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Extreme Heat Vulnerability among Older Adults: A Multi-level Risk Index for Portland, Oregon

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Abstract

Background and Objectives.

Extreme heat is an environmental health equity concern disproportionately impacting low-income older adults and people of color. Exposure factors, such as living in rental housing and lack of air conditioning, and sensitivity factors, such as chronic disease and social isolation, increase mortality risk among older adults. Older persons face multiple barriers to adaptive heat mitigation, particularly for those living in historically temperate climates. This study measures two heat vulnerability indices to identify areas and individuals most vulnerable to extreme heat and discusses opportunities to mitigate vulnerability among older adults.

Research Design and Methods.

We constructed two heat vulnerability indices for the Portland, Oregon metropolitan area: one using area scale proxy measures extracted from existing regional data and another at the individual scale using survey data collected following the 2021 Pacific Northwest Heat Dome event. These indices were analyzed using principal component analysis (PCA) and Geographic Information Systems (GIS).

Results.

Results indicate that the spatial distribution of areas and individuals vulnerable to extreme heat are quite different. The only area found among the most vulnerable on both indices has the largest agglomeration of age- and income-restricted rental housing in the metropolitan area.

Discussion and Implications.

Due to spatial variations in heat-related risk at the individual and area scales, measures addressing heat risk should not be spatially uniform. By focusing resources on older adult individuals and areas in particular need of assistance, heat risk management policies can be both highly efficient and cost-effective.

Keywords: environmental health equity, living environments, climate adaptation, heat-risk mitigation, socio-spatial analysis

Background and Objectives

The Pacific Northwest region of the U.S., known for its temperate climate, recently experienced several unprecedented extreme heat events. The Pacific Northwest Heat Dome event in late June of 2021 brought record-breaking temperatures over a five-day period, resulting in more than 1,000 excess deaths across the region. As with other extreme heat incidences, older adults proved to be particularly impacted during this event. In Portland, Oregon's Multnomah County alone, of the 69 confirmed hyperthermia-related deaths between June 28th and July 7th, 2021, 48 of those individuals were aged 60 or older (78 percent). Furthermore, all-cause mortality was double the normal level during the week of the heat dome event and hospital emergency departments saw a threefold increase in heat illness visits during the summer of 2021, following two additional heat waves that year (Multnomah County, 2022; Khatana et al., 2022).

Many of these deaths and illnesses could have been prevented if the underlying risk factors had been addressed. Among those who died, more than half lived in multifamily housing, the majority of individuals lived alone, and most did not have a working air conditioner (Multnomah County, 2022). Understanding these risk factors is an important step in predicting individual- and community area-level vulnerability to future death and illness related to extreme heat among older adults. This research describes the heat vulnerability landscape in the Portland, Oregon metropolitan region following the 2021 Pacific Northwest Heat Dome event and discusses opportunities to mitigate vulnerability among older adults in preparation for future extreme heat events. In so doing, this study describes policy implications for responding to future extreme heat events in the Pacific Northwest, which has witnessed a daily maximum temperature increase twice as rapid as the global average from 1900 to 2019, and is projected to face increasingly frequent, severe, and extended heat waves due to ongoing global warming (Philip et al., 2022).

Older adults tend to be particularly vulnerable to heat-related illness and mortality (Gamble et al., 2013; Macey & Schneider, 1993; McDermott-Levy et al., 2019). According to the Intergovernmental Panel on Climate Change (2007), vulnerability can be explained as a function of three primary factors:

- Exposure - the nature and degree to which individuals are exposed to hazardous conditions. This can be influenced by the built environment, such as housing with poor ventilation, lack of properly operating air conditioning, and urban heat island effect (Lim & Skidmore, 2020; Samuelson et al., 2020).
- Sensitivity - the degree to which individuals are affected by climate change conditions. This can be exacerbated by physiological systems and preexisting health conditions (Gamble et al., 2013; Hansen et al., 2011).
- Adaptive capacity - the ability of individuals to adjust or to cope with climate variations. This can include the willingness and ability to stay inside a well air-conditioned building, increase hydration, and wear light clothing (Hansen et al., 2011; Nitschke et al., 2013).

These processes of vulnerability are often compounded by social determinants of health (Cuthberson et al., 2019; Jeste, 2022), resulting in a complex social vulnerability (Rhoades et al., 2018). Economic status, race, ethnicity, housing, employment, built environment, social integration, social capital, and access to healthcare are a few examples of the social determinants that influence exposure, sensitivity, and adaptive capacity to changing climate conditions (Jung et al., 2021). The social determinants of health provide a conceptual framework for this research study in examining the contextual factors and mechanisms through which heat vulnerability is produced.

At the intersections of these social determinants is where we find the greatest climate vulnerabilities. For example, socially isolated low-income older adults and people of color are significantly overrepresented in heat-related illness and mortality (Lim & Skidmore, 2020; Reid et al., 2009; Klinenberg, 2002). Thermal inequities across the built environment within cities due to fewer trees and more impervious surfaces produce greater heat exposure in neighborhoods with higher low-income, Latinx and Black populations (Dialesandro, Brazil, Wheeler, & Abunnasr, 2021). As indicated in the Multnomah County case, living in multifamily or low-income housing, living alone, and lack of working air conditioner were the most significant and interconnected risk factors for older adults who suffered heat-related illness or lost their lives during the heatwave (Multnomah County, 2022).

Although older adults represent a diverse group, many face unique challenges to limiting exposure and sensitivity, as well as increasing adaptive capacity, resulting in increased vulnerability to heat stress. While many older adults are active and healthy, old age tends to be associated with physiological concerns including cognitive disorders, comorbidities (particularly diabetes, respiratory conditions, and cardiovascular disease), medication use, mobility issues, and thermoregulatory impairments (Gamble et al., 2013; McDermott-Levy et al., 2019). In addition to these physiological concerns, Hansen et al. (2011) found multiple barriers to extreme heat adaptation among older adults. Socioeconomic factors included barriers to using air conditioning, such as cost, landlord restrictions, or power outages, isolation, and housing issues (Palinkas et al., 2022). Psychological issues included health misconceptions, security issues, cognitive biases (Haraguchi et al., 2022; Palinkas et al., 2022), and resistance to change. Contextual factors included dependence on public transportation, ineffectiveness of warning systems, and inadequate resources to support coping and recovery (Rhoades et al., 2018). Within the city of Portland, researchers found that even in the best case scenario at a fast walking speed, less than one third of the population is within an accessible distance to a public heat refuge site (Voelkel et al., 2018), meaning that older persons with functional impairments would be at a particular disadvantage in reaching crucial adaptation resources. Older adults in historically temperate climates may not adopt adaptive heat mitigation behaviors at all simply because of the routines of living without the threat of extreme heat (Williams et al., 2019). For example, the majority of housing in the Pacific Northwest was built without central air conditioning.

