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To cite this article: Brendon Haggerty *et al* 2024 *Environ. Res.: Health* **2** 045005

ENVIRONMENTAL RESEARCH
HEALTH

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OPEN ACCESS

RECEIVED
19 December 2023

REVISED
14 August 2024

ACCEPTED FOR PUBLICATION
11 September 2024

PUBLISHED
30 September 2024

PAPER

Health impacts of excessive heat in Multnomah County, OR, 2021

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Keywords: health, Multnomah County, heat, climate change, hyperthermia, heat dome

Abstract
Human-induced climate change is leading to increased extreme weather events, such as the heat dome that occurred in Multnomah County, OR, in June 2021. Certain groups are at increased risk from excessive heat events, such as the very young and very old, persons without stable housing, and persons with certain health comorbidities. Our review of three data sources (deaths, hospitalizations, and emergency department visits) showed large increases in all three measures in the summer of 2021. Further, two-thirds of identified heat deaths occurred in or near neighborhoods that ranked among the most vulnerable to extreme heat. Despite thoughtful planning, a recently updated heat response plan, and an unprecedented mobilization of resources, we documented severe health impacts due to this heat event. We recommend that local health jurisdictions and emergency responders increase readiness for such events by interrogating existing plans and tailoring them not to events of expected severity, but to a worst case scenario that exceeds historic experiences.

1. Introduction

Human-induced climate change, including but not limited to more frequent and intense extreme weather events, is responsible for myriad adverse impacts, including damages and losses to both people and the environment (Intergovernmental Panel On Climate Change (IPCC) 2023, Kearl and Vogel 2023). Extreme heat events due to climate change are becoming increasingly common and more severe (Cheng *et al* 2021, EPA 2022, Kearl and Vogel 2023), with morbidity and mortality due to heat deaths concomitantly increasing. Heat kills more people than any other type of extreme weather (The Lancet Planetary Health 2022, EPA 2022). A review by Sheridan *et al* demonstrated that more than 700 heat deaths per year occurred in the United States between 2016 and 2018 (Sheridan *et al* 2021). More recently, the 2021 Western North American heat wave proved to be extremely deadly. In the last days of June 2021, areas of the Pacific Northwest in the United States and Canada experienced record breaking temperatures. In fact, Philip *et al* noted that these temperatures were so extreme that they lie outside the range of historic observed temperatures, making quantification of the anomaly of the event challenging (2022).

1.1. Effects on health

Extreme heat strains the body's ability to cool itself and can exacerbate underlying conditions, which can lead to a wide range of symptoms, ranging from more minor (muscle cramps) to more serious (heat exhaustion) and finally to very serious (heat stroke) which can lead to disability and death (Ahima 2020). Like other health conditions, the effects of extreme heat are not seen equally across age, sex, prevalence of chronic health conditions, occupation/industry, race and ethnicity, location, and other social/economic indicators. At least 20 factors influence the effects of heat on the body, including substance use, acclimatization, physical fitness, water intake, and workload (Ioannou *et al* 2022).

1.2. Vulnerable populations

There is an extensive literature describing the many measures of sensitivity, adaptive capacity, and disproportionate exposure that may make a person more susceptible to heat related morbidity and mortality (Gronlund 2014, Conlon *et al* 2020). The following is not a comprehensive review of all groups that are more likely to be affected by heat; rather, we summarize research findings on characteristics likely to be monitored or analyzed by a local health authority.

1.2.1. Age & gender

Age influences a person's capacity to maintain body temperature, as do certain prescription medications and drug use. Compared to younger persons, elderly adults have a diminished ability to sweat, while infants have a lower heat loss capacity compared to adults, making these groups highly vulnerable to the effects of heat (Oregon Health Authority, Public Health Division 2020, Ebi *et al* 2021). Reports on impacts from the 2021 Pacific Northwest heat dome event have documented disproportionate impacts among people older than 65 and younger than 1 year (Romanello *et al* 2021, Henderson *et al* 2022). However, this may not be consistent across health outcomes; recent data from the US show higher rates of ED visits for heat illness among the population aged 18–64 years compared to older and younger age groups (Vaidyanathan *et al* 2024). Gender differences in climate-related health outcomes are acknowledged as an under-studied impact of climate change (Romanello *et al* 2021). Some studies suggest that elderly women may be at higher risk of heat mortality than men (van Steen *et al* 2019) and Arsad *et al* (2022) reported mixed findings in a systematic review that included differential impacts of heat by gender. However, in the United States, epidemiologists have documented a higher rate of heat-related mortality among males (Vaidyanathan *et al* 2020).

1.2.2. Chronic conditions, disability & isolation

An increase in blood flow to the skin (to facilitate heat transfer) is one way human bodies attempt to thermoregulate (Ebi *et al* 2021). Since this requires the heart to work harder, people with cardiovascular and cerebrovascular disease can be especially at risk (Ebi *et al* 2021, Kearl and Vogel 2023). Respiratory diseases, such as COPD and asthma, also put people at risk, since hot days are often correlated with increased levels of pollutants, such as ozone (Cheng *et al* 2021, Ebi *et al* 2021, Kearl and Vogel 2023). People with disabilities or other individuals who are unable to care for themselves (e.g. bedridden, socially isolated) may not be able to access cooling locations and be at risk from extreme heat (Berko *et al* 2014, Dahl *et al* 2019, Oregon Health Authority, Public Health Division 2020). These concerns are elevated among the elderly population. Recent findings underscore the importance of social cohesion, or the strength of relationships and the sense of solidarity among members of a community (US HHS n.d.), in mitigating heat-related mortality, especially among the elderly. Indicators of social isolation (low mutual aid, infrequent social contact, detached single-family residences) among the elderly correlate with higher heat-related mortality in a heat event (Kim *et al* 2020), while interventions targeting the elderly to reduce social isolation correlate with decreased heat-related mortality (Orlando *et al* 2021).

