overall air quality, such as PM2.5, PM10, ozone, and overall AQI values. In this question, we analyze the relationship between the number of MBTA stops and those air quality indexes. After plotting the number of stops and the ozone values in figure 3, we found a negative correlation between the number of MBTA stops and ozone levels. This indicates that neighborhoods with more public transit tend to have a better air quality.

However, we also found that the AQI has a slight positive correlation with the number of MBTA stops. It seems that building more MBTA might lead to bad air quality, but we think there are other factors that should be considered, which are verified by our analysis in the extension project.

PPI Data: (Hemanshu)

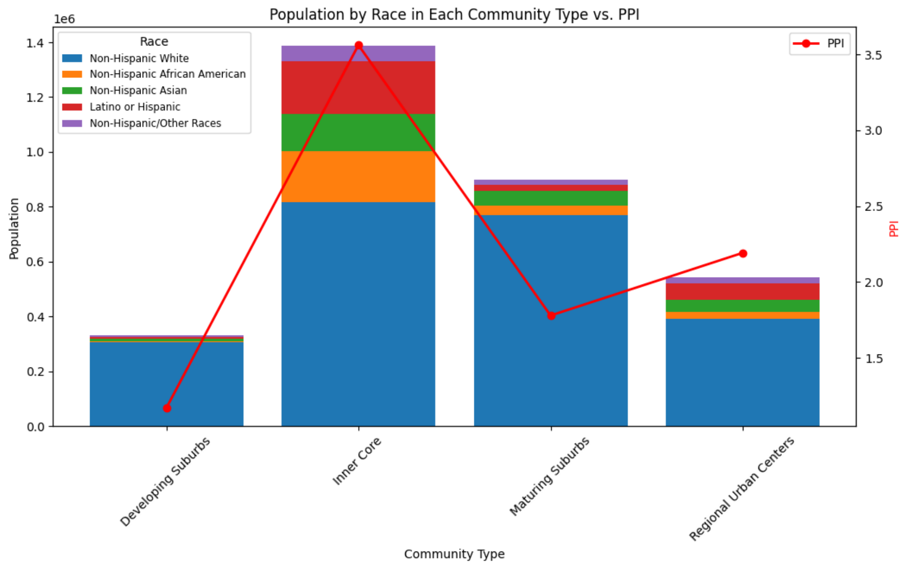

Figure 4: PPI for different type community (with race composition showed)

- **Developing Suburbs:** Outskirts of the city that are of high growth. Lowest Population, Lowest PPI.
- **Inner Core:** Central Part of the City. Highest Population, Highest PPI.
- **Maturing Suburbs:** Outskirts of the city that have undergone significant development and have matured over time. Second highest Population, Second Lowest PPI.
- **Regional Urban Centers:** Regions within a city that serve as an economic, cultural, or administrative hub. Second Lowest Population, Second Highest PPI.

In general, areas with higher population have higher PPI, however, it could be assumed that Regional Urban Centers have more PPI due to movement or people commuting to these areas for work. Resident population is not the sole determinant of air quality in a neighborhood.

Q2: How do areas in Boston with poor air quality compare to areas with better air quality based on different demographic characteristics? (Anulika)

In Deliverable 1, we conducted an initial assessment of air quality in various neighborhoods within Boston, focusing on Mattapan, Roslindale, West Roxbury/Roxbury, and Hyde Park. At that time, the data indicated that these neighborhoods had a red Air Quality Index, suggesting poor air quality.However, we now have access to updated information from the Google Air Quality API, which shows that all neighborhoods in Boston currently have good air quality. It's important to note that this new data only covers the past 30 days, and it may not provide a comprehensive view of air quality trends over a longer time frame. Therefore, it's crucial to consider the potential impact of a more extensive dataset when analyzing the relationship between air quality and various demographic characteristics. The information we found for housing and population density was not helpful to answer this question.

Based on the Social Vulnerability Factors by Neighborhood Population vs AQI in figure 5, it seems like people of color are a common vulnerability factor in each neighborhood.

