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Neighborhood Socioeconomic Context Predicts Pediatric Asthma Exacerbation

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Abstract

The causes of asthma exacerbation in children have been studied extensively at the individual level, but the contributions of neighborhood-level factors are less explored. We draw out the extent to which distinctive residential characteristics produce variation in uncontrolled asthma among pediatric patients. We extracted electronic medical record data from pediatric patients living in Southern California and used multilevel modeling techniques to isolate which neighborhood characteristics drive inequitable asthma control. We found that, above and beyond the individual-level factors known to predict inadequate disease control, neighborhoods with greater concentration of non-Hispanic Black residents (OR = 1.02; CI: 0.99−1.03; $p < 0.05$), higher proportions of female-headed households (OR = 1.01; CI: 0.99−1.01; $p < 0.05$), and higher levels of ambient air pollution (OR = 1.05; CI: 1.01−1.10; $p < 0.001$) associate with greater odds of asthma exacerbation. The interplay between community characteristics and asthma management during childhood is complex, and place-based initiatives are needed to narrow the gap in asthma exacerbation.

Keywords

Pediatric; Electronic Medical Records; Asthma; Neighborhoods; Asthma Exacerbation

Introduction

More than four million children in the United States have asthma [1]. Nearly half of these children have poorly controlled asthma [2], There are stark disparities in adequate disease control by child race/ethnicity, and non-Hispanic Black and Hispanic children are disproportionately burdened [3]. Individual factors including age [4], gender [4], and socioeconomic status (SES) [5] interdependently influence poor asthma control and may explain some of this variation. which is associated with school and work absenteeism, hospitalizations, and emergency department visits [6]. Further, asthma mortality rates are more than 600% higher for non-Hispanic Black, compared to those among non-Hispanic White, children [1], and children living in poverty are at a significantly heightened risk of asthma exacerbation, relative to children of higher social standing [7].

Beyond the important role of individual-level characteristics such as child race/ethnicity and familial poverty, the neighborhood factors that trigger or exacerbate asthma symptoms are equally as important to our understanding of asthma control [8,9]. Indeed, the neighborhood socioeconomic and physical infrastructure plays a role in asthma control disparities [8,9]. For example, neighborhood measures of disadvantage like high rates of poverty, unemployment, or female headed households, and low levels of education and income, are associated with poorly controlled asthma [8,9]. Children's neighborhood conditions affect asthma control through mutually dependent mechanisms that are embedded within structural processes of racial and socioeconomic stratification, such as the combination and concentration of racial/ethnic minorities in areas of deprivation with higher levels of ambient air pollutants like particulate matter ($PM_{2.5}$) [8-10]. Neighborhood-related differences then may, in part, explain the above-mentioned socioeconomic inequities in asthma control among children. While the causes of asthma exacerbation in children have been studied extensively at the individual level [2-5], the contributions of neighborhood-level factors are less explored.

Here, we examine how the social conditions of neighborhoods combine with demographic and familial characteristics. The main objective of the study is to draw out the extent to which distinctive residential characteristics produce variation in uncontrolled asthma among pediatric patients. We expect that, above and beyond individual-level factors, children living in communities characterized by disadvantage as well as those children living in areas with higher rates of pollution will have higher incidence of asthma exacerbation relative to those children living in areas characterized by affluence and/or lower levels of air pollution.

Methods

Data Sources

Electronic Medical Record (EMR) data were extracted from 0–21-year-old children who visited the hospital for asthma-related reasons between January 2014 and December 2020 (n = 8,799) across a range of care facilities. Patient addresses from the EMR data were geocoded and linked to the corresponding residential Census tract. To capture the appropriate time period for analysis, we assigned neighborhood measures to children temporally by taking the child's address from the EMR at the time of their diagnosis. Then, we used five-year American Community Survey (ACS) estimates, along with other neighborhood data, from that period for the Census tracts which 'surround' the timing of the child's records/diagnoses. Therefore, the five-year neighborhood estimates characterize the child's area within that five-year period. As previously done, we used Census tracts to represent neighborhoods [14]. We extracted the socioeconomic indicators from the 2016–2021 ACS, 2020 Decennial Census, and Washington University Regional Estimates of Chemical Composition of Fine Particulate Matter. We excluded observations unmatched to Federal Information Processing Series (FIPS) Codes (n = 1,146), as well as children living outside of California (n = 10), resulting in a total sample size of 7,343 children nested within 698 Census tracts or neighborhoods.