1.2.3. Occupation & industry

Workers in jobs that primarily work outside (agriculture, forestry, fishing, hunting) account for around 20% of heat-related deaths (Dahl *et al* 2019, Oregon Health Authority, Public Health Division 2020). Heat-related illness is estimated to be 20 times more likely for outdoor agricultural workers than workers in other industries in the United States due to high ambient temperatures during harvests, high levels of physical exertion, and difficulties maintaining sufficient hydration (Moyce *et al* 2017). Many of these outdoor occupations requiring high levels of physical exertion also require workers to use personal protective equipment (PPE) which can exacerbate the risk of heat-related illness even when temperatures are not excessively high, as PPE can prevent heat from leaving the body (Gubernot *et al* 2014). Occupational exposure to heat and risk of heat-related illness are also not evenly distributed: migrant and lower income workers are more susceptible to heat-related illness and financial harm of decreased productivity during extreme heat events, as many outdoor agricultural workers are paid by the amount they harvest (Gubernot *et al* 2014).

1.2.4. Race & ethnicity

Differential risk of heat-related morbidity and mortality is likely complicated by issues of racism. For example, heat-related mortality has shown to be higher among non-Hispanic American Indian/Alaska natives as well as Black non-Hispanic persons (Berko *et al* 2014, Vaidyanathan *et al* 2020). Historically, these groups were affected by a racist process called 'redlining,' which was refusal of home loans or insurance to certain neighborhoods based only on race. Correlation of this historical process with present urban heat islands (where lack of vegetation and a concentration of development cause a rise in both daytime and nighttime temperatures compared to adjacent rural areas) showed that redlined Portland neighborhoods are much hotter than other neighborhoods (Hoffman *et al* 2020, Kearl and Vogel 2023). Further, of the 108 urban areas that were analyzed, Portland had the greatest temperature discrepancy between redlined and non-redlined neighborhoods, by a difference of 7 °C (Hoffman *et al* 2020). Neighborhoods with urban heat islands often have a higher concentration of economically disadvantaged and/or minority populations (Cheng *et al* 2021). If these communities lack access to cooling interventions, such as air conditioning, this urban heat effect can disproportionately impact morbidity and mortality from heat (Kearl and Vogel 2023). Additionally, black, indigenous, and people of color (BIPOC) communities are often underrepresented participants in climate-health discussions and decision-making processes and excluded from local environmental groups and efforts resulting in limited political power and greater barriers to increasing adaptive capacity during extreme heat events (Phadke *et al* 2015). In addition to the spatial and socioeconomic ties to racial and ethnic disparities in heat exposure, research suggests that cultural background is also related to heat exposure through social norms, access to technology, religion, and traditional beliefs (Naheed and Shooshtarian 2021).

1.2.5. Socioeconomic status, housing, language

Educational attainment is closely associated with income and is a commonly used metric for assessing the capacity to respond and adapt to extreme heat. Research suggests that people with a high school education or less experience higher rates of heat-related death and a greater likelihood to live in neighborhoods with little tree canopy cover than those with higher educational attainment (Reid *et al* 2009, Conlon *et al* 2020). Living in rental housing is also associated with income and has been shown to increase susceptibility to heat-related illness due to the unavailability of amenities, less access to air conditioning, and the financial burden of utilities costs (Uejio *et al* 2011, Kearl and Vogel 2023). For people experiencing homelessness, the impact of heat can be substantial, since they are unable to avoid the direct exposure to climate and may be more likely to live in urban areas where the built environment retains heat (English *et al* 2022). People with limited English proficiency and those born outside of the United States have also been shown to experience linguistic and social isolation, which creates barriers to understanding heat event warnings and obtaining protective resources, thus increasing vulnerability to extreme heat (Uejio *et al* 2011, Chow *et al* 2012).

1.3. June 2021 heat dome event

The city of Portland, Oregon, lies within Multnomah County, the most populous county in Oregon (∼804 000) (U.S. Census Bureau 2022). The 2021 heat dome that settled over the Pacific Northwest brought record-breaking temperatures to the area, where daytime highs reached triple digits for three days, peaking at 116 °F (47 °C) at the Portland International Airport on June 28th (figure 1). This event occurred early in the summer, before residents could naturally acclimate to warmer temperatures, and at a prolonged intensity never experienced before. The heat event exceeded maximum temperatures in other years (independent of the month) by about 5 °C. Additionally, the event happened after an exceptionally dry spring in the Western U.S. so lack of evaporative cooling has been suggested as an important factor in the attainment of the record high temperatures (Philip *et al* 2022).

In response to this extreme event, Multnomah County and partnering jurisdictions mobilized an unprecedented effort to protect against the most severe outcomes of the heat dome. Early warning communications were posted in all available channels and translated into graphics and into multiple languages. An interactive map on the County's website showed places available for cooling. For the first time ever, 24 h cooling shelters were opened in three locations, ultimately housing 1400 people overnight. An additional nine locations were opened as daytime cooling centers. These shelters were staffed by over 350 City and County workers and volunteers. They offered pet accommodation, meals, behavioral health support, and COVID-19 vaccinations. Transportation could be arranged through a regional information line, 211 info.

The County conducted targeted outreach to sensitive populations such as older adults and families with infants, reaching tens of thousands of clients in multiple languages by text message and phone call. Nearly 100 outreach teams were dispatched as street teams, distributing cooling towels, hydration, and information, focused on people living outdoors or in vehicles. In the midst of the COVID-19 pandemic, County health officials contacted operators of affordable housing buildings, urging them to suspend policies on congregating indoors and to open common areas for cooling. The local transit agency, TriMet, paused fare collection for people seeking cooling. Portland Parks and Recreation revoked permits for organized athletic events.