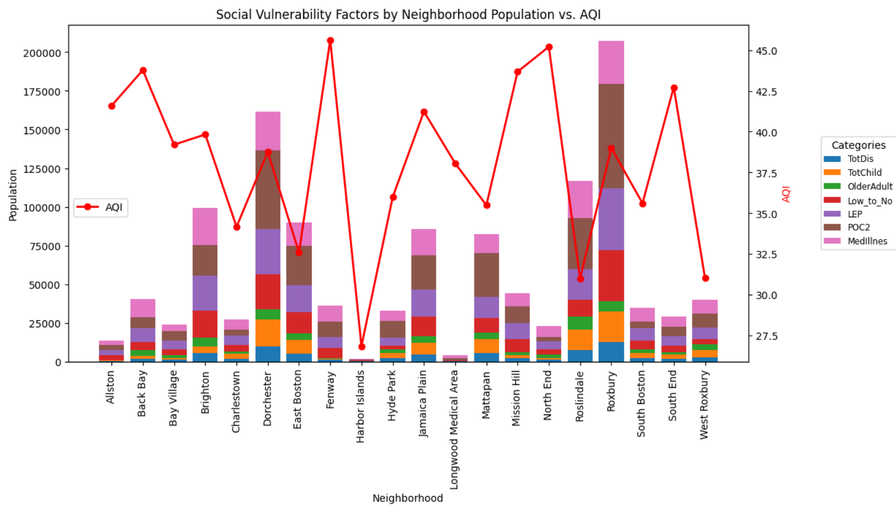

Figure 5: Social vulnerability factors by neighborhood and AQI

Based on the 2022 American Community Survey 1-Year Estimates from the Census, the median household income for Suffolk County is $85,358. Based on the 2022 American Community Survey 1-Year Estimates from the Census, figure 6 shows the race demographic in Suffolk County:

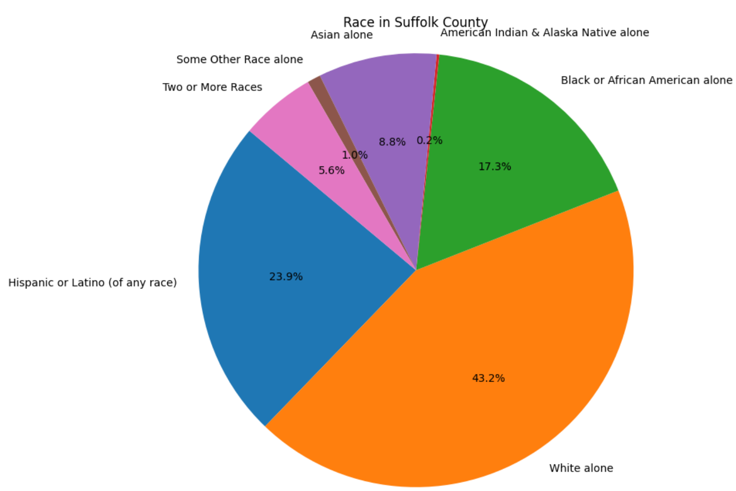

Figure 6: Race demographic in Suffolk County

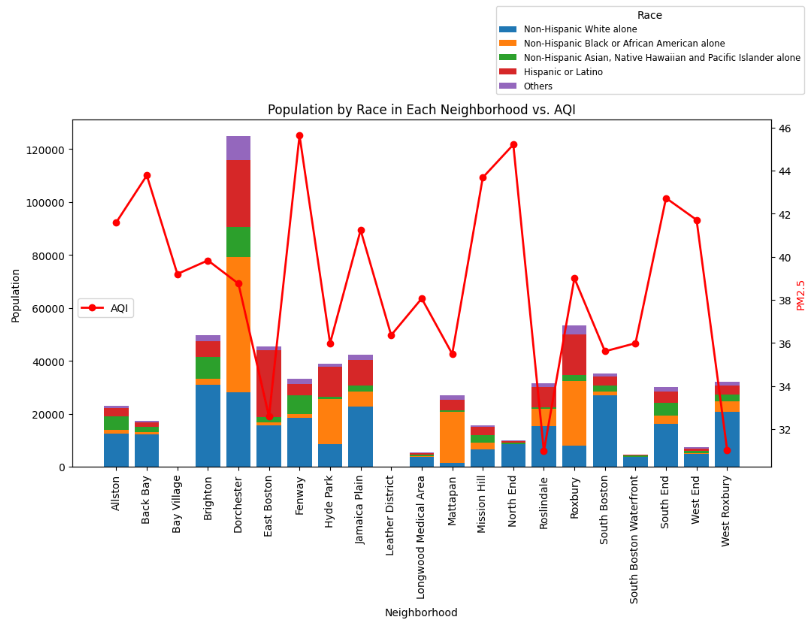

Figure 7: AQI for neighborhoods (population by race shown)

Q3: What is the relationship between health data and what are the trends in air quality for Boston residents by neighborhood? (Ziliang)

Our study utilized Air Quality Sensor Data alongside an integrated health dataset to analyze trends in air quality and their impact on the health of Boston residents by neighborhood and zip code. The air quality data comprised measurements such as the Air Quality Index (AQI), ozone, and particulate matter (PM2.5), categorized by Boston neighborhood or postcode. We enhanced the reliability of our analysis by rectifying prior data inconsistencies, grouping data by zip code, and integrating detailed air quality information from the Google Air Quality API. The health dataset included diverse health indicators, encompassing the prevalence of various medical conditions and demographic as well as socio-economic factors across Boston neighborhoods.