Variables

The key outcome is a binary measure of asthma exacerbation due to uncontrolled asthma. We generated this measure by summing the number of times a child visited the emergency department, was admitted as an inpatient to the hospital, or required oral steroids during an encounter due to uncontrolled asthma. Then, we created a dichotomous measure by assigning "1" if the child's score was greater than 0, and "0" otherwise [15]. We included all covariates available to us from the EMR to represent child and familial characteristics. Sociodemographic characteristics include age at time of first visit, biological sex (1 = Female, ref.; 2 = Male), race/ethnicity (1 = non-Hispanic White, ref.; 2 =Hispanic White; 3 = non-Hispanic Black; 4 = non-Hispanic Asian; 5 = Other Race; 6 = Missing), primary spoken language (1 = English, ref.; 2 = Spanish; 3 = Other), and insurance type (1 = Private, ref.; 2 = Public (e.g., MediCare or MediCal); 3 = Other/Missing) as a proxy for SES [16,17]. Seventeen percent of children were missing on race/ethnicity, and 5% were missing on insurance category, which is common with EMR data. Although we would typically impute values for children with missing data, multiple imputation would not be appropriate given the lack of comprehensive individual-level measures [18]. As such, we included an indicator for whether the child was missing on race/ethnicity and combined the "missing" category with "other" insurance. We examined the representativeness of our EMR data by comparing our racial/ethnic proportions to those from the United States Census Bureau in Orange County and Los Angeles County. For example, the population estimates in 2020 for the population in Orange County were 38.5% non-Hispanic White, 2.2% non-Hispanic

Black, 34.1% Hispanic, and 22.8% Asian alone, which aligns closely with our data (Table 1). Socioeconomic indicators of the child's neighborhood of residence come from the ACS and Decennial Census and include percent adults with < 12 years of education, median community-level income, median home value, median gross rent, percent unemployed, percent of female-headed households, percent receiving public assistance, percent in poverty, percent of homes in the tract that are vacant, population density, and percent of non-Hispanic Black residents. Air quality data are from Washington University's Regional Estimates of Chemical Composition of Fine Particulate Matter using a combined geoscience-statistical method drawn from satellite remote sensing, global clinical transport models, and ground-and-aircraft based observations to estimate annual mean levels of $PM_{2.5}$ in a given tract [19].

Statistical Analysis

We tested the influence of distinct neighborhood characteristics on children's asthma exacerbation using multilevel logistic regression modeling with Stata 17 software [20]. This technique treats level-1 children as nested within level-2 neighborhoods and offsets the lack of independence of data within higher groups. Our modeling approach uses adaptive quadrature to adjust for problems that may downwardly bias estimated standard errors, such as different sample sizes for level-1 and level-2 units, clustering within neighborhoods, variable numbers of cases within level-2 units, and heteroscedastic error terms [21]. We performed a series of models that first estimate an unconditional model, and then a set of conditional models that included the covariates of child- and family-level predictors (age, sex, race/ethnicity, insurance type, primary language) to test the influence of child and family factors on children's asthma control. In the next set of models, we included the community characteristics at the neighborhood-level (and a neighborhood-level error component), along with the child- and family-level predictors and an individual error term to determine the association between neighborhood characteristics and asthma exacerbation in children. We report odds ratios (OR) from the regression analyses for ease of interpretation.

