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Journal
The Lancet Planetary Health, 4(1)

ISSN
2542-5196

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Publication Date
2020

DOI
10.1016/s2542-5196(19)30241-4

Peer reviewed

HHS Public Access
Author manuscript
Lancet Planet Health. Author manuscript; available in PMC 2023 March 16.

Published in final edited form as:
Lancet Planet Health. 2020 January ; 4(1): e24–e31. doi:10.1016/S2542-5196(19)30241-4.

Associations between historical residential redlining and current age-adjusted asthma emergency department-visit rates across eight cities of California: an ecological study

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Abstract

Background: Asthma disproportionately affects communities of color in the United States, but the underlying factors remain poorly understood. We consider the role of historical redlining as outlined in maps created by the Home Owners' Loan Corporation (HOLC), the discriminatory practice of categorizing neighborhoods based on perceived mortgage investment risk.

Methods: An ecological study of HOLC risk grades and asthma exacerbations in California was conducted using the security maps available for the following eight cities: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Jose, San Francisco, and Stockton. Each census tract was categorized into one of four risk levels (A, B, C, or D) based on the location of population-weighted centroids on security maps, with the worst risk level (D) indicating historical redlining. We obtained census tract-level asthma emergency department-visit rates from CalEnviroScreen 3.0. The relationship between risk grade and log-transformed asthma emergency department-visit rates between 2011 and 2013 was assessed using ordinary least squares regression. We included

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Author contributions
Study design was developed by AN, NT, JB, MM, and RMF. Literature review was conducted by AN, MM, JB, and NT. AN was responsible for writing code and analyzing the data with input from JC and NT. AN takes full responsibility for the integrity of the data and the accuracy of the data analysis. All authors contributed to interpretation of findings, writing, and editing of manuscript.

Declarations of interest
The authors have no conflicts of interest.

potential confounding variables from the 2010 Census and CalEnviroScreen 3.0: diesel exhaust particle emissions, particulate matter less than or equal to 2.5 micrometers in diameter, and percent of the population living below two-times the federal poverty level. We also built random intercept and slope models to assess city-level variation in the redlining-asthma relationship.

Findings: As security map risk grade worsened, the population proportion of non-Hispanic black and Hispanic, percent living in poverty, and diesel exhaust particle emissions all significantly trended upwards (p<0.0001). The median age-adjusted asthma emergency department-visit rates were 2.4 times higher in census tracts that were previously redlined (median ± interquartile range: 63.5± 34.3 visits per 10,000 residents) compared to those tracts at the lowest risk level (26.5±18.4 visits per 10,000 residents). In adjusted models, redlined census tracts were associated with a 1.39 times increase (95% confidence interval: 1.21, 1.57) in asthma emergency department-visit rate compared to the lowest-risk census tracts.

Interpretation: Historically redlined census tracts have significantly higher rates of recent asthma emergency department visits, suggesting that this discriminatory practice may be contributing to current racial and ethnic asthma health disparities.

Funding: This work was funded in-part by the National Heart Lung Blood Institute (K23HL1255101A1).

Background

Asthma is the most racially and ethnically disparate health condition in the United States.[1] In comparison to non-Hispanic white populations, asthma is 1.25 times as common and nearly four times as likely to cause death in non-Hispanic black individuals.[2] Decades of scientific research have documented this disparity and have attempted to explain it by estimating the contribution of exposures concentrated in communities of color, including ambient air pollution, poverty, psychosocial stress, and lack of healthcare and medication access.[3–7] To our knowledge, few studies have considered historical policies that may explain the concentration of these social and environmental factors in communities of color.[8–11] We sought to assess whether historical discriminatory policies that shaped neighborhood development in the United States are associated with current asthma-related health disparities.

In 1933, the Home Owners' Loan Corporation (HOLC) was formed under the New Deal as a depression-era measure to refinance defaulted home mortgages and prevent foreclosures. To efficiently assess applicants' risk, HOLC generated security maps, which categorized urban neighborhoods into one of four perceived foreclosure risk groups.[12] Inner-city, black, and immigrant predominant neighborhoods were systematically graded as "hazardous" and outlined in red, while neighborhoods with higher property value, better housing quality, and less "infiltration" by people of color and "foreign-born" individuals (terms used in HOLC appraisal forms) were considered lower risk.[12] This practice of residential "redlining" that was derived, systematized, and disseminated by the federal government and adopted by the private sector has had extended effects by entrenching racial segregation and diminishing the appreciation of home values and wealth accumulation.[12–14] In-tandem with redlining, other policies in-effect at multiple legislative levels such as eminent domain and racial zoning also affected where schools, highways, and toxic hazard sites were placed, leaving behind a patchwork legacy of security maps and segregation in cities across the United States.[8] Across the United States today, previously redlined neighborhoods are predominantly low-to-moderate income with higher levels of income inequality and comprised predominantly of communities of color with greater levels of segregation.[11] These segregated communities of color have higher poverty, unemployment, violent crime, higher levels of industrial pollution, low home ownership, and are more likely to be identified as medically underserved.[15,16] As such, asthma exacerbations are of particular interest with regards to redlining, as neighborhood-level asthma-related exposures like as air pollution, psychosocial stress, and lack of access to care may be concentrated, in part, due to these policies.[8,9]