To gain insights into the distribution and trends of both air quality and health indicators, we conducted exploratory data analysis, producing summary statistics and visual representations. Subsequent correlation analyses were performed to investigate the relationships between AQI and various health indicators, including mental health prevalence, chronic diseases, and lifestyle factors.

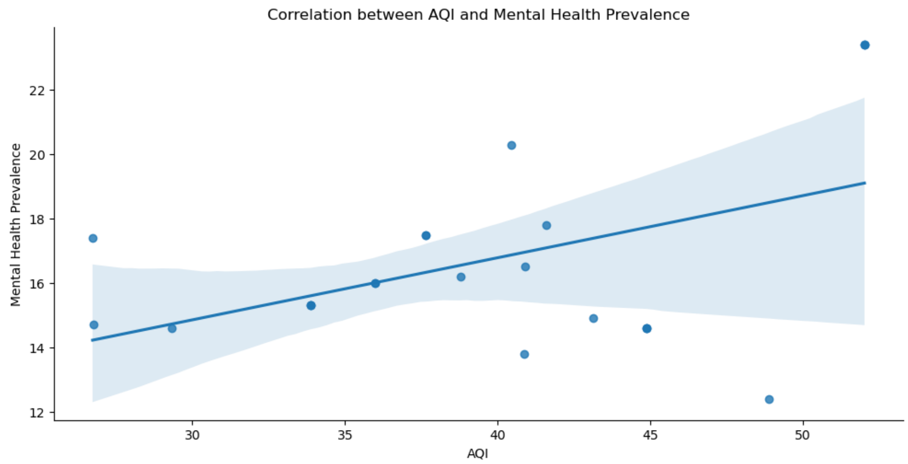

Figure 8: The relationship between AQI and Mental Health

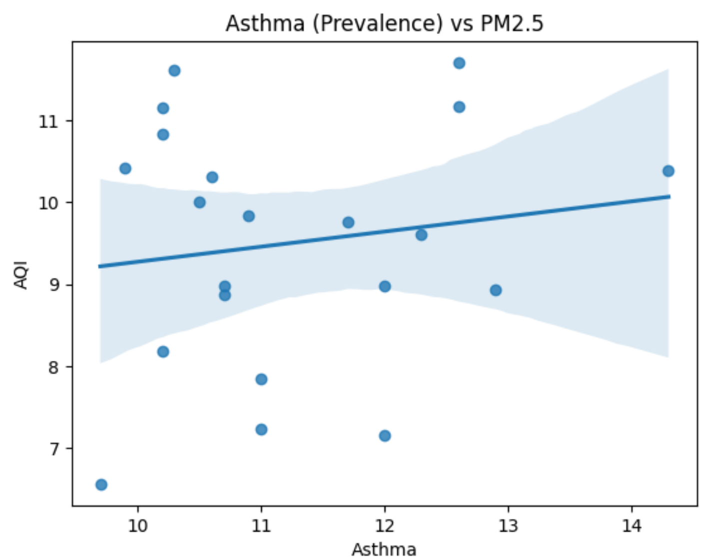

Figure 9: The correlation coefficient between Asthma and PM2.5

The key findings from our correlation analyses are as follows:

A statistically significant moderate positive correlation was observed between AQI/PM2.5 levels and the prevalence of mental health issues, indicated by the MHLTH_CrudePrev and asthma rates. This suggests that areas with inferior air quality (higher AQI and PM2.5 levels) are likely to have a greater prevalence of mental health challenges. Additionally, other health indicators related to chronic physical conditions such as Chronic Obstructive Pulmonary Disease (COPD), coronary heart disease, and stroke, as well as lifestyle factors like smoking and obesity, exhibited a negative correlation with AQI. This implies that neighborhoods experiencing higher AQI levels may also face increased prevalence of these health conditions.

