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SOCIOECONOMIC STATUS, AIR QUALITY, AND ASTHMA PREVALENCE TO ASSESS ENVIRONMENTAL JUSTICE IN PHILADELPHIA

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Abstract

Approximately twenty-five million individuals in the United States suffer from asthma, a chronic lung disease that makes it difficult to breathe. Environmental factors, such as air quality, contribute to asthma prevalence. Unfortunately, socioeconomic status is also a key risk factor for asthma, where people of color or of low-income have the highest prevalence of asthma. In the City of Philadelphia, policy-driven segregation helped create underserved and underrepresented communities, where this public health issue is highly prevalent. This study examines the relationship between community demographics, socioeconomic status, air quality, and asthma prevalence from an environmental justice perspective in the City of Philadelphia. Geospatial and correlation analyses were used to determine relationships between community demographics, median household income, yearly average concentration of PM 2.5, and asthma prevalence. Parts of North Philadelphia and West Philadelphia have a relatively high number of non-Hispanic Black residents, relatively low annual median household income, relatively high PM2.5 concentration, and relatively high asthma prevalence. Recommendations for improving air quality and public health include reducing PM2.5 sources, planting more vegetation to reduce PM2.5 levels, promotion of equitable health services, reduction of systemic racism, and implementation of policy-driven reform to promote equity leading to social and environmental justice.

Disciplines

Environmental Sciences | Physical Sciences and Mathematics

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ABSTRACT

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Approximately twenty-five million individuals in the United States suffer from asthma, a chronic lung disease that makes it difficult to breathe. Environmental factors, such as air quality, contribute to asthma prevalence. Unfortunately, socioeconomic status is also a key risk factor for asthma, where people of color or of low-income have the highest prevalence of asthma. In the City of Philadelphia, policy-driven segregation helped create underserved and underrepresented communities, where this public health issue is highly prevalent. This study examines the relationship between community demographics, socioeconomic status, air quality, and asthma prevalence from an environmental justice perspective in the City of Philadelphia. Geospatial and correlation analyses were used to determine relationships between community demographics, median household income, yearly average concentration of PM 2.5, and asthma prevalence. Parts of North Philadelphia and West Philadelphia have a relatively high number of non-Hispanic Black residents, relatively low annual median household income, relatively high PM2.5 concentration, and relatively high asthma prevalence. Recommendations for improving air quality and public health include reducing PM2.5 sources, planting more vegetation to reduce PM2.5 levels, promotion of equitable health services, reduction of systemic racism, and implementation of policy-driven reform to promote equity leading to social and environmental justice.

Introduction

One of the greatest challenges that modern cities face today is the fight against social inequalities. Resources and funding are distributed nonuniformly, leaving certain areas of a city underrepresented and underserved. Unfortunately, many of these underprivileged communities consist primarily of families of color or of low-income. These neighborhoods often lack assistance from the local jurisdiction and are disproportionately affected by environmental injustices due to their proximity to environmental health hazards such as polluting factories. Air quality-based health disparities, therefore, are one predictor of social inequality within a city. In order to create equity across the modern urban landscape, it is imperative to begin to incorporate environmental justice-based policymaking into the overall decision-making process.

