Community-based Air Monitoring in Historically Underserved Communities of Eastern San Francisco

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ABSTRACT

Environmental justice communities are usually predominately people of color or low income, who are subjected to a disproportionate burden of environmental pollution and reduced quality of life. California has taken the initiative to address these disparities by passing Assembly Bill 617 which aims to address the disproportionate impacts of air pollution exposure in the most heavily burdened communities throughout California. Traffic congestion in cities is a public health concern due to the air pollutant emissions that contribute to poor air quality in the surrounding environment. A local community-based organization, Brightline Defense, and UC Berkeley researchers utilized low-cost air-quality sensors to measure traffic-related air pollutants, black carbon, and ambient particulate matter ($PM_{2.5}$), in eastern San Francisco districts, Chinatown, Tenderloin, South of Market (SoMa), and Bayview-Hunters Point. We found through the CalEnviroscreen 4.0 indicator map that traffic patterns varied depending on location and average concentration levels for black carbon were associated with traffic patterns. The spatiotemporal trend for black carbon concentration levels had a strong weekday-to-weekend effect while $PM_{2.5}$ had a relatively consistent trend. Bayview-Hunters Point and inner-city districts did not have distinct differences in average concentration levels for black carbon and $PM_{2.5}$ with the exception of Tenderloin. The average hourly concentration levels for black carbon aligned with morning and evening rush hours while $PM_{2.5}$ had a flatter trend. Based on CalEnviroScreen 4.0 data, asthma rates near highways and high-traffic zones were greater.

KEYWORDS

Assembly Bill 617, environmental justice, spatiotemporal trends, black carbon, ambient particulate matter ($PM_{2.5}$)

INTRODUCTION

Environmental justice communities are usually predominantly people of color and or low income who face disproportionate exposure to environmental hazards and pollution that impact the quality of life of the community. Often, these communities lack access to environmental benefits such as parks and open space; they also experience social injustices such as poverty, high crime rates, lack of access to nutritious food, affordable and quality housing, access to health care, and employment (Rowangould et al. 2016). Through government policies and local community advocacy, there are initiatives to understand, mitigate, and eliminate environmental disparities to achieve an environment where people have access to clean spaces and are involved in the development, implementation, and enforcement of environmental laws, regulations, and policies (US EPA 2014).

California has taken the initiative to address the disproportionate impacts of air pollution exposure in the most heavily burdened communities by passing Assembly Bill 617. Assembly Bill 617 (C. Garcia, Chapter 136, Statutes of 2017) requires the California Air Resources Board (CARB) and air districts to develop and implement additional emissions reporting, monitoring, reduction plans, and measures in an effort to reduce air pollution exposure in disadvantaged communities ("San Joaquin Valley Community Engagement and Protection" n.d.). AB 617 communities are chosen based on nominations of air districts; and also community-based organizations which advocate for additional resources to be placed in these communities.

Within a city, there are differences in traffic density and traffic patterns that affect the quality of life and experience of communities. Communities in cities that are near major highways and high-traffic locations are exposed to higher concentrations of traffic-related air pollutants such as black carbon and $PM_{2.5}$ (Brunekreef et al. 1997). For example, a West Oakland study that deployed a black carbon network for 100-days over 100 West Oakland locations found there was variation over short distances (~ 100 m) and timespans (~ 1 hour) depending on traffic patterns, surrounding land use, and downwind distance from pollution (Caubel et al. 2019). Black carbon is a primary pollutant that is emitted directly from the exhaust pipe of diesel vehicles when there is an incomplete fuel combustion in the mobile engine which allows for an easier identification of emission source (Briggs and Long 2016). Black carbon has a short-atmospheric lifetime and a localized distribution and is associated with negative health effects such as the increased risk of asthma incidents, reduced lung function, premature death, and cardiovascular mortality (Matz et al. 2019, Janssen et al. 2011). Similarly, $PM_{2.5}$ is associated with increased mortality, morbidity, and a shortened life expectancy (Cohen et al. 2017). However, $PM_{2.5}$ is a secondary and primary pollutant: a primary pollutant when emitted directly from the emission source and a secondary pollutant when it is formed when reacting with other gases in the atmosphere. $PM_{2.5}$ has a regional distribution because it is a primary and secondary pollutant which makes it difficult to identify the emission sources and create mitigation strategies to reduce emissions (Nazarenko et al. 2021).