Extension Project

Overview: (Hemanshu)
In our extension project, we've included bus routes to take into account their crucial part in the public transport system and capture their role in reducing pollution. We're also examining Blue Bikes availability as a public infrastructure. Additionally, we're exploring green space data to see their effect on air quality and carbon absorption. For a more holistic overview of urban dynamics, we are taking a look at population by age, labor force statistics, payroll job numbers, and insights into vehicle ownership to gain a comprehensive overview of the socioeconomic characteristics.

Q1: How does the number of jobs and public transit availability affect air quality in different neighborhoods? (Anulika)
The relationship between the number of jobs, public transit availability, and air quality in various neighborhoods is a complex and multifaceted issue. Several factors interact to shape air quality outcomes, and it is essential to consider the interplay between these variables when assessing their impact. To illustrate this, we will compare two neighborhoods, Roxbury and Roslindale, both of which have a high number of transit stops but differ in terms of job availability.

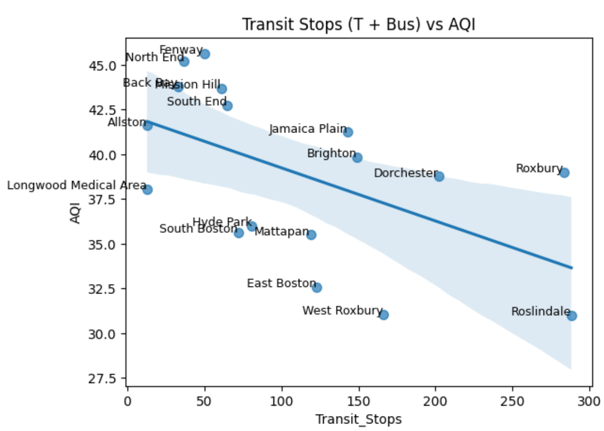

Figure 10: The relation between transit availability and AQI

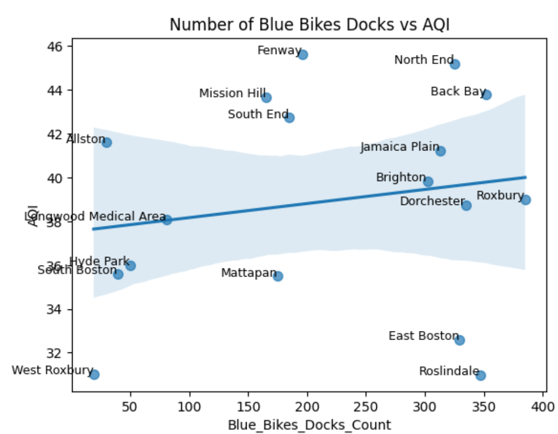

Figure 11: Graph showing the relation between Blue Bikes Docks and AQI

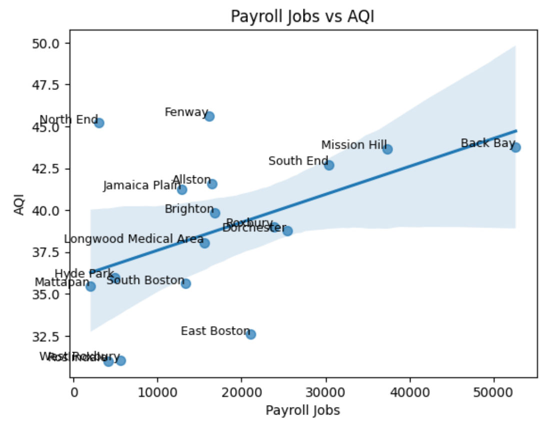

Figure 12: The relation between job availability and AQI

Based on the graphs, we can see that both Roxbury and Roslindale have a significant number of public transit stops, which generally suggests a positive influence on air quality as public transit can help reduce the number of individual vehicles on the road (Figure 10). We also see that Roxbury has more Blue Bike docks than Roslindale as indicated in Figure 11; however, the presence of bike docks alone may not have a substantial impact on air quality. One of the key differences between Roxbury and Roslindale is the availability of jobs; Roxbury offers a higher number of employment opportunities than Roslindale (Figure 12). This difference in job availability can significantly influence air quality in the two neighborhoods. The presence of transit stops generally indicates better air quality due to increased use of public transportation. However, the situation becomes more complex when we consider job availability. More job opportunities in Roxbury may attract a larger number of commuters, including those who use trains, buses, and cars to get to work. This influx of commuters can lead to increased traffic and congestion, potentially contributing to higher levels of air pollution. While public transit availability generally has a positive impact on air quality, this effect can be moderated by the availability of job opportunities. To mitigate air quality issues, policymakers and urban planners should consider a comprehensive approach that addresses both transportation infrastructure and employment opportunities while taking into account the unique characteristics of each neighborhood.