Despite the efforts of responding agencies, extreme heat in the summer of 2021 led to a record number of heat deaths in Multnomah County, nearly all of them during the June heat dome event.

1.4. Research aim

The purpose of this study is to describe the magnitude of the health impacts from the historic heat events of 2021, including deaths, hospitalizations, and emergency room visits. Where data are available, we also describe demographics, risk factors, and exposure patterns. Data compiled for this study were used to develop a heat vulnerability index (HVI) used in planning and response. We note that similar documentation has been published for this heat event, specific to different jurisdictional or geographic boundaries (Schramm *et al* 2021, Henderson *et al* 2022). It is in the same spirit that we offer these epidemiological findings: to inform local policy, to advance and document public health practice, and to demonstrate the use of these data in response planning and hypothesis generation. Documenting impacts within a single local public health jurisdiction has additional utility, as we may put findings in the context of decision making, planning, interventions, and subsequent protective actions that may be instructive to other jurisdictions.

2. Methods

2.1. Outcome data: deaths, hospitalizations, ED visits

We obtained data for this study from four main sources:

(1) Multnomah County analysis of vital records data from Oregon Health Authority. A heat death was defined as an underlying cause of death X30 (exposure to excess natural heat) or contributing cause of T67 (effects of heat and light). Data were limited to deaths occurring between May and September 2021 only for Multnomah County residents. Deaths in which the code W92 (exposure to heat of man-made origin) appeared in any cause field were excluded (this omits certain occupational related deaths). Deaths were geocoded by the Oregon Health Authority and assigned latitude and longitude.
(2) Chart review of heat deaths investigated by the Multnomah County medical examiner (ME) and certified by the Oregon State ME (a subset of deaths described in (1), above). Two independent reviewers coded ME investigation notes and photographic evidence of decedents' homes to detail the location of death, type/floor of residence, the presence of cooling mechanisms, and living arrangements (alone, with family, senior living facility, etc). Data were limited to deaths occurring between May and September 2021 where hyperthermia was listed as the immediate cause of death by the pathologist certifying the death certificate.
(3) Hospital records from Oregon Hospital Discharge data, Oregon Health Authority. Hospitalizations include any diagnosis code as described above for deaths, and were limited to Multnomah County residents who did not die during their hospital stay. Dates are based on admission date and are from 1 May to 30 September 2021.
(4) Emergency and Urgent care visits (henceforth shortened to 'ED visits') were obtained from OR-ESSENCE, our syndromic surveillance system. The query 'heat related illness V2' was used to find visits related to heat; this query is based both on chief complaint and discharge diagnosis. As described above, only visits between 1 May and 30 September 2021 were counted.

We present the total deaths by day, and overall total numbers of hospitalizations and ED visits. For death data, we present frequencies and percentages for some demographic variables using vital records, and other variables using ME records. More information about the ME record review has been previously described (Multnomah County Health Department 2022).

For ED visit data, two reviewers independently assessed triage notes to ascertain evidence of occupational exposure, vehicle involvement, housing instability, or intoxication from drugs or alcohol. Discordant findings were reconciled by consensus. To protect confidentiality in cross tabulations by cause, contributing factor, and demographics, we do not report cell counts of fewer than 5 hospitalizations, fewer than 5 ED visits, or fewer than 3 deaths. Definitions for deaths and hospitalizations as described previously were based on climate and health indicators proposed by the Council of State and Territorial Epidemiologists (Council of State and Territorial Epidemiologists [CSTE] 2018). The full query definition for OR-ESSENCE is listed in appendix A.

For comparison time periods, we used 2015–2019 data. We did not include 2020 due to impacts of the COVID-19 pandemic, which changed overall health seeking behavior, such as a decline in total emergency room visits (Hartnett *et al* 2020).

2.2. Analysis

To describe persons represented by our outcome data sources, we relied primarily on descriptive statistics (frequencies and percentages). For the heat vulnerability analysis, a spatial join with geocoded death data allowed an analysis of variance (ANOVA) test. All analyses were conducted using SAS 9.4 (SAS Institute, Cary, NC), RStudio, and ArcGIS. This analysis originated from the public health response to the 2021 heat

Table 1. Heat vulnerability index indicators and sources.

Sensitivity		
Youth	Percent of the population under 18 years of age	ACS 2016–2020
Seniors	Percent of the population over 64 years of age	ACS 2016–2020
Seniors living alone	Percent of the population over 64 year of age, living alone	ACS 2016–2020
Male	Percent of the population that is male	ACS 2016–2020
CHD	Estimated crude prevalence of adults with coronary heart disease	CDC PLACES 2020
Diabetes	Estimated crude prevalence of adults with diabetes	CDC PLACES 2020
Physical health	Estimated crude prevalence of adults with poor physical health for 14 d or more	CDC PLACES 2020
Exposure		
Population density	People per square mile	ACS 2016–2020
Housing density	Housing units per square mile	ACS 2016–2020
Tree canopy	Percent of land area covered by tree canopy	Metro 2019
Vegetation	Percent of land area covered by vegetation	NLCD 2019
Impervious surfaces	Percent of land area covered by impervious surfaces	NLCD 2019
UHI	2016–2020 mean surface temperature	Metro LANDSAT 2016–2020
Adaptive capacity		
Educational attainment	Percent of the population with less than a bachelor's degree	ACS 2016–2020
Rental housing	Percent of the population living in rental housing	ACS 2016–2020
Cognitive difficulty	Percent of adults with a cognitive disability	ACS 2016–2020
Foreign born population	Percent of the population born outside of the United States	ACS 2016–2020
English language proficiency	Percent of the population speaking English 'less than very well'	ACS 2016–2020
Race & ethnicity	Percent of the population that identifies as black, indigenous, or person of color	ACS 2016–2020

dome event in the Pacific Northwest. As such, this project was considered public health practice, not research, and did not require Institutional Review Board oversight. All personnel handling primary data signed applicable data use and confidentiality agreements with the Oregon Health Authority and Oregon State ME. No identifiable data were removed from secure servers.

