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Research Article

Heat and History: The Influence of Historical Redlining Practices on Heat-Related Illnesses in Modern U.S. Cities

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ABSTRACT

Heat illness is becoming one of the most fatal climate-related conditions. Its harmful effects disproportionately impact historically marginalized groups due to a long history of institutionalized racism. In the 1930s, the Home Owners' Loan Corporation (HOLC) assessed neighborhoods based on their investment risk. These grades discriminated against people of color, enforcing segregation and disinvestment long after the practice was outlawed. The process is now referred to as redlining, and its ongoing effects can be observed through various health and socioeconomic impacts. Our study intends to address the question "How does historical redlining influence the prevalence of heat-related illnesses in cities throughout the United States?". We created faceted maps and ran linear regression using data from the US Census Bureau, the Centers for Disease Control, and Mapping Inequality to investigate the correlation between the percentage of the Black population and heat illnesses. Our models yielded mixed results in the strength of correlation between our variables. Chicago had the highest statistical correlation. Nonetheless, our study forms a link between the perpetuation of racially biased housing policies and the current prevalence of heat morbidity in Black-dominant neighborhoods.

Keywords: heat-related illness; HOLC; redlining; segregation; urban heat islands; heat vulnerability index (HVI)

INTRODUCTION

In the past couple of years, the rates of emergency department visits for heat-related illnesses have substantially increased across several U.S. regions (1). These were partly due to the warming associated with climate change. Low-income or marginalized groups are particularly more inclined to feel the effects of heat waves. This can be partially explained by America's complicated history of institutional racism and segregation. Although de jure segregation (segregation based on law) ended in the 1960s, the effects of discriminatory practices and policies, notably redlining, continue to be felt today. Redlining is the targeted denial of credit and home mortgages to individuals living in neighborhoods deemed as high risk for investment (2). As a part of the New Deal, President Franklin D. Roosevelt implemented the Home Owners'

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Loan Corporation (HOLC) to provide mortgage relief to homeowners at risk of foreclosure during the Great Depression. HOLC conducted neighborhood assessments of investment risk, ranking them from A (best) to D (worst) and color-coding them from green to red on Residential Security Maps (3). The level of investment safety was assessed based on the percentage of people of color (POC) in a neighborhood. This exacerbated the existing racial socioeconomic gap: marginalized neighborhoods experienced disinvestment and reduced home value compared to white neighborhoods (4). HOLC and its residential security maps, therefore, turned into a new form of systemic racism and enforced residential segregation for decades after its initial approval.

These redlining maps also led to increased health risks for redlined neighborhoods. Due to reduced land value from disinvestments, governments often sponsored federal construction projects on the land, concentrating heat-retaining materials such as concrete (5). This led to the urban heat island (UHI) effect, in which urban areas with concentrated man-made structures and few green spaces are hotter than suburban/rural areas (7). Historically redlined neighborhoods rated at a D or C scale tend to have fewer green spaces and, therefore, are susceptible to higher levels of heat exposure (6). It was recorded that redlined neighborhoods are prone to be 5 to 20ºF warmer compared to non-redlined neighborhoods (8). Climate change only amplifies the effects redlined neighborhoods face because of their urban design features of impervious surfaces and lack of tree canopies, intensifying environmental hazards such as extreme heat, heavy precipitation, and flooding (9). Furthermore, urban areas are concentrated with high levels of nitrogen dioxide and fine particulate matter because of primary traffic emissions in compacted areas and closer proximity to factories and industrial areas (10) (11). The lack of greenspaces leads to little filtration in redlined neighborhoods (12). Hence, levels of nitrogen dioxide levels in D and C-graded census blocks are substantially higher compared to the A-graded census tracts (13).

Prior literature has connected the effects of historical redlining to many different health disparities, including asthma (13), obesity (14), adverse heart, lung, and brain effects (10), preterm birth, late-stage cancer diagnosis, poorer self-rated health (4), and more. Multiple studies have also proven that there is an increase in the prevalence of heat in previously redlined neighborhoods. Additionally, the difference in heat-related vulnerability varies drastically between redlined and non-redlined areas (15) (1). One study has developed an index to measure the vulnerability of certain neighborhoods to heat-related illnesses, the heat vulnerability index (HVI). This index measures temperature, prevalence of air conditioning, amount of green space, and median income (15). By using this index, it was found that those who have the highest HVI rates are marginalized populations, particularly Black and LatinX people. Black individuals are disproportionately affected by high heat levels due to disinvestment, which in part contributes to unequal opportunities for education, resources, housing, employment, and healthcare, ensuring unequal health outcomes. These negative effects of disinvestment correlate with the prevalence of heat-related illnesses and other adverse health outcomes. A lack of essential resources decreases individual’s ability to find adequate health care and mitigate their risks of suffering. These effects also make the prevalence of high heat levels more dangerous and limits the coping strategies a community can use to cool down and prevent heat-related illnesses.