Q2: How does vehicle ownership compare to public transportation in various neighborhoods, and does this impact air quality? (Hemanshu)

Analysis of vehicle ownership compared to public transportation underscored a notable pattern: neighborhoods characterized by a higher vehicle-to-household ratio consistently exhibit better air quality. This stood out to us.

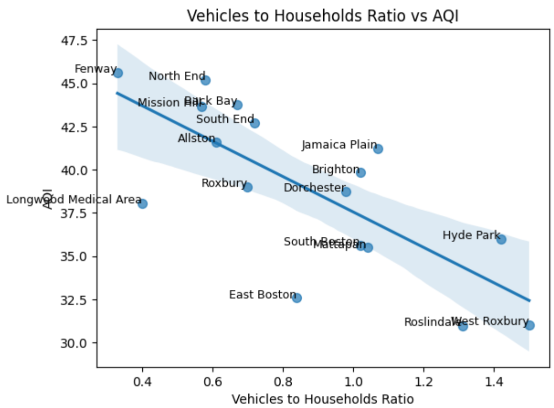

Figure 13: The relationship between vehicles to household ratio and air quality, public transportation

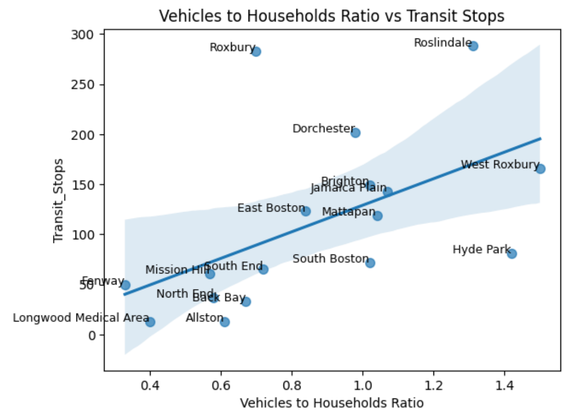

Figure 14: Relationship between vehicle to household ration and the availability of transit stops.

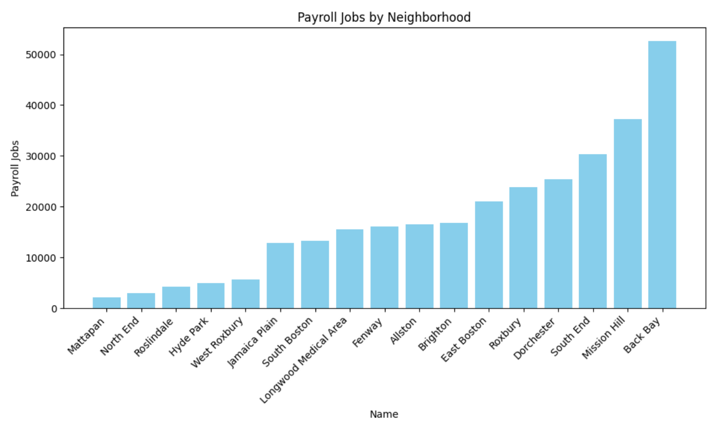

Figure 15: Overview of number of payroll jobs per neighborhood

Delving deeper to find links to other factors such as vehicle ownership vs transit stops and the number of payroll jobs available in an area, we noticed a robust positive correlation (Figures 14 & 15). Areas with a higher concentration of payroll jobs tend to experience heightened transit activities, either through public transit or private vehicles, resulting in a corresponding decline in air quality. Linking back to question 1 from our base analysis, we saw a similar effect where average PPI was higher for “inner core” areas, addressing previous limitations seen in the base analysis of why regions with enhanced transit accessibility exhibited suboptimal air quality.

Q3: How does the open areas in various neighborhoods (i.e. Green space parks), impact air quality and affect overall physical health? (Simon)

Open areas in the City are often used in building parks, malls, etc. We claim that building more parks would give more green spaces for trees to increase air quality, and this is proved by our analysis. We analyzed the relationship between park and air quality. From the analysis, we found that neighborhoods with more parks tend to have lower PM10 values. Then, we found a positive correlation between the number of parks and residents' physical health in the neighborhood.

