

Socio-Spatial Vulnerability to Heat: A Study of Mortality in Washington Neighborhoods During  
the 2021 Western North America Heat Wave

Emily Dalgo

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Kyle Crowder  
Steven Pfaff

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Emily Dalgo

University of Washington

**Abstract**

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Emily Dalgo

Chair of the Supervisory Committee:  
Kyle Crowder

Department of Sociology

This study is a spatially and temporally relevant analysis of mortality and heat patterns within Washington neighborhoods during the 2021 Western North America Heat Wave. Utilizing geocoded mortality data from the Washington State Department of Health, historic daily maximum temperature data from the National Oceanic and Atmospheric Administration, and zip code-level demographic information from the U.S. Census Bureau, this research presents a fine-scale, time-series analysis of the effect of temperature on mortality in Washington and exposes how the sociodemographic composition of neighborhoods can promote or undermine population health in the context of extreme heat. The study employs logistic, Poisson, and linear regression analyses and establishes relationships between increased weekly temperature, certain socio-demographic variables, and mortality at the neighborhood level. Findings at the individual level indicate a higher mortality risk for American Indian/Alaska Natives, men, and those over the age of 67 during an extreme heat scenario. At the community level, population-adjusted analysis reveals that neighborhoods with a higher proportion of individuals who are over 65, lack public transportation, who live alone, are without health insurance, and are foreign born experienced greater mortality. Neighborhoods with younger residents, those lacking access to public transit, and lower-income neighborhoods experienced hotter temperatures during the heat wave, a

finding that adds credence to environmental justice literatures imagining ecological disaster and hazards as an outcome of class-based inequality. Finally, this study stresses the potential misclassification and underreporting of heat-related deaths during the heat wave, a concern noted in previous research on the subject. The research contributes a place-based understanding of both individual and population health risks in the context of heat disaster and underscores the importance of equity-centered climate adaptation strategies, particularly in regions historically less affected by extreme heat that lack social and material adaptation strategies.

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Finally, I dedicate this project to my brother Eric, my biggest champion.

## INTRODUCTION

### Background

The 2021 Western North America heat wave occurred from June 26 to July 2, 2021, and impacted the Pacific Northwest region of Canada and the United States. Many locations broke all-time maximum temperature records and increased mortality was reported in British Columbia, Alberta, Washington, and Oregon (White et al. 2023). Preliminary estimates counted at least 868 deaths across the Pacific Northwest attributed to this heat wave, with most deaths occurring in private residences due to dangerously high indoor temperatures (White et al. 2023; Washington State Department of Health 2021). At the end of June 2021, emergency department visits for heat-related illnesses in the region were 69 times higher than in 2019, with disproportionate impacts on males and those 75 and older (Schramm et al. 2021). The Washington State Department of Health (DoH) reported that during the heat wave period, there were 100 heat-related deaths (2021), though Casey et al. (2023) have shown an overlapping three weeks exceeded the expected count of injury deaths alone, with an estimated total of 159 excess injury deaths during the period.

More Americans die from extreme heat events than from all other environmental or climate disasters (U.S. Environmental Protection Agency 2023). The duration, frequency, and intensity of heat waves has steadily increased since the mid-1960s (NOAA 2021), trends that are expected to continue as the annual average temperature over the contiguous United States is projected to rise approximately 2.5°F (1.4°C) over the period 2021–2050 (Vose et al. 2017). Heat events are associated with increased morbidity and mortality (Anderson and Bell 2011; Zanobetti and Schwartz 2008; Weinberger et al. 2020) though heat-health risks vary regionally and key explanatory variables assessing vulnerability to heat illness and death vary from one city to another (Hondula et al. 2012). Drastic temperature differences and heat-risk measures have been observed within the same city (Oke 1982). For example, Harlan et al. (2006) found significant temperature variations among eight Phoenix neighborhoods, while Hondula et al. (2012) found significant spatial variability in mortality response to high temperatures within Philadelphia County. Other studies have found associations between increased apparent temperature and risk of hospitalization based on residential zip code (Ostro et al. 2010).

