Connections between present-day water access and historical redlining

Charles W. Sterling III

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in

partial fulfillment of the requirements for the degree of

Master of Science

In

Biological Systems Engineering

William C. Hession, Chair

Thomas Pingel

LaDale Winling

14 November 2023

Blacksburg, VA

Keywords: Redlining; plumbing; drinking water; infrastructure; geospatial analysis

Connections Between Present-Day Water Access and Historical Redlining

Charles Sterling

Abstract (academic)

Although challenges in water and sanitation access are often assumed to be issues of low- and middle-income nations, over 400,000 homes in the United States still lack access to complete indoor plumbing. Previous research has demonstrated that the remaining plumbing challenges are more prevalent in communities with high Black and brown populations. This study hypothesizes that the 1930s practice of redlining by the Home Owners' Loan Corporation (HOLC), which systematically denied loans to minority populations, is linked to present-day inadequate plumbing access (i.e. defined as incomplete plumbing above the national average). Digitized HOLC maps for 202 urban areas across the country and US Census data from the 2016-2020 American Community Survey were combined to interpolate the modern-day plumbing access for historic neighborhoods (n=8871 communities). Analysis via binomial logistic regression demonstrated that nationally, redlined communities (HOLC Grade "D") are significantly more likely to have a rate of incomplete plumbing above the national average as compared to greenlined communities (HOLC Grade "A") (0.1352; CI= +0.036). This finding was also observed for three of the nation's four census sub-regions (Northeast, Midwest, West). Slight differences by region in relationships between the proportion of specific racial/ethnic populations on rates of incomplete plumbing demonstrate the need for targeted place-based interdisciplinary examinations of exclusionary practices. The demonstration of the present-day impacts of redlining after nearly 90 years emphasizes the need to intentionally mitigate past injustices to ensure modern-day equity.

Connections Between Present-Day Water Access and Historical Redlining

Charles Sterling

General Audience Abstract

Access to water is a prevailing issue in underserved communities. Over 400,000 homes in the United States still lack access to complete indoor plumbing. This condition is called incomplete plumbing which is defined by the US Census Bureau as not being able to use running water, or flush a toilet, or bath. Redlining is the historical practice of denying loans to homeowners in a certain area based on their race or economic status. Our study sought to discover whether redlining has negatively affected the presence of plumbing in homes. To do this we examined whether incomplete plumbing in 2020 was above the national average in areas that were previously redlined. We found that redlined communities are significantly more likely to have a rate of incomplete plumbing above the national average as compared to greenlined communities. The same trend was found in three of the nation's four census sub-regions (Northeast, Midwest, and West). These findings show that racist practices such as redlining have had a lasting effect on modern-day infrastructure such as plumbing.

Dedication

To my village,

Thank you for carrying me.

Table of Contents

List of Figures

List of Tables

Preface/ Attribution

Sterling III, C. W., Krometis, L. A., Pingel, T., & Winling, L. D. (2023). Connections Between Present-Day Water Access and Historical Redlining. *Environmental Justice*. https://doi.org/10.1089/env.2022.0115

1.0 Introduction

1.1 Background and Motivation

The United Nations established water access as a human right over a decade ago, with Sustainable Development Goal 6 (SDG6) calling for universal access to clean and safely managed drinking water and appropriate sanitation services by 2030 (United Nations Statistics Division, 2022). However, two billion people in the world today still live without access to this essential resource (Centers for Disease Control and Prevention, 2022). Although access to safe drinking water and sanitation services is often assumed to be primarily a concern for low- and middle-income countries (LMICs), there is recent and increasing attention on continuing issues of incomplete plumbing in high-income countries (HIC), particularly those in the United States, which are characterized by intensifying economic inequities (Meehan, Jepson, et al., 2020; Pew Research Center, 2020; United States Census Bureau, n.d.-a). The 2019 American Community Survey (ACS) estimated that over 400,000 occupied households in the United States still lack complete plumbing (United States Census Bureau, 2019); assuming an average household size of 2.61 people, this equates to more than 1 million Americans living in conditions that do not meet the stated goal of SDG6 (United States Census Bureau, 2021b). Under the current US Census definition, complete plumbing includes access to hot and cold running water, flush toilets, and bathtubs or showers (United States Census Bureau, n.d.-b).

Multiple examinations at the national and local scales suggest that incomplete plumbing in the United States is not only a function of local wealth inequalities but also strongly correlated with race and/or ethnicity (Balazs & Ray, 2014; Deitz & Meehan, 2019; Gasteyer et al., 2016;

Leker & Gibson, 2018; MacDonald Gibson et al., 2014; Mueller & Gasteyer, 2021). For example, a recent national examination by Muller and Gasteyer (2021) of plumbing access and Safe Drinking Water Act (SDWA) compliance determined that county levels of incomplete plumbing were significantly predicted by the Indigenous proportion of population, income, and poverty level (Mueller & Gasteyer, 2021). These findings concur with the national examination of Integrated Public Use Microdata Series (IPUMS) data by Deitz and Meehan (2019), who demonstrated that income, homeownership, and race/ethnicity were correlated with incomplete plumbing; that is, numbers of Black, Indigenous, and Hispanic or Latino households without complete plumbing access were higher than expected given representation within the national population (Deitz & Meehan, 2019).

Similar patterns linking decreases in safe water access and race/ethnicity have been observed at finer and more localized scales. Gibson *et al.* (2014) demonstrated that for every 10% increase in the Black population in Wake County, North Carolina, the probability of lacking municipal water services increased by over three percent (MacDonald Gibson et al., 2014). In a follow-up study, Lecker and Gibson (2018) identified historical practices of deliberate exclusion from municipal services to maintain racial segregation as a possible explanation for underserved peri-urban areas characterized by a higher proportion of lower-income Black populations (Leker & Gibson, 2018). Specifically naming a past exclusionary practice, Balazs and Ray (2014) noted that in San Joaquin Valley, California, the practice of redlining was used as a justification to not extend municipal infrastructure to underserved communities and that this past negligence is in part responsible for present-day inequities in water infrastructure (Balazs & Ray, 2014).

"Redlining" refers to the practice of divestment from certain communities based on economic, demographic, and environmental factors, and was formalized in the 1930s. Briefly, the Home Owners' Loan Corporation Act of 1933 created Home Owners' Loan Corporation (HOLC) to assist homeowners in attaining mortgages by providing loans at a reasonable rate. To ensure the security of these loans during the Great Depression, the HOLC collaborated with local real estate officials to map neighborhoods in each city according to the supposed risk of investment. Neighborhoods were graded on a system of "A" through "D," with "A" graded areas (green) labeled "Best"; "B" graded areas (blue) labeled "Still Desirable"; "C" graded areas (yellow) labeled "Definitely Declining," and "D" graded areas (red) labeled "Hazardous". Eventually known more commonly as "redlining", this practice evolved into *de jure* segregation as realtors attempted to group similar races together to maintain "racial harmony" (Greer, 2013; Rothstein, 2017). Together with measures such as racially restrictive covenants, redlining excluded African Americans from city neighborhoods and withheld investment from predominantly Black neighborhoods. This led to crowded conditions and apartment conversions in many urban neighborhoods that provided housing units for Black residents but often lacked services such as adequate plumbing. Through this process, individual discriminatory views were embedded in public policy and became structural forms of discrimination (Hirsch, 1998).

Although established nearly 90 years ago, an increasing number of studies have demonstrated that redlining continues to define the demographics of many American cities. For example, a study by Aaronson *et al.* (2020) of 149 US cities demonstrated that before the creation of HOLC maps, Black Americans made up, on average, nearly 15% of the population in "D" neighborhoods. By 1980, the average population of Black Americans had grown to more than 45% in "D" neighborhoods (Aaronson et al., 2020). There is also compelling evidence that redlining continues to negatively impact economically disadvantaged minority populations across the country. In their analysis of 58 redlined areas, Appel and Nickerson (2016) reported that properties in redlined neighborhoods were worth nearly 5% less than properties in adjacent neighborhoods (Appel & Nickerson, 2016). Similarly, Nardone *et al.* (2020) used 2010 census data to demonstrate that redlined neighborhoods had significantly lower median household incomes than greenlined areas ($39,800 vs. $61,200) (Nardone, Chiang, et al., 2020). Additionally, in an examination of 115 cities where neighborhoods had been assessed by the HOLC, Mitchell and Richardson (2018) determined that while over 90% of the greenlined areas were middle-upper income areas, over 70% of the redlined areas were lower-middle-income areas (Mitchell & Richardson, 2018).

Not surprisingly, the labeling of neighborhoods as declining or hazardous influences infrastructure investments within cities, which in turn can impact environmental health. For example, the EPA defines urban heat islands (UHIs) as areas where impervious surfaces are prevalent and greenspace is scarce, causing higher temperatures compared to surrounding areas. This is an issue of growing health concern as over 700 deaths occur annually in the US due to elevated temperatures (Vaidyanathan et al., 2020). Hoffman *et al.* (2020) recently used Landsat-derived land surface temperature (LST) maps within 108 US urban locations to examine the occurrence of urban heat island effects in redlined neighborhoods. Nationally, “D” graded areas were nearly 3 degrees Celsius warmer than “A” graded areas; this difference was statistically significant (Hoffman et al., 2020). Although multiple studies have documented the positive effects of community green spaces, including reductions in heat, crime, and improved stormwater management (Du et al., 2017; Gaffin et al., 2006; Huang et al., 2018; Kondo et al., 2015), recent work by Nowak et al. examining 30 urban areas in the United States demonstrated that HOLC-designated “D” neighborhoods had nearly 20% less tree cover and over 20% more impervious surface than grade “A” neighborhoods (Nowak et al., 2022).