HOLC maps also propelled divestment from perceived high-risk communities, influenced white-flight and urban decline, and likely contributed to subsequent disparities in housing quality and the ever-growing racial wealth gap.[8,14,17] Furthermore, intergenerational relationships exist between socioeconomic status and psychosocial stress with asthma, and may bolster the possibility that trauma imparted by racially discriminatory policies, like redlining, can influence the health of future generations.[18] Minimally, these maps reflected, with geographic specificity, the norms and values held by gatekeepers of financing, wealth and equity-generating resources, allowing for unique spatial analyses that can assess how historic policies contribute to present-day health disparities. To advance our understanding of the potential origins and persistence of racial and ethnic asthma disparities, we examined the association between residential redlining, the government sponsored practice of racially discriminatory mortgage appraisal and lending strategies during the 1930s and 40s, with present-day asthma exacerbations in California.

Methods

Study area and security maps

An ecological study design at the census tract level was adopted for this study. Security maps created by HOLC from 1935 onwards for eight California cities were included: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, San Jose and Stockton. Security maps from Oakland and Los Angeles contained multiple municipalities and referred to as “metropolitan areas” for the purpose of this analysis (see eMethods 1). Security maps are publicly available and were downloaded from the University of Richmond’s Mapping Inequality Project.[19] Neighborhoods appraised by HOLC were shaded one of four colors denoting risk; from lowest to highest risk: green (“Best”), blue (“Still Desirable”), yellow (“Declining”), and red (“Hazardous”).[19] “Redlined” were those neighborhoods shaded in red receiving a “hazardous” designation. We refer to these HOLC-defined risk levels as “HOLC risk grade”. Each map color was assigned a letter grade of A, B, C, and D, with lowest perceived risk grade assigned letter ‘A’ (i.e., green, “best”) and ‘D’ or “redlined” for highest perceived risk (i.e., red, “hazardous”). The main predictor of interest was HOLC risk grade of the census tract. Every 2010 census tract was assigned a HOLC risk grade by superimposing 2010 census tract centroids on HOLC security maps (Figure S1). Of the 3,696 tracts in our sample, we excluded 2,265 (61.3% of total tracts) as these tract centroids were located in uncategorized regions, areas that HOLC appraisers included on maps but did not assign risk grades, leaving 1,431 (38.7% of total) tracts in the final analytic sample.

Outcome and covariate data

CalEnviroScreen 3.0 (CES3.0) is a dataset created by the California Office of Environmental Health Hazard Assessment that merges health outcome data with outdoor environmental pollution data and demographic statistics from across the state at the census tract level. Asthma emergency department (ED) visit rates, air pollution, and demographic data were acquired from CES 3.0.[20] For this study, a census tract proxy of asthma-related health burden was assessed by total age-adjusted asthma ED-visit rates per 10,000 residents per year between 2011 and 2013. Rates reflect the total number of ED visits accumulated by residents of all ages from that census tract over the 3-year period; calculation is explained elsewhere.[21] Inclusion of covariates in models was determined *a priori* by associations identified in existing asthma literature and inclusion in CES3.0.[3,22] Specifically, we included the following census tract-level variables: percent of population living below two-times the federal poverty threshold in 2010, the 3-year average $PM_{2.5}$ in μg/m^3 from 2012–2014, and the estimated DEP emissions (kg) for a summer day in 2012.[21]

Analytic approach

In descriptive analyses, we examined the distribution of study variables and bivariate associations between HOLC risk grades, average asthma ED-visit rates, demographic data from the 2010 census and other study covariates using chi-squared tests/ANOVA. Asthma ED-visit rates were compared across HOLC risk grades using ANOVA and subsequent comparisons of asthma ED-visit rates by HOLC grade via the Tukey-Kramer test. Census tract choropleth maps were generated with the *GISTools* R-package to assess the qualitative associations between security maps and current asthma ED-visit rates at the census tract level.[23]