Environmental justice frameworks make clear the link between race, class, and environmental health risk broadly (Cutter 1995), and studies have shown the relationship between marginalized socio-demographic groups and vulnerability to extreme heat specifically (Voelkel et al. 2018; Hattis, Ogneva-Himmelberger, and Ratick 2012), which exacerbates existing health inequities (Romanello et al. 2021). For example, studies have shown that there are demographic and socioeconomic characteristics at both the individual-level (i.e., infants and the elderly; low socioeconomic status; social isolation) and community-level (i.e., higher material and social deprivation) that create increased vulnerability to heat illness or death (White et al. 2023; Reid et al. 2009; O'Neill et al. 2005; Klinenberg 2002). In urban areas, these health disparities are even further aggravated due to the urban heat island effect (Voogt and Oke 2003; Karl et al. 1988; Corburn 2009), which causes urban microclimates to maintain chronically higher temperatures compared to adjacent areas. Raju, Boyd, and Otto (2022) argue that disasters occur when hazards meet vulnerability; reducing the hazard of high heat and the vulnerability to it created by social inequities requires a better understanding of socio-spatial risk factors.

While past studies have found significant relationships between temperature, social and environmental conditions, and morbidity and mortality outcomes, they are often based on weather data derived from a single airport weather station (Hondula et al. 2012) or from the airport station closest to each city in comparative studies (O'Neill et al. 2005) which may significantly over- or under-estimate temperature within the actual location of illness or death. The most populous zip code in Philadelphia, for example, is over 18 miles from the PHL Airport, which was used to extract temperature data for Hondula et al.'s 2012 study on mortality across Philadelphia County. Past research has also often assessed mortality response during high heat conditions using residential zip code rather than the zip code of death (Lee et al. 2016). Therefore, there is a need for more localized estimates of the effects of temperature on mortality. Large-scale studies have typically analyzed the association of heat on death or hospitalizations at the county (Weinberger et al. 2019) or climate zone level, while others look at states (Casey et al. 2023) but have only so far used preliminary data without cause of death codes. These studies have provided a broad overview of climate patterns and their health impacts but lacked local precision; these large geographical areas of study may not accurately represent local temperature variations. Studying zip codes (neighborhoods) across the state, on the other hand, offers more

precision and granularity, capturing variability in climate, population characteristics, and socio-economic features on a fine scale.

### **A Socio-Spatial Analysis of Mortality in Washington**

This paper seeks to understand how socially and spatially relevant risk factors contributed to heat-related mortality in Washington neighborhoods during the 2021 Western North America Heat Wave – the deadliest environmental disaster in the state of Washington (Malcolm, Ryan, and Browning 2021). This study presents the first state-wide, fine-scale, time-series analysis of the impact of temperature on mortality in the United States by examining the impact of heat on morbidity in Washington neighborhoods during the 2021 heat wave. Previous studies on the disaster’s health impact in Washington have concluded that the heat wave led to excess injury deaths (Casey et al. 2023) but relied on preliminary death certificate data that did not specify cause or location of death (beyond state).

This study takes a more granular look at the impact in Washington, linking weather stations closest to the zip code of death for all fatalities in the state between 2016-2021, thereby capturing localized variations in temperature that may significantly impact health outcomes and offering a more contextually relevant, place-based understanding of the relationship between temperature and mortality. This research considers both spatial vulnerabilities and social inequalities to extreme heat, as there are multiple levels of heat-related risk; past population-level research linking temperature and mortality has rarely assessed both community and individual characteristics that influence or exacerbate heat vulnerability and has never done so at the neighborhood level for an entire state. Therefore, this study provides a multilevel design to remedy this gap, allowing for a more meaningful analysis of the socioeconomic traits of a neighborhood and their association with heat and its health effects. The study is guided by the following questions: Are there socially or spatially relevant characteristics at the individual or neighborhood level that 1.) should be considered health risk factors during a heat wave in Washington and 2.) were associated with higher temperatures during the heat wave?