To the best of our knowledge, there is only one other study that also connects heat-related illnesses to redlining. The study conducted by Li *et al.* compared the number of emergency department visits in 11 cities in Texas to historical redlining maps (1). They found that redlining was associated with an 87% increase in inpatient admission rates. However, there are few, if any, studies conducting research across multiple U.S. cities in different geographical regions.

We hypothesize that, in each of the cities we study, we will see a positive correlation between the redlining of neighborhoods, the percentage of Black residents, and the percentile ranking of heat-related illnesses. We hoped to close the gap in existing studies using quantifiable heat-related illness data while looking at a wide variety of cities spread geographically across the U.S. Our research is significant because heat-related illnesses are only increasing as climate change takes effect throughout the world, and “adverse health outcomes caused by extreme heat represent the most direct human health threat associated with the warming of the Earth’s climate” (15). It has been proven that extreme heat has a mortality rate twice that of storms and floods, and the intensity, frequency, and duration of hot days and extreme heat days continue to increase (1). These issues not only concern populations worldwide but they disproportionately affect historically marginalized groups. The climate crisis concerns not only researchers but also law and policymakers attempting to mitigate the effects of climate change and the disproportionate ways that they take form.

While the topic of historical redlining and its correlation to increased heat vulnerability has been studied and written about before, due to a lack of data, few studies have highlighted the link between HOLC redlining grades and heat morbidity to the extent that we do in this paper (1)(16). By analyzing five different cities in various geographical regions, we aim to gain a better understanding of how redlining affects heat-related illness throughout the U.S.

METHODS AND METERIALS

Our goal was to compare the HOLC redlining maps to current demographics using the 2020 Decennial Census Data to explore the perpetuation of redlining in modern U.S. cities. Our second goal was to compare current Black racial demographic areas to their heat-related illness percentiles to determine whether the two variables are correlated. We chose to focus on the Black population since these individuals experienced greatest adverse effects under redlining policies (3).

City Selection Criteria

Five US cities were selected for this study: Denver, CO; Philadelphia, PA; Atlanta, GA; San Francisco, CA; and Chicago, IL. The inclusion/exclusion criteria for this study were as follows:

- **Inclusion Criteria**
  - Cities must have been graded in the 1935–1940 HOLC redlining maps and are available on the Mapping Inequality project from the University of Richmond
  - Cities must be among the top 100 U.S. Metropolitan Statistical Areas (MSAs) by population size
  - Cities must provide availability of both HOLC mapping data and present-day demographic/health data at the tract or ZCTA level
  - Cities were chosen to ensure geographic diversity, with at least one city from each major U.S. region (Midwest, Pacific Southwest, South, and Northeast)
- **Exclusion Criteria**
  - Cities without digitized HOLC redlining maps or with incomplete/poor quality map scans
  - Cities not included in the top 100 MSAs, since smaller metropolitan areas may not offer sufficient sample size or comparability
  - Cities where current Census or CDC HHI datasets were unavailable or inconsistent at the spatial resolution required for analysis
  - Cities that were graded by HOLC but lacked adequate historical continuity in census tracts/ZCTAs to allow meaningful comparison

These criteria made sure that the selected cities not only had historical evidence of redlining but also sufficient and reliable modern datasets for racial demographics and heat morbidity analysis.

Redlining Maps

We observed various historic HOLC redlining maps of our cities of interest from 1935-1940 throughout this study to better understand the regions in cities that were categorized as D or C-graded compared to A or B-graded. Specifically, we used the Mapping Inequality maps provided by the University of Richmond. Our team downloaded scans of the maps from the five cities we included in our research. We conducted a side-by-side comparison of the redlining and modern racial demographic maps to observe how the historical HOLC grades are translated into current racial demographics within those same areas. This allowed us to use black demographics as a proxy for redlining in analyzing and measuring heat-related morbidity rates and how it affects different demographics based on systemic racism.