A local San Francisco community-based organization, Brightline Defense, launched a study with UC Berkeley researchers to measure with low-cost air quality sensors the traffic-related air pollutants, black carbon and $PM_{2.5}$, in eastern San Francisco districts, South of Market (SoMA), Chinatown, Tenderloin, and Bayview-Hunters Point due to the health and poor air quality concerns there is present in the community. To understand potential disparities in air pollution concentrations, we utilized spatiotemporal trends to better characterize emissions sources of black carbon and $PM_{2.5}$ and its impact on historically underserved communities in eastern San Francisco. Spatiotemporal trends of black carbon and $PM_{2.5}$ trends were compared between inner-city neighborhoods and Bayview-Hunters Point to comprehend how air pollutant concentrations in eastern San Francisco districts may differ depending on location and traffic patterns. To examine the public health implications of living in these districts, asthma rates and overall neighborhoods' health were analyzed to explore the potential health effects of air pollutant exposure.

METHODS

For a 4-week period during the wintertime, 20 low-cost sensors, Aerosol Black Carbon Detectors (ABCD) were deployed across eastern San Francisco districts, Bayview-Hunters Point (94124), Chinatown (94103), South of Market (SoMa) (94103), and Tenderloin (94102) by Brightline-Defense and UC Berkeley researchers as part of the Brightline Air Quality Monitoring Enhancement Initiative Bond (Sun 2005). The ABCDs sites were placed near the low-cost sensors, Clarity-Node S network, that measures $PM_{2.5}$, to reduce spatial variability between sites. One low-cost sensor was placed in Paranuass Heights (94131) as a "clean reference". Potrero Hill (94107) acts as the regulatory site for the study.

Study site

The study sites are Bayview-Hunters Point, Chinatown, SoMa and Tenderloin which all have a history of social and environmental injustices (Kang 2021). Chinatown, SoMa, and Tenderloin are located in the downtown area of San Francisco and have one of the highest population densities in San Francisco (Sumida 2021). Tenderloin has the largest houseless population residing in the district and many community members live in single-room occupancy (SRO) housing that has outdated infrastructure and lacks proper air ventilation (Minkler 1985). Recently added AB 617 community, Bayview-Hunters Point, has a history of environmental pollution from Naval Shipyard, particles from large-scale redevelopment, emissions from a wastewater treatment facility, diesel trucks idling, and industrial rendering plant (California Air Resources Board" n.d, Dillon 2014). Bayview-Hunters Point is also part of the neighborhoods that were redlined in San Francisco that caused divestment and holds the largest black population in San Francisco (Boeck et al. 2022).

Low-cost air sensors

Aerosol Black Carbon Detectors (ABCDs) are low-cost air sensors, that have a similar functionality as commercially-available aethalometer that measure black carbon. These sensors are designed to have limitations in their sensitivity to changes in temperature and relative humidity that allows for outdoor usage (Caubel et al. 2018). Sensors save data locally on an SD card and reports are made in hourly averages. Sensors run on battery or plug-in power with the option of having solar panel recharge for the battery-operated units. By utilizing low-cost sensors, community members can capture the heterogeneity within the city as it allows for greater coverage locally and also empowers community members to collect their own data. Due to traditional air monitors being expensive and time-intensive, a small number of sensors are used to cover a city and represent the concentrations that communities face (Morawska et al. 2018). As a result, it may cause a generalization and a lack of representation of the differences in concentrations.

Traffic patterns and neighborhood's concentration variability

To get a better understanding of the variability of traffic patterns in eastern San Francisco, the CalEnviroScreen 4.0 Indicators map was utilized to examine the traffic impacts percentile from 2017. The traffic impacts indicator is measured by getting the average traffic volumes per amount of roadways. More specifically, CalEnviroScreen divides the traffic volumes by the total road length within 150 meters around the census tract. Having a comprehensive understanding of traffic patterns gives insight to better characterize emissions sources of black carbon and $PM_{2.5}$.

In Microsoft Excel, the data that was collected from the ABCDs and Clarity-Node S network from the six locations were analyzed by creating hourly-average trends of the concentration of black carbon and $PM_{2.5}$. The diurnal trends were created by categorizing the data based on the hour it was collected and the locations: Chinatown, Tenderloin, South of Market, Bayview-Hunters Point, Parnassus Heights, and Potrero Hill. The diurnal trend is broken down into time intervals of midnight, early morning (6 am), noon, and evening (6 pm). The average hourly trends demonstrated the concentration levels of black carbon and $PM_{2.5}$ depending on the time of the day. It can display traffic patterns such as morning and evening rush hours if concentration levels follow this pattern.

Comparison between inner-city neighborhoods and Bayview-Hunters Point

To determine if there are differences in black carbon and $PM_{2.5}$ concentration levels between inner-city neighborhoods that are more densely populated and Bayview-Hunters Point which is near the ports, daily-average trends and the overall average concentrations for each location were calculated. The daily-average trends were created by categorizing the dates the data were collected to days of the week (Monday-Sunday). After, the averages were calculated for each day of the week for each neighborhood. The daily-average trends would reveal if there are differences between the weekday and weekend and as well as an indication of different emission sources. The daily-average trends would demonstrate the concentration levels of black carbon and $PM_{2.5}$ depending on the day of the week and can indicate the emission sources. For the overall average concentrations, the averages were attained by calculating the averages for each neighborhood over the 4-week period.