Washington state is an ideal study area for investigating spatial and social vulnerabilities to temperature-related mortality for several reasons: first, this is an understudied region; the Pacific Coast region has historically been the least affected by heat waves (Basu and Samet 2002), making research on extreme heat in the region scant even as heat waves become more

common. Second, the implications of the 2021 heat wave's impact on Washington matter to a broader knowledge of the effects extreme heat in areas whose residents are uniquely underprepared for this kind of climate disaster, as the Seattle metropolitan area is the second-least air-conditioned metro area in the country, with 46 percent of households lacking any kind of air-conditioning (U.S. Census Bureau 2021). Third, there is a wide array of climate variability in the state, including a wet western coastal climate, influence from climatic barriers such as the Cascade Mountain Range (known for its intense orographic effect), and the eastern semi-arid to arid climate with lower precipitation levels and drought conditions. This climatic diversity allows for the exploration of heat wave impacts on people living in diverse geographies and topographies – an important part of the political decision-making process when considering extreme heat adaptation strategies. Finally, the urban-rural contrasts in the state provide a basis for analyzing the impact of heat-related events on both urban and rural settings, providing a nuanced understanding of how diverse communities are affected by environmental changes.

As a growing number of communities across the country contend with heat waves and their health ramifications, high-impact, equity-centered climate adaptation plans will be of paramount importance. Analyzing localized vulnerabilities, i.e., the interaction of neighborhood social and environmental characteristics, is necessary to accurately estimate the impact of extreme heat events on population health and effectively implement climate adaptation policies that diminish health inequities caused by heat-related disasters.

## DATA AND METHODS

### **Historical Mortality Data**

Mortality data come from 2016-2021 Washington Death Statistical Files that were purchased from the Washington State Department of Health. These files include cause of death codes; residence county, city, and zip code; death county, city, and zip code; date of birth and death; place of death type; sex; age; marital status; education status; and race, among other data points. Death Statistical File data were used to identify the date of death, death zip code, demographic characteristics, and cause(s) of death for every death reported in Washington from 2016-2021. The causes of death in this data are classified in accordance with the International Classification of Diseases, Tenth Revision (ICD-10) published by the World Health

Organization. The underlying cause of death indicator shows the ICD-10 code classified by medical professionals as “(a) the disease or injury which initiated the train of events leading directly to death or (b) the circumstances of the accident or violence which produced the fatal injury” (Washington State Department of Health n.d.).

However, the actual magnitude of deaths that are “heat related” is likely much greater than reported (Basu 2002). Heat-related mortality is subject to misclassification since there is no widely accepted criteria for determining heat-related death. As such, heat may erroneously be unlisted on a death certificate as the underlying cause or a contributing cause of death. Instead, cardiovascular causes, ischemic heart disease, stroke, and heart failure are commonly reported as the underlying cause of death, since extreme heat is associated with a greater risk of mortality from these conditions, while heat as a contributing cause is left off records (Alahmad et al. 2023; Basu and Samet 2002). Heat as both the underlying (primary) and contributing cause of death will be considered a “heat-related death” in this study, though deaths during the heat wave that have no noted association with heat will also be critically assessed as there could still be a relation to extreme heat. As such, all-cause deaths during the period of extreme heat are assessed in detail, considering the known misclassification issue with heat-related deaths.

### **Historical Temperature and Zip Code Data**

Daily summaries of past maximum temperature in Washington come from the Global Historical Climatology Network daily (GHCNd) database managed and maintained by the National Oceanic and Atmospheric Administration’s (NOAA) National Centers for Environmental Information (NCEI). The GHCNd is a composite of quality-controlled climate records including temperature daily maximum/minimum, precipitation, snowfall, snow depth, and more, and is well suited for assessment activities related to the frequency and magnitude of extremes. The dataset is the world's largest collection of daily climatological data. I downloaded station names, geographic coordinates, and maximum temperatures for all weather stations in Washington over the 6-year period starting January 1, 2016, as well as those in Oregon and Idaho to account for border neighborhoods closer to an out-of-state weather station.