The interconnections between climate change, urbanization, and population aging present unique and persistent challenges (Antal & Bhutani, 2022; Haq & Gutman, 2014).

More than half of the world's population lives in urban areas and that proportion is expected to increase to over 68 percent by 2050 (World Health Organization, 2021). Urban densification has led to increased prevalence of the urban heat island effect (UHI), whereby the densification of heat absorbing, impervious surfaces and human activity creates pockets of communities within urban areas that become significantly hotter than surrounding communities, thereby exacerbating existing health risks (Heaviside et al., 2017). Additionally, UHI exposure varies by socioeconomic status of a neighborhood; poorer neighborhoods have been shown to be several degrees hotter in both normal and extreme summer heat (Dialesandro et al., 2021; Sidiqui et al., 2022). One study found a geographic link between UHI and historic redlining practices in 108 cities in the U.S., meaning that areas historically racially segregated by processes of housing discrimination and the refusal of home loans and insurance were found to have higher temperatures on average than the rest of the city (Hoffman et al., 2020). As the urban population ages, this translates to a higher proportion of older adults at risk of heat stress, particularly when extreme heat events exacerbate existing temperature variations within urban areas (Antal & Bhutani, 2022).

To understand geographic variation of risk to heat-related illness and mortality, researchers and municipalities employ heat vulnerability indices to inform planning for interventions through mitigation and adaptation mechanisms (Cutter et al., 2003; Preston et al., 2011). Heat vulnerability indices typically pair area-level data related to social determinants of heat-related illness and mortality, such as social isolation or economic status, with Geographic Information Systems (GIS) to identify the socio-spatial variation of "risk-scape" across a geographic region (Wilhelmi et al., 2004; Wolf & McGregor, 2013). Although much is known about the impact of extreme heat on older adults, we could not locate studies that paired individual- and area-level data to capture the heat vulnerability risk landscape with a specific focus on older adults. This study takes this multi-level approach to mapping the heat vulnerability risk landscape for older adults in the Portland metropolitan area, thereby addressing an increasingly important health equity issue.

Design and Methods

This study measures area-level heat vulnerability using existing regional data aggregated at the zip code-level (Table 2) and individual-level vulnerability with the use of individual-level responses to survey data (Table 3) to identify community areas and individuals vulnerable to heat waves.

Area-level Measures

To construct the area-level index, we used the variables employed in Wolf & McGregor's (2013) model of a heat vulnerability index, as these variables reflect risk factors associated with heat-related illness and mortality identified in the literature, notably including being an older adult, defined as "population above 65 years old" (Wolf & McGregor, 2013, p. 61). In their study, vulnerability is considered a latent variable represented by the synergistic effects of several variables. This inductive approach was first proposed by Cutter et al. (2003). Wolf & McGregor (2013) further developed this method and applied it to the City of London. Their study constructed and analyzed a vulnerability index for the 4,765 Lower Level Super Output Areas (SOAs) across the City of London, with an average of 1,500 residents per SOA. The unit of analysis in this study is the zip code, and the average population of each region is 26,093. Although this is a coarse analysis compared to Wolf & McGregor (2013), this study is unique in that it uses the same unit of analysis for not only area-level but also individual-level indices and performs a comparative analysis of the two. Area-level data in this study were derived from the US Census, LandSat, and CDC PLACES data (Manson et al., 2022; Oregon Metro, 2020). Table 2 summarizes variables related to vulnerability indicators by category based on Wolf & McGregor (2013), using their original terminology. As this table shows, various risk factors are categorized into those related to exposure and sensitivity (including older age), which interact to constitute a latent index of heat vulnerability.

Individual-level Survey

The individual-level survey data (n=897) were collected in February 2022, following the 2021 Pacific Northwest Heat Dome event. Using an external research company's panel, the survey targeted the general population who reside in the Portland metropolitan region in the State of Oregon, using quotas in proportion to the population in the region (e.g., gender and age). The online questionnaire included socioeconomic and demographic characteristics, such as respondents' living environment, health conditions, social isolation, age, and socioeconomic status. Invitations were sent to 2,811 people living in the study region, and we received a total of 1,031 responses (response rate: 36.7 percent). We excluded respondents who resided outside the study area at the time of the survey and those who provided incomplete responses. As a result, we utilized a total of 897 responses for our analyses (valid response rate: 32.0 percent).

Statistical Analysis

As in Wolf & McGregor (2013), this study uses principal component analysis (PCA). A question that arises when conducting a PCA is how many principal components (PCs) to retain. In this analysis, PCs with eigenvalues greater than 1.0 were selected according to the PC selection criteria outlined by Jolliffe (2002). Such PCs explain more variance than the original variable with a variance of 1.0. For each of the *n* components retained, a PC score was created for each observation (area or individual). These scores were then weighted by the variance explained by each component to produce a total PC score, which was treated as the heat vulnerability index value of this study.

The risk factors that make up the vulnerability index are all defined such that the higher the value, the higher the risk. Therefore, the calculated index is similarly interpreted as being more vulnerable to extreme heat when the value is positive and larger, and less vulnerable (more robust) when the value is negative and larger.

Results

Individual-level Survey

Demographic attributes of the individual-level survey sample included percentage of females, older adults, and college graduates, average household size, and household income (Table 1). Survey participants were slightly more likely to be homeowners (54 percent) than renters (41 percent), with 5 percent indicating “other” for their current housing situation, nearly mirroring the metropolitan area rate of homeownership of 53.4 percent (U.S. Census, 2020). Ages ranged between 20 and 81, with a mean of 43. Table 1 compares the sample to the population in the study area. It should be noted that the sample in this study tended to be slightly skewed toward females, as the ratio of males to females in the region is approximately 50/50. However, in terms of other attributes, the sample in this study reflected the characteristics of the three counties at a reasonable level.