Public health implications

To determine the public health implications of living in these districts, I utilized CalEnviroScreen 4.0 data to visualize asthma rates by creating a map on ArcGIS and the sensor locations. CalEnviroScreen attained this data through the Emergency Department and Patient Discharge Datasets from the State of California, Office of Statewide Health Planning and Development (OSHPD) from the years 2015 to 2017 (August et al. 2021). The asthma rates were spatially modeled, and the age-adjusted rate of emergency visits for asthma per 10,000 was averaged over 2015 - 2017. To examine the overall wellness and health of living in these districts, I utilized the California Healthy Places Index map from the Public Health Alliance of Southern California to evaluate the health percentile index (3.0) of each district. This tool allows for the exploration of community conditions that impact life expectancy (California Healthy Places Index, n.d.). This software allows the variability in the overall health of communities within the city's districts to be compared to other San Francisco districts.

RESULTS

Traffic patterns and neighborhoods' black carbon and $PM_{2.5}$ concentrations

The CalEnviroScreen 4.0 Indicator Map traffic impact percentile map feature demonstrated the variability in San Francisco's traffic patterns in the year 2017 (Figure 1). CalEnviroScreen 4.0 Indicator Maps categorized the traffic impact percentile by census tract that demonstrated the variability there is in traffic even within a district. In the Tenderloin district, the traffic impact percentile had a range of 30- 50 while SoMa's traffic impact percentile range was 70-90. In comparison to SoMa and Tenderloin, Chinatown's traffic impact percentile was lower at ~20. Meanwhile, half of the sensors of Bayview-Hunters Point had a traffic impact percentile range of 80 to 92 while the remaining sensors were in locations where the traffic impact percentile was 10 and 20. Although one sensor in Bayview-Hunters Point had a traffic impact percentile of 100. In Parnassus Heights which is the "clean reference" the traffic impact percentile was 30. For the regulatory site, Potrero Hill, the traffic impact perce was 96. The overall highest traffic impact percentile based on sensor locations in each district was in Bayview-Hunters Point.

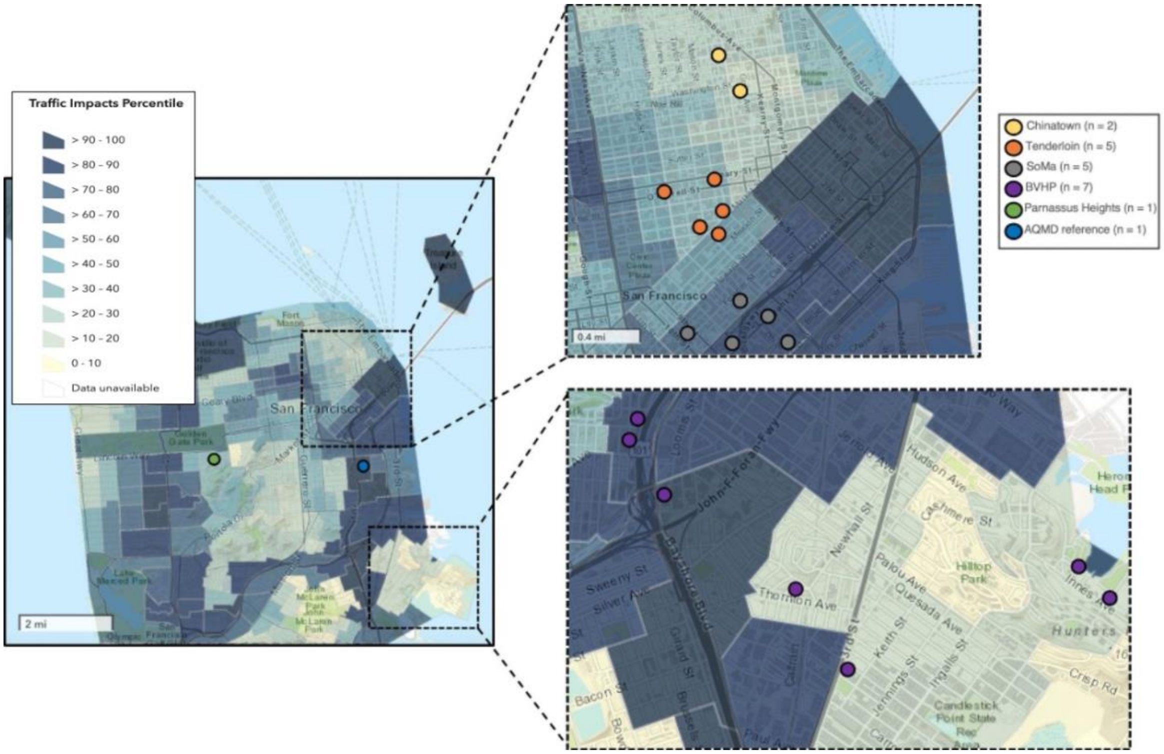


Figure 1. CalEnviroScreen map of San Francisco featuring the traffic impact percentile as a gradient from lowest to highest with sensor sites of the six neighborhoods. The traffic impact percentile is a measure of the number of vehicles on the road in an area.