To find daily maximum temperatures for each death zip code in the Death Statistical File, I first downloaded all 733 zip code coordinates in the state of Washington using [UnitedStatesZipCodes.org](https://www.unitedstateszipcodes.org). These data are extracted from administrative USPS address data, the

United States Census Bureau, and the Internal Revenue Service. Using the R Geosphere package (Hijmans 2023), I then matched all zip codes with their closest weather station, thereby generating a link between zip code and daily maximum temperature. The average distance between the place of death and the nearest weather station recording maximum temperature was 5.17 miles, with a median distance of 4.56 miles. By studying zip codes rather than counties or regions, this research provides a more accurate representation of the temperature on the day of death, as this more precise geographic point better reflects temperature in the area where death occurred. Having temperature information that is as reflective of the reality at the location of a death during a heat wave is crucial for targeting interventions, allocating resources, and responding effectively to specific geographic areas within zip codes during a heat wave. Records of maximum temperature are not available for every Washington weather station (though 91 percent of stations during the heat wave reported daily maximum temperature). To uphold the accuracy of the analysis, zip-code-days that did not record temperature data were excluded; linking zip-code-days without data to the next-closest the weather station proved to provide less precise results as certain zip codes were linked with stations across the state. No spatial or temporal pattern in missing data was identified. The final merged dataset thus includes observed daily death counts for all causes in all Washington zip-code-days and zip-code-weeks and their daily maximum temperatures and weekly average maximum temperatures, respectively, when available.

### **Death Zip Code Missing Values**

To avoid unnecessarily excluding deaths that had no recorded death zip code (due to administrative error or unknown location of death), I first identified death zip codes with obvious errors (i.e., a death in Seattle with a reported zip code of 981033 rather than 98103) and cleaned the files to reflect correct zip codes. I then assessed the reported death city and county; when deaths occurred in a city with a sole zip code, the zip was added. Next, I analyzed the Death Statistical File variables “Place of Death Type,” “Injury ACME Place,” and “Injury Place” to identify death locations coded as the individual’s home, residential institution, nursing home, or hospice facility. For these records, I considered the residential zip code to also be the death zip code. Records with an unknown and unidentifiable death zip code were included when possible in descriptive analysis but excluded from analyses directly related to place-based impact of

temperature on mortality. Approximately 98 percent of death records had an identifiable zip code and were retained for analysis (n=359,994).

### **Neighborhood Characteristics Data**

To examine potential links between heat wave-related deaths and specific social and spatial characteristics within Washington neighborhoods, zip code-level data were collected using the tidy census package in R (Walker 2023), which provides access to United States Census Bureau data. This package facilitated the retrieval of relevant demographic and socioeconomic information from the American Community Survey (ACS) 5-year estimates for 2019. Using multiyear estimates provides increased statistical reliability of the data for less populated areas and small population subgroups, which is useful for the study of rural Washington neighborhoods. This study utilized 2019 estimates, which capture data from 2015 to 2019 and provide a stable baseline for analysis. Most variables taken from the ACS were then structured as a percent at the zip code level, i.e., percent of residents in a zip code that are female, while a measure of median income reported in units of thousands of dollars was used.

### **Study Design and Data Analysis**

This study is a fine-scale, time-series analysis of the effect of temperature on mortality and the association between socioeconomic demographics on temperature in Washington. Using descriptive analysis, correlation analysis, and logistic, Poisson, and linear regression for state-wide, geocoded vital statistics and temperature data at the zip code level, I examine the distribution of both heat-related and non-heat-related mortality and how neighborhood characteristics can be linked to higher ambient temperatures during the heat wave. All statistical analyses were performed using R (version 4.3.2). A p-value of  $<0.05$  was considered statistically significant.