2.3. Exposure data: HVI

To assess the spatial distribution of heat-related mortality and possible factors contributing to heat exposure, we conducted a spatial analysis using geocoded deaths from the 2021 Heat Dome Event and Multnomah County's 2023 HVI. This index tool was constructed based on a review of similar heat vulnerability indices in peer reviewed literature which use principal component analysis (PCA) for index construction (Reid *et al* 2009, Conlon *et al* 2020). The 2023 HVI operationalizes vulnerability to extreme heat as a function of sensitivity to heat and illness, exposure to extreme heat, and the capacity to adapt and mitigate harm (Nonnamaker 2023). To calculate heat vulnerability scores for each census tract in Multnomah County, the 2023 HVI uses indicators based on a literature review and data availability to create scores for its sensitivity, exposure, and adaptive capacity domains (Nonnamaker 2023). Temperature data included in the HVI are satellite measurements of surface temperatures on warm days meeting a temperature and could cover criteria, averaged during the years 2016–2020. They reflect mean temperature in degrees Fahrenheit summarized by census tract. Surface temperature data were obtained and processed by Oregon Metro Regional Government and provided to the authors (Oregon Metro 2022). Detailed descriptions of indicators and data sources are provided in table 1.

3. Results

3.1. Deaths

A total of 78 deaths due to heat were identified in 2021. Those are displayed in figure 1 by date of death with an overlay of maximum temperature as recorded at the Portland International Airport. All deaths occurred between 24th June and 18th August. The highest daily total of deaths was 26 on 29th June, which was the day

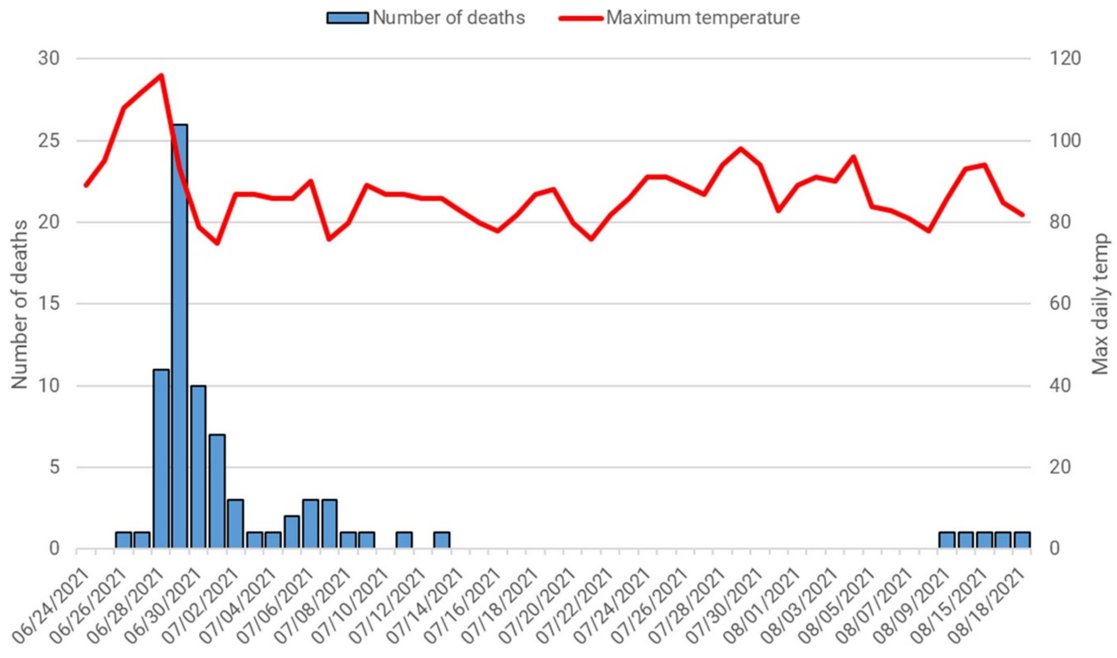

Figure 1. Time series of heat deaths and maximum temperature, June–August 2021.
*Source for temperature data: National Oceanic and Atmospheric Administration.

directly following the maximum recorded temperature of 116 degrees. In comparison, the total average number of deaths due to heat between 2015 and 2019 was less than one death per year (data not shown).

Figure 1 Deaths due to heat (environmental hyperthermia) by date with overlay of maximum daily temperature recorded at the Portland International, airport, 24 June–18 August 2021

Table 2 presents characteristics of deaths from heat in 2021. The majority of deaths were among males ($N = 54\%$, 69%). The mean age at death was 67 years, but ranged from a low of 36 to a high of 97. For 6 decedents who had heat as a contributing cause of death, the underlying causes were mainly drug overdose ($N = 5\%$, 83%, data not shown). The majority of people who died lived in multi-family dwellings ($N = 42\%$, 58%). Of these 42, 14 (33%) lived on floor three or higher of that building (data not shown). Four people died experiencing unstable housing. More than two-thirds of decedents died alone, and half of those who died only had a fan to provide cooling (table 2).