Preliminary ordinary least squares (OLS) regression models were built to examine the relationship between natural log-transformed asthma ED-visit rates and redlining when adjusted for potential confounders. OLS regression with a natural logarithm-transformed outcome was selected over Poisson regression in order to handle age-adjusted rates. We present our findings as back-transformed regression coefficients, calculated by exponentiation of model coefficients, and used the delta method to calculate coefficient standard errors.[24] Back-transformed coefficients can be interpreted as the times-increase in the age-adjusted asthma ED visit rate.

Residual spatial dependence may arise from the spatially dependent nature of asthma ED-visit rates and clustering of environmental factors in neighboring census tracts. We built random intercept and slope models using the *lme4* R package to address this potential model assumption violation.[25] Random intercepts were included at the city-level, with each intercept corresponding to a different security map. Random slopes allowed us to estimate differential relationships by city between the HOLC risk grade and asthma ED-visit rate. Random slope models were included since, during the time of residential redlining in the

1930s and 40s, a variety of policies were enforced across multiple legislative levels, from the federal level (redlining) down to state and local government levels, and since HOLC risk grade assignment varied by city (Table S1).[8]

In a sensitivity analysis, we identified the presence of spatial autocorrelation using Moran's *I*.[26] Therefore, we built a conditional autoregression (CAR) model using the *spdep* package in R, as OLS models may produce biased results in the presence of residual spatial autocorrelation (eMethods 2).[27] Compared to mixed-effects models which compare census tracts within a given city, the CAR accounts for potential relationships between neighboring census tracts.

Role of funder

Funding for this project played no role in data collection, analysis, interpretation, or the decision to submit this manuscript. All authors had access to the data and jointly decided to submit the manuscript.

Results

Across eight California cities, 1,431 census tracts (38.7% of all tracts encompassed by maps) were assigned HOLC risk grades, with the largest proportion of census tracts receiving grade 'C' (50.2%), followed by 'D' (28.4%, highest risk), 'B' (16.8%), and 'A' (4.5%, lowest risk) (Table 1). Significant trends across demographic groups, poverty rate, and air pollutant exposures were observed. The percentage of non-Hispanic black and Hispanic populations both increased as risk grade worsened. Conversely, the percentage of non-Hispanic white individuals within a census tract demonstrated the opposite trend: 'A' rated tracts contained 67.1% non-Hispanic white individuals compared to 18.3% in 'D' rated tracts. Poverty rate more than tripled between low-risk ('A' rated) and redlined ('D' rated) tracts, with over half of residents living below two-times the federal poverty level in the 'D' rated tracts, on average. Lastly, estimated DEP emissions in 'D' rated tracts were nearly twice that of 'A' rated tracts. Uncategorized tracts had demographics, poverty rate, and air pollutant measures most similar to those of Grade B and C tracts (Table S2).

Figure 1 illustrates the geospatial overlap between census tract risk grade assignment (top row) and asthma ED-visit rates across the San Francisco and the Oakland metropolitan area (n=246), San Diego (n=98), and Los Angeles (n=1,015) metropolitan area. In each area, risk grade appears spatially correlated with age-adjusted asthma ED-visit rates. Figure 2 illustrates unadjusted asthma ED-visit rates across HOLC risk grades. Redlined ('D' rated) tracts had 2.4 times higher median asthma ED-visit rates (median ± interquartile range: 63.5±34.3 visits per 10,000 residents) than the grade A tracts (26.5±18.4 visits per 10,000 residents) and 1.7 times higher than the grade B tracts (37.9±31.2 visits per 10,000 residents). Grade C tracts had median asthma ED-visit rates between that of grade B and grade C census tracts (52.6±38.1 visits per 10,000 residents). In an unadjusted linear regression model, HOLC risk grade was a statistically significant predictor of asthma ED-visit rate ($p<0.0001$).

Adjusted OLS regression showed a significant relationship between worsening HOLC grade and census tract-level asthma ED-visit rates. Tracts with B, C, and D grades were associated with 14%, 18% and 39% higher asthma ED-visit rates, respectively, compared to grade A tracts (Table 2). Predicted values from the adjusted OLS model, holding other variables at their mean, showed that historical redlining (grade D) was associated with 15.6 (95% CI: 8.8, 23.3) additional age-adjusted asthma ED-visits per 10,000 residents per year. The random intercept (city-level) mixed model was consistent with the main findings (Table 2). When we added a random slope, the Oakland metropolitan area, San Diego, and San Francisco had the strongest relationships between risk grade and asthma ED-visit rates (Table S3). A sensitivity analysis using a CAR model that accounted for spatial autocorrelation was consistent with the main results (Table S4).