To assess the direct impact of average maximum temperature on the transformed death ratio across zip-code-weeks, I constructed a series of linear regression models. Model 1 is a simple, bivariate linear regression model where the logarithm of the death ratio ( $\log(\text{death.ratio})$ ) was analyzed in relation to the average maximum temperature across zip-code-weeks. Model 2 is an extended model that includes a range of sociodemographic variables alongside average maximum temperature and incorporates predictors that have previously been identified as risk factors in an extreme heat scenario. This comprehensive model aims to capture the combined effect of these

variables on the logarithm of the death ratio, providing insights into how demographic and social factors might interact with temperature to affect mortality rates. Model 3 is a more focused model, considering only a subset of the variables included in Model 2 that were found to be statistically significant. This model is intended to isolate the effects of these particular variables, shedding light on their specific contributions. I repeated these steps to assess the impact of various sociodemographic characteristics of neighborhoods as predictors of heat in the neighborhood. This second set of models (Heat Model 1 and 2) was chosen to determine whether certain populations were disproportionately heat burdened during the heat wave.

## RESULTS

### Socio-Demographic Characteristics of Mortality

From June 26 to July 2, 2021, 1,636 people in Washington died of any cause. This represents a 51.16 percent increase in deaths compared to the average death count during the same seven-day period in the five years preceding the heat wave. Of these deaths, 127 were reported to be heat related. Table 1 illustrates deaths in Washington from 2016-2021 and highlights deaths during the heat wave period of all causes and of heat-related causes, as identified in state DoH vital records used in this study.

Table 1

Deaths in WA: 2016-2021				
Year	All Cause Deaths (Annual)	Heat-Related Deaths (Annual)	All Cause Deaths (June 26-July 2)	Heat-Related Deaths (June 26-July 2)
2016	56,069	7	1,036	0
2017	58,385	10	1,092	0
2018	58,279	8	1,076	0
2019	59,697	8	1,071	0
2020	64,469	9	1,136	1
2021	70,455	173	1,636	127

Among individuals whose death during the heat wave was attributed to heat as a direct or underlying cause, the most frequently reported multiple cause of death codes included unspecified obesity, type 2 diabetes mellitus without complications, nicotine dependence (other

tobacco product), and chronic ischemic heart disease. For deaths not reported as heat-related during the heat wave, the most common underlying causes of death were atherosclerotic heart disease of the native coronary artery, Alzheimer's disease, malignant neoplasm of an unspecified part of the bronchus or lung, and acute myocardial infarction. Common contributing causes of death were tobacco/nicotine dependence, sepsis, essential hypertension, type 2 diabetes mellitus without complications, and cardiac arrest (cause unspecified).

Across the state, the median age for heat-related fatality was 68 years, with a mean age of 67.1 years. Notably, no heat-related deaths of those under the age of 26 were reported during the heat wave. The median age for deaths of all causes during this period was 75, with a mean age of 73.3. Tracking with previous research in Chicago (Klinenberg 2002), more heat-related fatalities occurred among men. A significant majority of those who died of heat-related causes, approximately 85 percent of individuals, were widowed, divorced, or single. Of those who died of heat, 45 percent had completed high school education, while nearly 15 percent had less than a high school diploma or GED. Nearly 19.3 percent of heat fatalities were nonwhite individuals, slightly less than Washington's 21.3 percent nonwhite population (Office of Financial Management 2021).

Binary variables for each ethno-racial group in the data and for heat-related death based on specific cause of death ICD-10 codes were created. Logistic regression analysis revealed that only the American Indian/Alaska Native racial group showed a statistically significant association with heat-related mortality (Estimate = 0.9277, Std. Error = 0.3650, z value = 2.541, p = .011). No significant associations were observed for other racial or ethnic categories.