Results

In Table 1, we display overall descriptive information for child, family, and neighborhood characteristics. Twenty-three percent (SD = 0.42) of children in the full sample presented with asthma exacerbation. The mean age for the entire sample is 7.56 years. Majority of children are Hispanic (62%, SD = 0.48) with 'Public' insurance (74%, SD = 0.44) and primarily speak English (66%, SD = 0.47). The median household income is $66,280 (SD = $25,250). Twenty seven percent (SD = 0.12) of households are female-headed. Average $PM_{2.5}$ exposure is 11.00 mg/m^3, which translates to an air quality index (AQI) index value of "Good", based on the Environmental Protection Agency's (EPA) 2012 revisions [22].

In Table 2, we present the results from our hierarchical logistic regression models that predict asthma exacerbation. Model 1 partitions the total variation in poor asthma control into within- and between- neighborhood variance. Model 2 included only the child- and family-level characteristics (age, sex, race/ethnicity, health insurance, primary spoken language). In the fully specified Model 3, we included the neighborhood-level characteristics (median household income, median home value, median gross rent, % non-Hispanic Black, % of residents in poverty, % of homes vacant, % female-headed households, % with <12 years of education, % unemployed, population density, and annual mean $PM_{2.5}$). The random effects estimated across all models indicate significant variation in pediatric asthma exacerbation across neighborhoods.

In Model 1, intraclass correlation from an unconditional model reveals that around 12% of the variation in children's asthma exacerbation is attributed to between neighborhoods. In Model 2, we see that each additional year of age is associated with an 8% decline (OR: 0.92; 95% CI: 0.90−0.93) in the odds of asthma exacerbation. Males (OR: 1.15; 95%CI: 1.02−1.30), relative to Females, Hispanic (OR: 1.23; 95% CI: 1.04−1.45), non-Hispanic Black (OR: 1.79; 95% CI: 1.27−2.54), and Non-Hispanic Asian children (OR: 1.30; 95% CI: 1.07−1.69), relative to non-Hispanic White, have significantly higher odds of inadequate asthma control. Publicly insured children (OR: 0.68; 95% CI: 0.58−0.79), those with other forms of, or missing information on, insurance (OR: 0.36; 95% CI: 0.27−0.48), and those whose primary language is 'Other' than English (OR: 0.67; 95% CI: 0.59−0.77) have significantly lower odds of asthma exacerbation. Model 3 largely mirrors Model 2 in other child- and family-level factors, which indicates that neighborhood factors independently associate with higher odds of asthma exacerbation. Model 3, accounting for neighborhood characteristics, slightly attenuates the racial/ethnic and socioeconomic differences in asthma exacerbation, which indicates that some of the higher odds of inadequate disease control for non-Hispanic Black, and non-Hispanic Asian children, relative to non-Hispanic White, and lower odds of asthma exacerbation for privately insured children, is due to the neighborhood environment. More specifically, children living in areas with higher concentration of non-Hispanic Black residents (OR: 1.02; 95% CI: 0.99−1.03), as well as larger proportion of residents with female-headed households (OR: 1.01; 95% CI: 0.99−1.01), associates with significantly higher odds of poor asthma control. Pediatric patients residing in communities with higher concentrations of $PM_{2.5}$ associates with 5% (OR: 1.05; 95% CI: 1.01−1.10) greater odds of asthma exacerbation.

In Figures 1−3, we mapped each neighborhood characteristic that increases the odds of inadequate disease control in our sample. In North-East Orange County, we see a high concentration of non-Hispanic Black residents (Figure 1), small percentage of female-headed households (Figure 2), and lower levels of ambient air pollution (Figure 3). North-West Orange County has a high percentage of non-Hispanic Black residents, high percentage of female-headed households, as well as higher levels of environmental toxins. South-East Los Angeles County has a combination of low-to-medium-to-high concentration of non-Hispanic Black individuals, small percentage of female-headed households, and higher levels of $PM_{2.5}$. The disparities in these spatial distributions underscore the importance of studying risk in a comprehensive way.