3.2. Hospitalizations

In the 2021 season, there were 55 hospitalizations due to heat, compared to an average of 7 between 2015 and 2019 (Moland *et al* 2021). Most admissions in 2021 were in June ($N = 41\%$, 75%). The proportion of men hospitalized was greater than women (58% vs 42%), and the average age was 64 years (range: 27–100). Analysis of race and ethnicity was not possible due to small numbers in all but the White, non-Hispanic category ($N = 38\%$, 69%).

3.3. ED visits

In the 2021 season, there were 258 ED visits due to heat. In contrast, the 2015–2019 total average for the same period (May–September) was 86 visits ED visits (figure 2). The proportion of men with ED visits was greater than women (60% vs 40%), and the average age was 53 years (range: $<$1–93). Analysis of race and ethnicity showed that the majority of visits were among White, non-Hispanic ($N = 180\%$, 70%), followed by Black non-Hispanic ($N = 27\%$, 10%) and Hispanic ($N = 16\%$, 6%) (data not shown). Using the ED visit triage notes, we noted that:

- Evidence of occupational exposure was noted in 12% of visit records, including evidence of exposure on the job or in a work vehicle;
- Evidence of housing instability was noted in about 10% of visit records;
- Evidence of intoxication was noted in 9% of visit records; and
- In-vehicle exposure, including among people living in vehicles, was noted in 6% of visit records (data not shown).

Table 2. Characteristics of heat-related deaths, May–September 2021[a].

	Number (%)
From analysis of vital records	
Total	78 (100)
Sex	
Male	54 (69)
Female	24 (21)
Mean age (range)	67 (36–97)
Race & ethnicity	
White NH	61 (78)
Black NH	6 (8)
American Indian/Alaska Native NH	3 (4)
Hispanic	3 (4)
From chart review of ME cases	
Total	72 (100)
Housing characteristic	
Multi-family residence	42 (58)
Single family residence	18 (25)
Trailer/mobile home	8 (11)
Unstable housing	4 (6)
Live alone (excludes houseless)	
Yes	48 (71)
No	9 (13)
Unknown	11 (16)
Cooling	
Fan only	36 (50)
None	13 (18)
A/C with or without fan	10 (14)
Unknown	13 (18)

[a] Suppression of numbers for some race/ethnicity groups (Asian NH, Pacific Islander NH) means totals may not sum to 100%.

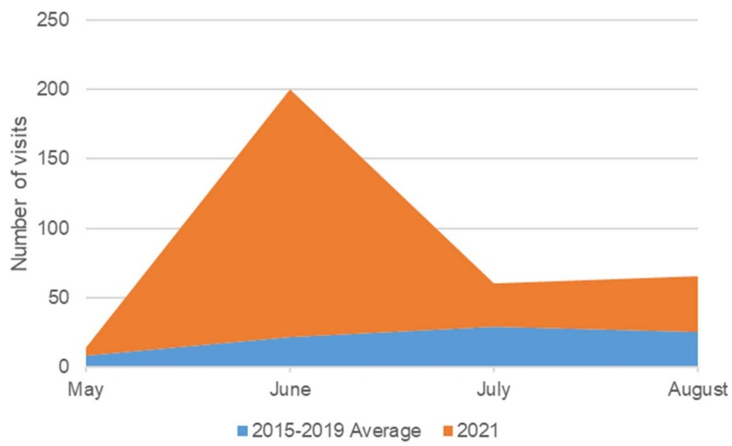

Figure 2. Heat related ED visits by Month, 2015–2019 monthly averages compared to 2021 monthly averages (May–August only*), Multnomah County residents.
*September values suppressed due to small numbers.

3.4. HVI

To test the application of Multnomah County's HVI and its ability to visualize (figure 3) how vulnerability to heat varies throughout the county, we analyzed how the distribution of composite heat vulnerability scores compared to the 72 heat-related deaths which occurred between May through September of 2021 in Multnomah County (limited to deaths where heat was the underlying cause of death only and not a contributing cause). Death data were geocoded by the Oregon Health Authority and then merged back with our local analytic file and de-identified prior to analysis. The locations used for each death primarily reflect

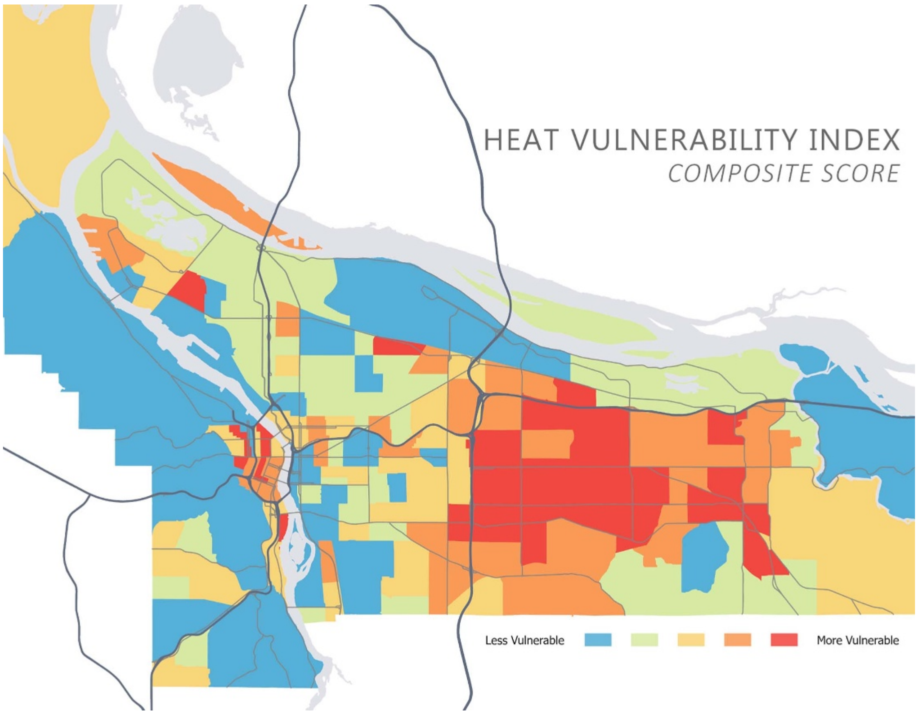

Figure 3. Map of heat vulnerability by census tract.

the residence of the decedents, as 94% of the deaths used in our analysis occurred in the decedent's personal residence.