Asthma is one such health disparity that reflects the complex relationship between health, environmental risk factors, and socioeconomic vulnerability (Kreger et al., 2011). Approximately 25 million Americans suffer from chronic asthma, a debilitating lung disease making it difficult to breathe (Akinbami, 2012). Environmental risk factors causing increased air pollution have been shown to contribute to increases in asthma rates (Lanphear et al., 2001). There have been numerous studies looking at the associations between particulate matter concentration and asthma prevalence, both in adults and in children (Sarnat and Holguin, 2007; Gowers et al., 2012). Strong associations have been described between a specific air quality measure, concentration of particulate matter 2.5 microns or smaller in diameter (PM2.5), and asthma prevalence (Fan et al., 2016; Williams et al., 2019; Mirabelli et al., 2016). Increased PM2.5 concentrations have been correlated with increased hospitalizations (Fan et al. 2016; Gleason et al., 2014), respiratory diseases (Hopke et al., 2019; Xing et al., 2016), and morbidity (Apte et al., 2015; Franklin et al., 2008). Coarse particulate matter, such as PM5 and PM10, has been investigated in its relationship to asthma as well. However, the results for coarse particulate matter having an association with asthma prevalence are still contested (Donaldson et al., 2000). Interestingly, fine particulate matter like PM2.5 is typically considered to be primarily anthropogenic in its origin, suggesting that manmade sources of air pollution are larger contributing factors to asthma development than naturally occurring sources of air pollution (US EPA, 2012). Therefore, as a demonstrated air quality measure associated with asthma development and prevalence, PM2.5 concentration was the air quality metric chosen for analysis in this research.

In addition to air quality, socioeconomic status plays a role in asthma prevalence as well (Claudio et al., 2006; McDaniel et al., 2006; Keet et al., 2017). Within the City of Philadelphia, Pennsylvania, asthma prevalence, as a function both of environmental and socioeconomic status, has remained largely unexplored. This research project aims to explore the relationship between these contributing factors to asthma within the City of Philadelphia. Using the findings from this research, policy recommendations can be made in order to help mitigate environmental injustices that are prevalent within the city limits.

Background/Literature

Previous studies have examined the relationship between asthma and environmental risk factors. It has been well established that the amount of air contaminants that a person is exposed to is correlated with the risk of developing asthma (Lanphear et al., 2001; Mooreman et al, 2012; Khreis et al., 2019). Air pollution from fuel combustion has also been linked to increases in asthma rates (Alotaibi et al., 2019). Transportation-related air pollution disproportionately affects underrepresented communities in urban areas and may be a contributing factor to increased asthma rates in these communities (Fuller and Brugge, 2020). This is largely due to redlining policies that were implemented in order to systematically segregate minority populations, in particular the African-American communities (Hillier, 2003a; Hillier, 2003b). These underrepresented communities had fewer opportunities to prosper and were typically underfunded, had worse health outcomes, and were considered an afterthought for policymakers when it came to future urban development (Nardone et al., 2020; Kempin-Reuter, 2019).

Transportation-related pollution is not the only factor that disproportionately affects underrepresented communities. Air contamination from industry, burning of fossil fuels, and waste treatment also significantly contribute to degraded air quality for these communities (Banzhaf et al., 2019b). Both transportation- and industrial-based air pollution generate locally elevated concentrations of PM2.5 which contribute to asthma development (US EPA, 2012). However, air quality itself is not the sole environmental factor responsible for the increase in asthma rates that can be observed in underrepresented communities. Previous literature has shown that in addition to outdoor air quality, indoor household air quality also contributes to asthma prevalence (Akar-Ghibril and Phipatanakul, 2020). Household air quality has been studied as an environmental justice factor and it has been shown that underrepresented communities have worse indoor air quality compared to well-represented community counterparts (Rickenbacker et al., 2019).

There is also a correlation between socioeconomic status and asthma prevalence in the US population. It has been found that asthma prevalence is dependent on race, where Hispanics and non-Hispanic Blacks are up to twice as likely to develop asthma as compared to Whites (Morelli et al., 2017; Urqhart and Clarke, 2020). It has also been shown that non-Hispanic Black children are more likely to develop asthma as compared to White children of comparable family income (Assari and Moghani-Lankarani, 2018). Poverty is also a risk factor for the development of asthma in children (Kravitz-Wirtz, 2018).