Racial Demographics

We utilized data from the 2020 Decennial Census to measure racial demographics in the cities we planned to observe. We chose the Decennial Census because it surveyed all individuals who reside in the U.S., including non-residents (U.S. Census Bureau, 2024), offering a better representation of the demographic makeup of the U.S. population. We compared the present-day racial demographics to its historical redlining grades. We collected our data from the package called “tidycensus” in the coding software R. Using the estimated Black population and total population within each census tract, we calculated the percentage of the Black population. We could not create racial demographic maps of each city individually because the census data did not provide data at such a small spatial scale. Instead, we outlined the municipal border within the county. Then, we used the package “tmap” to develop choropleth maps, specifically faceted maps. The faceted maps provided a percentage range of the racial demographics color-coded for an easily readable map to compare present-day race concentrations to HOLC's redlining maps.

Heat Morbidity

We obtained our morbidity data from the Centers for Disease Control's (CDC) Heat and Health Index (HHI). We specifically focused on the PR_HRI column, which represents the percentile rank of the rate of heat-related emergency medical services (EMS) Activations reported to the National Emergency Medical Services Information System (NEMSIS) between the years 2020-2022. It was organized by ZIP Code Tabulation Areas (ZCTA), which are groupings of ZIP codes in the U.S. Census Bureau used to allow mapping (Finn *et al*., 2024). We used this as a proxy for specific neighborhoods. After importing the CSV dataset into RStudio and reading it into a data frame, we subsetted the data to include only the ZCTAs of the five cities we were studying. Packages we used include "ggplot2", "sf", and "tidyverse". We matched ZCTA to specific cities by using Zip Code Crosswalk files (18).

Furthermore, in order to compare the level of segregation and the percentage of the Black population in each ZCTA, we obtained demographic data from the 2022 5-Year American Community Survey (ACS). We were unable to directly use the 2020 Decennial Census because it did not contain data at the ZCTA level. To find the level of segregation, we calculated the dissimilarity index for the regions and merged it with the original dataset. The dissimilarity index is a measure of segregation that quantifies the evenness with which two groups are distributed across a geographic area (17). It served as a control in our linear regression model. We then conducted descriptive analyses for each of the five cities, finding the minimum, median, mean, and maximum values. We particularly focused on the values of the percentile ranking of heat-related illnesses (PR_HRI) and the percentage of the Black population.

In order to generate spatial maps of each city according to their PR_HRI, we first added geometry to the dataset. We downloaded ZCTA shapefiles from the US Census Bureau and merged the two data frames. Then, we created faceted choropleth maps using the "ggplot2" package. These maps were compared to the redlining and racial demographic maps to show a visual correlation between discriminatory housing practices and heat illnesses. Lastly, we ran linear regression on heat morbidity (dependent variable) and the percentage of Black population (independent variable), controlling for the dissimilarity index, poverty rate, and unemployment rate for each of the five cities. We better visualized the regression models using "stargazer" and "sjPlot" packages.

RESULTS

Our results demonstrate a correlation between the redlining of a neighborhood and its percentile rank of heat-related illnesses. In the HOLC maps, the grading system is organized as so: A-graded (best) are colored green; B-graded (still-desirable) are colored blue; C-graded (definitely declining) are colored yellow; and D-graded (hazardous) are colored red. In the Black demographic maps, the percentages are categorized as lightest color being the lowest percentage range and darkest color being the highest percentage range. In the heat-related illness percentile maps, lighter colors indicate an area is ranked higher in the percentile rankings while darker colors indicate a lower percentile ranking. In the linear regression tables, the Black percentage stands for the percentage of Black people per area, the D index is the dissimilarity index, P POV stands for the percentage of people below 150% poverty estimate, and P UNEMP stands for the unemployment rate estimate for the designated county.

When comparing Figure 1A to Figure 1B, neighborhoods once graded as C or D in the HOLC system had a higher percentage of Black residents, compared to those graded an A or B. It is important to note that there had been a southward movement of the population. Figure 1B shows areas categorized as 66.92 to 97.8% of Black residents were once D-graded, or hazardous, neighborhoods. In modern-day Chicago, there are trends of areas with a high percentage of Black residents receiving a higher percentile ranking compared to areas with a lower concentration of Black residents. Areas whose population of Black residents made up 66.92 to 97.8% of the population were ranked as highly as in the eightieth percentile, as demonstrated in Figure 1C. In addition, areas whose population of Black residents made up 0.05 to 2.59% of the population were ranked as low as in the 40th percentile.