Discussion

In order to achieve racial and ethnic health equity, it is crucial to understand how historically discriminatory policies may influence health disparities today. Our results indicate that redlining policies that denied wealth-generating opportunities in communities of color and undermined the physical environments of neighborhoods may in-turn affect present-day asthma-related outcomes across eight cities of California.[8,14]

To our knowledge, this is the first study to examine the association between historical government-sponsored redlining practices and age-adjusted asthma ED-visit rates. There are two other studies that examined historical redlining as a driver of current health. McClure *et al.* identified that historical redlining, as defined by security maps, functioned as a confounder of the association between mortgage disclosure rates and self-rated health during the subprime mortgage crisis between 2008 and 2013 in Detroit, Michigan.[10] In a study in Austin, Texas, Huggins *et al.* found that rates of tuberculosis cases were, at most, 20-times higher in redlined neighborhoods compared to non-redlined neighborhoods in 1952.[28] Both of these prior studies only considered redlined neighborhoods (grade 'D') as exposed, while our analysis extends these findings by assessing and identifying poorer health outcomes in grade 'B', 'C', and 'D' (redlined) neighborhoods, in which asthma ED-visit rates were 14%, 18%, and 39% higher than grade 'A' neighborhoods, respectively. Increases in asthma ED-visit rates associated with previous redlining were similar in magnitude to the effect of a five-unit increase in poverty rate. Even after adjusting for potential confounders and accounting for spatial dependence, this observed association persisted and remained statistically significant.

Other studies have assessed how *modern* forms of redlining are associated with adverse health outcomes. In these studies, *modernly* redlined neighborhoods have higher rates of mortgage denial based on Home Mortgage Disclosure Act data. Improved mental and physical health as well as insurance coverage has been found in these redlined neighborhoods.[29,30] These findings with *modern* redlining are contrary to the associations we identified with historical redlining. The evidence of economic and health benefits of living in so-called ethnic enclaves is mixed. Some studies suggest that some immigrant communities of color overcame discriminatory policies denying them financing by creating their own financial networks that enable access to credit to invest in their property.[29,31]

Also, the context in which black and Hispanic populations were subjected to different forms of historical racism and thereby segregated likely plays-out differently than for immigrant enclaves that were formed through other racist policies. However, no studies to our knowledge have considered the relationship between current forms of redlining and historical redlining.

Regarding the social and physical aspects of neighborhoods, we found that historically redlined census tracts had DEP emission estimates nearly twice as high as in grade ‘A’ tracts. Highways, a major source of diesel emissions, were often constructed in the 1940s and 50s in so-called “blighted areas” where community resistance to land acquisition was weakest and likely overlapped with areas categorized as “hazardous” by HOLC security maps.[8] This history of freeway construction may partially explain the higher ambient air pollutant levels at the homes and schools associated with asthma in communities of color.[3,32] Additionally, we found that current poverty rates were 3.3 times higher in historically redlined census tracts compared to grade ‘A’ tracts, a relationship similar to the one identified by Mitchell *et al.* across 115 cities in the United States.[11] Neighborhood- and individual-level low socioeconomic status and high psychosocial stressors, including neighborhood violence, have been shown to contribute to asthma incidence, prevalence, and severity.[33,34]

Another mechanism by which historical redlining may affect asthma is through racially disparate forms of wealth acquisition. Americans living in redlined neighborhoods who were denied financing missed out on home ownership opportunities or lost home value appreciation.[14] This disparity in opportunities to build home equity is reflected by the persistent racial and ethnic wealth gap in the United States in which an African American family owns an average of $11,000 in assets, while a white family owns 13 times that amount—an average of $142,000.[17] Inability to accumulate wealth can ultimately impact asthma risk by reducing quality housing options and ability to buffer stress.[35]

Similar to Mitchell *et al*, we identified that historically redlined census tracts currently have higher percentages of non-Hispanic black and Hispanic populations.[11] The practice of historical redlining contributed to and solidified segregation. Michney *et al.* found that, although HOLC lending patterns do not align with the risk delineated by their security maps, the lending policy reinforced pre-existing segregation at the time of the maps’ use.[13] Such forms of structural discrimination that shaped spatial patterns of disinvestment can undermine the socioeconomic and physical environments of neighborhoods in ways that amplify health disparities.[36] While current forms of discrimination in housing may impact health disparities, the resultant racial segregation in the United States is associated with a variety of health risks adverse health outcomes.[37,38] Given that racial/ethnic disparities in asthma outcomes disproportionately burden Hispanic and black populations, which are also more likely to live in census tracts with higher DEP emissions and poverty rates, our findings suggest that historical redlining may play a role in the confluence of these factors in California.