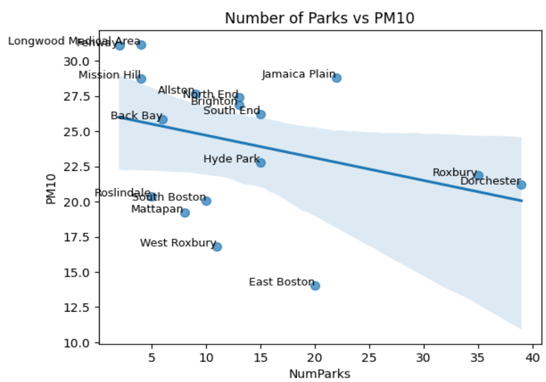

Figure 16: The relationship between the number of parks and PM10 values

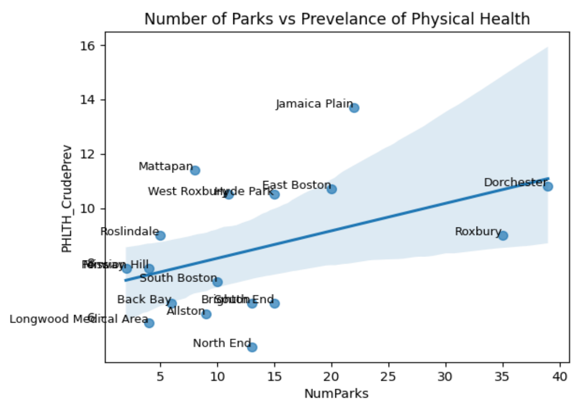

Figure 17: Relationship between number of parks and overall physical health

We also tried to normalize the data because there are some large parks that count equally as small ones. After analyzing the total area of parks, we also found a relationship that more park areas will have lower PM2.5 values. Although the correlations aren't very significant, these results show that open spaces like parks will potentially increase the air quality and the residents' physical health.

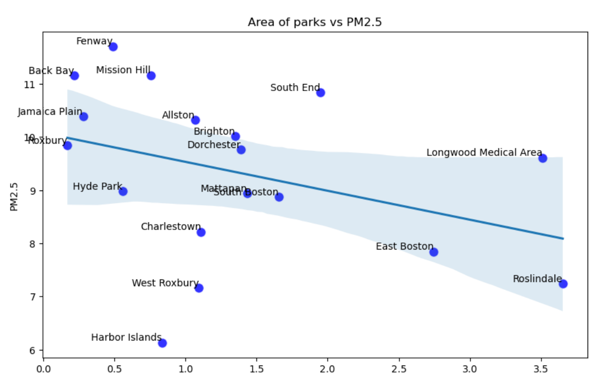

Figure 18: The relationship between green space area and PM2.5

Q4: How does the availability of green spaces and blue bikes affect the air quality across Boston's neighborhoods? (Ziliang)

By analyzing and comparing the number of blue cycle stations to the number of parks, and comparing the number of green spaces and the number of blue bikes stations to air quality respectively, we have found a positive correlation between them:

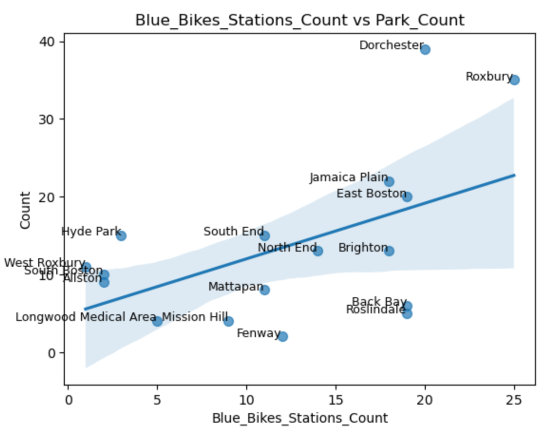

Figure 19: Relationship between the number of Blue Bike stations vs the number of parks in an area

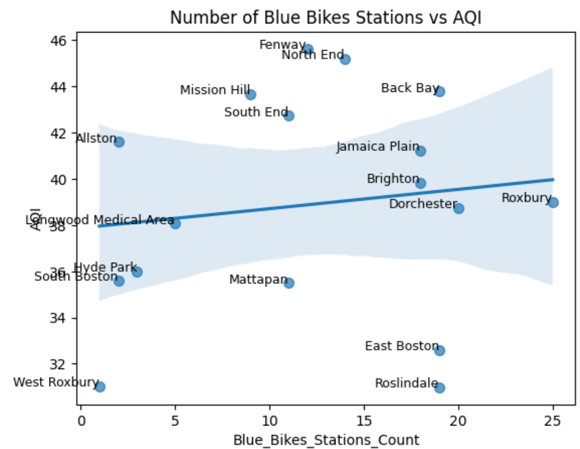

Figure 20: Relationship between the number of Blue Bike stations vs average AQI by neighborhood