More than three quarters of respondents reported being affected by the 2021 extreme heat wave, with 51 percent reportedly being somewhat affected and 27 percent greatly affected. Actions taken during the 2021 extreme heat event included, staying at home (59 percent), adjusting clothing (57 percent), using an air conditioner (54 percent), cooling their body (50 percent), using sunscreen (48 percent), adjusting medication (44 percent), and increasing fluid intake (44 percent), among other actions.

Principal Component Analysis

For the area-level vulnerability index (Table 2), the application of the eigenvalue 1 criterion resulted in three PCs being retained for analysis. These explained 79.3 percent of the variance. As mentioned above, the value of the percentage of variance for each PC was used as a weight in calculating the index. Component 1 is interpreted to represent residential status (rental, multi-family housing) and living conditions (poverty, living alone). Similarly, component 2 is interpreted to represent climate (UHI), health status, and race (non-white), while component 3 represents population density, older age, and type of residence (living in institution).

The same criteria were applied to the individual-level vulnerability index (Table 3), resulting in four principal components retained for analysis. These explained 60.3 percent of the variance. As Table 3 shows, PC1 represents housing status (rental, air conditioning availability) and poverty. Similarly, PC2 represents urban area climate (UHI) and population density, PC3 represents older age and living alone, while PC4 is interpreted as representing multi-family housing, health status, and social isolation, respectively.

The majority of the respondents comprising the sample are relatively robust to the impact of extreme heat. Table 4 summarizes the area- and individual-level vulnerability indices calculated based on the PCA. At both levels, the mean value of the index is zero and the median value is also close to zero. This indicates that the index is negative in about half of the areas, implying that vulnerability to heat waves is a concern, and the same is true for individuals.

Figure 1 illustrates the distribution of area-level and individual-level vulnerability indices. Both distributions have Kurtosis values above 3, indicating that the shape of the distribution deviates from the normal distribution, with steeper peaks and longer tails. The value is particularly high for the area-level indicator (7.91), indicating that this trend is particularly pronounced.

Area-level Analysis

The limited sample size of the area-level indicator (n=58 zip codes) makes it unavoidable to some extent that the distribution shape deviates from a normal distribution. Nevertheless, the shape of the distribution is distinctive, with particularly large variation in samples taking positive values, a factor that spreads the tail of the distribution.

Figure 2 shows a spatial distribution of the area-level vulnerability index divided into eight isometric classes. Darker colors indicate higher vulnerability. As this figure shows, the values of the vulnerability index are not spatially uniform, but are unevenly distributed. The vulnerability index values tend to be higher in downtown Portland and in the eastern part of the city. Outside the city, a similar trend is observed in a neighboring city (Beaverton) located in the western part of the study region.

Overall, the high value areas appear to be clustered, indicating a spatial trend. To rigorously verify this, we performed a Moran's I test of spatial autocorrelation. The result was significant at 0.583, confirming a high positive spatial autocorrelation. This means that when the vulnerability of an area is high (low), its neighboring areas tend to show the same trend, indicating significant spatial similarity.

We also performed a Getis-Ord local G* test of spatial agglomeration. The results showed significant spatial agglomeration in the area centered on the downtown Portland area, indicating that vulnerable neighborhoods are not randomly distributed but form clusters around this area.

Individual-level Analysis

Figure 3 displays the average individual-level vulnerability index per area. As with the area-level index, the values are divided into eight isometric classes. As can be seen from this figure, the index values are not spatially uniform, but rather unevenly distributed. Areas with the highest value classifications can be found in one area of downtown, as well as the eastern and northern parts of the city.

To compare spatial trends between individual-level indicators and area-level indicators, we again conducted a Moran's I test of spatial autocorrelation, and the result was significant at 0.343. Although to a lesser degree than at the area level, positive spatial autocorrelations were also shown to exist for the individual-level index. A Getis-Ord local G* test was then conducted to verify the presence of spatial agglomeration. The results confirmed significant spatial agglomeration not in Portland's downtown area, but on its East and North sides. As at the area level, vulnerable neighborhoods were shown to form clusters rather than being randomly distributed, but their spatial patterns differed.

To see the relationship between the spatial distribution of both vulnerability indices, we performed a correlation analysis between the two. The calculated correlation coefficient is only 0.08, indicating that there is no significant relationship between the two spatial patterns. In fact, only one neighborhood (Old Town-Pearl District-Slabtown, a triangle-shaped area slightly above the center of the map) was classified as the most vulnerable class for both indicators. The spatial distribution of both indicators was statistically shown to be more different than it appears.

Discussion and Implications

This study constructed two indices to measure socio-spatial heat vulnerability of individuals and areas in the metropolitan area of Portland, Oregon, U.S. We built on prior methods (Wolf & McGregor, 2013) by using proxy measures (notably including percent of the population that is 65 and older) extracted from existing regional data and survey data and mapped vulnerability at the individual and area levels. These indices can be used to assess the potential risk of older adults to extreme heat events relative to other population groups.

Our analysis differs from Wolf & McGregor (2013) in that we add an individual-level index of comparable proxy variables to their area-level index. This second level of analysis shows some clustering of vulnerable individuals outside of high-risk areas. In their study, which also uses PCA, exposure factors varied together while sensitivity factors varied together. Conversely, in our study, exposure and sensitivity factors were mixed in the PC loadings. Both studies show spatial variability with clustering of high vulnerability areas, rather than random dispersion.

The low correlation between both the area- and individual-level indices implies that people vulnerable to extreme heat do not necessarily live in vulnerable areas. Rather, our analysis shows that the spatial distribution of vulnerable individuals differs from that of the area-level indicators. In fact, among the 14 regions in the top 25 percent in terms of average individual-level indicators, eight are relatively robust (negative area-level indicators) to extreme heat.

The Old Town-Pearl District-Slabtown neighborhood, found to be the most vulnerable in both the area- and individual-level indices, is a unique neighborhood. Multnomah County's research found the Old Town-Pearl District-Slabtown neighborhood to have had the highest number of heat deaths among all zip codes and among the highest number of emergency department and urgent care visits by zip code for heat illness during the summer of 2021 (Multnomah County, 2022). As indicated in a recent *State of Aging in Portland* report, this neighborhood has the largest agglomeration of age- and income-restricted rental housing in the metropolitan area, typically restricted to applicants who are 62 or 65 and older who have economic resources well below the poverty threshold (DeLaTorre et al., 2021). This is an important observation given that prior research has found that being over 65 years of age and living in rental or multi-family housing with limited economic resources are significant heat risk factors (Klinenberg, 2002; Lim & Skidmore, 2020). In fact, as discussed, more than half of the heat-related deaths attributed to the 2021 heat dome event, 70 percent of which were victims over 60 years old, occurred in the individual's multi-family dwelling (Multnomah County, 2022).