While many studies have explored either environmental factors or sociodemographic factors contributing to asthma, few have looked at the interaction between both of these factors. One particular method of addressing this interaction is through the use of geospatial analysis. A case study in the Bronx neighborhood of New York City concluded that individuals living within a specified distance of a noxious polluting source were 60 percent more likely to be hospitalized for asthma-related health conditions. Furthermore, of those individuals that were hospitalized, there was a socioeconomic component associated with the asthma-related hospitalizations, where admitted patients were 30 percent more likely to be poor and 13 percent more likely to be a minority (Maantay, 2007). Similar associations were found in Baltimore and Chicago, cities that have explicitly studied the associations between socioeconomic status, air quality, and asthma prevalence. These studies have found corroborating conclusions that race, income and air quality are contributing factors towards asthma prevalence (Persky et al, 1998; Kimes et al, 2004).

In the City of Philadelphia, there has not been a study looking at the interplay between asthma, environmental justice, and air pollution. However, there have been recent studies that explicitly examine a single factor and asthma prevalence. Two studies investigated neighborhood air quality and health, including childhood asthma, and found that asthma rates are higher in North and West Philadelphia, areas of the city that primarily consist of minorities (Zerbo et al., 2018; Conway, 2020). Yet, neither study looked at air pollution in relation to the spatially defined asthma cases. Other recent studies that examined outdoor air pollution as a risk factor for asthma within Philadelphia city limits did not include demographic information or use spatial analysis (Plaugic, 2019; Haung et al., 2021). This research project attempts to correlate multiple factors to asthma prevalence within the boundaries of the City of Philadelphia.

Methods

Existing verified datasets were utilized to determine the relationships between asthma prevalence, air quality, and socioeconomic factors within the City of Philadelphia. Socioeconomic determinants for this project were obtained from the 2010 United States Census Bureau Dataset (U.S Census, 2010). Asthma data was obtained from the 2017 Centers for Disease Control and Prevention, 500 Cities Project (500 Cities, 2017). Air quality data, as measured by the concentration of particulate matter <2.5 microns in diameter (PM2.5), was obtained from a 2020 Philadelphia Air Quality Survey conducted by Air Management Services of the Department of Public Health of the City of Philadelphia (Air Management, 2020). In addition to geospatial analysis, a complementary correlation analysis was performed in order to quantitatively determine whether there is a direct correlation between these factors of interest. By further understanding the relationships between asthma, air quality, and community demographics, policy recommendations can be made that can improve air quality, public health, and environmental justice in the City of Philadelphia.

Census and CDC data used for socioeconomic status and asthma prevalence were obtained at the census tract geospatial level. Air quality data, specifically PM2.5 concentrations collected by Air Management Services at approximately 50 individual locations across Philadelphia, was extrapolated to zip code boundaries of the monitored areas. Regions in which data was not collected were marked accordingly in the geospatial maps and were not included in correlational analysis.

A geospatial analysis was performed using ESRI's ArcMap software (Version 10.7.1) to produce thematic maps visualizing PM2.5 concentration, socioeconomic status, and asthma prevalence. Since the datasets available for information varied in geospatial resolution, correlation analyses were limited to information found at a zip code spatial level when comparing PM2.5 concentrations and asthma prevalence, otherwise data was analyzed at the census tract level. For correlation analyses, socioeconomic factors, PM2.5 concentration, and asthma prevalence were calculated as a function of geospatial location. Asthma prevalence for each zip code was computed by taking the average asthma prevalence for each census tract found within a given zip code. Pearson correlation coefficients (r) along with the associated statistical probabilities (p) for obtaining these coefficients were computed. Correlation analyses were performed in MATLAB (Version 2020b). Statistical significance was determined with a probability value less than 0.05.

Results

Geospatial analysis revealed a qualitative association between asthma prevalence, socioeconomic factors, and PM2.5 concentrations in the City of Philadelphia as shown in Figures 1-3. Figure 1 shows two socioeconomic variables, the number of non-Hispanic Black residents and the median household income, for each census tract. On average, the number of non-Hispanic Black residents is indirectly proportional to the median household income by census tract in Philadelphia. Areas of the city that have more non-Hispanic Black residents are generally lower income communities. In order to relate socioeconomic conditions shown in Figure 1 to asthma, a geospatial map looking at asthma prevalence as a function of geospatial location was generated (Figure 2). Figure 2 shows the percentage of individuals in each census tract that have