Redlining through the creation of security maps encouraged discriminatory categorization of neighborhoods based on racial demographics and hence eroded the reputations of low-graded neighborhoods and subsequent investment or divestment.[14] The presence of greenspace, as an example, may reflect prior infrastructure investment, which is influenced by land ownership and government involvement. Prior studies have identified that people of color and low-income are more likely to live in neighborhoods that lose more greenspace over time than white individuals.[39] While greenspace is associated with a variety of health outcomes, the presence of trees is associated with significantly less ambient nitrogen dioxide, a traffic-related air pollutant strongly implicated in racial asthma disparities.[40] It is also possible that the practice of redlining influences the placement of healthcare services, thus potentially limiting future access to care, and hence, may contribute to current asthma disparities.[16,41]

Additionally, the historical context upon which institutions in these communities function can perpetuate inequity. For example, two recent studies found that historical concentrations of enslaved populations during the 1800s in the Deep South are associated with current poor health outcomes.[42,43] Even though a historically racist practice has been abolished, underlying discriminatory mechanisms may persist within social, political, and economic institutions in ways that lead to health disparities. Our finding of persistently higher asthma ED-visits 80-plus years after the development and use of security maps coupled with higher DEP emissions and poverty rates may partially reflect a discriminatory legacy of redlining.

Our analysis had several limitations. The outcome variable, age-adjusted asthma ED-visit rates, is a proxy of asthma severity, control, and lack of access to preventative services, and therefore captures census tracts most burdened by asthma.[44] Healthcare access, insurance coverage, and baseline asthma prevalence may be variable in redlined census tracts, leading to differential use of healthcare overall, and it is possible that our findings under or over-estimate the true association. As we know, asthma prevalence is associated with neighborhood deprivation and racial segregation, underlying our findings that census tracts previously redlined likely also have higher asthma prevalence.[45] This warrants further investigation as targeted policies addressing redlining may have larger effects if also aimed at reducing overall asthma prevalence in high-burdened communities.

In order to limit our focus to the association between HOLC security map grades and current asthma ED-visit rates, we excluded uncategorized census tracts, that is, census tracts for which the centroid was outside the security map categorized regions. Jacoby *et al.* found that adjusted violent crime rates in Philadelphia were highest in uncategorized neighborhoods, suggesting an effect of non-categorization that was possibly omitted by our analysis.[9] However, this is unlikely as the mean asthma ED visit-rate for excluded census tracts was between the mean rates of grade B and C census tracts (Table S2).

Given the amount of time between creation of security maps and the asthma ED visit-rates in 2011–2013, it is possible that some or all of our included confounders are mediators of redlining and current health. When these potential mediators are excluded from our OLS and mixed models, HOLC risk grade estimates remained similar. As prior socio-demographic factors such as 1940s demographics, 1940s housing quality, and 1940s median value of owner-occupied homes could confound our results, model coefficients may overestimate the true association.[9] In particular, current housing quality is related to a variety of asthma-associated exposures that are also more common in public housing, where lower-income people of color are more likely to reside, and hence, may mediate or confound our findings.[35] Our exposure assessment strategy likely introduced some exposure classification bias, as we categorized census tracts into HOLC risk grades based on the location of the centroid. Crossney *et al.* developed a continuous metric for HOLC risk grade based on proportion of geographic area within each HOLC grade, offering a more nuanced way to capture the HOLC risk grades within present-day census tracts.[46] We used HOLC categories to improve interpretation of the results. Further, Figure 1, qualitatively demonstrates minimal exposure misclassification when compared to original security maps. Other analytical limitations included limited publicly available data such as the prevalence of smoking, which is associated with asthma, as well as other processes that could confound our results such as ongoing gentrification.[47,48] Lastly, like all ecological analyses, our results are susceptible to ecological fallacy and residual confounding.