This research indicates that measures addressing extreme heat events should not be spatially uniform. From a policymaking perspective, it may be reasonable to identify areas vulnerable to extreme heat through region-level statistics and to concentrate countermeasure resources in those areas. However, such a policy may result in the omission of a significant number of vulnerable individuals in need of assistance. By focusing resources on both community areas and individuals in particular need of assistance, it is possible to develop heat risk management policies that are both efficient and cost-effective. It will therefore be necessary to combine regional and individualized targeting in policymaking. Policy geared toward creating and funding climate resilience initiatives outside of times of emergency could improve heat resilience at the individual level. There could be resources that enable community-based organizations, faith organizations, senior centers, neighborhood associations, health clinics, and other neighborhood institutions to regularly screen for heat vulnerability, provide education, help individuals sign up for emergency alerts, and other individual level interventions. (Bryant et al, 2022).

This analysis assesses socio-spatial vulnerability to heat stress. One next step is to assess and increase adaptive capacity among older adults, both as individuals and within communities located within geographic areas that are presenting as higher on the vulnerability scale. Working in collaboration with older adults to understand their perspectives and address potential barriers to adaptation is an important part of increasing resilience and building adaptive capacity (Rhoades et al., 2018). This may be particularly important for older adults living in traditionally temperate climates, as they are less likely to employ heat mitigation and adaptation measures (Williams et al., 2019).

Adaptation measures for older adults at the individual level include providing emergency preparedness educational materials and trainings (Gamble et al., 2013; Rhoades et al., 2018); measures to combat social isolation and build social capital, such as identification of vulnerable individuals via peers and family to provide proactive outreach (Bryant et al., 2022); and distributing and/or subsidizing air conditioner use and transportation to cooler indoor environments (Gamble et al., 2013; Worfolk, 2000). The latter intervention is particularly important given the data demonstrating the loss of life as a result of lack of access to a working air conditioner and other barriers to air conditioner use (Hansen et al., 2011). Gerontological nurses and other health care professionals can support the unique care needs of older adults in climate emergencies by using proven strategies to promote resilience and altering plans of care during prolonged heat events to monitor hydration and electrolyte levels, particularly for those with comorbidities such as heart failure and renal disease (McDermott-Levy et al., 2019). Advocacy from gerontological nurses and health care administrators through research, practice, and policy is crucial in supporting the health needs of older adults related to climate change.

Climate resilience interventions at the neighborhood and community levels include government agencies working closely with community-based organizations, senior centers, nonprofit organizations, and faith leaders to ensure that there are trained emergency response volunteers and plans in all neighborhoods, including those with fewer formal services and social capital (Bryant et al., 2022). Many cities convene Community Organizations Active in Disaster (COAD) groups, which act as an important bridge between government and various types of community organizations in disaster resilience efforts. In addition to COAD, Portland is taking this neighborhood response approach with its Neighborhood Emergency Teams (NETs) made up of residents trained in emergency response. Neighborhood level interventions provide opportunities for intergenerational collaboration, which could “result not only in better mitigation and adaptation efforts, but also in a world for all ages, in which chronological age is no longer a barrier or a hurdle” (Ayalon et al, 2022, p. 12).

Mitigation measures to reduce heat vulnerability, such as urban greening, are important complements to any adaptation strategy as they aim to address the root causes of increased heat stress by reducing greenhouse gasses while simultaneously providing cooling and shade (Atwoli et al., 2021). Mitigation and adaptation measures, such as addressing housing conditions and building design to reduce energy use and provide for cooler indoor environments, offer significant opportunities for health co-benefits, such as reduced heat-related illness and mortality (Sharifi et al., 2021).

Mitigation measures and adaptation support are particularly important in supporting environmental health equity among older adults at the various scales of residential environments, including the urban-rural spectrum, the neighborhood context, and individual homes (Molinsky & Forsyth, 2022). In addition to the Old Town-Pearl District-Slabtown area found to be the only neighborhood classified at the highest level of vulnerability on both indices, the spatial agglomeration of vulnerable areas includes the city’s historically redlined district and areas of East Portland, another historically marginalized region of the city. This region has fewer environmental amenities, like tree canopies, and greater environmental burdens, such as a higher urban heat island effect compared to other Portland neighborhoods (Voelkel et al. 2018), raising racial and health equity issues. As mentioned, at the neighborhood-scale, historical policies based on race have resulted in a higher prevalence of UHI in historically marginalized communities. Mitigation measures to reduce these spatial inequalities and adaptation measures targeted at both individuals and communities are necessary to combat this unfortunate historical legacy. This is particularly salient in cities like Portland, where one study found that temperature variations between redlined areas and non-redlined areas in Portland were among the highest of all cities observed (Hoffman et al., 2020).

At the individual home-scale, living in a rental unit with no access to a working air conditioner has consistently been associated with heat illness and mortality (Wolf & McGregor, 2013; Multnomah County, 2022; Reid et al., 2009). Other home features, such as type of air conditioning systems, amount of insulation, ventilation, roof and wall albedo (light and radiation reflection), shade on exterior surfaces, and construction quality, are key to understanding and addressing indoor heat exposure but can be difficult and costly to measure (Samuelson et al., 2020). More research is needed to understand nuances of residential environments and their role in moderating heat exposure, sensitivity, and adaptive capacity (Molinsky and Forsyth, 2022; Samuelson et al., 2020), particularly for vulnerable groups who spend the majority of their time indoors, such as older adults.

Greater interdisciplinarity focused on the intersecting challenges of climate change, urbanization, and population aging is needed to build depth to a “climate gerontology” perspective (Haq & Gutman, 2014; Antal & Bhutani, 2022). Future research on the social factors related to adaptation to climate events (Hansen et al., 2011) could shed light on existing nuances and barriers unique to older adults and lead to reduced illness and mortality. There is also a need to examine the long-term effects of disasters on older adults, including impacts on mental health (Ayalon et al., 2021). Furthermore, “climate gerontology” can benefit from greater intergenerational connections and greater deployment of the assets that older adults bring to climate-related problem solving.