1.2 Research Hypothesis

Previous research has demonstrated the influence of race/ethnicity on incomplete plumbing, as well as research confirming likely links between the redlining practices of nearly a century ago, and present-day infrastructure and environmental health disparities (Krieger, van Wye, et al., 2020; Krieger, Wright, et al., 2020; Nardone, Casey, et al., 2020). We, therefore, hypothesize here that areas of present-day incomplete plumbing within United States cities (i.e., communities with a proportion of homes lacking complete plumbing above the national average) are significantly associated with HOLC neighborhood designations. To test this hypothesis and explore potential implications, we applied a geospatial technique to link historical redlining maps with present-day (2020) census housing and demographic data. Understanding the relative influence of past structural racist practices on present-day disparities is an essential first step in correcting past injustice and prioritizing the extension of in-home safe water and sanitation access to all Americans.

1.3 Organization of Thesis

This thesis is organized around a manuscript published in *Environmental Justice* on August 11th 2023 (reference it here). While the manuscript encompasses the bulk of this thesis. The latter part of this document outlines conclusions drawn and a possible direction for future research, including possible methods and data sources. The appendix of this document includes alternative analysis that were explored.

2.0 Connections between present day water access and historical redlining

2.1 Abstract

Although challenges in water and sanitation access are often assumed to be issues of low- and middle-income nations, over 400,000 homes in the United States still lack access to complete indoor plumbing. Previous research has demonstrated that the remaining plumbing challenges are more prevalent in communities with high Black and brown populations. This study hypothesizes that the 1930s practice of redlining by the Home Owners' Loan Corporation (HOLC), which systematically denied loans to minority populations, is linked to present-day inadequate plumbing access (i.e. defined as incomplete plumbing above the national average). Digitized HOLC maps for 202 urban areas across the country and US Census data from the 2016-2020 American Community Survey were combined to interpolate the modern-day plumbing access for historic neighborhoods (n=8871 communities). Analysis via binomial logistic regression demonstrated that nationally, redlined communities (HOLC Grade "D") are significantly more likely to have a rate of incomplete plumbing above the national average as compared to greenlined communities (HOLC Grade "A") (0.1352; CI= +0.036). This finding was also observed for three of the nation's four census sub-regions (Northeast, Midwest, West). Slight differences by region in relationships between the proportion of specific racial/ethnic populations on rates of incomplete plumbing demonstrate the need for targeted place-based interdisciplinary examinations of exclusionary practices. The demonstration of the present-day impacts of redlining after nearly 90 years emphasizes the need to intentionally mitigate past

injustices to ensure modern-day equity.

2.2 Introduction

The United Nations established water access as a human right over a decade ago, with Sustainable Development Goal 6 (SDG6) calling for universal access to clean and safely managed drinking water and appropriate sanitation services by 2030 (United Nations Statistics Division, 2022). However, two billion people in the world today still live without access to this essential resource (Centers for Disease Control and Prevention, 2022). Although access to safe drinking water and sanitation services is often assumed to be primarily a concern for low- and middle-income countries (LMICs), there is recent and increasing attention on continuing issues of incomplete plumbing in high-income countries (HIC), particularly those in the United States, which are characterized by intensifying economic inequities (Meehan, Jepson, et al., 2020; Pew Research Center, 2020; United States Census Bureau, n.d.-a). The 2019 American Community Survey (ACS) estimated that over 400,000 occupied households in the United States still lack complete plumbing (United States Census Bureau, 2019); assuming an average household size of 2.61 people, this equates to more than 1 million Americans living in conditions that do not meet the stated goal of SDG6 (United States Census Bureau, 2021b). Under the current US Census definition, complete plumbing includes access to hot and cold running water, flush toilets, and bathtubs or showers (United States Census Bureau, n.d.-b).

Multiple examinations at the national and local scales suggest that incomplete plumbing in the United States is not only a function of local wealth inequalities but also strongly correlated with race and/or ethnicity (Balazs & Ray, 2014; Deitz & Meehan, 2019; Gasteyer et al., 2016;

Leker & Gibson, 2018; MacDonald Gibson et al., 2014; Mueller & Gasteyer, 2021). For example, a recent national examination by Muller and Gasteyer (2021) of plumbing access and Safe Drinking Water Act (SDWA) compliance determined that county levels of incomplete plumbing were significantly predicted by the Indigenous proportion of population, income, and poverty level (Mueller & Gasteyer, 2021). These findings concur with the national examination of Integrated Public Use Microdata Series (IPUMS) data by Deitz and Meehan (2019), who demonstrated that income, homeownership, and race/ethnicity were correlated with incomplete plumbing; that is, numbers of Black, Indigenous, and Hispanic or Latino households without complete plumbing access were higher than expected given representation within the national population (Deitz & Meehan, 2019).

Similar patterns linking decreases in safe water access and race/ethnicity have been observed at finer and more localized scales. Gibson *et al.* (2014) demonstrated that for every 10% increase in the Black population in Wake County, North Carolina, the probability of lacking municipal water services increased by over three percent (MacDonald Gibson et al., 2014). In a follow-up study, Lecker and Gibson (2018) identified historical practices of deliberate exclusion from municipal services to maintain racial segregation as a possible explanation for underserved peri-urban areas characterized by a higher proportion of lower-income Black populations (Leker & Gibson, 2018). Specifically naming a past exclusionary practice, Balazs and Ray (2014) noted that in San Joaquin Valley, California, the practice of redlining was used as a justification to not extend municipal infrastructure to underserved communities and that this past negligence is in part responsible for present-day inequities in water infrastructure (Balazs & Ray, 2014).

“Redlining” refers to the practice of divestment from certain communities based on economic, demographic, and environmental factors, and was formalized in the 1930s. Briefly, the Home Owners' Loan Corporation Act of 1933 created Home Owners' Loan Corporation (HOLC) to assist homeowners in attaining mortgages by providing loans at a reasonable rate. To ensure the security of these loans during the Great Depression, the HOLC collaborated with local real estate officials to map neighborhoods in each city according to the supposed risk of investment. Neighborhoods were graded on a system of "A" through "D," with "A" graded areas (green) labeled "Best"; "B" graded areas (blue) labeled "Still Desirable"; "C" graded areas (yellow) labeled "Definitely Declining," and "D" graded areas (red) labeled "Hazardous". Eventually known more commonly as "redlining", this practice evolved into *de jure* segregation as realtors attempted to group similar races together to maintain "racial harmony" (Greer, 2013; Rothstein, 2017). Together with measures such as racially restrictive covenants, redlining excluded African Americans from city neighborhoods and withheld investment from predominantly Black neighborhoods. This led to crowded conditions and apartment conversions in many urban neighborhoods that provided housing units for Black residents but often lacked services such as adequate plumbing. Through this process, individual discriminatory views were embedded in public policy and became structural forms of discrimination (Hirsch, 1998).

Although established nearly 90 years ago, an increasing number of studies have demonstrated that redlining continues to define the demographics of many American cities. For example, a study by Aaronson *et al.* (2020) of 149 US cities demonstrated that before the creation of HOLC maps, Black Americans made up, on average, nearly 15% of the population in "D" neighborhoods. By 1980, the average population of Black Americans had grown to more than 45% in "D" neighborhoods (Aaronson et al., 2020). There is also compelling evidence that redlining continues to negatively impact economically disadvantaged minority populations across the country. In their analysis of 58 redlined areas, Appel and Nickerson (2016) reported that properties in redlined neighborhoods were worth nearly 5% less than properties in adjacent neighborhoods (Appel & Nickerson, 2016). Similarly, Nardone *et al.* (2020) used 2010 census data to demonstrate that redlined neighborhoods had significantly lower median household incomes than greenlined areas ($39,800 vs. $61,200) (Nardone, Chiang, et al., 2020). Additionally, in an examination of 115 cities where neighborhoods had been assessed by the HOLC, Mitchell and Richardson (2018) determined that while over 90% of the greenlined areas were middle-upper income areas, over 70% of the redlined areas were lower-middle-income areas (Mitchell & Richardson, 2018).

Not surprisingly, the labeling of neighborhoods as declining or hazardous influences infrastructure investments within cities, which in turn can impact environmental health. For example, the EPA defines urban heat islands (UHIs) as areas where impervious surfaces are prevalent and greenspace is scarce, causing higher temperatures compared to surrounding areas. This is an issue of growing health concern as over 700 deaths occur annually in the US due to elevated temperatures (Vaidyanathan et al., 2020). Hoffman *et al.* (2020) recently used Landsat-derived land surface temperature (LST) maps within 108 US urban locations to examine the occurrence of urban heat island effects in redlined neighborhoods. Nationally, “D” graded areas were nearly 3 degrees Celsius warmer than “A” graded areas; this difference was statistically significant (Hoffman et al., 2020). Although multiple studies have documented the positive effects of community green spaces, including reductions in heat, crime, and improved stormwater management (Du et al., 2017; Gaffin et al., 2006; Huang et al., 2018; Kondo et al., 2015), recent work by Nowak et al. examining 30 urban areas in the US demonstrated that HOLC-designated “D” neighborhoods had nearly 20% less tree cover and over 20% more impervious surface than grade “A” neighborhoods (Nowak et al., 2022).