In the hourly-average black carbon trend by neighborhood, all districts follow a general trend where there is a peak in black carbon concentrations during morning rush hour and evening rush hour (Figure 2a). All the districts with the exception of Parnassus Heights, are relatively close together with the lowest estimated hourly-average black carbon concentration being 0.23 (μg/m^3) at noon. The lowest hourly-average black carbon concentration is found in Parnassus Heights at 0.17 (μg/m^3) around 5 pm. The highest hourly-average black carbon concentrations are around 1 (μg/m^3) during morning rush hour in Bayview-Hunters Point and Potrero Hill. The hourly-average black carbon concentration during evening rush hour is 0.8 (μg/m^3).

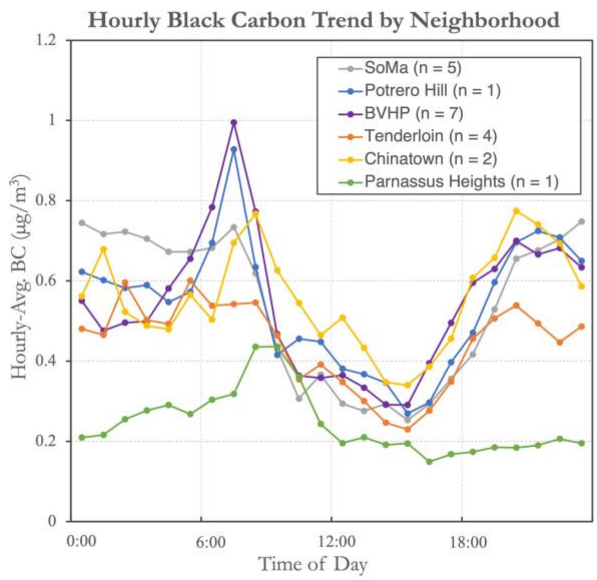


Figure 2a. Hourly-average black carbon concentrations over a daily cycle for the six neighborhoods. In the legend, the number of sites is assigned as (n) to each neighborhood.

In comparison to the hourly average black carbon trends, the hourly average $PM_{2.5}$ concentrations have a flatter trend and a weak morning and evening rush hour trend (Figure 2b). From midnight to morning, the concentrations stay relatively the same with a minor increase during the morning. Chinatown follows a more similar path to Tenderloin whose peak happens around noon and late evening. Overall, Tenderloin had the highest hourly average $PM_{2.5}$ concentrations. The highest hourly average for $PM_{2.5}$ is 9.2 ($\mu g/m^3$) around noon. Overall, the lowest hourly average $PM_{2.5}$ is found in Parnassus Heights.

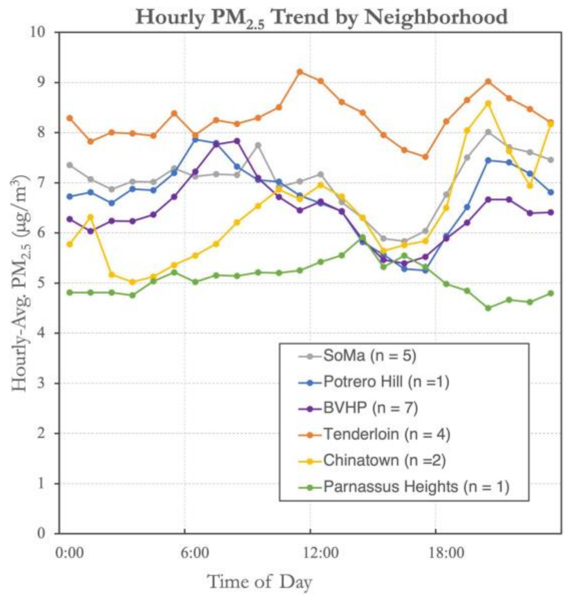


Figure 2b. Hourly average $PM_{2.5}$ concentrations over a daily cycle for the six neighborhoods. In the legend, the number of sites is assigned as (n) to each neighborhood.