According to Table 1, for each one-percentage point increase in the Black population, the percentile ranking of heat-related illnesses is expected to increase by 0.34 percentage points, holding other factors constant. For each one-percentage point increase in the poverty rate, the PR_HRI is expected to decrease by 0.56 percentage points. These two factors were the only two statistically significant predictors of heat morbidity.

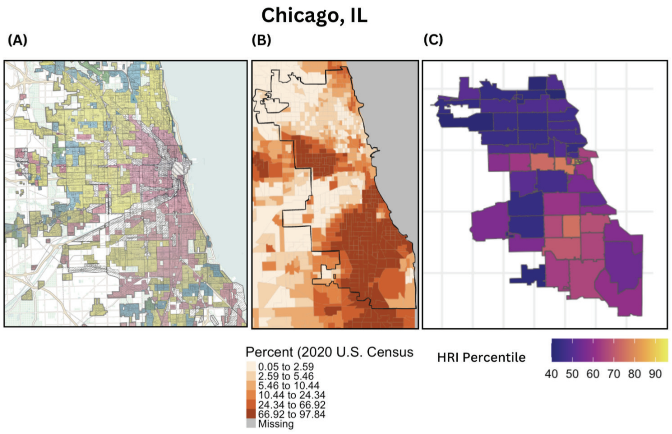

Figure 1. Maps for Chicago, Illinois, showing the relationship between historical redlining, present-day demographics, and heat-related illness risk. Panel (A) is the HOLC redlining map: neighborhoods graded from "A" (green, "best") to "D" (red, "hazardous"). Panel (B) shows the percentage of Black residents by census tract, with darker shades indicating higher concentrations. Panel (C) shows the Heat and Health Index percentile ranking of heat-related illness rates by ZCTA, with yellow areas reflecting higher rates of EMS activations and purple areas reflecting lower rates. Sources: Mapping Inequality, U.S. Decennial Census Data, and CDC Heat and Health Index.

Table 1. Chicago PR_HRI Linear Regression

Predictors	*Estimates*	*CI*	*p*
(Intercept)	59.10	(51.33, 66.87)	**<0.001**
Black percentage	0.34	(0.02, 0.66)	**0.035**
D index	-35027.75	(-75101.33, 5045.82)	0.085
P POV	-0.56	(-1.01, -0.12)	**0.014**
P UNEMP	0.94	(-0.32, 2.19)	0.140
Observations	56		
R^2 / R^2 adjusted	0.218 / 0.157		

Linear regression model predicting heat-related illness percentile rank (PR_HRI) for Chicago. Predictors include percentage of Black residents, segregation (D index), poverty rate (P POV), and unemployment rate (P UNEMP). Estimates, 95% confidence intervals (CI), and p-values are reported. Significant predictors include Black percentage ($p = 0.035$) and poverty rate ($p = 0.014$). Model fit: $R^2 = 0.218$, adjusted $R^2 = 0.157$, with 56 observations.

It is important to note that Figures 2B and 2C are within the main square redlined portion of Figure 2A. When comparing Figures 2A and 2B, there appears to be an overlap of heavy Black population concentrations within modern-day Denver and D-graded and C-graded neighborhoods of Denver's HOLC map. The D-graded neighborhoods in Figure 2a have a Black population as high as 28.71 to 82.36%. Neighborhoods once graded as A or B in Figure 2A have a Black population consisting of only 0.00 to 2.69% of the current population. Figure 2C displays that areas with a higher percentage of Black demographics can be ranked as high as the ninetieth percentile of heat-related illnesses. This is significant, considering that neighborhoods where Black people are a minority (0.00 to 2.69%) are ranked as low as within the 40th percentile.

Table 2 indicates that for every one percent increase in the black population, there is a 0.46 percent increase in PR_HRI. However, this predictor is not statistically significant ($p > 0.05$).

In modern Atlanta, as seen in Figure 3B, there is a higher concentration of the Black population (between 74.03% to 97.11%) in the southwestern census tracts of the city. This matches the redlining maps from 1938 (Figure 3A), where the majority of the D-grade and C-grade