Given significant previous research demonstrating the influence of race/ethnicity on incomplete plumbing, as well as research confirming likely links between the redlining practices of nearly a century ago and present-day infrastructure and environmental health disparities (Krieger, van Wye, et al., 2020; Krieger, Wright, et al., 2020; Nardone, Casey, et al., 2020), we hypothesize here that areas of present-day incomplete plumbing within US cities (i.e., communities with a proportion of homes lacking complete plumbing above the national average) are significantly associated with HOLC neighborhood designations. To test this hypothesis and explore potential implications, this study applies a geospatial technique to link historical redlining maps with present-day (2020) census housing and demographic data. Understanding the relative influence of past structural racist practices on present-day disparities is an essential first step in correcting past injustice and prioritizing the extension of in-home safe water and sanitation access to all Americans.

2.3 Materials and Methods

The present work merged geospatial data from two sources:1) the Mapping Inequality database (University of Richmond)(Nelson et al., n.d.) and 2) the 2016-2020 American Community Survey Census Data (United States Census Bureau)(United States Census Bureau, n.d.-a). The Mapping Inequality database consists of digitized HOLC maps for 202 locations in the United States. In brief, digitized HOLC boundaries are available as downloadable shapefiles with accompanying metadata describing the neighborhood name, HOLC grade (“A”- “E”), and area description when available (Figure 2-1). The definitions of HOLC boundaries within this database have been previously used to examine air pollution, late-stage cancer diagnosis, and emergency room visits in peer-reviewed manuscripts (Krieger, Wright, et al., 2020; Lane et al., 2022; Nardone, Casey, et al., 2020). Data downloaded from the 2016-2020 American

Community Survey (ACS) included plumbing facilities, homeownership, poverty status, race, ethnicity, country of origin, mobile home units, and age of house construction at the block group level. The plumbing facilities data was separated into two categories: incomplete plumbing as defined earlier and complete plumbing. As stated previously, within this dataset, complete plumbing is defined as access to hot and cold running water, flush toilets, and bathtubs or showers.

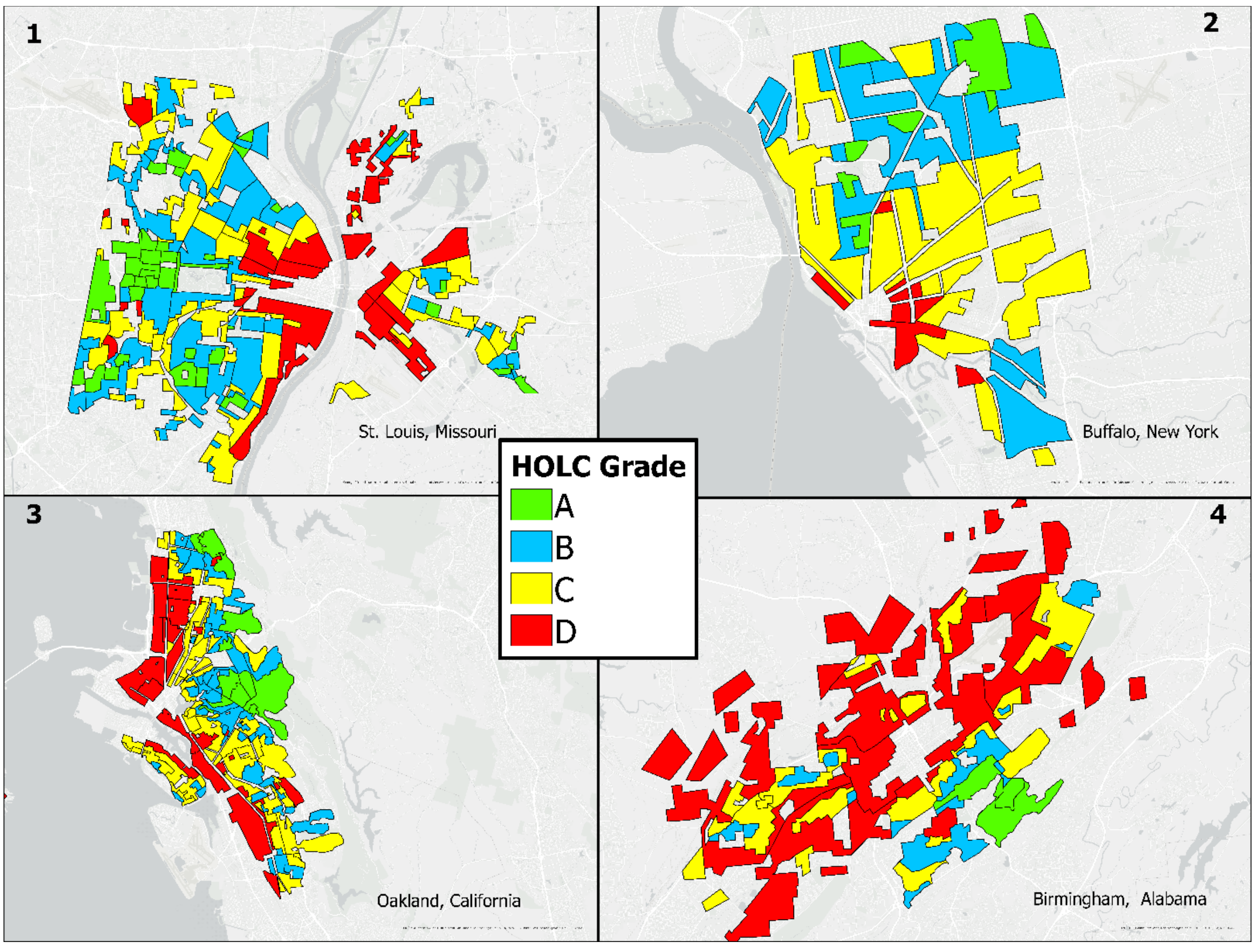

Figure 1: Example HOLC security maps for each of the four US Census designated regions: (1) Midwest: St. Louis, Missouri (2) Northeast: Buffalo, New York (3) West: Oakland, California (4) South: Birmingham, Alabama

To account for the incongruous geometry between census block groups and HOLC polygons (i.e., communities), simple areal interpolation was used to assign values to the HOLC polygons. Areal interpolation (Goodchild et al., 1993; Goodchild & Siu-Ngan Lam, 1980; I. N. Gregory, 2002) is a widely-used and effective method to allow for geospatial analysis of socioeconomic data when areal units differ (Freeman et al., 2017; Mugglin et al., 2000; Wardrop et al., 2018), and has been used to support HOLC-based analysis specifically (Fricker & Allen, 2022; Ian N. Gregory & Healey, 2007). Areal interpolation was converted to a Python package that was accessible after creating a Python environment on Jupyter Notebook 6.4.5 (*GitHub - Pysal/Tobler: Spatial Interpolation, Dasymetric Mapping, & Change of Support*, n.d.). Using this method, quantitative values were determined for relevant census parameters (e.g., total population and total incomplete plumbing) in each HOLC neighborhood. The resulting shapefiles were then combined using ArcGIS Pro 2.9.2.

Potential relationships between HOLC grade and plumbing status were examined via binary logistic regression. This model can predict the likelihood of one of the two events occurring based on prespecified predictors (Harrell, 2015). To increase power, and in keeping with recent work by Meehan et al. (2020) (Meehan, Jurjevich, et al., 2020), incomplete plumbing was transformed into a binary dependent variable: (1) a higher percentage of unplumbed houses than the national average (0.3%) or (0) neighborhoods with a value lower than 0.3. Our chosen regression outputs logarithmic odds as a result. To make results more meaningful, the average marginal effects of each variable on the model were calculated using the “margins” package in R. The average marginal effect (AME) of a variable is the percentage change in the probability when a variable is changed by one increment and all other variables are held constant. This method is commonly used for the results of logistic regressions (Norton et al., 2019).

To limit the number of explanatory variables, house age, which is given by the census as a 10-year range, was separated into two periods, pre- and post-1980. This year was selected as the breakpoint given the passing of the US Safe Drinking Water Amendments commonly referred to as the "Lead Ban" which occurred just prior. The dependent variable for the first model was a binary variable for plumbing. The independent variables were HOLC grade and (all in %): Black population, Hispanic or Latino population, residents below the poverty line, mobile homes, houses built in 1980 or newer, rented housing units, Indigenous population, and foreign-born population. A stepwise function was used to eliminate highly correlated variables and to reduce multicollinearity in the model. Both backward and forward elimination were used to determine the significant parameters that should be included in the final model (Venables & Ripley, 2002). The stepAIC package in R studio was used to conduct this analysis. As expected, % White population % was heavily negatively correlated with % Black population (r = -0.85) and was therefore removed from the model (Figure 2-2). We used HOLC Grade A as the reference group in keeping with recent work by Krieger et al 2020; it is worth noting that the proportion of incomplete plumbing did differ significantly between grades (Dunn's Test, p=2.10E-03, 6.09E-28, 7.25E-85; see Table A1) (Krieger, van Wye, et al., 2020).