Comparison between inner-city districts and Bayview-Hunters Point

We found no major differences in average concentrations of black carbon when comparing inner-city districts to Bayview-Hunters Point. The lowest average concentration based on the neighborhood was Parnassus Heights and after was Tenderloin. The districts of Chinatown, Bayview-Hunters Point, Potrero Hill, and SoMa have similar average concentrations of 0.55 ($\mu g/m^3$) (Figure 3a). The average $PM_{2.5}$ concentrations for SoMa, Potrero Hill, Bayview-Hunters Point, and Chinatown are around 6.5 to 7 ($\mu g/m^3$) (Figure 3b). The district with the highest average $PM_{2.5}$ concentrations is Tenderloin at 8.3 ($\mu g/m^3$). Parnassus Heights had the lowest concentrations at 5 ($\mu g/m^3$).

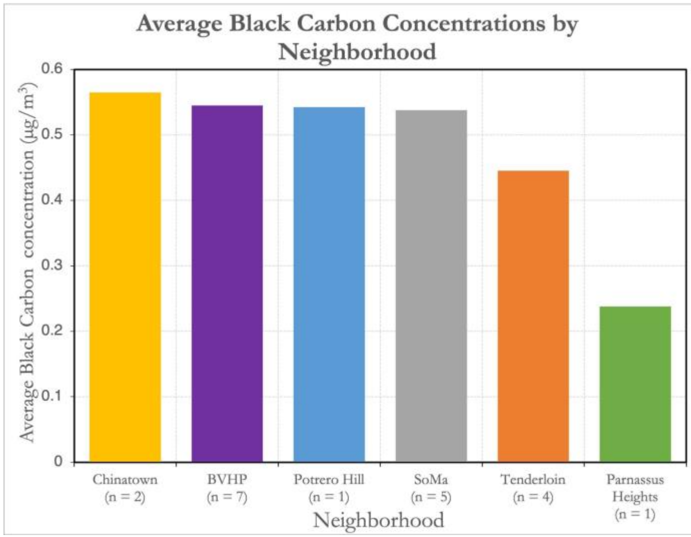


Figure 3a. Average black carbon concentrations for the 6 neighborhoods over a 4-week time period.

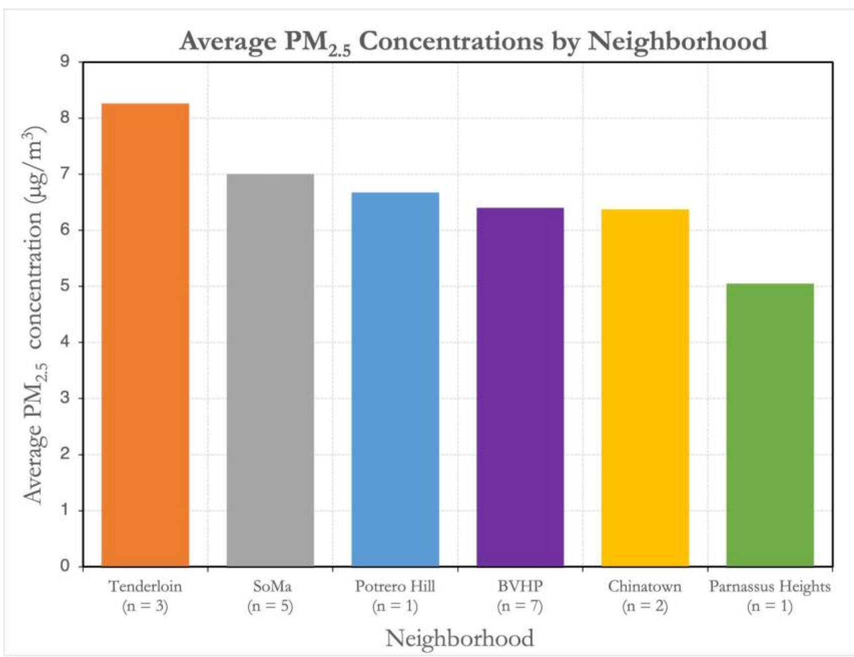
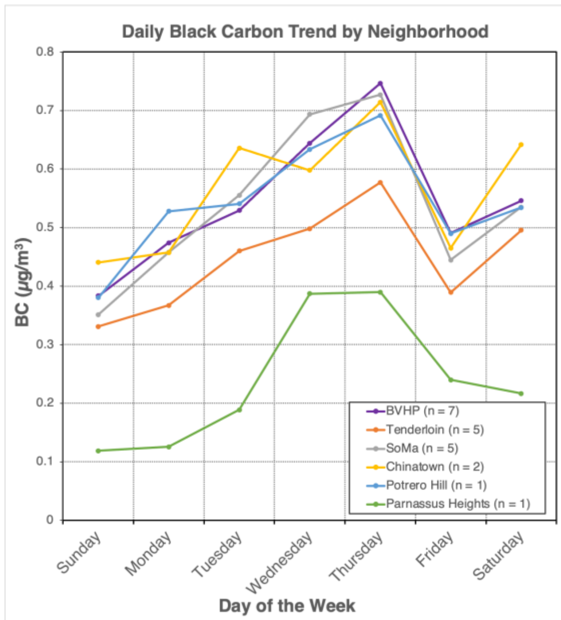


Figure 3b. Average $PM_{2.5}$ concentrations for 6 neighborhoods over a 4-week time period.