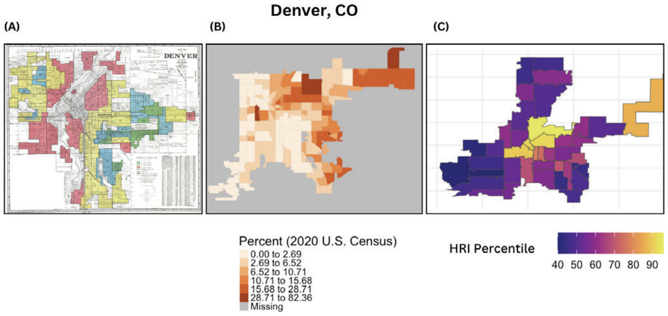

Figure 2. Redlining, Demographic, and Heat-Related Illness Maps For Denver, Colorado. Panel (A) displays the 1938 HOLC redlining map, where neighborhoods were graded from "A" (green, "best") to "D" (red, "hazardous"). Panel (B) shows the proportion of Black residents by census tract, with darker shades indicating higher concentrations. Panel (C) illustrates the Heat and Health Index percentile ranking of heat-related illness rates by ZCTA. Higher percentile values (yellow) represent greater rates of EMS activations, while lower values (dark purple) indicate lower risk. Sources: Mapping Inequality, U.S. Decennial Census Data, and CDC Heat and Health Index.

neighborhoods are concentrated in the southwest. Figure 3C shows a similar trend of higher percentile ranking of heat-related illnesses (generally around 80th-90th) found in the more southern zip codes. In comparison, formerly A-graded northern parts of Atlanta tend to have a lower concentration of the Black population (mostly between 4.14-6.27%) and a lower percentile rank of heat-related illnesses (up to 60th percentile). This means that the percentage of the Black population can only predict around 9% of the variability in the percentile rank of heat-related illnesses.

Table 2. Denver PR_HRI Linear Regression

Predictors	*Estimates*	*CI*	*p*
(Intercept)	47.13	(28.58, 65.68)	**<0.001**
Black percentage	0.46	(-0.19, 1.10)	0.161
D index	-157212.44	(-353195.60, 38770.71)	0.112
PR POV	19.28	(-6.02, 44.5)	0.131
PR UNEMP	17.46	(-22.82, 57.7)	0.385
Observations	39		
R^2 / R^2 adjusted	0.236 / 0.146		

Linear regression model predicting heat-related illness percentile rank (PR_HRI) for Denver. Predictors include percentage of Black residents, segregation (D index), poverty rate (P POV), and unemployment rate (P UNEMP). None of the predictors reached statistical significance at the 0.05 level. Model fit: $R^2 = 0.236$, adjusted $R^2 = 0.146$, with 39 observations.

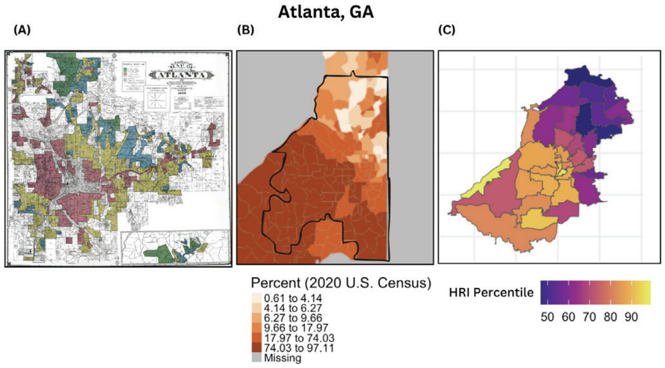

Figure 3. Redlining, Demographic, and Heat-Related Illness Maps for Atlanta, Georgia. Panel (A) displays the HOLC redlining map, with neighborhoods graded from "A" (green, "best") to "D" (red, "hazardous"). Panel (B) shows the percentage of Black residents by census tract, where darker shades indicate higher concentrations. Panel (C) illustrates the Heat and Health Index percentile ranking of heat-related illness rates by ZCTA. Lighter yellow areas represent higher rates of EMS activations, while darker purple areas indicate lower risk. Sources: Mapping Inequality, U.S. Decennial Census Data, and CDC Heat and Health Index.

Table 3 indicates that the chosen indicators, including the percentage of black population, are not statistically significant predictors and therefore cannot predict the values of PR_HRI. Furthermore, the R^2 adjusted value is negative, suggesting that this model is not particularly useful or accurate in predicting the heat-related illnesses in Atlanta.

The comparisons of maps in San Francisco in Figure 4 show a tendency for the southeastern region of the city to have a higher percentage of Black population (up to 53.54%), a region where neighborhoods were historically redlined according to Figure 4A. Figure 4C shows a slightly higher percentile ranking (around 50th) of HRI for eastern San Francisco with two specific hotspots. This can be compared to the lower percentage and percentile ranking of the Black population and HRI for the western parts of the city, which aligns with the greenlined/A-graded neighborhoods in HOLC's maps. A particular point to note is that the original redlining maps do not include the northeastern neighborhoods.