Discussion

More than one-half of children with asthma have poorly controlled asthma [1], a phenomenon that is disproportionately linked to racial/ethnic minorities and/or areas with higher levels of air pollution [3,6-7]. We extracted EMR data from pediatric patients living in Southern California and used multidimensional neighborhood measures to isolate which neighborhood characteristics drive inequitable asthma control. We found that, above and beyond the individual-level factors known to predict inadequate disease control, neighborhood characteristics associate with a heightened risk of asthma exacerbation. Specifically, neighborhoods with greater concentration of non-Hispanic Black residents, higher proportions of female-headed households, and higher levels of ambient air pollution are associated with poor asthma management in children.

Our results are consistent with previous findings showing that communities with higher levels of ambient air pollutants contribute to inadequate disease control [8,15]. We add to this literature by isolating additional contributing factors that differentially influence asthma exacerbation. We show that, in Southern California, the concentration of racial/ethnic minorities and female-headed households heightens the risk for asthma exacerbation. Crucially, children living in communities characterized by disadvantage are often disproportionately racial/ethnic minorities [5-7], who also tend to be exposed to higher levels of pollution [8] that can exacerbate asthma symptoms [10]. Notably, only 2.3% of the entire population in Orange County is African American [23]; yet we find that areas with higher concentrations of non-Hispanic black residents have significantly increased odds of asthma exacerbation. This finding aligns with theoretical and empirical research describing how various forms of inequality cluster in social environments such as neighborhoods [24]. Further, the lack of health-promoting infrastructure in neighborhoods characterized by deprivation limits access to health care resources and impedes a parent's ability to weaken the effect of poor air quality on children's lung functioning through pharmacologic treatment, thus influencing the likelihood of hospitalization.

Still, the odds of asthma exacerbation for children with public insurance, relative to private insurance holders, and those whose primary language is 'Other' than English, relative to English-speaking individuals, are lower. These results provide evidence that publicly funded insurance and cultural variation may act as an equalizer and buffer the deleterious effects of factors which exacerbate asthma in other groups. The protocols may differ for children with publicly funded insurance (e.g., requirement to provide written Asthma Action Plan [25]) and, based on our sample, those who speak a language 'Other' than English may live in families that are more likely to engage in healthy behaviors (e.g., nutritious dietary patterns [26]). Also, other types of family and community resources such as higher parental income and educational attainment [27] and unrestricted greenspace [15] function as protective factors for asthma management. Our results indicate that differential exposure to air pollution, and differences in community-level racial/ethnic composition and family structure, contribute to variation in asthma exacerbation.

Although our study is informative, it is not without limitations. The cross-sectional nature of our data, as well as rudimentary measures of child and family characteristics, limit the scope of our analysis. However, researchers often lack access to data that explicitly link socioeconomic determinants of health to children's asthma management. It is important to better understand how ambient air quality issues combine with other individual/family/environmental risks that influence asthma exacerbation. Also, we use insurance type as a proxy measure for SES. This is not ideal but insurance type is a widely used marker for individual-level SES that has reasonable validity and reliability [16,17]. Additionally, it is unclear whether the same relationships between specific neighborhood characteristics and asthma exacerbation exists in the broader U.S. population. However, leveraging EMR and neighborhood and environmental contextual data in Southern California, an area with a diverse population [28] and some of the highest concentrations of ambient air pollution in the United States [29], provides a rich and comprehensive account of the communities in which children live, and allows deeper insight into the links between environment and asthma management.

Conclusion

Crucially, our findings have implications for research on asthma exacerbation. Although children living in areas exposed to higher levels of environmental toxins have higher risk of inadequate disease control, these differences alone do not drive asthma exacerbation across neighborhoods. Instead, inequalities across communities appear to create an environment where children presenting with asthma exacerbation, despite protective factors associated with publicly funded insurance, remain at a heightened risk. This difference may be due to collective socialization differences shaped by the availability of socioeconomic and environmental resources, and/or a lack of health-promoting infrastructure. Research on physical and social neighborhood-level protective factors on pediatric asthma is scant.[30] Still, creating more social capital, which measures the broad levels of trust and efficacy in the community, may lessen the risk of uncontrolled asthma.[31-32] Our findings underscore the complex interplay between community characteristics and asthma management during childhood. A crucial implication of our findings is the need to develop community-based initiatives such as the deployment of mobile units in these and other at-risk communities to aid in narrowing the asthma exacerbation gap.