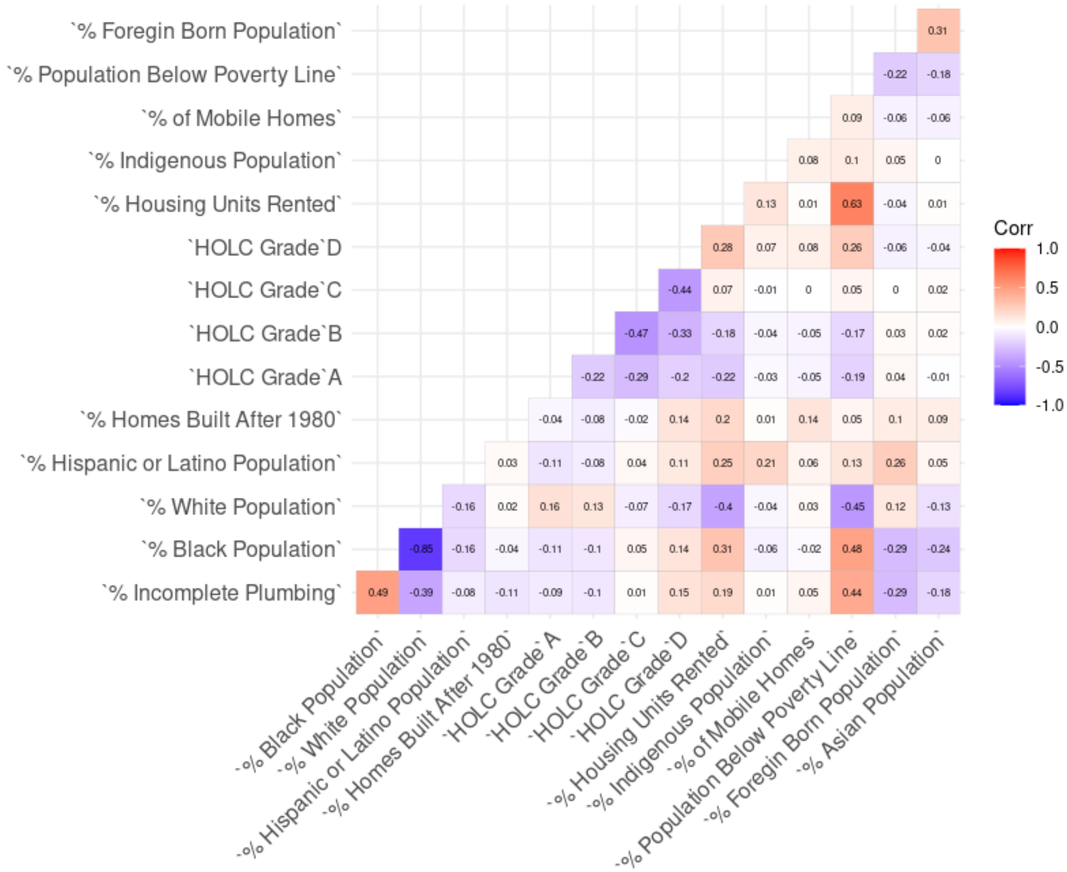

Figure 2: Correlation plot for potential predictive variables.

In addition to a national analysis, the data were also separated according to the four US Census regions (Northeast, Midwest, South, and West) with binary logistic regression performed independently for each region to explore potential regional differences. Three records from the national dataset were deleted from the model analysis because of missingness (not available/zero population). In the process of separating the data into four regions, one polygon was deleted because it fell between the regions. It is also important to note that polygons assigned HOLC Grade "E" were not considered in the full analysis (4 communities out of a total of 8878). HOLC Grade "E" was assigned to some majority Black neighborhoods before the standardization of the grades and was eventually phased out of the grading system (Michney, 2021). Removing HOLC Grade “E” reduced the amount of “noise” in the model, increasing its statistical power.

Because the average rate of incomplete plumbing within our 202 metropolitan area dataset was higher than the national average of 0.3% (2.61%; see Table A2 and varied between the four Census subregions (from 3.76% in the Midwest region to 0.78% in the West region), we also conducted the same analyses described using these average values as “breakpoints” defining below/above average incomplete plumbing nationally and for each region. In order to maintain uniformity throughout analysis, we primarily focus our discussion of the results using 0.3% (the national average) as the breakpoint, as results using regional specific breakpoints did not alter many findings of significance for the predictive variables (Tables A3-A7; see Results section).

2.4 Results

The results from the national-level analysis echo previous research: a higher % of Black, Indigenous, and Hispanic or Latino populations, as well as higher household poverty, was significantly associated with a level of incomplete plumbing above the national average of 0.3% when holding HOLC grade constant (0.0044, 0.0186, 0.0012, and 0.0066; CI= ($\pm$0.001, $\pm$0.009, $\pm$0.001, and $\pm$0.001) respectively (Figure 2-3). Elevated incomplete plumbing was also significantly associated with HOLC designations C and D on a national scale after holding all other variables constant (0.0477 and 0.1352; CI = ($\pm$0.032 and $\pm$ 0.036)) respectively (Table 1). These designations were also significant when using the overall average observed for these 202 urban areas (2.61%) as the breakpoint defining an elevated rate of incomplete plumbing (Table A3).

Table 2-1: Average Marginal Effects (i.e., change in probability for a 1% change in each variable) as determined via the binary logistic regression model. Grade A was used as comparison baseline for statistical analysis of the HOLC grades. “Not significant” indicates that the variable was included in the model (i.e., increased predictive capacity), but its result was not statistically significant. “Not in model” indicates that a variable was excluded from that model to reduce multicollinearity.

Variables	**National (n=8871)**	**Northeast (n=2460)**	**South (n=1893)**	**Midwest (n=3237)**	**West (n=1283)**
Black population %	0.0044 (±0.001)***	0.0052 (±0.002)***	0.0041 (±0.001)***	0.0036 (±0.001)**	*Not in model*
Indigenous population %	0.0186 (±0.009)***	0.0643 (±0.035)***	*Not in model*	0.0289 (±0.021)**	0.0242 (±0.017)**
Asian population %	-0.0012 (±0.001)*	0.0014 (±0.002)	-0.0136 (±0.007)***	-0.0029 (±0.003)	*Not in model*
Hispanic or Latino population %	0.0012 (±0.001)***	*Not in model*	0.0016 (±0.001)**	0.0021 (±0.001)***	0.0028 (±0.001)***
Foreign Born population %	-0.0011 (±0.000)***	-0.0015 (±0.001)**	*Not in model*	-0.0006 (±0.001)*	*Not in model*
% Below the Poverty Line	0.0066 (±0.001)***	0.0109 (±0.003)***	0.0024 (±0.002)*	0.0072 (±0.002)***	*Not in model*
% of Housing Units Rented	0.0017 (±0.001)***	0.0019 (±0.001)***	0.0013 (±0.001)	0.0025 (±0.001)***	*Not in model*
% of Mobile Homes	0.0045	*Not in model*	0.0367	*Not in model*	*Not in model*

	(+0.004)*		(+0.017)***		
% of Houses Built in 1980 or later	-0.0032 (+0.001)***	-0.0026 (+0.002)**	0.0042 (+0.001)***	-0.0022 (+0.002)**	*Not in model*
HOLC Grade					
B	0.001 (+0.032)	0.0598 (+0.062)	-0.0532 (+0.061)	0.0186 (+0.053)	-0.0267 (+0.088)
				0.0599	0.0306 (+0.087)
C	0.0477 (+0.032)**	0.1131 (+0.062)***	-0.0446 (+0.059)	(+0.052)*	0.2013 (+0.100)***
				0.1376	
D	0.1352 (+0.036)***	0.1574 (+0.070)***	0.0523 (+0.064)	(+0.058)***	
Significance codes: *** p<0.001, ** p <0.01, * p<0.05					