Table 3. Atlanta PR_HRI Linear Regression

Predictors	*Estimates*	*CI*	*p*
(Intercept)	64.35	(44.75, 83.95)	**<0.001**
Black percentage	-0.07	(-0.56, 0.41)	0.764
D index	-55640.19	(-151505.64, 40225.26)	0.243
PR POV	0.00	(-0.04, 0.05)	0.890
PR UNEMP	15.76	(-33.89, 65.41)	0.519
Observations	29		
R^2 / R^2 adjusted	0.091 / -0.060		

Linear regression model predicting heat-related illness percentile rank (PR_HRI) for Atlanta. Predictors include percentage of Black residents, segregation (D index), poverty rate (P POV), and unemployment rate (P UNEMP). None of the predictors were statistically significant at the 0.05 level. Model fit: $R^2 = 0.091$, adjusted $R^2 = -0.060$, with 29 observations.

Through Table 4, we show that for every percent increase in the poverty rate, there is a 0.99 percent increase in PR_HRI. For every percent increase in the unemployment rate, there is a 3.65 decrease in PR_HRI. These were the only two statistically significant factors. The R^2 adjusted value means that the model explains approximately 28% of the variation, which is a relatively good model fit.

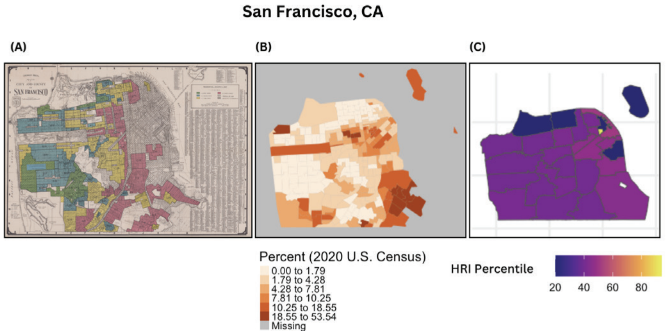

Figure 4. Redlining, Demographic, and Heat-Related Illness Maps for San Francisco, California. Panel (A) shows the HOLC redlining map, where neighborhoods were graded from “A” (green, “best”) to “D” (red, “hazardous”). Panel (B) depicts the proportion of Black residents by census tract, with darker shades representing higher concentrations. Panel (C) illustrates the Heat and Health Index percentile ranking of heat-related illness rates by ZCTA. Higher percentile values (yellow) indicate greater rates of EMS activations, while lower values (dark purple) represent reduced risk. Sources: Mapping Inequality, U.S. Decennial Census Data, and CDC Heat and Health Index.

Table 4. San Francisco PR_HRI Linear Regression

Predictors	*Estimates*	*CI*	*p*
(Intercept)	32.92	(18.60, 47.23)	**<0.001**
Black percentage	0.01	(-1.07, 1.10)	0.979
D index	122852.93	(-69326.24, 315032.09)	0.199
P POV	0.99	(0.34, 1.64)	**0.005**
P UNEMP	-3.65	(-5.96, -1.35)	**0.003**
Observations	27		
R^2 / R^2 adjusted	0.392 / 0.281		

Linear regression model predicting heat-related illness percentile rank (PR_HRI) for San Francisco. Predictors include percentage of Black residents, segregation (D index), poverty rate (P POV), and unemployment rate (P UNEMP). Unemployment rate ($p = 0.003$) and poverty rate ($p = 0.005$) were significant predictors of PR_HRI, while other variables were not statistically significant. Model fit: $R^2 = 0.392$, adjusted $R^2 = 0.281$, with 27 observations.

Figures 5A and 5B demonstrated some influence of historical redlining on present-day Black population concentrations, but there seems to be some movement of the demographic. While the A-graded and B-graded neighborhoods in northeastern Philadelphia translate to a 0.00 to 4.30% Black population in figures 5A and 5B, the once D-graded neighborhoods in southern Philadelphia have a Black demographic making 62.40 to 100% of the population. A large percentage of the Black demographic in southern modern-day Philadelphia appears to move westward in Figure 5B compared to where it was mostly populated in Figure 5A. There appears to be a correlation between neighborhoods with a high concentration of Black residents compared to their percentile ranking of heat-related illnesses. In Figure 5C, the northern region of Philadelphia has a ranking as low as roughly in the fortieth percentile. Observing that same area in Figure 5B, there is a low percentage of Black residents, 0.0 to 4.3%. Similarly, we see the same trend in southwestern