Conclusion

We found associations between government-sponsored, discriminatory redlining practices from the1930s and current age-adjusted asthma ED-visit rates in eight major cities in California. Despite current policies like the Community Reinvestment Act that have funneled billions of dollars into disadvantaged communities around the country, security maps drawn and color-coded 80 years ago to designate perceived investment risk, in part, on the basis of race, are associated with asthma healthcare utilization in urban census tracts of California today. Future studies should attempt to incorporate individual-level data and additional covariates to better delineate this association.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

Susan Ivey, Jason Coburn, and Stephanie Holm supported the growth and progression of this project.

Funding role

NT was supported by a career development grant from the NHLBI (K23HL1255101A1). RMF was supported by the National Institutes of Health Environmental Influences on Child Health Outcomes (ECHO) program (UG3OD023272 and UH3OD023272) and JAC by a NIEHS K99 award (K99ES027023).

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Research in context

Evidence before this study

We searched PubMed, Web of Science, and Embase for studies investigating the relationship between historical residential redlining maps and current health outcomes prior to May 2019. Only three articles focused on historical redlining and subsequent societal wellbeing: (1) an observational study of redlining maps and subsequent tuberculosis cases in Austin, Texas in the 1950s (2) an analysis of historical redlining and recent crime rates in Philadelphia, Pennsylvania and (3) a study of how historical redlining was associated with self-rated mental health and foreclosure rates during the subprime mortgage crisis in Detroit, Michigan. No studies to our knowledge have assessed how historical redlining is associated with current asthma health disparities.

Added value of this study

To our knowledge, this is the first study to assess asthma health outcomes associated with historical redlining. In addition, this is also the first study to assess the potential health impacts of redlining in eight metropolitan areas across California. Our analysis included recent data from over 1,400 census tracts. We found that median age-adjusted asthma emergency department-visit rates were 2.4 times higher in historically redlined census tracts compared to tracts that were not redlined in the 1930s. Asthma emergency department-visit rates in redlined census tracts remained significantly elevated after adjusting for present-day poverty rate, diesel particle emissions, particulate matter less than or equal to 2.5 micrometers in diameter, and spatial autocorrelation.

Implications of all the available evidence

Historical redlining, enforced over 80 years ago in over 200 cities across the United States, may contribute to current asthma health outcomes in urban census tracts of California. Similar research in other geographic regions and with individualized data should be conducted in order to assess the generalizability of these findings.