Of the 72 deaths where heat was the underlying cause, 23 (32%) occurred in census tracts within the highest quintile for heat vulnerability. Forty (56%) of the 72 heat-related deaths occurred in tracts within the top two quintiles for heat vulnerability. Within 200 m of the tracts forming the top two quintiles of heat vulnerability, the number of heat-related deaths increased to 47 (65%). Meanwhile, 7 (10%) of heat-related deaths occurred in tracts making up the bottom quintile of heat vulnerability, 18 (25%) in the bottom two quintiles, and 26 (36%) of the total 72 deaths occurred within 200 m of the bottom two quintiles. However, there are areas throughout Multnomah County where tracts in the bottom two quintiles are adjacent to those in the top two and some heat-related deaths may have occurred within 200 m of both groupings. Using a one-way ANOVA test, we also found a significant difference ($p < 0.01$) in the distribution of heat-related deaths between HVI score quintiles (figure 4).

4. Discussion

4.1. Exposure response

Across all outcome data sources, we observed a large effect size as a result of population-wide exposure to extreme heat. In a typical year Multnomah County sees zero hyperthermia deaths, but in 2021 there were 78. There were three times the number of emergency department and urgent care visits for heat illness as are seen during a typical year, and nearly eight times the number of hospitalizations. Two-thirds of deaths occurred in or near neighborhoods that ranked among the most vulnerable to extreme heat based on our HVI. Relative to the immediately preceding local conditions, these were extremely severe outcomes surpassing anything documented in the region historically. Furthermore, the outcomes documented here are likely a substantial under-representation of the total burden of illness and premature death associated with this event. Whereas we focused only on hyperthermia-related cases, many other health outcomes may have been affected. As Ebi *et al* (2021) point out, cause-specific mortality during heatwaves also includes cardiovascular, respiratory, cerebrovascular, mental illness, and other causes.

4.2. Risk factors

Many of the risk factors that emerge from these findings are consistent with other published research (Vaidyanathan *et al* 2020, Ebi *et al* 2021). The findings in table 2 are largely in alignment with past studies. Decedents were mostly older and living alone. Almost all deaths occurred at the victims' residence, and nearly all were stably housed. Six in ten decedents lived in multifamily buildings, which make up 39% of

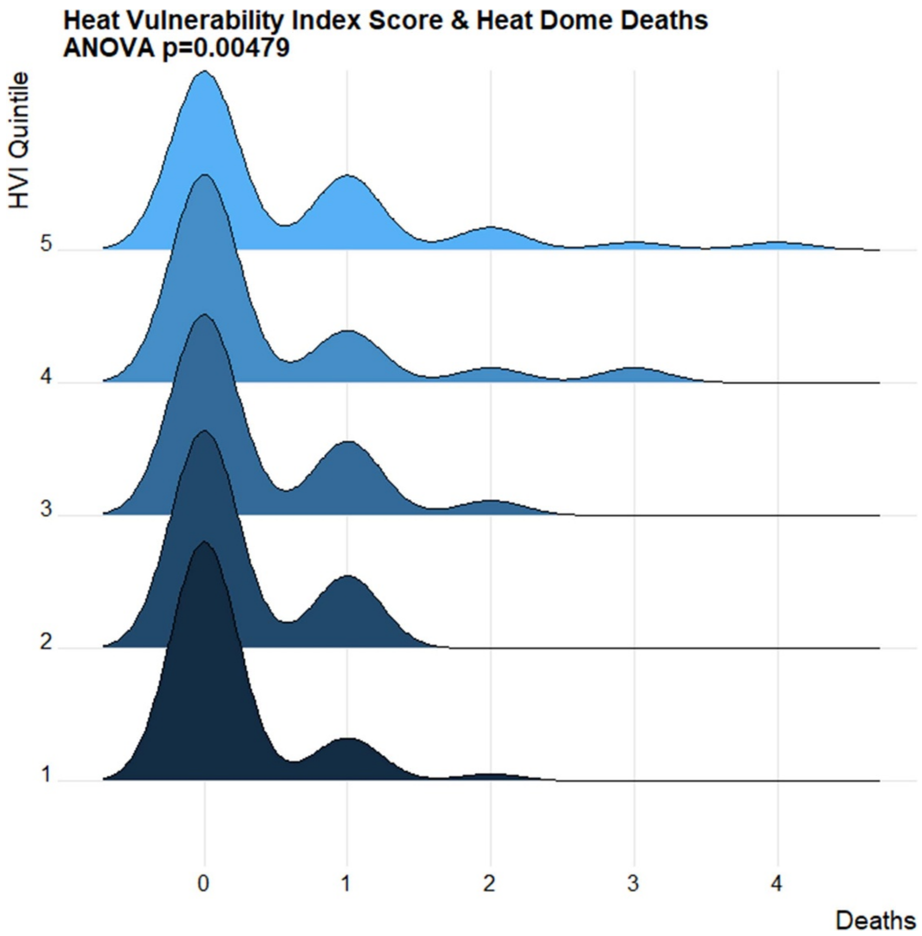

Figure 4. Heat vulnerability index and heat dome deaths (with 5 representing highest vulnerability tracts).

housing units in Multnomah County (US Census Bureau 2022). Lack of cooling was a risk factor: nearly 70% of decedents had no cooling at all or only a fan. Only 10 of the decedents (14%) had air conditioning, and ME records indicate that in at least 7 of these cases the units were unplugged or not functional. In a departure from the literature reviewed in the introduction, we cannot conclusively determine whether there was a disproportionate burden of death or illness in the BIPOC (non-white) population.