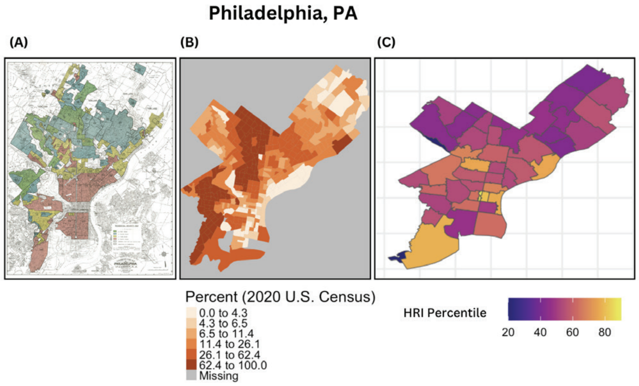

Figure 5. Redlining, Demographic, and Heat-Related Illness Maps for Philadelphia, Pennsylvania. Panel (A) shows the HOLC redlining map, where neighborhoods were graded from “A” (green, “best”) to “D” (red, “hazardous”). Panel (B) depicts the proportion of Black residents by census tract, with darker shades representing higher concentrations. Panel (C) illustrates the Heat and Health Index percentile ranking of heat-related illness rates by ZCTA. Higher percentile values (yellow) indicate greater rates of EMS activations, while lower values (dark purple) represent reduced risk. Sources: Mapping Inequality, U.S. Decennial Census Data, and CDC Heat and Health Index.

Philadelphia. In Figure 5B, 62.4 to 100 percent of the population is Black, and in that same location in Figure 5C, it is ranked in the 80th percentile of heat-related illnesses.

According to Table 5, for every percent increase in unemployment rate, there is a 42.46 percentage point decrease in PR_HRI. This was the only statistically significant predictor for heat morbidity in Philadelphia. For every percentage increase in the black population there is a 0.11 percentage point increase for PR_HRI, but this was not statistically significant.

Table 5. Philadelphia PR_HRI Linear Regression

Predictors	*Estimates*	*CI*	*p*
(Intercept)	71.37	(56.33, 86.41)	**<0.001**
black percentage	0.11	(-0.13, 0.35)	0.343
D index	-5356.83	(-56282.75, 45569.09)	0.833
PR POV	19.47	(-3.30, 42.24)	0.092
PR UNEMP	-42.46	(-71.03, -13.89)	**0.005**
Observations	46		
R^2 / R^2 adjusted	0.183 / 0.103		

Linear regression model predicting heat-related illness percentile rank (PR_HRI) for Philadelphia. Predictors include percentage of Black residents, segregation (D index), poverty rate (P POV), and unemployment rate (P UNEMP). Unemployment rate ($p = 0.005$) was a significant predictor of PR_HRI, while other variables were not statistically significant. Model fit: $R^2 = 0.183$, adjusted $R^2 = 0.103$, with 46 observations.

DISCUSSION

This study contributes to a growing body of literature investigating the role of historical discrimination in the housing market and extreme heat in urban areas. While earlier studies focused on disparities in land surface temperatures and redlining, our research filled the gap in literature as we looked into quantitative data for heat related illnesses while observing geographically dispersed cities in the United States and aimed to form a connection between redlining and levels of heat-related illnesses. We also investigated the persistence of redlining patterns in ongoing residential segregation in U.S. cities today. For all of the cities we studied, we found a moderate correlation between all three factors of historical redlining, modern demographics, and rates of heat-related illnesses. First, by examining the redlining with the racial demographic maps, it is clear that the majority of neighborhoods that were formerly deemed as "hazardous" or "declining" continue to have higher, if not the highest, concentrations of the Black population today. This especially holds true for Chicago, Atlanta, and Philadelphia. This is contextualized when considering that redlining was most severe in the Northeast and Midwest census regions. Therefore, despite the banning of redlining in the Fair Housing Act of 1968, residential segregation persisted. However, as expected, there were also some demographic shifts in certain areas. In Denver, for example, the population of Black people became much more confined to a couple of census tracts in the northeastern part of the city. San Francisco, too, has its Black population increasingly concentrated in the southeast. This pattern could reflect the effects of gentrification and displacement, a process during which an influx of wealthy white homebuyers move into low-income neighborhoods and displaces the original residents. San Francisco and Denver are currently the top two cities experiencing the most gentrification (19).