Limitations

This study has a few key limitations. The individual-level survey used a general population sample, resulting in a low response from older adults in the individual-level index. Of the 897 respondents, 120 were 65 or older (13 percent of respondents). No responses from two specific zip codes in southwest Portland were received during survey administration; therefore, those two zip codes are not represented in the study findings. In the area-level analysis, data reduction from the PCA led to a small number of samples in specific zip code areas. Though the individual-level analysis included measures of social isolation, these data were unavailable at the area scale beyond simply the number of people per household (living alone). Social isolation and other more robust indicators of community social capital could support further understanding of variations in heat-related illness and mortality. Finally, the results of this study are specific to the Portland, Oregon metropolitan area. The method may be applied to and support greater heat-risk management in other urban regions.

Conclusions

This study constructs and analyzes multi-level indices of heat vulnerability and discusses extreme heat risk mitigation particularly among older adults in the Portland, Oregon metropolitan area. This method expands on previous research with individual-level indicators, beyond the typical area-level focus. Addressing the increasing challenges of supporting older adults in managing extreme heat risk on these two scales has important health equity implications. Focusing policy priorities and resources on both area-level and individual-level interventions has important implications for reduced morbidity and mortality among older adults, especially as summer temperatures continue to become more severe in our changing climate.

References

Antal, H., & Bhutani, S. (2022). Identifying Linkages Between Climate Change, Urbanisation, and Population Ageing for Understanding Vulnerability and Risk to Older People: A Review. *Ageing International*. https://doi.org/10.1007/s12126-022-09504-7

Atwoli, L., Baqui, A. H., Benfield, T., Bosurgi, R., Godlee, F., Hancocks, S., Horton, R., Laybourn-Langton, L., Monteiro, C. A., Norman, I., Patrick, K., Praities, N., Olde Rikkert, M. G. M., Rubin, E. J., Sahni, P., Smith, R., Talley, N., Turale, S., & Vázquez, D. (2021). Call for emergency action to limit global temperature increases, restore biodiversity, and protect health: Wealthy nations must do much more, much faster. *The Gerontologist*, *61*, 1184–1187. https://doi.org/10.1093/geront/gnab117

Ayalon, L., Roy, S., Aloni, O., & Keating, N. (2022). A scoping review of research on older people and intergenerational relations in the context of climate change. *The Gerontologist*, gnac028. https://doi.org/10.1093/geront/gnac028

Ayalon, L., Keating, N., Pillemer, K., & Rabheru, K. (2021). Climate change and mental health of older persons: A human rights imperative. *The American Journal of Geriatric Psychiatry*, *29*(10), 1038-1040. https://doi.org/10.1016/j.jagp.2021.06.015

Bryant, N., Stone, R., Connelly, C., & Boerner, K. (2022). *Research report: The impact of climate change: Why older adults are vulnerable*. The LeadingAge LTSS Center, University of Massachusetts Boston. https://ltsscenter.org/resources/

Centers for Disease Control and Prevention. (2020). *PLACES: ZCTA Data (GIS Friendly Format), 2020 release*. [Data file and code book]. Retrieved from https://chronicdata.cdc.gov/dataset/PLACES-ZCTA-Data-GIS-Friendly-Format-2020-release/kee5-23sr

Cuthbertson, J., Archer, F., Rodriguez-llanes, J., & Robertson, A. (2019). The Social Determinants of Health in Disaster Risk Reduction. *Prehospital and Disaster Medicine, 34*(s1), s95–s95. https://doi.org/10.1017/S1049023X19001973

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, *84*(2), 242-261. http://www.jstor.org/stable/42955868

DeLaTorre, A., Lycan, D.R., & Neal, N.B. (2021). State of Aging in Portland. Institute on Aging, Portland State University. Retrieved from: https://soaportland.cupa.pdx.edu/overview/

Dialesandro, J., Brazil, N., Wheeler, S., & Abunnasr, Y. (2021). Dimensions of Thermal Inequity: Neighborhood Social Demographics and Urban Heat in the Southwestern US. *International Journal of Environmental Research and Public Health, 18*(3):941. https://doi.org/10.3390/ijerph18030941

Gamble, J. L., Hurley, B. J., Schultz, P. A., Jaglom, W. S., Krishnan, N., & Harris, M. (2013). Climate change and older Americans: state of the science. *Environmental Health Perspectives*, *121*(1), 15-22. https://doi.org/10.1289/ehp.1205223

Hansen, A., Bi, P., Nitschke, M., Pisaniello, D., Newbury, J., & Kitson, A. (2011). Perceptions of heat-susceptibility in older persons: Barriers to adaptation. *International Journal of*

Environmental Research and Public Health, *8*(12), 4714-4728. https://doi.org/10.3390/ijerph8124714

Haq, G., Gutman, G. (2014). Climate gerontology: meeting the challenge of population ageing and climate change. *Zeitschrift für Gerontologie und Geriatrie, 47*(6), 462-467. http://dx.doi.org/10.1007/s00391-014-0677-y

Haraguchi, M., Toyota, T., Kikuchi, G., & Taniguchi, M. (2022). Cognitive biases affect adaptive behaviours to prevent heat-related illnesses: a survey of older adults in Kyoto, Japan. *The Lancet. Planetary Health*, *6*, S2–S2. https://doi.org/10.1016/S2542-5196(22)00264-9

Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The urban heat island: Implications for health in a changing environment. *Current Environmental Health Report*, *4*, 296-305. https://doi.org/10.1007/s40572-017-0150-3

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):12. https://doi.org/10.3390/cli8010012

Intergovernmental Panel on Climate Change, (2007). *Climate change 2007: impacts, adaptation and vulnerability*. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Parry, M. L., Canziani, O. F., Palutikof J. P., van der Linden, P. J., & Hanson, C. E. (Eds.). Cambridge University Press, Cambridge, UK.

Jeste, D. V. (2022). Non-medical social determinants of health in older adults. *International Psychogeriatrics*, *34*(9), 755–756. https://doi.org/10.1017/S1041610222000709

Jolliffe, I. T. (2002). *Principal Component Analysis*. *Springer Series in Statistics* (2nd ed.). Springer, New York, Berlin, Heidelberg, Hong Kong, London, Milan, Paris, Tokyo.