4.3. Implications for practice

The experience of Multnomah County and other jurisdictions in the region during the Pacific Northwest Heat Dome is a cautionary tale. Despite thoughtful planning, a recently updated heat response plan, and an unprecedented mobilization of resources, we documented severe health impacts. Local health jurisdictions and emergency responders can increase readiness for such events by interrogating existing plans and tailoring them not to a paradoxical 'average extreme' event, but to a catastrophic scenario more severe than historic examples or local experience. This is the situation that responders found themselves in during the summer of 2021 in Multnomah County. Attribution studies have suggested that the conditions precipitating the 2021 heat dome were not only impossible without climate change, but also so far outside the range of observed temperatures as to make it difficult to characterize the magnitude of the anomaly (Philip *et al* 2022). Preparing for roughly a 100 year return event was not adequate to protect against the health impacts of such an extreme event. As the climate continues to change, others (Heeter *et al* 2023) have estimated that the Pacific Northwest Heat Dome of 2021 could become not a ∼1000 year event, but something that could have a 50% chance of occurring in any year by mid-century. Shortcomings of preparedness planning may be in part attributable to the constraints that inhibit local governments from fully considering the connections between extreme events, such as discrete decision timescales and jurisdictional boundaries (Raymond *et al* 2020). Nevertheless, the practice is well supported by evidence. In guidance for public health practitioners, Hess *et al* (2023) note that pre-event interventions (primary prevention) are effective at reducing health risk during extreme heat events. They further recommend heat action plans that fit the scope of emergency management for a given jurisdiction.

The necessity to increase readiness for extreme heat events like the 2021 Heat Dome extends far beyond the Pacific Northwest. Over the past two decades, extreme heat events with substantial public health impacts have occurred across the globe, highlighting the strain that such events present to local public health and health care delivery systems and the need to improve preparedness (Hess *et al* 2023). To reduce the global public health impacts of extreme heat, consistent, accurate, and high-resolution measurements of the climate and demographic forces contributing to disparities in exposure are needed, as existing global exposure assessments are insufficient to address the growing threat of extreme heat in urban areas worldwide (Tuholske *et al* 2021). While this report details the impact of the 2021 Pacific Northwest Heat Dome event in Multnomah County, our results can be used by public health organizations within and outside of the United States to help inform heat mitigation policies and preparedness planning.

This descriptive analysis was possible in a relatively large local health department with the staffing resources commensurate with a population of over 800 000. If we had more capacity and had the event not coincided with the COVID-19 pandemic, we may have been able to undertake more thorough and more timely investigation, providing more robust decision support through disaster epidemiology (Malilay *et al* 2014).

4.4. Future research

The 2021 Pacific Northwest heat dome warrants additional investigation. The authors were unable to resolve questions about why the death rate in Multnomah County was apparently much higher than in neighboring counties, and whether differing death investigation practices between states and provinces within the region may partially explain that finding. Anecdotal evidence suggests rapid uptake of air conditioning in the region, but we found no data to confirm this. As noted, investigating morbidity and mortality beyond hyperthermia could provide a more comprehensive characterization of impacts and suggest opportunities for intervention. In this case, an expected ozone advisory during the heat event did not materialize, possibly because of reduced activity and its attendant combustion, but as other studies have noted (Tong *et al* 2010, Hansel *et al* 2015), accounting for the influence of higher air pollution would elucidate the potential for prevention. Finally, our results suggest that mapping tools such as heat vulnerability indices are applicable in intervention planning, but prior to the summer of 2021 we would not have been able to validate it using hyperthermia deaths. Investigation and dissemination of best practices for using such indices *prior* to extreme events would have informed our response and may benefit other jurisdictions in the future.

5. Conclusions

This study describes the heat dome event that occurred in Multnomah County, OR, in June 2021 and the health effects of heat overall in summer 2021. Across all outcome data sources, population-wide exposure to extreme heat resulted in large effect sizes. Despite thoughtful planning, a recently updated heat response plan, and an unprecedented mobilization of resources, we documented severe health impacts. We suggest that local health jurisdictions and emergency responders can increase readiness for such events by stress-testing existing plans and consider tailoring them to a scenario more severe than those contemplated by existing plans.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://github.com/multco-hhc/MultCo_2023HVI/blob/main/HVI2023_DataDictionary.xlsx.

Appendix A: Heat-related illness V2 query definition

Chief Complaint History, Discharge Diagnosis TERMS: (,^[;/]992[0–9];^,or,^[;/]992.[0–9];^,OR,^[;/]E900;^,OR,^[;/]E900.[09];^,OR,^[;/]E900[09];^,OR,^[;/]T67^,OR,^[;/]X30.X^,OR,^[;/]X30X^,),OR,(,(,^HEAT,OR,^HEAT[-/\.;:]^,OR,^HEATCRAMP^,OR,^HEATEX^,OR,^HEATST^,OR,^HYPERTHERM^,OR,^SUNSTR^,OR,^SUN STROKE^,OR,^SUN-STR^,OR,^ TO HOT^,OR,^ TOO HOT^,OR,(,(,^HEET^,OR,^HOT^,),AND,(,^EXCESSIVE^,OR,^EXHAUST^,OR,^EXPOS^,OR,^FATIGUE^,OR,^CRAMP^,OR,^STRESS^,OR,^IN CAR^,OR,^OUTSIDE^,OR,^PROSTRATION^,),),),ANDNOT,(,^ALLERG^,OR,^FEELING HOT^,OR,^FEELS HOT^,OR,^FELT HOT^,OR,(,^HOT^,AND,^SENSATION^,),OR,^HEAT SENSATION^,OR,^ INFLAM^,OR,(,^PAIN^,AND,(,^LIMB^,OR,^ARM^,OR,^SHOULDER^,OR,^ELBOW^,OR,^WRIST^,OR,^HAND^,OR,^LEG^,OR,^HIP^,OR,^GROIN^,OR,^THIGH^,OR,^KNEE^,OR,^ANKLE^,OR,^FOOT^,OR,^FEET^,OR,^BACK^,OR,^NECK^,OR,^FLANK^,OR,^RED^,OR,^JAW^,OR,^MOUTH^,