Declaration of Interest Statement

The authors received financial support for the research from the Kay Family Foundation Data Analytics Grant. Z.N.K. serves as a consultant for Edwards Lifesciences, Medtronic, and Huron consulting, and is the President of the American College of Perioperative Medicine. All other authors have no conflicts of interest to report.

Author Contributions

A.W.K. conducted the statistical analyses, geocoded the data, drafted the manuscript, and revised the article for intellectual content. M.A.W., Z.N.K., and B.N.J. contributed to the conception and design of the larger study, acquisition of the data, and reviewed and revised the article for intellectual content. L.E. extracted and preprocessed the data and reviewed and revised the article for intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Ethics Approval

This study was performed in line with the principles of the Institutional Review Boards at the Children's Hospital of Orange County (IRB NetID: 1359937-13) and Chapman University (IRB #: IRB-23-47).

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Table 1. Descriptives for Independent and Dependent Variables; n = 7,343 in 698 Census Tracts

	Overall	
Dependent Variable	Mean, Median, or %	SD
Child has Asthma Exacerbation	0.23	0.42
Independent Variables		
Sociodemographic		
Age	7.56	4.62
Sex		
Girl	0.39	0.49
Boy	0.61	0.49
Race/ Ethnicity		
Non-Hispanic White	0.17	0.38
Hispanic	0.62	0.48
Non-Hispanic Black	0.03	0.16
Non-Hispanic Asian	0.06	0.23
Other Race	0.07	0.26
Missing	0.06	0.23
Health Insurance		
Private	0.19	0.40
Public	0.74	0.44
Other/Missing	0.07	0.26
Patient Characteristics		
Primary Language		
English	0.66	0.47
Spanish	0.01	0.12
Other Language	0.33	0.47
Neighborhood Characteristics		
Median Household Income (in $10K)	66.28	25.25
Median Home Value (in $10K)	454.23	189.54
Median Gross Rent (in $10K)	15.32	3.79
% Non-Hispanic Black	0.02	0.03
% of Residents in Poverty	0.15	0.08
% of Homes Vacant	0.04	0.03
% Female-Headed Households	0.27	0.12
% < 12 years of Education	0.26	0.18
% Unemployed	0.08	0.03
Population Density (1K people per sq. mile)	110.97	68.69
$PM^{2.5}$	0.11	0.01

Source: Data are from 2014-2020 Electronic Medical Records, the 2016-2021 American Community Survey (ACS), 2020 Decennial Census, and 2016 Washington University Regional Estimates of Chemical Composition of Fine Particulate Matter

Table 2. Multilevel Logistic Regression Models Predicting Asthma Exacerbation; N = 7,343 in 698 Census Tracts