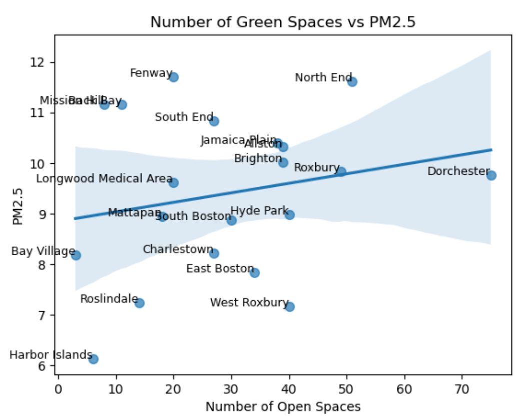

Figure 21: The relationship between open spaces and PM2.5

There exists a notable positive correlation between the presence of Blue Bike stations and green spaces in Boston's neighborhoods. This suggests that areas with more Blue Bike stations tend to have more green spaces. However, the correlation between the number of Blue Bike stations and the Air Quality Index (AQI) is relatively weak. Although a higher concentration of Blue Bikes and green spaces is associated with a lower AQI, indicating better air quality, the direct impact of Blue Bike stations on air quality improvement is limited. This implies that other factors also play a significant role in influencing the AQI. We also find out that there is a positive correlation between the number of Green Spaces and PM2.5 (A main indicator of air quality). This shows that more availability of green spaces they have, the air quality will become better.

Limitations: (Hemanshu/Anulika)

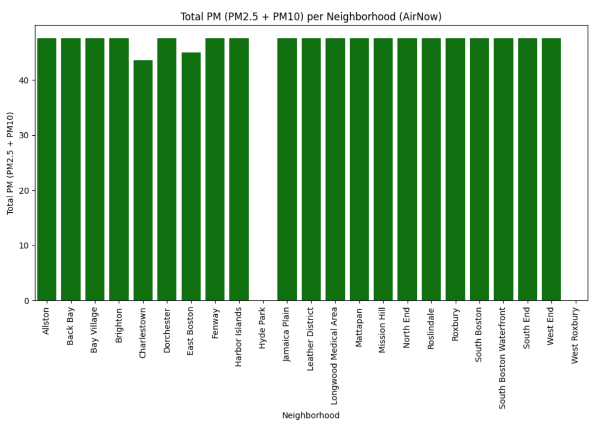

Figure 22: Total Particulate Matter (PM) across different neighborhoods in Boston using the AirNow API

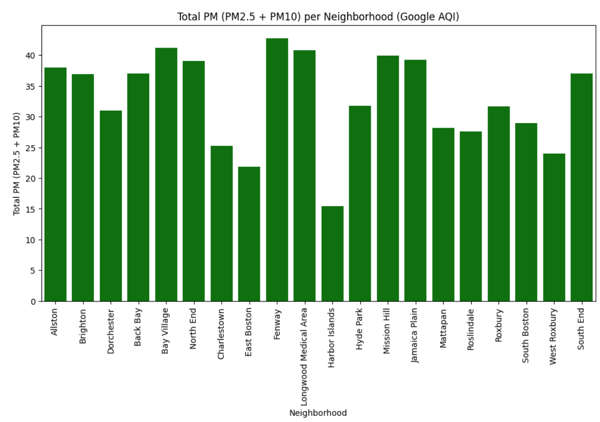

Figure 23: Total Particulate Matter (PM) across different neighborhoods in Boston using the Google Maps Air Quality API

Over the course of the project, we faced many challenges and limitations. The biggest limitation we encountered was the availability of quality data. For example, the Air Quality dataset initially provided to us was an interactable database rather than an exportable file. We were made aware of the APIs behind the dashboard, AirNow, Purple Air, and a few others but most of these were behind a paywall. The AirNow data had API access rate limitations, meaning it took over 30 hours to get the information we needed, however, the main challenge we faced was that there were only three active sensors, giving us a very limited range of data to work with (Figure 22). After some further research, we found the Google Maps Air Quality API. This API gave us access to a greater range of sensors, however, we were limited by access to only thirty days of data (Figure 23). We decided to go ahead with the Google Maps Air Quality API, because we felt that the benefits of having a variety of sensors across Boston far outweighed having five-year data across only three sensors. Therefore, we changed the scope of our project to focus on a snapshot of Boston rather than a five-year period.