Secondly, according to the maps, neighborhoods that were historically redlined and currently have a greater black population tend to have a higher percentile ranking of heat-related illnesses. The most direct correlation could be observed in the cities of Chicago, Denver, and Philadelphia. This could be attributed to the lasting impacts of disinvestment, which was particularly severe in the Northeast and Midwest regions of the U.S. As previously mentioned, disinvestment in redlined communities led to a lack of green spaces in urban heat islands, which then created higher land surface temperatures for 108 cities across the U.S. (20). Disinvestment and the entrenchment of poverty also meant reduced access to cooling resources such as air conditioning and cooling centers (21). In contrast to the results for Chicago, Denver, and Philadelphia, San Francisco had little significant variation in the percentile ranking of heat-related illnesses across different zip codes. This could be explained by the Mediterranean climate of coastal California, which tends to be more stable with fewer and less extreme heat waves compared to other states (22). However, the linear regression models yielded mixed results. Chicago was the only city with statistically significant results for a positive correlation between the percentage of the Black population and heat-related illness percentile rankings. We believe this to be due to the limitations of our datasets for heat-related illnesses.

Fortunately, with proper policy and infrastructure intervention, the prevalence of heat-related morbidity can be mitigated. Previous literature has led us to suggest legislation promoting the increase of green spaces, cooling centers, and health clinics for areas below the poverty line, communities of color, and disinvested neighborhoods (12). Many low-socioeconomic neighborhoods are known to be concrete jungles or areas with little vegetation and are constructed using impervious materials that only enhance heat vulnerability (5). An increase of infrastructure that would promote green spaces such as parks would help lower temperatures in marginalized neighborhoods. An increase in these green spaces would also lead to a more efficient drainage system of cities due to the permeable properties of green spaces. An expansion of cooling centers such as libraries, recreational centers, and pools, would provide the vulnerable communities with accessible spaces to cool down during extreme heat events. These cooling centers would provide many resources to improve an individual's health such as programming or exercise equipment, therefore making them less susceptible to heat-related morbidity. If space is too limited to create new cooling centers, current buildings in these communities could be retrofitted instead. The practice of retrofitting could add cooling systems where needed, make current cooling systems more efficient and affordable to residents, paint structures lighter colors to avoid heat absorption, and intertwine green spaces within the infrastructure itself (23).

While our data makes some key progress in analyzing heat-related illnesses' correlations, further research is needed to fully understand this issue. Some of our main limitations in this study include the limited number of cities we analyzed, which restricts the applicability of our findings to other urban cities across the U.S. The observed associations may differ in regions with distinct climates, socioeconomic profiles, or racial compositions. Another limitation is the presence of possible unmeasured confounders, including but not limited to housing quality, prevalence of chronic illnesses, or local infrastructure investments, which may influence both demographic distributions and heat morbidity but were not captured in our datasets. Additionally, we faced limited availability of heat and health data and an overall lack of reported cases of heat-related illnesses. Because health data involves many privacy concerns, our datasets did not include all cities or provide comprehensive longitudinal measures. Our data only included rates from 2024, which do not fully cover the long-term burden of heat morbidity. A further limitation is the mismatch in spatial scales: census demographic data were measured at the census tract level, while heat morbidity data were measured at the ZCTA level. Finally, our research primarily focused on Black populations. However, in cities such as San Francisco and Denver, where non-White Hispanic populations represent a significant portion of the community, this exclusion limits the scope of our findings. These limitations highlight the need for more comprehensive, multi-city datasets that include a broader range of demographic groups, more detailed health outcomes, and longitudinal tracking to fully capture the impacts of redlining on present-day heat vulnerability.

CONCLUSION

In this study, it was found that the HOLC redlining grades from 1935-1940 are correlated with both where Black populations live today and the rates of heat-related illness in cities. Many factors contribute to the creation of these disparities, such as lack of green spaces, presence of impervious surfaces, and heat-absorbing infrastructure, but also disinvestment in communities and systemic policies that enable historically redlined communities to suffer avoidable health effects. Our study focused on five cities across the US, but in each of them, we found a moderate correlation between the number of heat-related illnesses and the percentage of Black residents, particularly in Chicago. Contextual factors for each city play a large role in why a correlation may differ between cities. Our results yield important implications for further research. As the effects of climate change become a more frequent and pressing issue each year, the number of heat-related illnesses is only projected to rise. However, heat-related deaths and illness occurrences could be mitigated in the future, especially for marginalized populations.

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