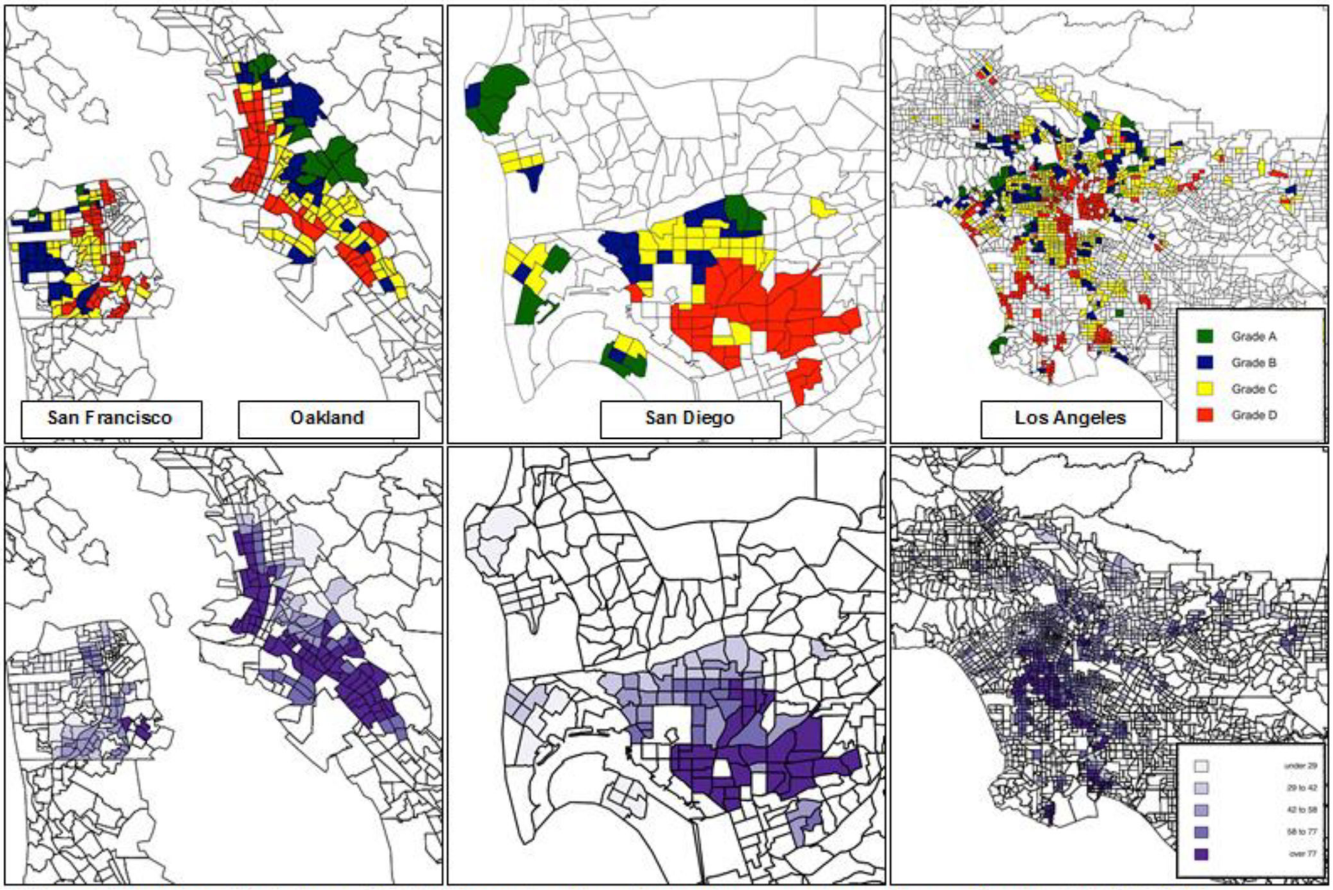

Figure 1:

Relationship between HOLC risk grade-categorized 2010 census tracts (top row) and total 2011–2013 age-adjusted emergency department-visit rates per 10,000 residents (bottom row) across three metropolitan areas in California. Census tracts shaded white were not categorized and therefore were excluded from the analysis.

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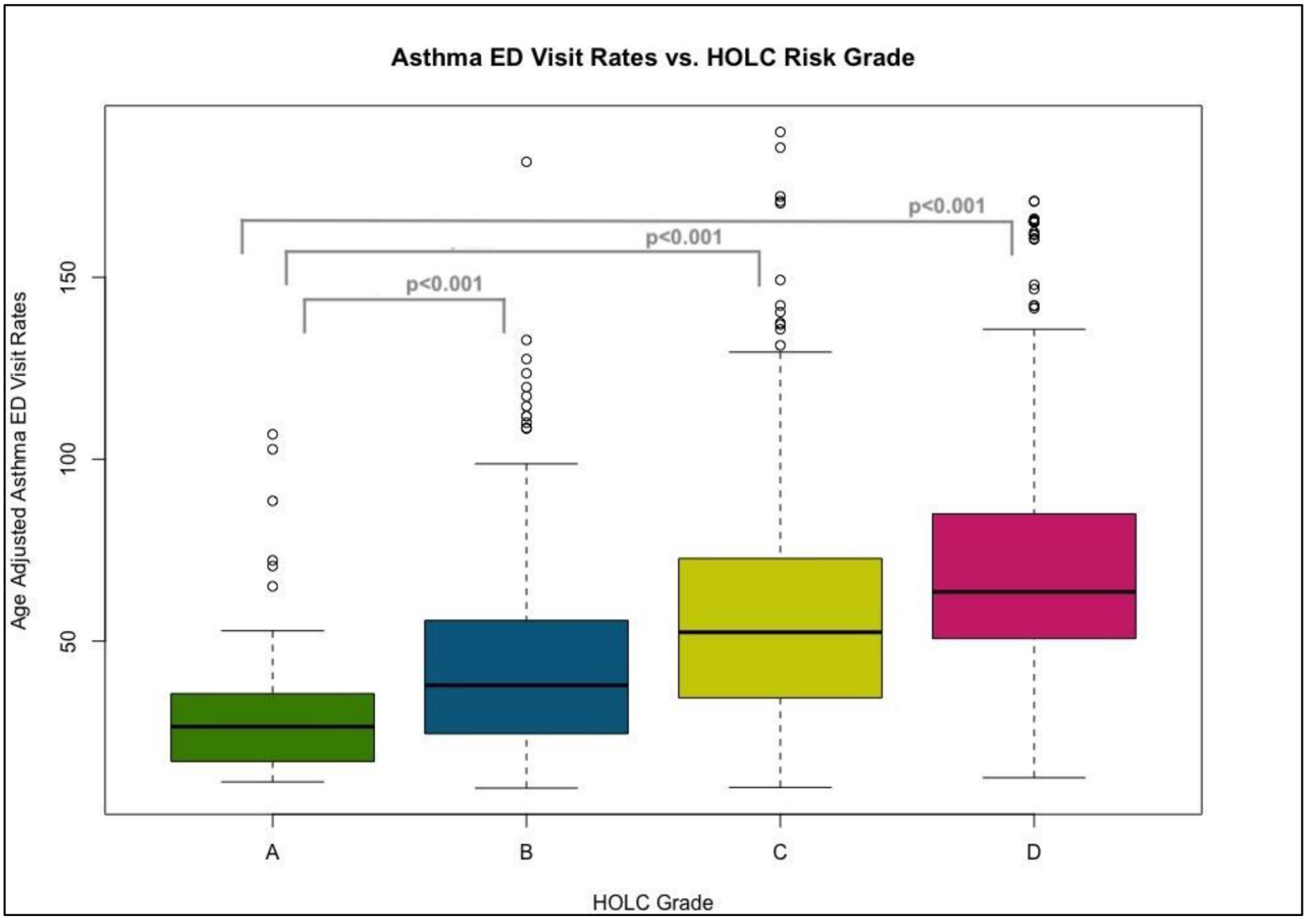