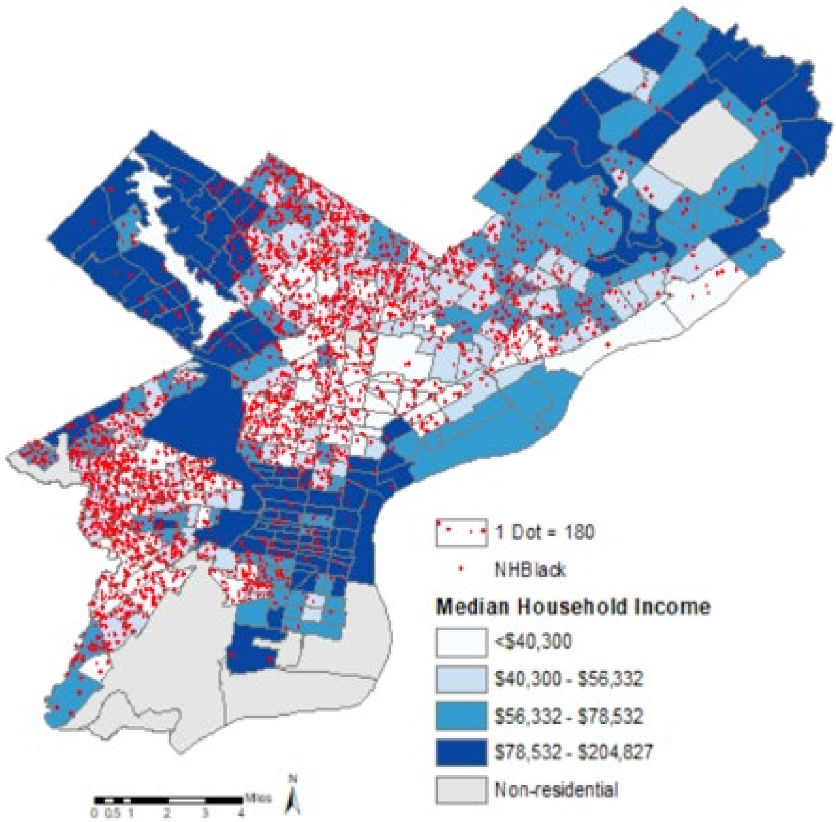

Figure 1: Socioeconomic status of the Philadelphia area. The two socioeconomic traits shown are mean household income (blue gradient) and race (dot density). Data acquired from (U.S. Census, 2010). Data is shown for each Census Tract.

been diagnosed with asthma. Figure 2 shows that areas of higher asthma prevalence generally align with tracts of higher non-Hispanic Black residents and of lower median household income. Lastly, a geospatial map was generated for 12-month average PM2.5 concentrations based on fifty air monitoring stations that measured air quality over the course of one year (Figure 3). Unlike Figures 1 and 2 based on census tract data, Figure 3 shows 12-month average PM2.5 concentrations by zip code in which each monitoring station was located. In comparing Figure 3 and Figure 1, it appears that the highest 12-month average PM2.5 concentrations were measured in North Philadelphia and in parts of West Philadelphia, regions of the city that are home to relatively high numbers of non-Hispanic Black residents and having relatively low median household income.