Initially, our extension project sought to utilize zoning data as a proxy for characterizing the urban composition of different Boston neighborhoods, with a focus on their commercial, residential, and industrial attributes. However, several limitations emerged during the data acquisition and analysis phase that necessitated acknowledgment and for us to adjust the extension project. One limitation was the outdated zoning data primarily from the late 1990s and early 2000s. This temporal gap created challenges as urban landscapes evolve over time due to development, policy shifts, and economic transformations, rendering the acquired data less accurate and relevant to current conditions. Furthermore, the data available often lacked the necessary detail, offering only broad categorizations of zoning areas, which hindered precise neighborhood assessments. Due to these limitations, we decided to shift the focus of our extension project.

Another limitation in our extension project revolved around the availability of neighborhood data, particularly concerning payroll, vehicle ownership, and socioeconomic characteristics. The data we had access to was primarily from around the 2015 timeframe, which posed several challenges. The most evident issue was that this data did not reflect the current socioeconomic conditions of the neighborhoods we were studying. Urban dynamics change considerably over a decade, making it difficult to draw accurate conclusions about the present state of these neighborhoods. Also, we couldn't capture real-time insights into evolving urban trends, hindering our ability to provide a comprehensive, up-to-date overview. This limitation could introduce biases and inaccuracies in our analysis, as it might not account for recent policy changes or infrastructure investments.

Conclusion (Ziliang):

Our exploration of the intersection of air quality, traffic and demographic characteristics in Boston. Our exploration of the intersection of air quality, transport and demographic characteristics in Boston culminated in a series of insightful findings and important significance. The data we analyzed presents a picture of the relationship between urban infrastructure, particularly the transport system, and changes in air quality in different parts of Boston, relationship between the transport system, in particular, and changes in air quality in different neighborhoods of Boston. Relationship between changes in air quality in the neighborhoods. This study not only highlights the environmental challenges facing urban areas but also reveals the social differences embedded in these challenges.

Additionally, there is a clear correlation between the availability of public transportation options, like MBTA stops and Blue Bike stations, and improved air quality. The study revealed a negative correlation between MBTA stops and ozone levels, suggesting better air quality in areas with more public transit. However, a slight positive correlation was found between AQI and MBTA stops, indicating that increased public transit might adversely affect air quality. Our analysis indicates a positive relationship between the presence of green spaces, such as parks, and air quality. Areas with more extensive green spaces showed lower levels of particulate matter (PM2.5 and PM10).

Disparities in air quality were observed among different neighborhoods, aligning with variations in demographic and socioeconomic factors. The study found that communities of color might be more vulnerable in each neighborhood, based on social vulnerability factors related to air quality. Also, implying that vulnerable populations often faced poorer air quality.

Overall, our project demonstrates the intricate relationship between air quality, transportation infrastructure, and urban planning. It highlights the potential of sustainable transportation and green spaces in improving air quality, while also emphasizing the need for policies that address environmental justice. The insights gained can guide policymakers, urban planners, and community leaders in making informed decisions to create a healthier, more sustainable Boston.

Individual Contribution:

Anulika Nnadi:

I worked on creating some graphs for the base questions. I wrote the introduction, the goals and background for the project, the significance and impact of the project, and part of the limitations section with Hemanshu. I answered Q2 in the base project question and answered Q4 in the extension project. I also assisted Hemanshu by constructing new datasets for the open spaces and neighborhood of boston data we acquired. Also, I extracted data from the Census API as necessary. I made the cover page and the table of contents.

Ziliang Wang:

I mainly completed main question 3 and extension Q4 while adding some graphs. Meanwhile, I completed the conclusion part. I summarized the various results across deliverables. In extension Q4, I use the neighborhood dataset and openspace dataset to create a new graph.

Xinzhu Liang:

Include graphs and analysis for base question 1, and extension question 3. Reorganized the graph in the report and added captions under each graph.

Hemanshu Bhojwani:

I worked on creating most of the graphs, except figures 6, 8, and 18. I wrote the Problem Statement, EDA, and analysis for the PPI section for Base Q1. I also wrote the Extension overview, analysis for Extension Q2, and helped with limitations sections. I also made the merged data map which was then published as a dashboard website and updated and reorganized the github and helped organize the report. I worked on pulling data from most datasets and processing all the datasets for analysis.