Figure 2:

Age-adjusted asthma emergency department-visit rates by previous HOLC risk grade. Reported p-values were calculated using the Tukey-Kramer test. Green, blue, yellow, and pink indicate previous HOLC risk grade of A, B, C, and D, respectively.

Table 1:

Census tract socio-demographic and air pollution characteristics by previous HOLC risk grade

	Grade A (n=64)	Grade B (n=241)	Grade C (n=719)	Grade D (n=407)
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
% Hispanic *	10.9 (8.8)	27.6 (27.3)	46.5 (28.1)	55.5 (30)
% Non-Hispanic Asian	12.2 (12.2)	15.8 (17.4)	14.9 (17.0)	12.9 (14.9)
% Non-Hispanic Black *	6.2 (16.1)	8.5 (16.2)	10.1 (12.5)	10.9 (13.7)
% Non-Hispanic White *	67.1 (22.6)	44.8 (28.4)	25.9 (26.6)	18.3 (21.9)
% Other *	3.5 (1.0)	3.1 (1.5)	2.4 (1.5)	2.2 (1.6)
% Poverty[a] *	15.6 (9.4)	29.7 (17.2)	47.3 (19.9)	51.9 (19.9)
Mean $PM_{2.5}$	11.1 (1.6)	11.0 (1.6)	11.5 (1.4)	11.4 (1.6)
Mean Diesel PM *	22.6 (14.3)	27.8 (16.2)	29.8 (15.9)	39.7 (23.5)

Abbreviations: n-number of census tracts; $PM_{2.5}$-Particulate matter less than or equal to 2.5 μm in diameter, PM-particulate matter, SD-standard deviation

* indicates linear p-trend <0.001

[a] defined by the percent of the population living below two-times the federal poverty level

Table 2:

Association between HOLC risk grade and age-adjusted asthma ED-visit rates across 1,431 California census tracts, 2011–2013

	Grade B	Grade C	Grade D
	RR (95% CI)*	RR (95% CI)*	RR (95% CI)*
Unadjusted OLS	1.42 (1.22, 1.62)	1.85 (1.60, 2.10)	2.34 (2.02, 2.66)
Adjusted OLS[a]	1.14 (1.00, 1.28)	1.18 (1.03, 1.33)	1.39 (1.21, 1.57)
MEM-random intercept[b]	1.24 (1.09, 1.39)	1.30 (1.15, 1.45)	1.53 (1.34, 1.72)
MEM-random slope[c]	1.15 (0.99, 1.31)	1.29 (1.09, 1.49)	1.54 (1.08, 2.00)

Abbreviations: CI-Confidence Interval; MEM-mixed-effects model; OLS-Ordinary least squares; RR-relative risk

[a] Adjusted for poverty rate, diesel exhaust particle emissions, and $PM_{2.5}$ level

[b] Random intercepts were generated at the city level and corresponded to each of the maps included in the analysis c-Random slopes were generated for HOLC grade at the city level

[c] Random slopes were generated for HOLC grade at the city level

[*] Asthma ED-visit rates were natural log-transformed and estimates were back-transformed via exponentiation and can be interpreted as the *times* increase in asthma ED-visit rates compared to Grade A census tracts. 95% CIs were calculated with the delta method.