Jung, J., Uejio, C. K., Kintziger, K. W., Duclos, C., Reid, K., Jordan, M., & Spector, J. T. (2021). Heat illness data strengthens vulnerability maps. *BMC Public Health, 21*, 1-13. https://doi.org/10.1186/s12889-021-12097-6

Khatana, S. A. M., Werner, R. M., Groeneveld, P. W. (2022). Association of extreme heat with all-cause mortality in the contiguous US, 2008-2017. *JAMA Netw Open, 5*(5):e2212957. https://doi.org/10.1001/jamanetworkopen.2022.12957

Klinenberg, E. (2002). *Heat wave: A social autopsy of disaster in Chicago.* Chicago, IL: University of Chicago Press.

Lim, J., & Skidmore, M. (2020). Heat vulnerability and heat island mitigation in the United States. *Atmosphere, 11*(6):558. https://doi.org/10.3390/atmos11060558

Macey, S. M., & Schneider, D. F. (1993). Deaths from excessive heat and excessive cold among the elderly. *The Gerontologist*, *33*(4), 497–500. https://doi.org/10.1093/geront/33.4.497

Manson, S., Schroeder J., Riper, D. V., Kugler, T., & Ruggles, S. (2022). IPUMS National Historical Geographic Information System: Version 17.0 [dataset]. Minneapolis, MN: IPUMS. http://doi.org/10.18128/D050.V17.0

McDermott-Levy, R., Kolanowski, A. M., Fick, D. M., & Mann, M. E. (2019). Addressing the Health Risks of Climate Change in Older Adults. *Journal of Gerontological Nursing, 45*(11), 21-29. https://doi.org/10.3928/00989134-20191011-04

Molinsky, J. & Forsyth, A. (2022) Climate Change, Aging, and Well-being: How Residential Setting Matters, *Housing Policy Debate,* https://doi-org.proxy.lib.pdx.edu/10.1080/10511482.2022.2109711

Multnomah County. (2022, June). *Final Report: Health impacts from excessive heat events in Multnomah County, Oregon, 2021*. https://www.multco.us/help-when-its-hot/reports-and-analysis-heat-events

Nitschke, M., Hansen, A., Bi, P., Pisaniello, D., Newbury, J., Kitson, A., Tucker, G., Avery, J., & Dal Grande, E. (2013). Risk factors, health effects and behaviour in older people during extreme heat: A survey in south australia. *International Journal of Environmental Research and Public Health*, *10*(12), 6721-6733. https://doi.org/10.3390/ijerph10126721

Oregon Metro. (2020). *Climate data by census tract*. [Data file and code book]. Retrieved from https://regionalbarometer.oregonmetro.gov/datasets/drcMetro::climate-data-by-census-tract/about

Palinkas, L. A., Hurlburt, M. S., Fernandez, C., De Leon, J., Yu, K., Salinas, E., Garcia, E., Johnston, J., Rahman, M. M., Silva, S. J., & McConnell, R. S. (2022). Vulnerable, resilient, or both? A qualitative study of adaptation resources and behaviors to heat waves and health outcomes of low-income residents of urban heat islands. *International Journal of Environmental Research and Public Health*, *19*(17):11090. https://doi.org/10.3390/ijerph191711090

Philip, S. Y., Kew, S. F., van Oldenborgh, G. J., Anslow, F. S., Seneviratne, S. I., Vautard, R., Coumou, D., Ebi, K. L., Arrighi, J., Singh, R., van Aalst, M., Pereira Marghidan, C., Wehner, M., Yang, W., Li, S., Schumacher, D. L., Hauser, M., Bonnet, R., Luu, L. N., … Otto, F. E. L. (2022). Rapid attribution analysis of the extraordinary heat wave on the Pacific coast of the US and Canada in June 2021. *Earth System Dynamics*, *13*(4), 1689–1713. https://doi.org/10.5194/esd-13-1689-2022

Preston, B. L., Yuen, E. J., & Westaway, R. M. (2011). Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. *Sustainability Science, 6*, 177-202. https://doi.org/10.1007/s11625-011-0129-1

Reid, C. E., O'Neill, M. S., Gronlund, C. J., Brines, S. J., Brown, D. G., Diez-Roux, A. V., & Schwartz, J. (2009). Mapping community determinants of heat vulnerability. *Environmental Health Perspectives, 117*(11), 1730-1736. https://doi.org/10.1289/ehp.0900683

Rhoades, J. L., Gruber, J. S., Horton, B. (2018). Developing an in-depth understanding of elderly adult's vulnerability to climate change, *The Gerontologist*, *58*(3), 567–577. https://doi.org/10.1093/geront/gnw167

Samuelson, H., Baniassadi, A., Lin, A., González, P. I., Brawley, T., & Narula, T. (2020). Housing as a critical determinant of heat vulnerability and health. *The Science of the Total Environment*, 720, 137296. https://doi.org/10.1016/j.scitotenv.2020.137296

Sharifi, A., Pathak, M., Joshi, C., He, B. (2021). A systematic review of the health co-benefits of urban climate change adaptation. *Sustainable Cities and Society, 74*. https://doi.org/10.1016/j.scs.2021.103190

Sidiqui, P., Tariq, M. A. U. R., & Ng, A. W. M. (2022). An investigation to identify the effectiveness of socioeconomic, demographic, and buildings' characteristics on surface urban heat island patterns. *Sustainability*, 14(5):2777. https://doi.org/10.3390/su14052777

U.S. Census Bureau. (2020). U.S. Census quick facts. https://www.census.gov/quickfacts/portlandcityoregon

World Health Organization. (2021, October 29). *Urban health fact sheet.* https://www.who.int/news-room/fact-sheets/detail/urban-health

Voelkel, J., Hellman, D., Sakuma, R., & Shandas, V. (2018). Assessing vulnerability to urban heat: A study of disproportionate heat exposure and access to refuge by socio-demographic status in Portland, Oregon. *International Journal of Environmental Research and Public Health*, *15*(4):640. https://doi.org/10.3390/ijerph15040640

Wilhelmi, O. V., Purvis, K. L., & Harriss, R. C. (2004). Designing a geospatial information infrastructure for mitigation of heat wave hazards in urban areas. *Natural Hazards Review, 5*, 147–158. https://doi.org/10.1061/(ASCE)1527-6988(2004)5:3(147)