In the daily average concentrations for the black carbon trend by neighborhood, all districts follow a general upward trend where Thursday to Friday it peaks in black carbon average concentrations at around 0.75 (μg/m^3) (Figure 4a). There is a more pronounced weekday-to-weekend trend for black carbon. During Saturday, there is also a small peak in concentration levels that occurs. We found no clear difference between inner-city districts and Bayview-Hunters Point daily average concentrations. Tenderloin had the lowest average black carbon concentrations when excluding the Parnassus Heights. The lowest concentration for all districts was Sunday.

Figure 4a. Daily-average black carbon concentrations over a weekly cycle for the six neighborhoods. In the legend, the number of sites is assigned as (n) to each neighborhood.



In the daily $PM_{2.5}$ trend by neighborhood, there are no major differences in the daily average $PM_{2.5}$ concentrations between the inner-city districts and Bayview-Hunters Point (Figure 4b). Although Tenderloin had the highest concentrations of $PM_{2.5}$ overall with the highest concentration estimated to be 9.4 (µg/m^3). The daily-average trend for $PM_{2.5}$ is fairly consistent throughout the week; although there is a peak on Saturday. Parnassus Heights had the lowest daily average $PM_{2.5}$ concentrations. For all districts, the lowest daily average concentrations were on Sunday.

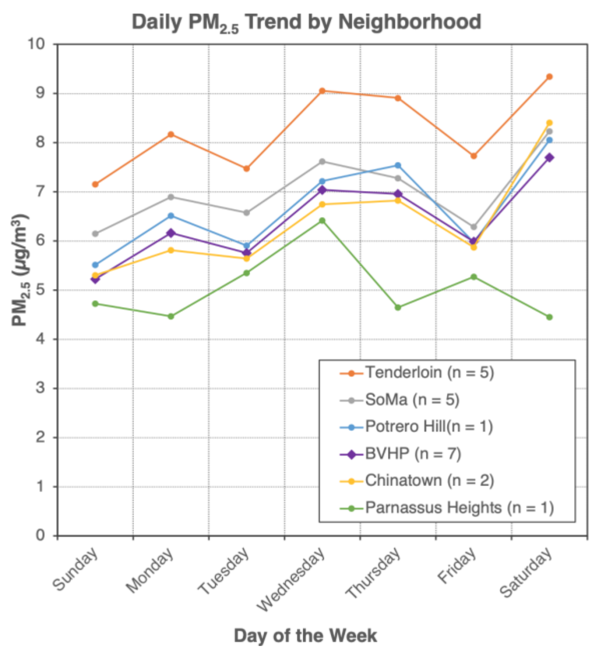


Figure 4b. Daily average $PM_{2.5}$ concentrations over a weekly cycle for the six neighborhoods. In the legend, the number of sites is assigned as (n) to each neighborhood.

Public health concerns related to respiratory illnesses

Throughout San Francisco, asthma rates varied but in comparison eastern San Francisco had higher asthma rates. Within the study sites, there was also a difference in asthma rates (Figure 6). The districts of Tenderloin, SoMA, and Bayview-Hunters Point had higher asthma rates compared to Chinatown. Within the Tenderloin area, there was a range of 40-70. For Chinatown, there are fewer data reportings but asthma rates were reported to be 33. For SoMa, there were reports that ranged from 65 - 98. For Bayview-Hunters Point, the asthma rates were overall higher.