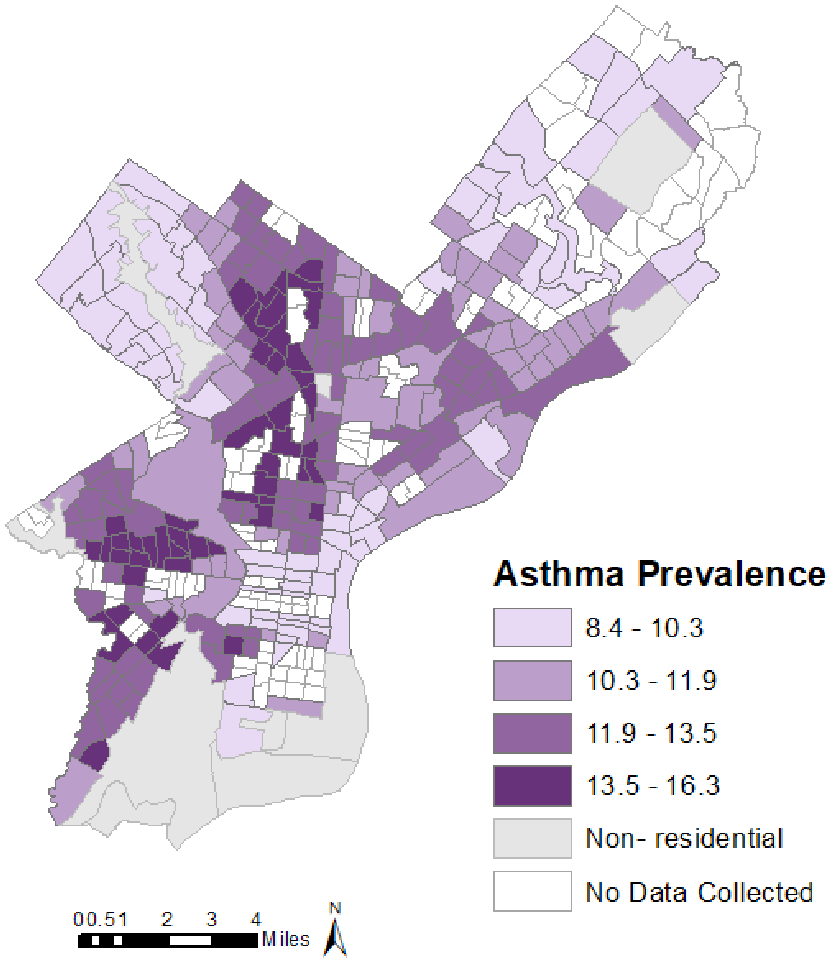

Figure 2: Asthma prevalence within Philadelphia city limits. The proportion of individuals that have been diagnosed with asthma are shown in this geospatial map. Data acquired from Centers for Disease Control and Prevention, 500 Cities Project.

While geospatial maps provide visualizations of socioeconomic conditions as represented by mean household income and race, asthma prevalence as represented by the percentage of individuals diagnosed with asthma, and PM2.5 concentrations as represented by the 12-month average across the city of Philadelphia, they are qualitative in nature. In order to determine if there are statistically significant geospatial associations between asthma prevalence, socioeconomic status, and PM2.5 concentrations in the City of Philadelphia, a linear regression analysis was used.