Williams, A. A., Spengler, J. D., Catalano, P., Allen, J. G., & Cedeno-Laurent, J. G. (2019). Building vulnerability in a changing climate: Indoor temperature exposures and health outcomes in older adults living in public housing during an extreme heat event in Cambridge, MA. *International Journal of Environmental Research and Public Health, 16*(13):2373. https://doi.org/10.3390/ijerph16132373

Wolf, T. & McGregor, G. (2013). The development of a heat wave vulnerability index for London, United Kingdom. *Weather and Climate Extremes, 1*, 59-68. https://doi.org/10.1016/j.wace.2013.07.004

Worfolk, J. B. (2000). Heat waves: their impact on the health of elders. *Geriatric Nursing (New York, N.Y.), 21*(2), 70–77. https://doi.org/10.1067/mgn.2000.107131

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Conflict of Interest

None

Data Availability

Data used in the area-level analysis of this study are available to the public via the US Census, LandSat, and CDC PLACES data. Individual-level data used in this study are currently unavailable for sharing, as additional planned analyses are underway. This study was not pre-registered.

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Tables

Table 1 Characteristics of individual-level survey sample and study region

	Sample				Study region			
	Clackamas	**Multnomah**	**Washington**	**All**	**Clackamas**	**Multnomah**	**Washington**	**All***
Sample size and population	151	470	276	897	375,992	735,334	529710	1,641,036
(%)	(16.8%)	(52.4%)	(30.8%)	(100.0%)	(22.9%)	(44.8%)	(32.3%)	(100.0%)
% of female population	62.9%	62.8%	59.1%	61.6%	50.7%	50.5%	50.5%	50.5%
% of people aged > 65	16.6%	13.8%	10.9%	13.4%	18.8%	13.9%	13.9%	15.0%
% of college graduates & higher	53.0%	45.9%	57.2%	50.6%	37.4%	45.9%	44.4%	43.5%
Persons per household	2.8	2.6	2.9	2.8	2.6	2.4	2.3	2.4
Median household income (USD)	87500.0	62500.0	87500.0	62500.0	80484.0	69176.0	82215.0	75977.1

* Population weighted average for three counties

USD: United States Dollar

Table 2 Principal component loadings and descriptive statistics for each of the heat risk proxy variables (Area-level)

PC loading*	Risk factors from literature**	Type	Variable	N	Mean	Std. dev.	Min	Max
1	Thermo isolation of home	Exposure	Share of renter-occupied housing units	58	0.57	0.17	0.11	0.91
(43.0%)	Living on a high floor of multi-story buildings	Exposure	Share of total housing units within housing structures with 5 units or more	58	0.29	0.21	0.00	0.95
	Low economic status	Sensitivity	Households with income below poverty level the last 12 months	58	0.11	0.06	0.04	0.40
	Living alone	Sensitivity	Share of population living alone	58	0.14	0.13	0.00	0.77
2	Being exposed to UHI	Exposure	Mean of % variation from regional average temperature	58	-0.25	2.78	-7.69	3.82
(22.0%)	Pre-existing illness	Sensitivity	Model-based estimate for annual crude prevalence of fair or poor health among adults aged >=18 years, 2019	58	0.16	0.04	0.10	0.25
	Minority status	Sensitivity	Percent non-white population	58	0.28	0.11	0.12	0.57
3	High population density	Exposure	Population density (people/km^2)	58	4437.77	2619.12	105.29	14422.13
(15.0%)	Being Elderly	Sensitivity	Percent population 65 years and older among total population	58	0.15	0.05	0.09	0.43
	Living in institution	Sensitivity	Percent population in group quarters	58	0.02	0.04	0.00	0.33
–	AC	Exposure	–	–	–	–	–	–
–	Social isolation	Sensitivity	–	–	–	–	–	–

* The values in parentheses indicate percentage variance explained by each principal component.

** Adapted from Wolf and McGregor (2013).

PC: Principal Component; Std. dev.: Standard deviation; UHI: Urban Heat Island effect; AC: air conditioning; km^2: square kilometers

Table 3 Principal component loadings and descriptive statistics for each of the heat risk proxy variables (Individual-level)

PC loading	Risk factors from literature	Type	Variable	N	Mean	Std. dev.	Min	Max
1	Thermo isolation of home	Exposure	1 if your current residence is a rental	897	0.41	0.49	0.00	1.00
(20.0%)	AC	Exposure	1 if your current residence is not equipped with air conditioning	897	0.71	0.45	0.00	1.00
	Low economic status	Sensitivity	1 if annual household income is less than 35,000 dollars	897	0.25	0.44	0.00	1.00
2	Being exposed to UHI	Exposure	Mean of % variation from regional average temperature	897	0.10	2.56	-7.69	3.82
(15.0%)	High population density	Exposure	Population density (people/km2)	897	4664.60	2633.21	105.29	14422.13
3	Being Elderly	Sensitivity	1 if age is 65 or older	897	0.13	0.34	0.00	1.00
(14.0%)	Living alone	Sensitivity	1 if living alone.	897	0.08	0.28	0.00	1.00
4 (12.0%)	Living on a high floor of multi-story buildings	Exposure	1 if your current residence is an apartment or condo	897	0.46	0.50	0.00	1.00
	Pre-existing illness	Sensitivity	Composite index of cognitive questions about health status (higher values indicate illness)	897	0.71	0.24	0.00	1.00
	Social isolation	Sensitivity	1 if often feel isolated from others	897	0.21	0.41	0.00	1.00
–	Minority status	Sensitivity	–	–	–	–	–	–

_	Living in institution	Sensitivity	–	–	–	–	–	–	–

* The values in parentheses indicate percentage variance explained by each principal component.