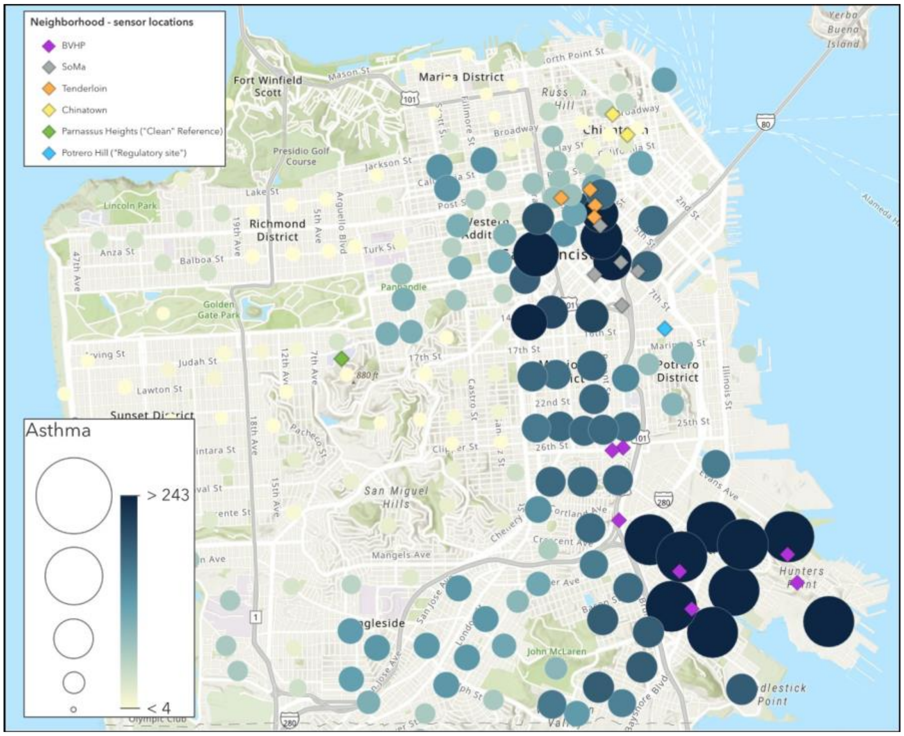


Figure 5. A map of San Francisco indicating asthma rates across San Francisco and sensor sites. Asthma rates are denoted by increasing circle size and darkening color. Data source (CalEnviroScreen). Software used to create map ArcGIS.

Through the map from California Healthy Places Index, we found the health percentile index (3.0) varies between census tracts and zip codes. When examining the health percentile index (3.0) based on zip codes, the health percentile index was generally higher in comparison to the census tract (Figure 6). Although most neighborhoods that were part of the study in comparison to the rest of San Francisco were a lower health percentile index. Based on the zip code, the health percentile index was the following: Tenderloin (39.3); Bayview-Hunters Point (44.9); Chinatown (56.6 percentile); South of Market (75.9); Potrero Hill (98.4); and Parnassus Heights (99.0). Based on the census tract, the health percentile index was the following: Tenderloin (1 -75); Bayview-Hunters Point (12 - 58); Chinatown (10 - 85); South of Market (54 - 85); Potrero Hill (83 - 99); and Parnassus Heights (98.2).

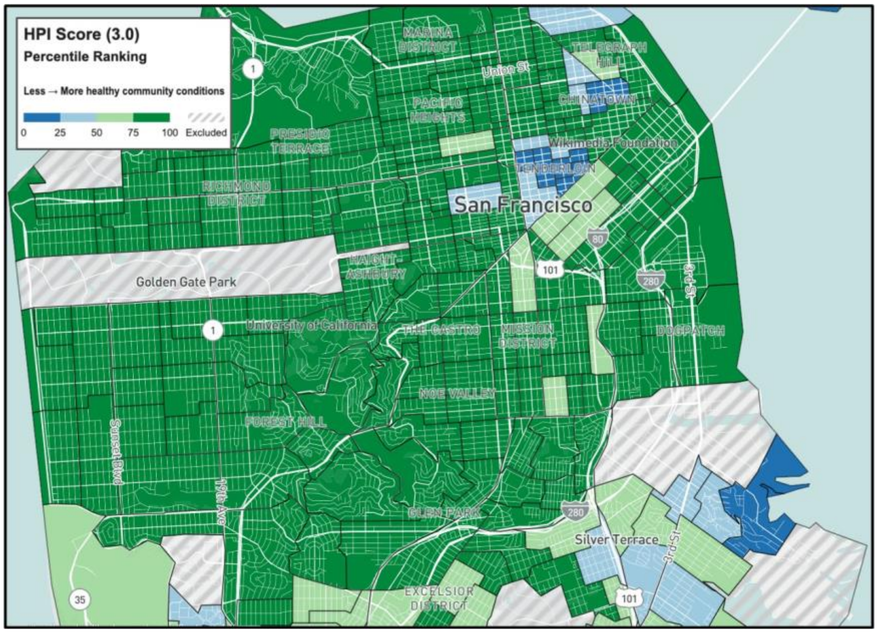


Figure 6. Map of San Francisco with Health Percentile Index. Map from California Healthy Places Index by the Public Health Alliance of Southern California.

DISCUSSION

Based on our findings, it is indicated that there are disparities amongst communities living near heavy traffic areas as it exposes them to higher traffic-related air pollutants. Through our findings, we are able to conclude that factors of our surrounding environment impact the overall health and risk of illnesses in communities.