	Model 1		Model 2		Model 3	
	OR	95% CI	OR	95% CI	OR	95% CI
Intercept	0.30***	8.31—12.23	0.70***	0.58—0.85	0.30**	0.12—0.71
Patient-Level						
Sociodemographic						
Age			0.92***	0.90—0.93	0.92***	0.91—0.93
Sex (Female, ref)						
Male			1.15*	1.02—1.30	1.15*	1.02—1.29
Race/ Ethnicity (Non-Hispanic White, ref)						
Hispanic			1.23**	1.04—1.45	1.17	0.98—1.39
Non-Hispanic Black			1.79**	1.27—2.54	1.71*	1.20—2.43
Non-Hispanic Asian			1.30*	1.07—1.69	1.30*	0.99—1.71
Other Race			1.04	0.81—1.34	1.03	0.80—1.34
Missing			0.49***	0.35—0.68	0.47***	0.33—0.65
Health Insurance (Private Provider, ref)						
Public Provider			0.68***	0.58—0.79	0.65***	0.55—0.76
Other/Missing			0.36***	0.27—0.48	0.33***	0.24—0.45
Patient Characteristics						
Primary Language (English, ref.)						
Spanish			0.70	0.41—1.19	0.71	0.41—1.21
Other			0.67***	0.59—0.77	0.69***	0.60—0.79
Neighborhood-Level						
Median Household Income (in $10K)					1.00	0.99—1.00
Median Home Value (in $10K)					1.00	0.99—1.00
Median Gross Rent (in $10K)					1.00	0.99—1.00
% Non-Hispanic Black					1.02*	0.99—1.03
% of Residents in Poverty					1.00	0.98—1.01
% of Homes Vacant					1.00	0.98—1.01
% Female-Headed Households					1.01*	0.99—1.01
% < 12 years of Education					1.00	0.98—1.01
% Unemployed					1.00	0.98—1.02
Population Density (1K people per sq. mile)					1.00	0.99—1.00
$PM^{2.5}$					1.05***	1.01—1.10
Random Effects						
Intercept	0.21***	0.20—0.30	0.03***	0.00—0.04	0.02***	0.00—0.03

Source: Data are from 2014-2020 Electronic Medical Records, the 2016-2021 American Community Survey (ACS), 2020 Decennial Census, and 2016 Washington University Regional Estimates of Chemical Composition of Fine Particulate Matter
****p<0.001, **p<0.01, *p<0.05*

Figure 1. % Non-Hispanic black by census tracts, Southern California.