### **Excess Heat and Mortality in Washington**

Statewide, from June 26-July 2, 2021, deaths of heat-related causes occurred in neighborhoods with a median temperature of 97°F, with temperatures ranging from 69°F to 116°F. Neighborhoods across the state experienced an average of five deaths of any cause during this time. However, 28 percent of neighborhoods experienced higher mortality rates. Figure 1 illustrates the 10 zip codes with the highest death count during the seven-day period of the heat wave and the highest temperature reached in the neighborhood during the week. Figure 2 illustrates the daily number of deaths from all causes during the week.

I employed logistic regression to model the probability of dying from heat as a function of daily maximum temperature during the summer months (May - September) for all Washington zip codes and years in the study period. The logistic regression model was fitted to the data using the formula Died of Heat ~ Temperature. As expected, findings reveal a significant positive association between temperature and the likelihood of heat-related death. The log-odds of heat-related mortality (max temp coefficient) increased by 0.144145 (SE = 0.006852) units (z-value of max temp = 21.04,  $p < 0.001$ , intercept at -18.636592 (SE = 0.634132)). Model fit statistics indicated an AIC value of 2272.

Date	Deaths
6-26-2021	201
6-27-2021	211
6-28-2021	288
6-29-2021	317
6-30-2021	225
7-01-2021	198
7-02-2021	169

Figure 1

I next conducted a Poisson regression analysis to assess the relationship between average max temperature and the number of all-cause deaths within all zip codes in the state in weekly intervals, for both the full year (January 1, 2016, through December 31, 2021) and for the summer months (May 1 - September 31 from 2016 through 2021). Both analyses revealed a statistically significant positive relationship

Zip Code	Death Count	Highest Temp Reached
98372	40	99
98405	38	105
99204	35	109
98122	30	104
98201	29	101
98632	28	103
99208	28	113
98664	27	116
98034	24	107
98225	24	86

Figure 2

between heat and mortality, indicating that higher weekly average temperatures were linked to an increased count of deaths of any cause at the zip code level. The effect of temperature on death toll at the zip code level in the full year model (Estimate = 0.000245,  $p < 0.001$ , AIC = 587098) was slightly weaker than the summertime model (Estimate = 0.0035575,  $p < 0.001$ , AIC = 249019), and the summertime model also provided a better fit to the data.

To assess the effect of summertime neighborhood heat on causes of death unrelated to heat, I conducted a Poisson regression analysis that excluded heat-related deaths and examined the impact of weekly average maximum temperature on the count of deaths within zip codes.

The results showed a statistically significant positive association between temperature and death counts (Estimate = 0.0036253,  $p < 0.001$ , AIC = 248923). This indicates that higher summer temperatures were linked to increased death of all causes at the neighborhood level. This also underscores the impact of higher temperature on causes of death reportedly “unrelated” to heat.

### Neighborhood Characteristics

Zip codes were grouped by week/year and a population-adjusted count of deaths during each week was determined, along with the average maximum temperature for each zip code week. The heat wave occurred during the 25<sup>th</sup>, 26<sup>th</sup>, and 27<sup>th</sup> weeks of 2021 and were the focus of the following analysis. To better understand the relationship between neighborhood sociodemographic composition and all-cause mortality during these weeks, I conducted linear regression analyses utilizing ACS 5-year survey data. In Washington, several mortality risk factors previously identified by Hondula et al. (2012), among others, were identified. I applied a logarithmic transformation to

normalize the zip code week ratio of death and conducted a linear regression to find that neighborhoods with a higher proportion of residents who 1.) are foreign born, 2.) do not use public transportation, 3.) are living alone, 4.) are over 65, and 5.) lack health insurance had a significantly greater likelihood of death during the heat wave weeks.