Indications of traffic patterns impacting black carbon and $PM_{2.5}$ average concentration levels

Based on our findings, locations in high-traffic areas such as main roads, highways, and near ports experience a higher traffic impact percentile and traffic-related air pollutant exposure. For example, in the CalEnviroScreen 4.0 Indicator Map, a census tract of Bayview-Hunters Point had a traffic impact percentile of 91 which means it is higher than 91% of the census tracts in California. Bayview-Hunters Point has ports that as a result can increase the number of diesel trucks in the area to move shipments. In SoMa, some of the traffic impact percentiles are 90, meaning it is 90% higher than other census tracts in California. The reason for this high traffic impact percentile may be a result of the highway that is near the district. When analyzing the hourly average of black carbon, the concentrations align with traffic patterns as there are peaks in concentration levels during morning and evening rush hours. For this reason, the hourly average concentration levels of black carbon indicate that the emission source is diesel vehicles. There is a large peak in black carbon hourly-average concentrations during morning rush hour for Bayview-Hunters Point and Potrero Hill. This may suggest a large volume of vehicles being present during that time that as a result can increase black carbon concentrations. The hourly average $PM_{2.5}$ concentration levels are more consistent and have a weaker morning-to-evening rush hour trend. These findings suggest that there is a consistent source of emission, and also aligns with $PM_{2.5}$ being a regional air pollutant due to it being a primary and secondary air pollutant. For the hourly average $PM_{2.5}$ concentrations, Tenderloin had a higher overall concentration which suggests there may be more emission sources or an emission source that is emitting more $PM_{2.5}$.

Average black carbon and $PM_{2.5}$ concentration levels throughout districts

We found that average black carbon concentrations by neighborhood did not have a major difference in concentrations. Chinatown, Bayview-Hunters Point, Potrero Hill, and SoMa have very similar concentrations when not accounting for the margin of error. This indicates that overall during the 4-week period, the data was collected, these districts experienced similar black carbon concentrations of 0.56 ($\mu g/m^3$). Tenderloin has lower average-black carbon levels of 0.43 ($\mu g/m^3$). Meanwhile, Tenderloin has the highest average $PM_{2.5}$ concentrations levels of 0.83 ($\mu g/m^3$). These differences in Tenderloin concentration levels for black carbon and $PM_{2.5}$ indicate there may be fewer diesel vehicles present and there may be another emission source.

Based on the daily average black carbon and $PM_{2.5}$ trends, we found there is no distinct difference between Bayview-Hunters Point and inner city districts concentrations. The daily average concentration of black carbon trends demonstrates a strong weekend and weekday effect that creates an upside U-shape curve. The peak on Thursday going to Friday suggest there are more diesel vehicles. We can conclude this because black carbon is a localized air pollutant emitted from diesel vehicles; thus, diesel vehicles drive black carbon trends. Sunday had the lowest average black carbon levels which can be an indication of fewer vehicles being present. This may be due to people not working on Sundays which means people are not commuting to

San Francisco and people are staying in. $PM_{2.5}$, on the other hand, is a relatively flat and steady trend that indicates its emission source is constant. Because $PM_{2.5}$ is a regional air pollutant, there is not a strong weekday-to-weekend effect.

The health of historically underserved San Francisco communities matters

By examining past data on asthma rates in each neighborhood, we observed different asthma rates within districts. For example, residents living in Bayview-Hunters Point had higher asthma rates compared to Chinatown residents. Residents living in Tenderloin and SoMa experienced similar asthma rates. Because the asthma rates are calculated based on the number of emergency visits, there are some limitations to fully analyzing the presence of asthma in these districts. These asthma rates do not account for preventive care, deaths caused due to complications of asthma, and diagnosis of asthma. Despite these limitations, the asthma rates may indicate the potential likelihood of needing to go to the emergency room depending on which district one resides in. These implications are underlined in the California Healthy Places Index map that displayed differences in health percentile index even within districts. For example, when exploring the zipcode visualizer tool, most districts appeared to have a higher health percentile index compared to the census tract. Because there are differences within districts, the exposure that residents experience can also be different. The California Healthy Places Index map tool highlighted the importance of conducting local data collection.

According to our findings, living near high-traffic areas can expose communities to higher traffic-related air pollutants; thus, by understanding traffic patterns, it is easier to identify air pollutant hotspots for localized air pollutants like black carbon. Traffic patterns demonstrated the different concentration levels during the morning and evening rush hours. When comparing the six districts with each other, most districts experienced similar average black carbon and $PM_{2.5}$ levels during the 4-week period. Tenderloin was the only district that had high concentration levels for $PM_{2.5}$ but low concentration levels for black carbon. Through public health records, the records helped reveal the potential effects of living in an area that is exposed to high traffic levels. Although, there are multiple confounding factors that cause health issues and diseases such as lifestyle, genetics, and environmental and social conditions. Knowing the conditions and illnesses that are present in these historically underserved eastern San Francisco communities helps stakeholders better understand the impact and strategies to mitigate the effects. For future studies, research can be done to compare and contrast how demographics, income, access to green spaces, and public transportation can influence the exposure to traffic-related air pollutants. Further research can be conducted to examine building density and if that influences the presence or absence of traffic in the area. Community-based research is critical for historically underserved communities to reduce the disparities that are confronted and reduce the gap in resources.

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