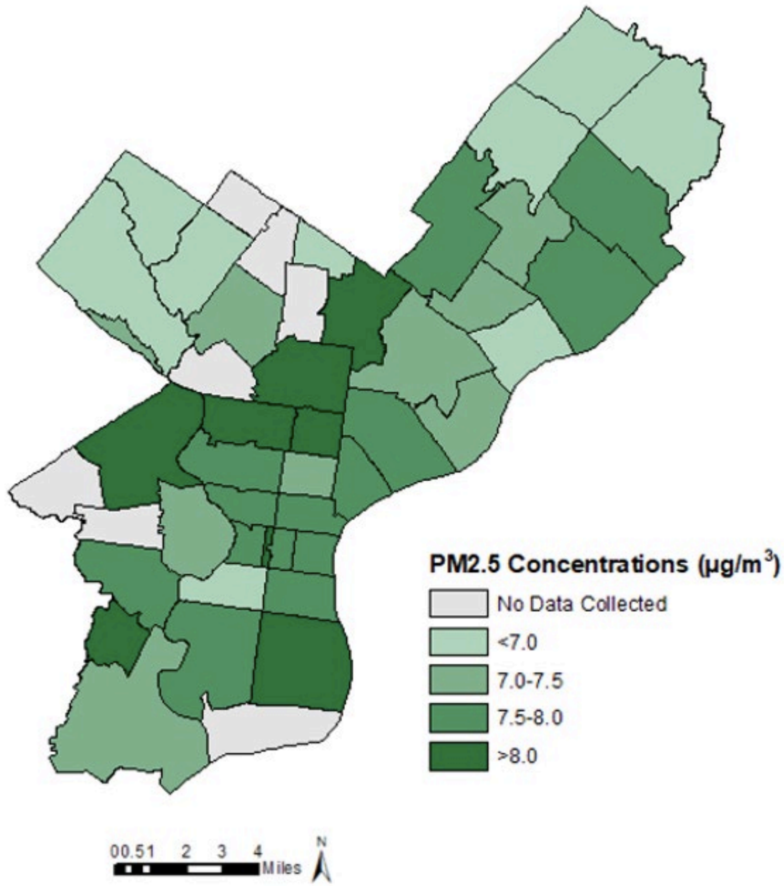

Figure 3: PM2.5 concentrations within the city of Philadelphia. Air particulate matter acquired from the Air Management Services of the Department of Public Health of the City of Philadelphia (Air Management, 2020). 12-month average PM2.5 concentrations are shown from 50 individual measurement locations. Measurements that were collected were extrapolated to the entire zip code for this geospatial map.

Figure 4A shows the regression analysis for median household income and asthma prevalence, where the Pearson correlation coefficient was determined to be -0.7436. This is related to a strong negative correlation between household income and asthma prevalence. Furthermore, the likelihood of this association being observed by chance is less than one in ten-thousand, suggesting that the correlation shows a true inverse relationship between income and asthma prevalence. The linear regression for demographics and asthma prevalence is shown in Figure 4B, where there is a strong positive correlation between the number of non-Hispanic Black residents and asthma prevalence. The Pearson correlation coefficient was computed to be