Neighborhoods with more men, non-English speakers, higher educated residents, and residents

below the poverty line also had a positive

relationship with mortality during the heat wave, those these

relationships were not found to be statistically significant. Additionally, median household

	Model 1	Model 2	Model 3
(Intercept)	-5.056 (0.313)***	-5.861 (0.979)***	-6.721 (0.294)***
`Average Max Temp`	0.013 (0.004)***	0.010 (0.003)***	0.011 (0.003)***
`Female (% in zip)`		-0.007 (1.279)	
`Foreign Born (% in zip)`		-1.939 (0.736)**	-1.095 (0.412)**
`English not spoken (% in zip)`		1.444 (1.759)	
`Percent below poverty`		0.088 (0.846)	
`Use Public Transit (% in zip)`		-1.934 (0.817)*	-2.071 (0.679)**
`Living Alone (% in zip)`		3.556 (0.559)***	4.012 (0.422)***
`Median HH Income`		-0.004 (0.003)	
`Over 65 (% in zip)`		3.579 (0.565)***	4.007 (0.528)***
`Uninsured (% in zip)`		3.510 (1.589)*	5.167 (1.082)***
`Percent White`		-0.261 (0.446)	
`Bachelors or Higher (% in zip)`		0.216 (0.393)	
R2	0.016	0.296	0.288

Table 2

income and percent of white residents were negatively associated with death, though these variables were also not statistically significant. Table 2 includes results from the linear regression.

### Predicting Heat

I then assessed how differences in demographic composition of Washington neighborhoods relate to heat to determine whether certain populations were disproportionately heat burdened during the heat wave. Linear regression revealed that the proportion of residents who are over 65 and do not use public transportation had a significant, negative relationship with average temperature, meaning areas with older residents and with greater public transit usage were cooler during the heat wave.

Median income was also significantly negatively associated with heat, while the percentage of white residents was significantly positively associated with heat in Washington. Table 3 includes results from these models.

### Limitations

This study estimated the daily ambient maximum temperature for every zip code in Washington by assigning it to the closest weather station logging temperature data. However, by assigning these outdoor temperature readings to a neighborhood and using this reading as the basis for a proposal of linear relationships between

	Heat Model 1	Heat Model 2
(Intercept)	83.268 (11.818)***	92.440 (2.772)***
`Female (% in zip)`	3.335 (15.938)	
`Foreign Born (% in zip)`	14.560 (9.151)	
`English not spoken (% in zip)`	-5.461 (21.921)	
`Percent below poverty`	12.011 (10.535)	
`Use Public Transit (% in zip)`	-21.405 (10.152)*	-28.791 (9.315)**
`Living Alone (% in zip)`	-10.388 (6.960)	
`Median HH Income`	-0.115 (0.042)**	-0.111 (0.024)***
`Over 65 (% in zip)`	-26.442 (6.978)***	
`Uninsured (% in zip)`	7.944 (19.800)	
`Percent White`	15.255 (5.533)**	7.469 (3.232)*
`Bachelors or Higher (% in zip)`	8.252 (4.890)+	7.727 (4.068)+
over_65		-29.240 (6.731)***
R2	0.090	0.080

Table 3

heat and mortality, this study assumes that all people in the area are exposed to the temperature in the same way. Ambient temperatures indoors can vary greatly from household to household in the same neighborhood. Additionally, adaptive behaviors such as use of air conditioning drastically impact exposure to heat (Basu and Samet 2002) and were not considered in this study.

Thus, some degree of misclassification of neighborhood maximum temperature is expected. Though, as Basu and Samet (2002) have argued, “For the purposes of population-based analyses, ambient temperature is the strongest determinant of variation over time in the exposure of populations to heat.”

Additionally, this study only considered zip code weeks in Washington where weather data were available; as such, about 6 percent of zip code weeks from 2016-2021 were excluded from the study, which could lead to over or underinflation of relationships between key variables.

For neighborhood-level analysis, the ACS 5-year estimates for the year 2019 were used for both 2020 and 2021. These estimates do not entirely cover the study period and could lead to limitations in the analysis. Neighborhood composition changes that occurred after 2019, for instance, are not reflected in the data. Finally, the models utilized in this study do not account for all social, spatial, or demographic characteristics that could influence death outcomes during a heat wave. The sometimes-weak explanatory power of these chosen variables as well as the potential influence of other unmeasured factors should be noted.