OR,^TEETH^,OR,^TOOTH^,),),OR,^RADIAT^,OR,^REDNESS^,OR,^SWELL^,OR,^SWOLLEN^, OR,^SURG^,OR,^POST OP^,OR,^IBUPROFEN^,OR,^IBUPROPHEN^,OR,^ALIEVE^, OR,^MOTRIN^,OR,^TYLENOL^,OR,^INJUR^,OR,^TRAUMA^,OR,(,(,^HEAT,OR,^HEAT[-/\.;:]^,),AND,(,^ ICE^,OR,^APPLIED^,OR,^APPLY^,OR,^APPLYING^,OR,^TRIED^, OR,^USED^,OR,^USING^,OR,^COLD^,OR,^ RASH^,),),OR,^HEAT PACK^,OR,^HEATING PAD^,OR,^LUMBAGO^,OR,^RELIEF^,OR,^RESOLVE^,OR,^RELIEVE^,OR,^RELEIVE^, OR,^DENTAL^,OR,(,^HOT^,AND,(,^COLD^,OR,^COFF^,OR,^SHOWER^,),),OR,(,^ORAL^, AND,^SURG^,),OR,(,^SENSITIV^,AND,(,^HEAT^,OR,^HOT^,),),OR,^HOT DOG^,OR,^HOT GREASE^,OR,^HOT EPPERS^,OR,^HOT TEA^,OR,^HEAT ACHE^,OR,^HEAT CONDITION^, OR,^HEATACHE^,OR,^HEAT ATTACK^,OR,^HEAT BEAT^,OR,^HEATBEAT^,OR,^HEAT FAILURE^,OR,^HEAT BURN^,OR,^HEATBURN^,OR,^HEAT FLUTTER^,OR,^HEAT RACING^,OR,^HEAT RATE^,OR,^HEATRATE^,OR,^HEATLH^,OR,^HEATH^, OR,^HEATTH^,OR,^HITTING HEAT^,OR,^PALPITATION^,OR,^CHEAT^,OR,^WHEAT^, OR,^HEATER^,OR,^HEATHER^,OR,^HEATING^,OR,^HOTEL^,OR,^LITHOTR^, OR,^METHOTR^, OR,^PHOTO^,OR,^PSYCHOTIC^,OR,^SHEATH^,OR,^SHEET^,OR,^SHOT^,OR,^SUNDAY^, OR,^THEAT^,OR,^WHEAT^,OR,^ACCIDENT^,OR,^ALCOHOL^,OR,^ETOH^,OR,(,^BURN^, AND,^MOUTH^,),OR,^DISTRESS^,OR,^FEVER^,OR,^GETS HOT^,OR,^HEAT FLASH^,OR,^HOT FLASH^,OR,^HIVES^,OR,^HOT TUB^,OR,^NO HEAT^,OR,^OVEN^,OR,^SUICID^,OR,^HEAT OF THE MOMENT^,OR,^CONTACT WITH OTHER HEAT AND HOT^,OR,^W92^,),)

Appendix B: Additional heat vulnerability index methods

Following the index construction methods of Conlon *et al* (2020), we also conducted a supervised PCA. In contrast to our unsupervised PCA, the indicators for the supervised PCA were chosen based on their correlation with heat-related illness data. To identify variables for our supervised PCA, we regressed hospital visits for heat-related illness from May–September of 2020–2022 with each individual indicator used in our unsupervised PCA and selected indicators with the strongest associations to heat-related illness. Heat-related illness hospitalization data was only available at the zip code level and were apportioned to census tracts based on tract population as a proportion of zip code population. With the indicators that were moderately significantly associated ($p < 0.20$) with heat-related illness, we conducted PCAs for each domain. The variables removed from index construction in this process were percent of the population that is male, percent of the population under the age of 18, percent of the population over the age of 64, and average annual surface temperature. This resulted in a reduced number of factors in the sensitivity domain, creating a composite score that appeared to overrepresent the exposure domain. However, the differences between our supervised and unsupervised composite HVI scores were minimal, leading us to select the index constructed using the unsupervised PCA methods as it is difficult to justify removing four important indicators from index construction and any assumptions introduced into the model in an attempt to bridge hospitalization data across geographies.

Additionally, we constructed a composite index score using an unsupervised PCA for all indicators rather than summing domain scores. Many of the heat vulnerability indices that we reviewed use this method and assign domains to individual PCA factor loadings based on which variables account for the largest degree of variance. While the composite HVI scores from this method and those from summing domains scores were similar once visualized, we opted to use our original method of calculating composite scores as sum of domain scores. This method is best suited for guiding intervention approaches because after identifying locations where people experience high vulnerability to heat, vulnerability can be disaggregated into its sensitivity, exposure, and adaptive capacity components, highlighting areas where domain-specific interventions can make the most substantial reductions in overall heat vulnerability.

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