** Adapted from Wolf and McGregor (2013).

PC: Principal Component; Std. dev.: Standard deviation; UHI: Urban Heat Island effect; AC: air conditioning; km^2: square kilometers

Table 4 Summary statistics of heat vulnerability indices

Level	N	Mean	Median	Std. dev.	Min.	Max.
Area	58	0	-0.13	1.21	-1.91	5.61
Individual	897	0	-0.09	0.64	-1.64	2.04

Figures

Figure 1 Heat vulnerability index at area-level (left) and individual-level (right)

Figure 2 Spatial distribution of heat vulnerability index (area-level)

Figure 3 Spatial distribution of heat vulnerability index (individual-level)*

* Two areas in the southwest were not included in the analysis because there were no study respondents in these neighborhoods

Figure 1

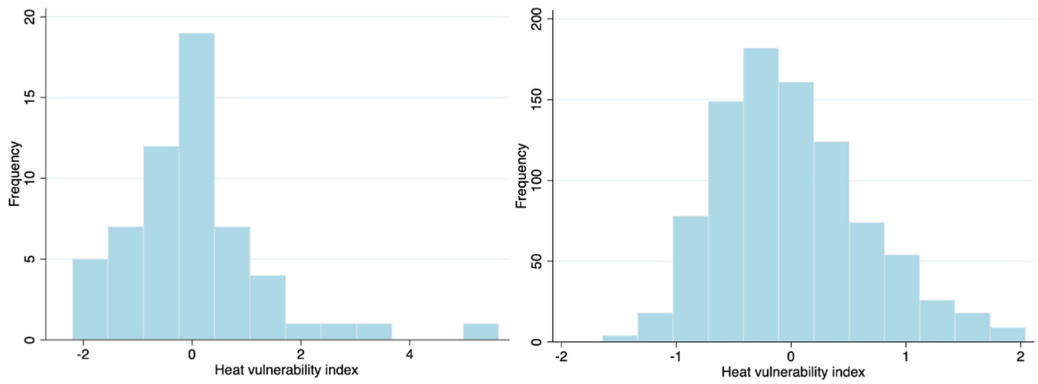

Frequency
Heat vulnerability index
Frequency
Heat vulnerability index

Figure 2

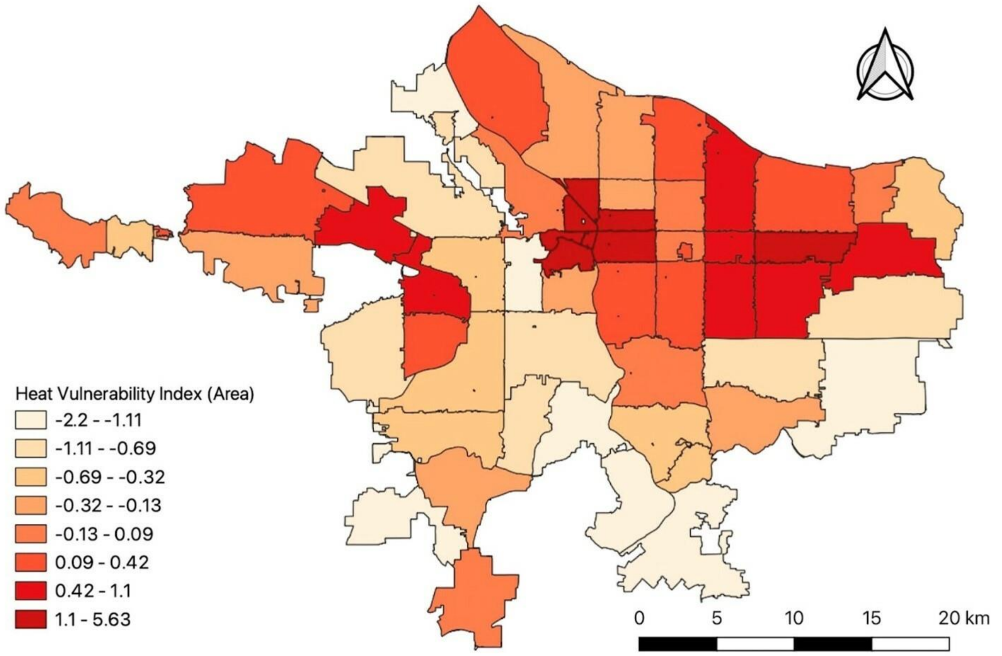
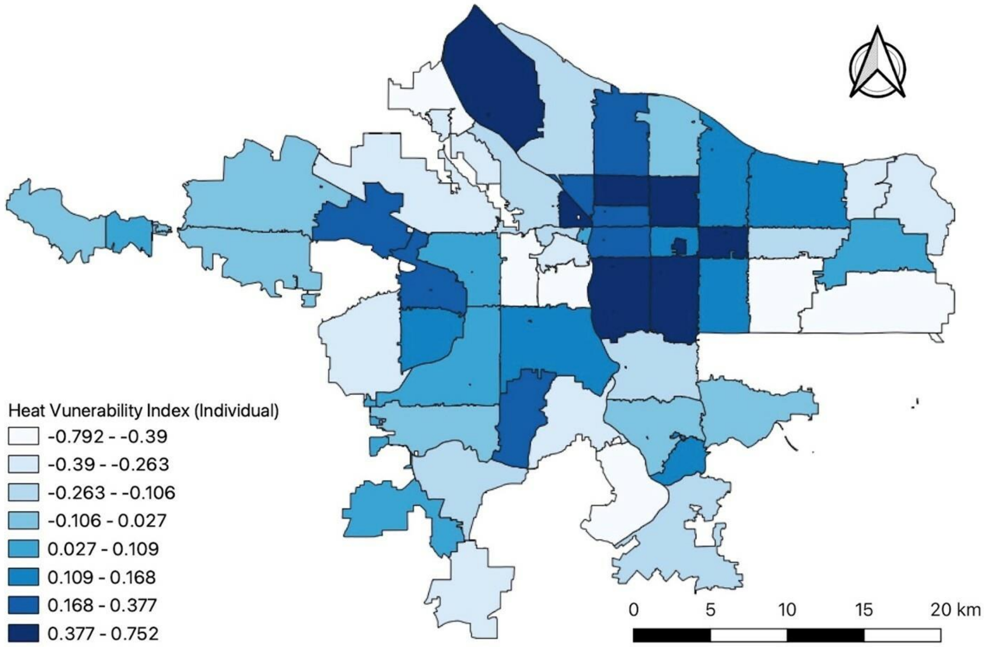

Heat Vulnerability Index (Area)
-2.2 - -1.11
-1.11 - -0.69
-0.69 - -0.32
-0.32 - -0.13
-0.13 - 0.09
0.09 - 0.42
0.42 - 1.1
1.1 - 5.63
0
5
10
15
20 km

Figure 3


Heat Vunerability Index (Individual)
-0.792 - -0.39
-0.39 - -0.263
-0.263 - -0.106
-0.106 - 0.027
0.027 - 0.109
0.109 - 0.168
0.168 - 0.377
0.377 - 0.752
0
5
10
15
20 km