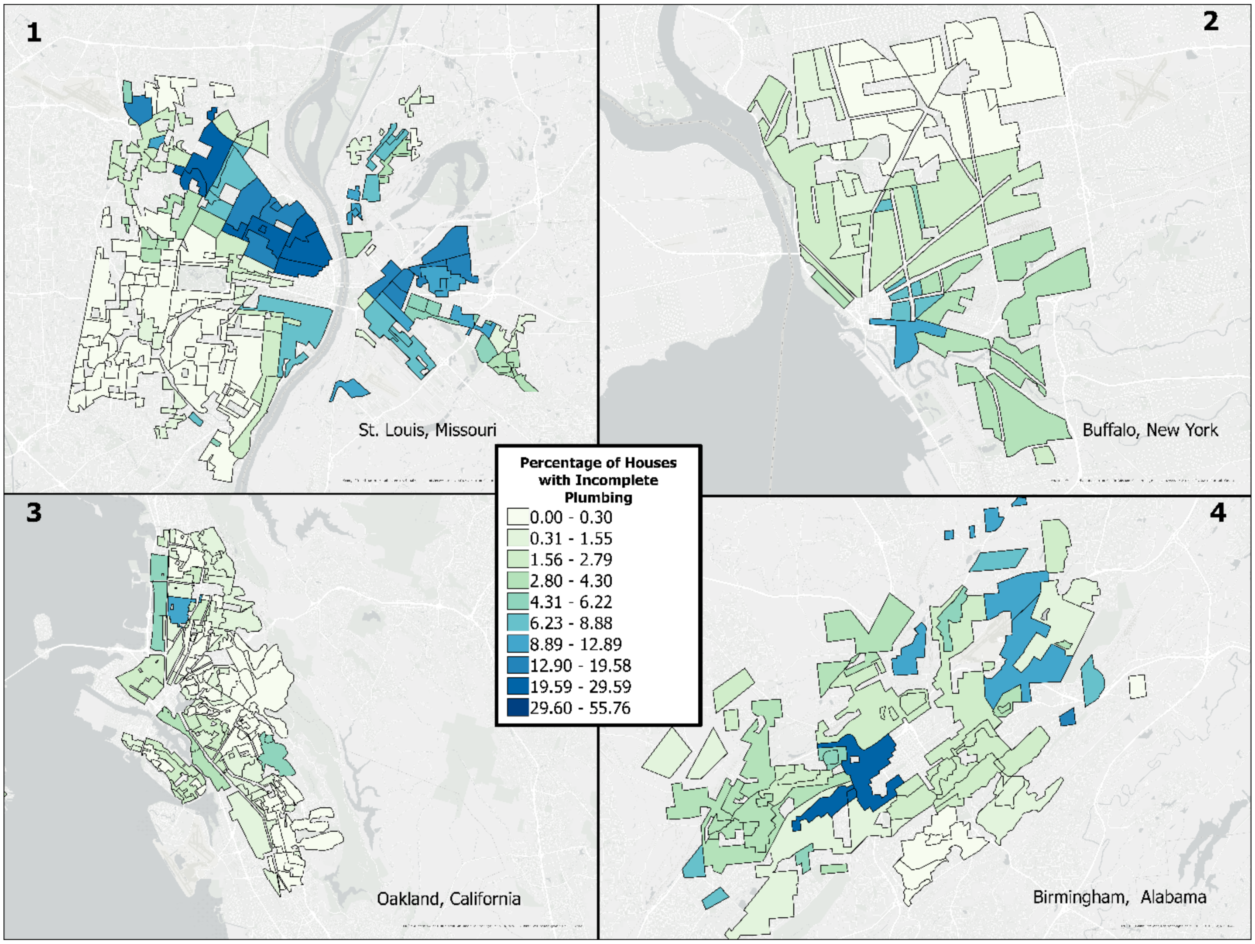

Figure 3: Example maps for each of the four US Census designated regions: (1) Midwest: St. Louis, Missouri (2) Northeast: Buffalo, New York (3) West: Oakland, California (4) South: Birmingham, Alabama created using Areal Weighted Interpolation. Each map displays the % of Households without complete plumbing within each HOLC neighborhood.

Results from the regional analysis yielded similar relationships between HOLC designation and incomplete plumbing for the Northeast and Midwest, although only HOLC designation D was significantly predictive in the West (Table 1). HOLC designation was not related to higher rates of incomplete plumbing in the South, regardless of whether national (Table 1) or local dataset breakpoints (Table S5) were used, which was unexpected. An increase in percent Black population was associated with an increased probability of higher levels of incomplete plumbing for the South, Northeast, and Midwest, in keeping with national results (0.0041, 0.0052, and 0.0036; CI= (± 0.001, ±0.002, ± 0.001)) respectively. These results were consistent regardless of whether the overall national average of 0.3% lacking indoor plumbing (Table 1) or local data set breakpoints (Tables A4-A6), were used. The percentage of the Indigenous population was associated with an increased probability of incomplete plumbing for all regions, Northeast, Midwest, and West (0.0643, 0.0289, and 0.0242; CI = (± 0.035, ±0.021, ± 0.017)), except the South, where it was not included in the model due to multicollinearity (AIC =1862 in the original model and 1856 in the stepwise model); when using local dataset breakpoints, it was also not included in the Midwest.

Although the percentage of mobile homes in a neighborhood was significantly positively correlated with elevated incomplete plumbing nationally, in the regional analysis, this relationship only remained for the South (Table 1). This relationship was unchanged when using local dataset breakpoints. Both an increase in the percentage of houses built after 1980 and a decrease in the percentage of the population below the poverty line increased the probability of a higher rate of complete plumbing for all regions except the West, where it was not included in the model (AIC =1521.8 in the original model and 1511.7 in the stepwise model).

2.5 Discussion

The results presented in Table 1 demonstrate a relationship between the redlining practices of the 1930s and present-day incomplete plumbing on a national scale; that is, over 90 years later, community HOLC designations (particularly designations C and D) still impact the modern-day living conditions of those who live there. Notably, Black population had the highest correlation to HOLC Grade “D” (r = 0.14) while White population had the lowest (r = -0.17)

(Figure 2-2). Black population was also associated with elevated incomplete plumbing in most of the models (Table 7). This finding is in keeping with our original hypothesis and is not surprising given that the practice of redlining specifically targeted Black Americans and that previous work has demonstrated tangible evidence of present-day economic and health inequities in redlined communities (Aaronson et al., 2020; Appel & Nickerson, 2016; Krieger, Wright, et al., 2020; Nardone, Chiang, et al., 2020).

Although the establishment of the HOLC and practice of redlining is most associated with marginalization and disinvestment in predominantly Black communities, it is worth noting that the effect of Indigenous population % on the probability of elevated incomplete plumbing was higher than any other demographic variable, while holding all other variables constant (Table 1). This is in keeping with national and more localized examinations of the interactions between race/ethnicity and water injustice in the United States. For example, Deitz and Meehan (2019) reported that Indigenous households are over three times more likely than average American households to have incomplete plumbing (Deitz & Meehan, 2019).

Application of the model to each of the four Census designated regions revealed significant relationships between HOLC designations and present-day incomplete plumbing in all regions, with the exception of the South. This result was initially surprising, given that struggles against slavery, segregation, and structural racism are perhaps the most well-documented for this region. However, it is worth noting that the South had a larger amount of HOLC Grade D polygons compared to other regions (Table 2). This most likely weakened the statistical power of this model to assess the relationship between redlining and elevated incomplete plumbing.

Table 2-2: The number of each grade polygon in each dataset. The percent of the total dataset that this number accounts for is in parenthesis.

	National (n=8871)	**Northeast (n=2460)**	**South (n=1893)**	**Midwest (n=3237)**	**West (n=1283)**
Grade A Polygons	1040 (11.72)	281 (11.42)	240 (12.68)	346 (10.69)	173 (13.48)
Grade B Polygons	2332 (26.29)	702 (28.54)	470 (24.83)	775 (23.94)	385 (30.01)
Grade C Polygons	3381 (38.11)	935 (38.01)	659 (34.81)	1308 (40.41)	479 (37.33)
Grade D Polygons	2118 (23.88)	542 (22.03)	524 (27.68)	808 (24.96)	246 (19.17)

Regional differences in the relationships between specific races/ethnicities and higher levels of incomplete plumbing may reflect regional differences in demographics. Notably, the highest decrease in the probability of having an average or lower than average incomplete plumbing for the Hispanic or Latino population was observed in the American West, which may reflect denser areas of the Hispanic or Latino population 0.0028 (±0.001). While 18.9% of the population is Hispanic or Latino nationally, four of the five states with the highest Hispanic or Latino populations are in the West (New Mexico: 50%, California: 40%, Arizona: 32%, Nevada: 29) (United States Census Bureau, 2021a). Interestingly, % Foreign Born was associated with a decrease in incomplete plumbing, that is, a higher percentage of foreign-born was significantly predictive of communities with higher complete plumbing than the national average, at the national level, and specifically for the Northeast and Midwest. This may reflect regional differences in demographics.

Although the history of redlining has previously been used as a lens to examine the historical causes of other present-day inequalities, including environmental health, to the best of our knowledge, this is the first study to explicitly examine the potential effects on water infrastructure, though previous publications have hypothesized a connection (Balazs & Ray, 2014; Brown et al., 2023). When considering the relevance of this effort to ongoing discussions of water inequities within the United States, several key inherent methodological limitations must be considered. As previously mentioned, the examination was limited to available digitized HOLC maps. The original goal of HOLC was to increase economic growth in urban areas (Winling & Michney, 2021). Therefore, the work does not consider incomplete rural plumbing, which previous national examinations suggest is of significant concern (Mueller & Gasteyer, 2021). The US Regions are not as finite as census block groups, resulting in the loss of five polygons (communities). It is worth noting that while it appears that redlining did significantly influence infrastructure development, it was likely not the sole cause, and instead part of a myriad of interconnected drivers including local political histories, landscapes, available technology, economic opportunities, and justice movements. Future transdisciplinary efforts linking historical examinations of infrastructure development at the individual city scale considering all of these factors are encouraged in order to identify necessary strategies to reduce these disparities.

2.6 Conclusion

The results of this analysis support our initial hypothesis that the 1930s practice of redlining significantly impacts access to plumbing in present-day America: when historical HOLC boundaries are applied to modern-day Census block groups, present-day plumbing status is dependent on whether the neighborhood was designated as "less desirable" or "hazardous" (i.e., HOLC Grades "C" and "D"), holding all demographic variables and other HOLC Grades in the model constant. This trend was consistent for the Northeast, Midwest, and West Regions, although the influence of specific minority populations differed, perhaps because of regional differences in demographics and urbanicity.