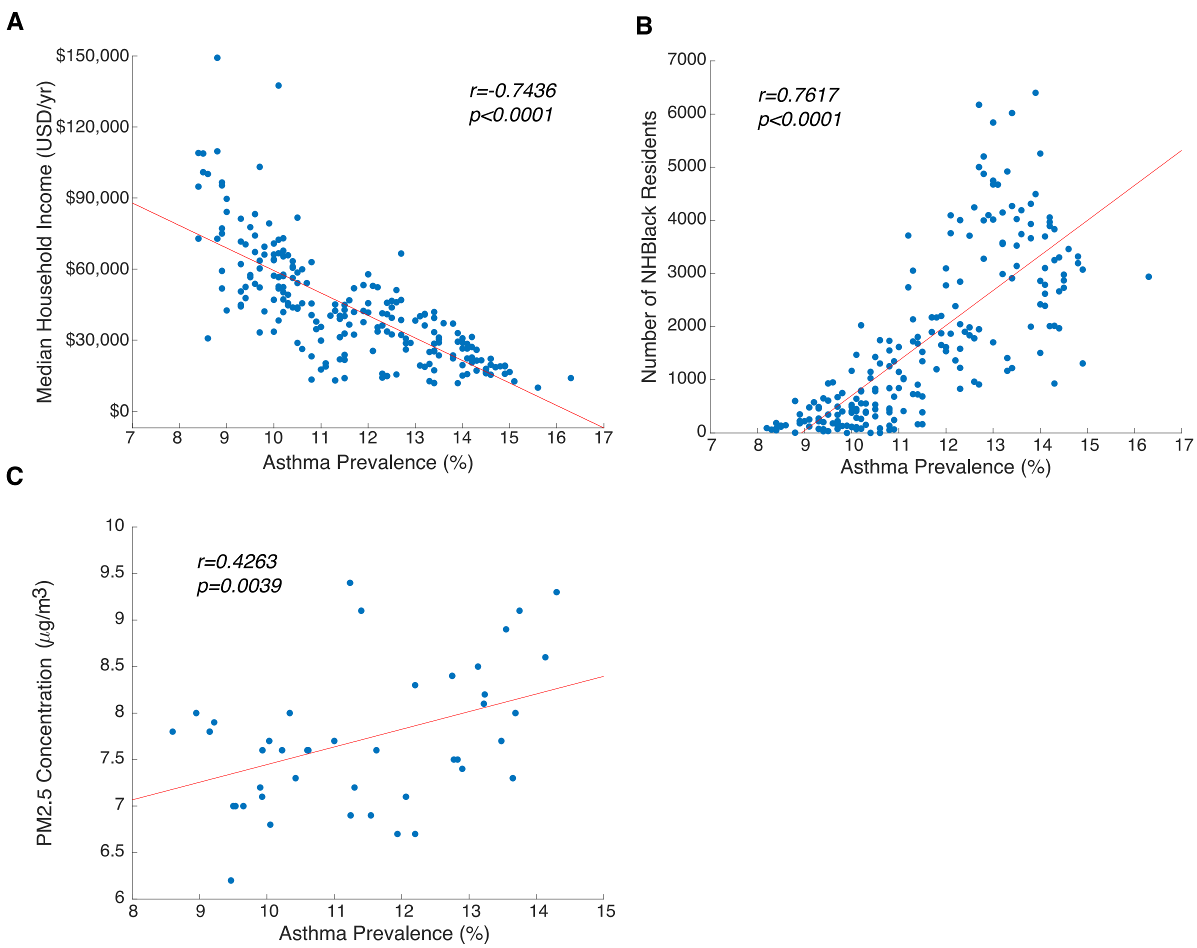

Figure 4: Linear regression analysis of socioeconomic factors and PM2.5 concentrations with asthma prevalence. Census tract-level geospatial linear regressions between asthma prevalence and (A) Median Household Income and (B) Number of non-Hispanic Black Residents. (C) Linear regression between PM2.5 concentration and asthma prevalence at a zip code geospatial level. Pearson correlation coefficient and associated p-values are displayed for each regression analysis.

0.7617, with a less than one in ten-thousand chance to be observed by chance. This result suggests that the more non-Hispanic Black residents in a given census tract, the higher likelihood of seeing individuals diagnosed with asthma. Lastly, Figure 4C shows the results of a linear regression analysis between asthma prevalence and PM2.5 concentrations. Due to the sparsity of measurements for the PM2.5 data collection, the linear regression analysis shown in Figure 4C was limited to a geospatial resolution of zip codes. Asthma prevalence for each zip code was computed by taking the average asthma prevalence across each census tract within each zip code.

The results of the regression analysis demonstrate a positive correlation between PM2.5 concentrations and asthma prevalence. The Pearson correlation coefficient was computed to be 0.4263, with a p-value of 0.0039, meaning that the positive correlation between PM2.5 concentration and asthma prevalence have a less than four in one-thousand chance to be observed randomly.

Discussion

This project has provided novel insight regarding the relationship between public health, environmental health, and community-based equity in Philadelphia. Geospatial and linear regression analyses demonstrate that socioeconomic status, as indicated by the number of non-Hispanic Black residents and median household income, and PM2.5 concentration, as indicated by the 12-month average concentration, play a pivotal role in asthma prevalence as indicated by the number of residents diagnosed with asthma by census tract in the City of Philadelphia. These results are similar to those that have been found in other metropolitan case studies of socioeconomic and air quality relations to asthma prevalence (Mooreman et al, 2010; Persky et al, 1998; Kimes et al, 2004). Unfortunately, these contributing factors are related in such a way that underrepresented communities of Philadelphia are the ones that suffer the most from this particular public health issue. Not only asthma prevalence, but social, environmental, and political injustices all occur in these neighborhoods that have been rooted in systematic disenfranchisement (Banzhaf et al., 2019a; Banzhaf et al., 2019b; Braveman, 2006). However, by raising awareness of the public health issue at hand, in particular the increased prevalence of asthma depending on where an individual lives, the air quality of that area, their race, and their economic status, change can be brought forth in a more efficient and just manner.