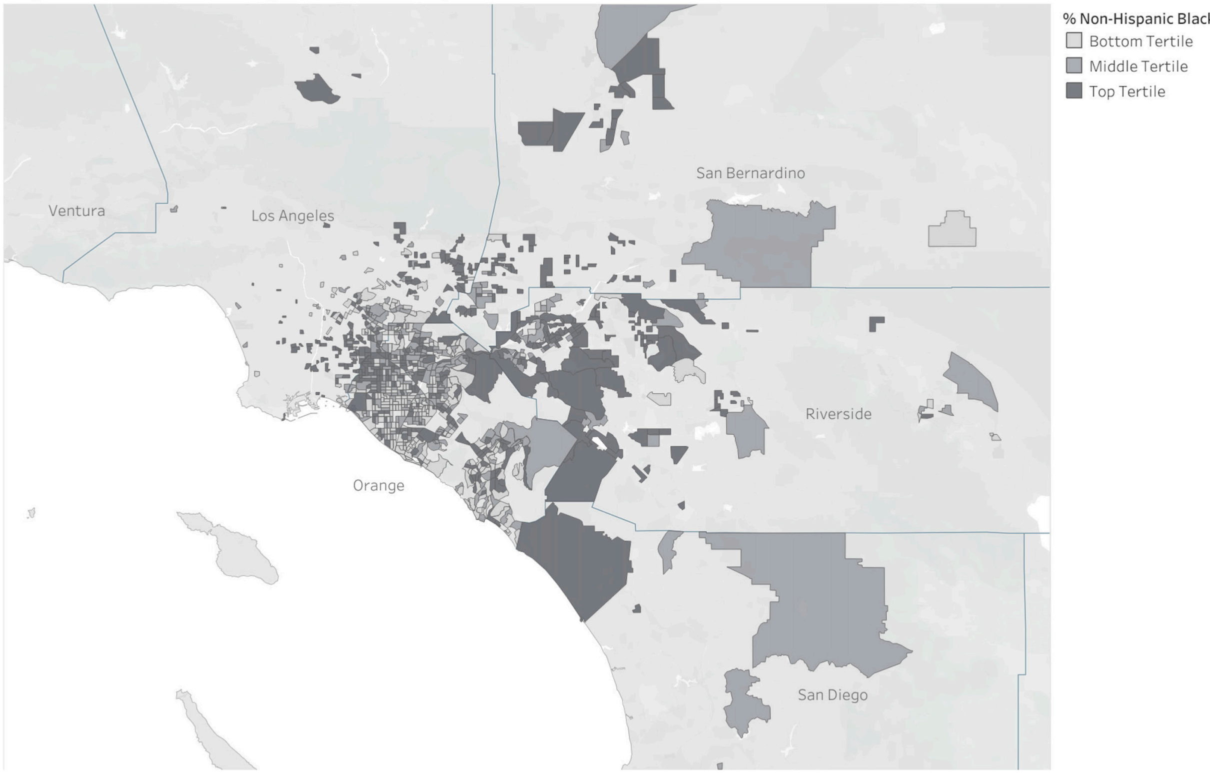

Figure 2. % Female headed households by census tracts, Southern California.

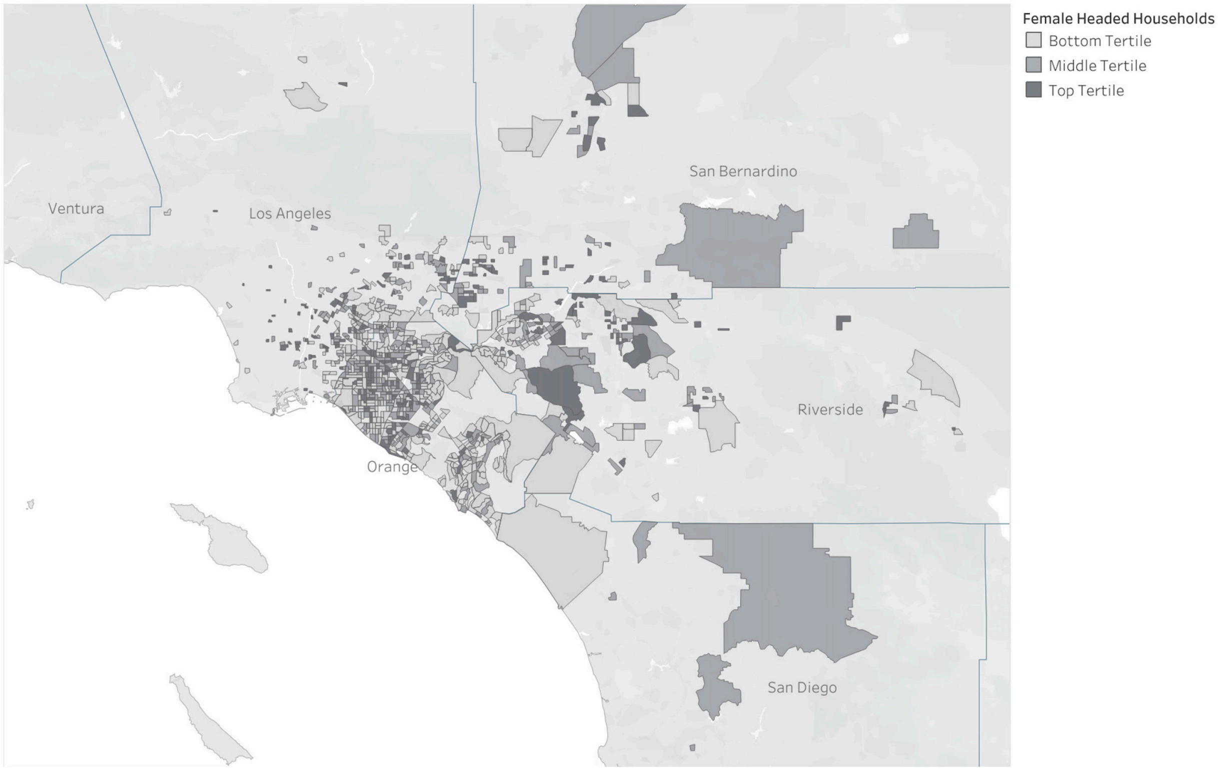

Figure 3. Annual mean particulate matter$^{2.5}$ by census tracts, Southern California.