Although this work adds compelling evidence of how redlining continues to shape the demographics, wealth, natural resources, and health of present American communities, significant questions remain and demand an interdisciplinary approach. The history of the implementation and impact of redlining can be localized: understanding the decision-making, process, and experience of infrastructure exclusion within individual cities will require shared examinations by historians, economists, urban planners, and engineers (Rothstein, 2017). Understanding potential shifts in the impacts of HOLC designation on community infrastructure access over time, rather than solely comparing to present-day metrics, may yield insights into how past socioeconomic movements and stressors contributed to the persistence of this structural inequity.

Although the Flint, MI lead crisis captured public attention in 2014 (Teodoro et al., 2022) and led to increasing public and academic awareness of present-day water inequity within the United States (Deitz & Meehan, 2019; Mueller & Gasteyer, 2021), new water crises within predominantly Black cities continue to emerge(Felton, 2022; Ganim, 2018; Portnoy, 2022;

Smith, 2021). Historical evidence has made clear that the divestment from communities of color was intentional. Policies were put in place to increase the gap of equity between racial groups (Brown et al., 2023; Carrera & Flowers, 2018; Gaber, 2021). Identifying both present-day and historical political, economic, and sociological forces that contribute to these crises is critical to the design of just, sustainable, and long-term equitable solutions to ensure high-quality and affordable access to water and sanitation services. Awareness of the impacts of redlining on community development, as well as the identification of neighborhoods that continue to suffer its consequences, is essential to prioritize future infrastructure investment. While federal level funding and oversight are necessary, decisions related to infrastructure and housing investment are likely best led at the local level and must include those within marginalized communities.

3.0 Possible direction for future research

Meehan et. al, (2021) tracked plumbing trends over time from 2000 to 2017. Their findings revealed that two major United States cities, Portland, and San Francisco, had worsening plumbing access over this time period. Plumbing data is available from the Census starting in 1940. This begs the question, how has redlining impacted plumbing access in the past nine decades? To examine this, one must consider what Census data are available from these records and their reliability (Meehan et al., 2021). Additionally, census block groups are not available as far back as 1950, so census tracts must be used. After an exploration into available census data, we found that black population, plumbing access, and homeownership would be the best variables to consider. There are twelve cities whose census tracts encompass the neighborhoods from the mapping inequality database: Flint, Cleveland, Los Angeles, Indianapolis, New York, Hartford, Macon, St. Louis, Savannah, Des Moines, Duluth, San Fransisco, and Oklahoma City. Given that total population for each variable was not available, density of target populations is an option to consider.

Geospatial analysis may be completed using pycnophylactic interpolation, a method developed by Waldo Tobler, was used (Tobler, 1979) to resolve dissimilar geometries. This method calculates the most probable values for overlapping areas based on multiple iterations. Unlike other interpolation methods, volume of data is preserved meaning existing values are reallocated across the region(Comber & Zeng, 2019; Tobler, 1979). At the end of the process, the sum of interpolated values in each polygon or region equals the sum of original values. Pycnophylactic interpolation has been implemented as a Python package that is accessible after creating a Python environment on Jupyter Notebook 6.4.5. Population density being a key part of analysis makes it important to preserve the original total as much as possible.

Statistical trend analysis can be used to examine how redlining's impact has fluctuated over time. This process would evaluate the change in probability across the 9 decades and additionally highlight years where monumental legislatures were passed. This would provide information on whether the results observed during the current study were an anomaly or part of a larger trend. It may also be useful to examine the impact of the legislature on the influence of redlining on water infrastructure. Understanding these two points may assist in further analysis of policies and their lasting impacts. It may also be interesting to study how long after policies have changed do conditions improved. This analysis would need to include variables that may also explained improved conditions such as homeownership and median household income.

3.1 References

Aaronson, D., Hartley, D., Revised, B. M., Mazumder, B., Boustan, L., Collins, B., Fishback, P., Keys, B., Lin, J., Molloy, R., Neal, D., Shertzer, A., Twinam, T., Walsh, R., Greer, J., & Winling, L. (2020). *The Effects of the 1930s HOLC "Redlining" Maps The Effects of the 1930s HOLC "Redlining" Maps* ☐.

Appel, I., & Nickerson, J. (2016). *Pockets of Poverty: The Long-Term Effects of Redlining*. https://ssrn.com/abstract=2852856Electroniccopyavailableat:https://ssrn.com/abstract=2852856

Balazs, C. L., & Ray, I. (2014). The Drinking Water Disparities Framework: On the Origins and Persistence of Inequities in Exposure. *American Journal of Public Health*, *104*(4), 603–611. https://doi.org/10.2105/AJPH.2013.301664

Brown, J., Acey, C. S., Anthonj, C., Barrington, D. J., Beal, C. D., Capone, D., Cumming, O., Pullen Fedinick, K., MacDonald Gibson, J., Hicks, B., Kozubik, M., Lakatosova, N., Linden, K. G., Love, N. G., Mattos, K. J., Murphy, H. M., & Winkler, I. T. (2023). The effects of racism, social exclusion, and discrimination on achieving universal safe water and sanitation in high-income countries. *The Lancet Global Health*, *11*(4), e606–e614. https://doi.org/10.1016/s2214-109x(23)00006-2

Carrera, J. S., & Flowers, C. C. (2018). Sanitation Inequity and the Cumulative Effects of Racism in Colorblind Public Health Policies. *American Journal of Economics and Sociology*, *77*(3–4), 941–966. https://doi.org/10.1111/ajes.12242

Centers for Disease Control and Prevention. (2022, May 21). *Global WASH Fast Facts | Global Water, Sanitation and Hygiene | Healthy Water*. https://www.cdc.gov/healthywater/global/wash_statistics.html

Comber, A., & Zeng, W. (2019). Spatial interpolation using areal features: A review of methods and opportunities using new forms of data with coded illustrations. *Geography Compass*, *13*(10), e12465. https://doi.org/10.1111/GEC3.12465

Deitz, S., & Meehan, K. (2019). Plumbing Poverty: Mapping Hot Spots of Racial and Geographic Inequality in U.S. Household Water Insecurity. *Annals of the American Association of Geographers*. https://doi.org/10.1080/24694452.2018.1530587

Du, H., Cai, W., Xu, Y., Wang, Z., Wang, Y., & Cai, Y. (2017). Quantifying the cool island effects of urban green spaces using remote sensing Data. *Urban Forestry & Urban Greening*, *27*, 24–31. https://doi.org/10.1016/J.UFUG.2017.06.008

Felton, E. (2022, September 3). In Jackson, Mississippi, a water crisis of unparalleled scale. *The Washington Post*. https://www.washingtonpost.com/nation/2022/09/03/jackson-mississippi-water-crisis/

Freeman, V. L., Boylan, E. E., Pugach, O., Mclafferty, S. L., Tossas-Milligan, K. Y., Watson, K. S., & Winn, R. A. (2017). A geographic information system-based method for estimating cancer rates in non-census defined geographical areas. *Cancer Causes and Control*, *28*(10), 1095–1104. https://doi.org/10.1007/s10552-017-0941-8

Fricker, T., & Allen, D. L. (2022). A place-based analysis of tornado activity and casualties in Shreveport, Louisiana. *Natural Hazards*, *113*(3), 1853–1874. https://doi.org/10.1007/s11069-022-05373-0

Gaber, N. (2021). Blue lines and blues infrastructures: Notes on water, race, and space. *Environment and Planning D: Society and Space*, *39*(6), 1073–1091. https://doi.org/10.1177/02637758211065451

Gaffin, S., Lynn, B., Rosenzweig, C., Solecki, W., Parshall, L., Goldberg, R., Cox, J., & Hodges, S. (2006). *Mitigating New York City's heat island with urban forestry, living roofs, and light surfaces*. https://www.researchgate.net/publication/242139673

Ganim, S. (2018, November 28). *For 10 years, a chemical not EPA approved was in their drinking water*. CNN: Health. https://www.cnn.com/2018/11/11/health/denmark-sc-water-chemical-not-epa-approved

Gasteyer, S. P., Lai, J., Tucker, B., Carrera, J., & Moss, J. (2016). BASICS INEQUALITY: Race and Access to Complete Plumbing Facilities in the United States. *Du Bois Review*, *13*(2), 305–325. https://doi.org/10.1017/S1742058X16000242

GitHub - pysal/tobler: Spatial interpolation, Dasymetric Mapping, & Change of Support. (n.d.). Retrieved November 2, 2022, from https://github.com/pysal/tobler

Goodchild, M. F., Anselin, L., & Deichmann, U. (1993). A framework for the areal interpolation of socioeconomic data. In *Environment and Planning A* (Vol. 25).

Goodchild, M. F., & Siu-Ngan Lam, N. (1980). Areal interpolation: a variant of the traditional spatial problem. *Geo-Processing*, *1*(3), 297–312.