## DISCUSSION

### **Key Findings**

This study sought to understand 1.) the socially and spatially relevant risk factors that increased the likelihood of mortality in Washington neighborhoods during the 2021 Western North America Heat Wave, and 2.) the relationship between neighborhood composition and temperature. In doing so, this study aimed to better understand how heat and death were distributed amongst the population during an extreme heat event in Washington.

From June 26 to July 2, 2021, 1,636 people in Washington died of any cause. Of these deaths, 127 were reported to be heat related. This study found a significant positive association between temperature and the likelihood of heat-related death as well as all-cause death at the zip code level and found that deaths of causes reportedly unrelated to heat were most commonly those that are known risk factors for heat-related illness (i.e., heart disease, Alzheimer’s disease, type 2 diabetes, cardiac arrest). In Washington, those who died of heat-related causes were 68 years old on average, were more likely to be men, and 85 percent were widowed, divorced, or single. This finding is consistent with past research that has showed a connection between social

isolation and an increased risk of heat-related fatalities, underscoring the importance of social networks as a safety mechanism during heat-related climate disasters. During the heat wave, American Indian/Alaska Natives (AI/AN) were much more likely to die of heat-related causes compared to all other ethnoracial groups. This finding is consistent with research on the disproportionate mortality burden of AI/AN people specifically in the Pacific Northwestern states, (Dankovchik et al. 2015) which are home to about 7 percent of the country's AI/AN population.

Neighborhoods with heat-related death had an average maximum temperature of 97°F during the week of the heat wave. A lower use of public transportation in an area was positively associated with death. This might be reflective of the rural, arid, rural, eastern Washington regions that largely lack public transit. Neighborhoods with a greater proportion of residents living alone saw greater death rates during the heat wave, consistent with previous findings that social networks are important and protective in the context of heat-related disaster. Areas with older residents and with residents lacking health insurance also had a greater likelihood of death during the heat wave weeks. This underscores the need to target emergency assistance to the elderly and to those who may be lower income, yet unqualified for government provided healthcare.

Notably, this study did not find that nonwhite neighborhoods or those with a larger proportion of residents living below the poverty line had a greater likelihood of death; previous studies have found these to be key predictors of death, with nonwhite neighborhoods trending hotter due to the urban heat island effect and the racialized legacies of redlining. In fact, this study found that whiter neighborhoods were hotter than those with more minority residents. However, this could be because more expensive, urban areas susceptible to the heat island effect, such as Seattle, draw a higher-income, primarily white residential body. This study found that median household income, while not a predictor of death in zip codes, had a strong, negative association with heat, meaning that lower income areas experienced hotter temperatures during the heat wave period. This adds credence to environmental justice literatures imagining ecological disaster and hazards as an outcome of class-based inequality. Neighborhoods with younger residents and those lacking access to public transit also experienced hotter temperatures during the heat wave.

### **Directions for Future Research**

As most studies on the topic of extreme heat and mortality have focused on urban areas, more state-wide, fine-scale research is needed to capture the impact of heat on rural communities. Additionally, as the physical environment of a neighborhood plays a critical lifesaving (or threatening) role in the context of heat disaster, identifying the impact of public heat-mitigating measures (such as urban tree canopy, urban creek watersheds) and understanding where they are abundant or deficient is a critical area for further investigation. Neighborhood-level indexes mapping heat-mitigating mechanisms would be useful for a broader understanding of meso-level vulnerabilities to heat. Further, public heat mitigators are communal in nature, have the potential to be improved by the municipal government, and are not intrinsically energy intensive (like air conditioning), characteristics that are particularly important given the unequal access to private air conditioning and the unsustainable demands cooling units place on the energy grid during an extreme heat event. This research has shown that heat and death risk is not equally distributed across the state during an extreme heat event; additional critical research investigating how to make cooler micro-climates accessible to all will only become more essential as heat waves become increasingly common.

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