This study can help provide critical information on implementation of public health and environmental justice policy in the city. By establishing the current relations between air quality, socioeconomic status, and asthma prevalence within the City of Philadelphia, a greater understanding can be attained for important issues regarding social and environmental justice. By identifying the relationships between asthma prevalence, air quality, and socioeconomic status, there can be a greater awareness of the extent of underfunding in underrepresented communities across the city. This, in turn, can lead to more effective decision-making in the context of environmental justice, reduction of air pollution, and improvement of equitable public health in the areas of the city that are of most need. Environmental and social justice and equity are necessary in order for the entire city to grow as a whole, and by establishing core relationships between asthma prevalence, socioeconomic status, and air quality based on PM2.5 concentration, both social and environmental equity can be improved in the city (Agyeman et al., 2002).

Asthma prevalence has the potential to be ameliorated through several avenues of reform. First and foremost, the implementation of natural green infrastructure could be a simple, yet effective tactic towards improving air quality throughout the city, especially in underrepresented communities (Vos et al., 2013; Leung et al. 2011). Vegetation in urban settings has been shown to significantly improve air quality, specifically by reducing local PM2.5 concentrations (Novak et al., 2013; Jin et al., 2014). Urban vegetation also reduces the heat island effect and has additional health benefits to individuals and communities (Rosenfeld et al., 1998; Pataki et al, 2021).

Other methods of asthma prevalence reduction could be achieved through the promotion of equitable health services, reduction of systemic racism, and implementation of social justice.

Equitable healthcare could provide for those at risk, who otherwise do not have access to a healthcare professional, by helping to treat and perhaps preventing cases of asthma and other medical maladies (Hussein et al., 2016; South et al., 2020). Reducing and ultimately preventing systemic racism also has the potential to reduce asthma rates in underrepresented groups. This could be attained through the provision of childhood development resources, equal income support opportunities, and addressing social needs as part of community management (Castle et al., 2019; Williams and Cooper, 2019). Incorporation of social justice incentives into city policy could also mitigate disparities in asthma prevalence amongst other social- and health-related discrepancies (Goodman, 2011).

While this study was able to correlate socioeconomic status, specifically median household income and number of non-Hispanic Black residents, with asthma prevalence and PM2.5 concentrations in the City of Philadelphia, there are some study limitations. First, the data used for this analysis is aggregated from datasets that span across a decade of data collection. If all the data analyzed was collected at a single point in time, the resulting conclusions could be more impactful. However, given the sheer amount of data that is needed to perform social, economic, and environmental assessments across an entire city, the data acquisition strategy used throughout this paper is rational. One other limitation of this study was the extrapolation of PM2.5 concentration readings to zip codes, areas differing in size and shape than the census tracts for which socioeconomic status and asthma prevalence were assessed. This has the potential to reduce significant associations between asthma prevalence and PM2.5 concentrations. Perhaps a census tract regression analysis could be performed for asthma prevalence and PM2.5 concentration measurements, which could provide additional insight on the relationship between fine particulate matter air quality and asthma prevalence. Regardless, the key findings of the study provide new insight into the relationship between public health, environmental health, and community-based equity in Philadelphia, which will provide critical information on implementation of public health and environmental justice policy in the city.

Conclusion

While further analysis will be required to elucidate whether or not there is a causative linkage between socioeconomic status, air pollution as indicated by PM2.5 concentration, and asthma rates, this study helps clarify some of the complexities of asthma prevalence. By studying the relationship between asthma, air quality, and socioeconomic status of individual neighborhoods within the city limits, more equitable policymaking can be established in order to optimize city funding with equity and justice as the priorities. Additionally, greater awareness leading to increased representation of underserved communities in the policy decision making process will be an equally important benefit of this study. Improvement of air quality will not only benefit the residents of each community, but will also have secondary benefits for the city as well, such as increased tourism and economic growth. Increasing public awareness of environmental injustices that exist in the city is an important step in developing solutions that will lead to greater equity and a true “City of Brotherly Love and Sisterly Affection”.

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