Greer, J. (2013). The home owners' loan corporation and the development of the residential security maps. *Journal of Urban History*, *39*(2), 275–296. https://doi.org/10.1177/0096144212436724

Gregory, I. N. (2002). The accuracy of areal interpolation techniques: Standardising 19th and 20th century census data to allow long-term comparisons. *Computers, Environment and Urban Systems*, *26*(4), 293–314. https://doi.org/10.1016/S0198-9715(01)00013-8

Gregory, Ian N., & Healey, R. G. (2007). Historical GIS: Structuring, mapping and analysing geographies of the past. *Progress in Human Geography*, *31*(5), 638–653. https://doi.org/10.1177/0309132507081495

Harrell, F. E. (2015). *Binary Logistic Regression*. 219–274. https://doi.org/10.1007/978-3-319-19425-7_10

Hirsch, A. R. (1998). *Making the Second Ghetto: Race and Housing in Chicago 1940-1960 (Historical Studies of Urban America)*. University of Chicago Press.

Hoffman, J. S., Shandas, V., & Pendleton, N. (2020). The effects of historical housing policies on resident exposure to intra-urban heat: A study of 108 US urban areas. *Climate*, *8*(1). https://doi.org/10.3390/cli8010012

Huang, M., Cui, P., & He, X. (2018). Study of the Cooling Effects of Urban Green Space in Harbin in Terms of Reducing the Heat Island Effect. *Sustainability 2018, Vol. 10, Page 1101*, *10*(4), 1101. https://doi.org/10.3390/SU10041101

Kondo, M. C., Low, S. C., Henning, J., & Branas, C. C. (2015). The impact of green stormwater infrastructure installation on surrounding health and safety. *American Journal of Public Health*, *105*(3), e114–e121. https://doi.org/10.2105/AJPH.2014.302314

Krieger, N., van Wye, G., Huynh, M., Waterman, P. D., Maduro, G., Li, W., Charon Gwynn, R., Barbot, O., & Bassett, M. T. (2020). Structural racism, historical redlining, and risk of preterm birth in New York City, 2013-2017. *American Journal of Public Health*, *7*, 1046–1053. https://doi.org/10.2105/AJPH.2020.305656

Krieger, N., Wright, E., Chen, J. T., Waterman, P. D., Huntley, E. R., & Arcaya, M. (2020). Cancer Stage at Diagnosis, Historical Redlining, and Current Neighborhood Characteristics: Breast, Cervical, Lung, and Colorectal Cancers, Massachusetts, 2001-2015. *American Journal of Epidemiology*, *189*(10), 1065–1075. https://doi.org/10.1093/aje/kwaa045

Lane, H. M., Morello-Frosch, R., Marshall, J. D., & Apte, J. S. (2022). Historical Redlining Is Associated with Present-Day Air Pollution Disparities in U.S. Cities. *Environmental Science and Technology Letters*, *9*(4), 345–350. https://doi.org/10.1021/ACS.ESTLETT.1C01012/ASSET/IMAGES/LARGE/EZ1C01012_0002.JPEG

Leker, H. G., & Gibson, J. M. D. (2018). Relationship between race and community water and sewer service in North Carolina, USA. *PLoS ONE*, *13*(3). https://doi.org/10.1371/journal.pone.0193225

MacDonald Gibson, J., DeFelice, N., Sebastian, D., & Leker, H. (2014). Racial Disparities in Access to Community Water Supply Service in Wake County, North Carolina. *Frontiers in Public Health Services and Systems Research*, *3*(3), 6. https://doi.org/10.13023/FPHSSR.0303.06

Meehan, K., Jepson, W., Harris, L. M., Wutich, A., Beresford, M., Fencl, A., London, J., Pierce, G., Radonic, L., Wells, C., Wilson, N. J., Adams, E. A., Arsenault, R., Brewis, A., Harrington, V., Lambrinidou, Y., McGregor, D., Patrick, R., Pauli, B., … Young, S. (2020). Exposing the myths of household water insecurity in the global north: A critical review. In *Wiley Interdisciplinary Reviews: Water* (Vol. 7, Issue 6). John Wiley and Sons Inc. https://doi.org/10.1002/wat2.1486

Meehan, K., Jurjevich, J. R., Chun, N. M. J. W., & Sherrill, J. (2020). Geographies of insecure water access and the housing–water nexus in US cities. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(46), 28700–28707. https://doi.org/10.1073/pnas.2007361117

Meehan, K., Jurjevich, J. R., Griswold, A., Chun, N. M. J. W., & Sherrill, J. (2021). *Plumbing poverty in US cities: A report on gaps and trends in household water access, 2000 to 2017*.

Michney, T. M. (2021). How the City Survey's Redlining Maps Were Made: A Closer Look at HOLC's Mortgagee Rehabilitation Division. *Journal of Planning History*. https://doi.org/10.1177/15385132211013361

Mitchell, B., & Richardson, J. (2018). *HOLC "redlining" maps: The persistent structure of segregation and economic inequality*. https://doi.org/10.13140/RG.2.2.21841.48486

Mueller, J. T., & Gasteyer, S. (2021). The widespread and unjust drinking water and clean water crisis in the United States. *Nature Communications*, *12*(1). https://doi.org/10.1038/s41467-021-23898-z

Mugglin, A. S., Carlin, B. P., & Gelfand, A. E. (2000). Fully Model-Based Approaches for Spatially Misaligned Data. In *Source: Journal of the American Statistical Association* (Vol. 95, Issue 451).

Nardone, A., Casey, J. A., Morello-Frosch, R., Mujahid, M., Balmes, J. R., & Thakur, N. (2020). Associations between historical residential redlining and current age-adjusted rates of emergency department visits due to asthma across eight cities in California: an ecological study. *The Lancet*

Planetary Health, *4*(1), e24–e31. https://doi.org/10.1016/S2542-5196(19)30241-4

Nardone, A., Chiang, J., & Corburn, J. (2020). Historic Redlining and Urban Health Today in U.S. Cities. *Environmental Justice*, *13*(4), 109–119. https://doi.org/10.1089/env.2020.0011

Nelson, R., Winling, L., Marciano, R., Connolly, N., & Ayers, E. (n.d.). *Mapping Inequality*. Retrieved September 28, 2023, from https://dsl.richmond.edu/panorama/redlining/#loc=5/39.1/-94.58&text=about

Norton, E. C., Dowd, B. E., & Maciejewski, M. L. (2019). Marginal Effects - Quantifying the Effect of Changes in Risk Factors in Logistic Regression Models. In *JAMA - Journal of the American Medical Association* (Vol. 321, Issue 13, pp. 1304–1305). American Medical Association. https://doi.org/10.1001/jama.2019.1954

Nowak, D. J., Ellis, A., & Greenfield, E. J. (2022). The disparity in tree cover and ecosystem service values among redlining classes in the United States. *Landscape and Urban Planning*, *221*. https://doi.org/10.1016/j.landurbplan.2022.104370

Pew Research Center, W. D. C. (2020, January 9). *Trends in U.S. income and wealth inequality*. https://www.pewresearch.org/social-trends/2020/01/09/trends-in-income-and-wealth-inequality/

Portnoy, J. (2022, September 30). *E. coli in Baltimore water blamed on aging infrastructure*. The Washington Post. https://www.washingtonpost.com/dc-md-va/2022/09/30/baltimore-water-ecoli-infrastructure/

Rothstein, R. (2017). *The Color of Law: A Forgotten History of How Our Government Segregated America*. Liveright Publishing.

Smith, C. (2021, February 11). “If white people were still here, this wouldn’t happen”: the majority-Black town flooded with sewage. *The Guardian*. https://www.theguardian.com/us-news/2021/feb/11/centreville-illinois-flooding-sewage-overflow

Teodoro, M. P., Zuhlke, S., & Switzer, D. (2022). The Profits of Distrust: Citizen-Consumers, Drinking Water, and the Crisis of Confidence in American Government. *The Profits of Distrust*. https://doi.org/10.1017/9781009244893

Tobler, W. R. (1979). Smooth Pycnophylactic Interpolation for Geographical Regions. In *Source: Journal of the American Statistical Association* (Vol. 74, Issue 367).

United Nations Statistics Division. (2022). *The Sustainable Development Goals Report*. https://unstats.un.org/sdgs/report/2022

United States Census Bureau. (n.d.-a). *American Community Survey 2016-2020 5-Year Data Release*. Retrieved May 4, 2023, from https://www.census.gov/newsroom/press-kits/2021/acs-5-year.html

United States Census Bureau. (n.d.-b). *Plumbing and Kitchen Facilities in Housing Units*. Retrieved January 29, 2022, from https://www.census.gov/library/working-papers/2015/acs/2015_Raglin_01.html

United States Census Bureau. (2019). *Selected housing characteristics, 2019 American Community Survey 1-year estimates*. https://data.census.gov/cedsci/table?tid=ACSDP1Y2019.DP04

United States Census Bureau. (2021a). *AGE AND SEX*. https://data.census.gov/cedsci/table?q=race 2021&tid=ACSST1Y2021.S0101

United States Census Bureau. (2021b). *Average Number of People per Household, by Race and Hispanic Origin, Marital Status, Age, and Education of Householder*. https://www.census.gov/data/tables/2021/demo/families/cps-2021.html

Vaidyanathan, A., Malilay, J., Schramm, P., & Saha, S. (2020). Heat-Related Deaths — United States, 2004–2018. *MMWR. Morbidity and Mortality Weekly Report*, *69*(24), 729–734. https://doi.org/10.15585/MMWR.MM6924A1

Venables, W. N., & Ripley, B. D. (2002). *Modern Applied Statistics with S*. Springer New York. https://doi.org/10.1007/978-0-387-21706-2

Wardrop, N. A., Jochem, W. C., Bird, T. J., Chamberlain, H. R., Clarke, D., Kerr, D., Bengtsson, L., Juran, S., Seaman, V., & Tatem, A. J. (2018). Spatially disaggregated population estimates in the absence of national population and housing census data. In *Proceedings of the National Academy of Sciences of the United States of America* (Vol. 115, Issue 14, pp. 3529–3537). National Academy of Sciences. https://doi.org/10.1073/pnas.1715305115

Winling, L. D. C., & Michney, T. M. (2021). The Roots of Redlining: Academic, Governmental, and Professional Networks in the Making of the New Deal Lending Regime. *Journal of American History*, *108*(1), 42–69. https://doi.org/10.1093/JAHIST/JAAB066

Appendix A: Additional Tables

Table A-1: The results of the Dunn Test to determine whether incomplete plumbing % in Grade A is significantly different than the other Grades.

Comparison	Z	P.unadj	P.adj
A - B	-3.575	3.51E-04	2.10E-03
A - C	-11.119	1.02E-28	6.09E-28
B - C	-9.695	3.17E-22	1.90E-21
A - D	-19.613	1.21E-85	7.25E-85
B - D	-20.300	1.29E-91	7.74E-91
C - D	-12.571	3.06E-36	1.84E-35

Table A-2: The average % for each predictive variable broken down by HOLC grade and region.

	National	Northeast	South	Midwest	West
Variable by HOLC grade at the Census Block Group Level (%)					
% of Houses with Incomplete plumbing:					
A	1.42	0.80	2.24	1.69	0.78
B	1.82	1.11	2.68	2.57	0.60

C	2.70	1.43	3.40	4.02	0.66
D	3.91	2.26	4.63	5.36	1.31
AVERAGE	2.61	1.45	3.41	3.76	0.78
Black population %:					
A	11.87	12.06	13.08	14.66	4.27
B	15.79	12.99	20.75	20.33	5.70
C	21.69	17.30	29.64	26.57	6.22
D	26.64	19.70	37.38	30.47	6.63
AVERAGE	20.19	1.6.00	27.47	24.78	5.88
Hispanic or Latino population %:					
A	9.24	10.42	11.40	5.51	11.79
B	12.27	13.21	13.92	7.49	18.14
C	15.81	17.39	12.97	12.45	25.73
D	18.57	19.84	14.27	14.87	36.89

AVERAGE	14.76	15.94	13.37	11.12	23.71
% Below the Poverty Line:					
A	8.93	7.37	11.48	9.63	6.56
B	11.61	9.50	14.89	13.08	8.48
C	15.62	12.43	19.12	17.82	11.03
D	20.34	16.54	23.49	22.25	15.77
AVERAGE	14.91	11.92	18.31	16.92	10.57
% of Mobile Homes:					
A	0.30	0.19	0.41	0.31	0.29
B	0.40	0.27	0.53	0.47	0.36
C	0.62	0.32	0.78	0.77	0.60
D	0.97	0.40	0.96	1.36	0.95
AVERAGE	0.61	0.31	0.72	0.79	0.55
% of Housing Units Rented:					

A B C D	27.06 33.37 41.52 50.20	24.91 32.26 40.25 50.30	34.16 37.85 45.49 53.32	25.15 31.19 39.68 46.79	24.52 34.36 43.51 54.46
AVERAGE	39.76	38.43	44.33	37.87	40.30
Indigenous population %:					
A B C D	0.35 0.37 0.43 0.59	0.19 0.24 0.29 0.39	0.46 0.37 0.44 0.64	0.24 0.32 0.34 0.46	0.66 0.72 0.95 1.36
AVERAGE	0.44	0.28	0.48	0.36	0.92
Foreign Born population %:					
A	78.54	83.05	70.29	76.66	86.44

B	77.03	81.45	71.19	71.91	86.47
C	75.77	82.08	69.26	70.17	87.73
D	73.28	75.92	69.59	69.24	88.67
AVERAGE	75.84	80.65	69.96	71.05	87.36
Asian population %:					
A	5.02	5.91	2.35	2.85	11.60
B	5.40	6.79	1.96	2.75	12.38
C	5.41	8.64	2.04	2.50	11.65
D	4.60	7.31	1.78	2.56	11.27
AVERAGE	5.17	7.51	1.99	2.61	11.79

Table A-3: AME Table for the Nation using the average 2.61168 as the threshold for the binary variable.

factor	AME	SE	z	p	lower	upper
Asian population %	-0.0083	0.0009	-8.7797	0	-0.0101	-0.0064
Black population %	0.0027	0.0001	18.3196	0	0.0024	0.003
Foreign Born population %	-0.0011	0.0002	-6.8716	0	-0.0014	-0.0008
HOLC Grade B	-0.0216	0.0149	-1.4475	0.1477	-0.0509	0.0077
HOLC Grade C	-0.0066	0.0144	-0.4569	0.6477	-0.0349	0.0217
HOLC Grade D	0.0579	0.0159	3.6352	0.0003	0.0267	0.0892
Hispanic or Latino population %	-0.0004	0.0002	-1.7199	0.0855	-0.0008	0.0001
% of Mobile Homes	0.0096	0.0016	6.1224	0	0.0065	0.0127
Indigenous population %	-0.0043	0.0004	-11.3916	0	-0.0051	-0.0036
% of Houses Built in 1980 or later	0.0084	0.0004	23.2685	0	0.0076	0.0091

Table A-4: AME Table for the Northeast region using the average 1.447623 as the threshold for the binary variable.

factor	AME	SE	z	p	lower	upper
Asian population %	-0.0034	0.0011	-3.0581	0.0022	-0.0055	-0.0012
Black population %	0.0027	0.0004	7.3198	0	0.002	0.0035
Foreign Born population %	-0.0021	0.0004	-5.1965	0	-0.0029	-0.0013
HOLC Grade B	0.0148	0.0282	0.5272	0.5981	-0.0404	0.07
HOLC Grade C	0.0418	0.0277	1.5069	0.1318	-0.0126	0.0962
HOLC Grade D	0.1145	0.0318	3.6061	0.0003	0.0523	0.1768
Hispanic or Latino population %	-0.0012	0.0005	-2.34	0.0193	-0.0021	-0.0002
Indigenous population %	0.0292	0.0102	2.8559	0.0043	0.0092	0.0493
% of Houses Built in 1980 or later	-0.0036	0.0009	-4.0803	0	-0.0053	-0.0019
% Below the Poverty Line	0.0094	0.0009	10.3574	0	0.0077	0.0112

Table A-5: AME Table for the South region using the average 3.414391 as the threshold for the binary variable.

factor	AME	SE	z	p	lower	upper
Asian population %	-0.0209	0.0044	-4.7009	0	-0.0296	-0.0122
Black population %	0.0032	0.0003	10.1404	0	0.0026	0.0038
Foreign Born population %	-0.0007	0.0003	-2.0135	0.0441	-0.0013	0
HOLC Grade B	-0.021	0.0338	-0.6206	0.5348	-0.0873	0.0453
HOLC Grade C	0.0019	0.0326	0.059	0.953	-0.062	0.0659
HOLC Grade D	0.0528	0.0348	1.5152	0.1297	-0.0155	0.1211
% of Mobile Homes	0.0239	0.0051	4.659	0	0.0138	0.0339
% of Houses Built in 1980 or later	-0.0064	0.0007	-8.922	0	-0.0078	-0.005
% Below the Poverty Line	0.0072	0.0008	9.48	0	0.0057	0.0086

Table A-6: AME Table for the Midwest region using the average 3.756471 as the threshold for the binary variable.

factor	AME	SE	z	p	lower	upper
Asian population %	-0.0054	0.002	-2.7275	0.0064	-0.0094	-0.0015
Black population %	0.0033	0.0002	16.8087	0	0.0029	0.0037
Foreign Born population %	-0.0015	0.0002	-6.4901	0	-0.0019	-0.001
HOLC Grade B	-0.0058	0.0265	-0.218	0.8275	-0.0578	0.0462
HOLC Grade C	0.0009	0.0252	0.0352	0.972	-0.0485	0.0502
HOLC Grade D	0.0748	0.0272	2.7477	0.006	0.0215	0.1282
% of Mobile Homes	0.0061	0.0017	3.6619	0.0003	0.0028	0.0093
% of Houses Built in 1980 or later	-0.0054	0.0008	-6.4417	0	-0.007	-0.0037
% Below the Poverty Line	0.0082	0.0006	14.4529	0	0.0071	0.0094

Table A-7: AME Table for the West region using the average 0.7836609 as the threshold for the binary variable.

factor	AME	SE	z	p	lower	upper
HOLC Grade B	-0.0518	0.0415	-1.2479	0.2121	-0.1331	0.0295
HOLC Grade C	-0.0005	0.0415	-0.0127	0.9899	-0.0819	0.0808
HOLC Grade D	0.1285	0.0502	2.5586	0.0105	0.0301	0.2269
Hispanic or Latino population %	0.0021	0.0005	3.9817	0.0001	0.0011	0.0032
Indigenous population %	0.0305	0.0071	4.2734	0	0.0165	0.0445
% of Houses Built in 1980 or later	-0.0016	0.0011	-1.4088	0.1589	-0.0039	0.0006