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Area-level risk factors for heat-related illness in rural and urban locations across North Carolina, USA

Margaret M. Kovach [a,*], Charles E. Konrad II [a], Christopher M. Fuhrmann [b]

[a] Department of Geography, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
[b] Department of Geosciences, Mississippi State University, Mississippi State, MS, USA

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ABSTRACT

An improved understanding of heat vulnerable populations and locations is needed, especially in rural communities. The objective of this study was to identify area-level risk factors for heat-related illness (HRI) at the ZIP code level for urban and rural locations. We aggregated ZIP code-level emergency department visits into rural and urban locations based on population density. Area-level risk factors included previously established heat health risk factors (e.g. poverty, minority) and unexamined area-level risk factors common to rural locations (e.g. mobile homes, agriculture). Due to high spatial autocorrelation, a spatial error regression model was applied to identify risk factors with a significant relationship with HRI. Our results suggest that rural locations are also heat vulnerable, with greater rates of HRI compared to urban locations. Previously unexamined heat-health risk factors, including the number of mobile homes, non-citizens, and the labor-intensity of the agriculture, were all associated with increases of HRI in rural locations. In urban locations, previously established risk factors for heat-related mortality, such as decreased vegetation, living in poverty, and low education attainment were associated with increases in HRI.

Background

Every year, a large number of hospitalizations and deaths occur in association with exposure to heat (Basu & Samet, 2002). This exposure is detrimental to a person's health when it overwhelms their ability to thermoregulate, increasing the likelihood of succumbing to heat stroke or exacerbating pre-existing health conditions (Kovats & Hajat, 2008; Luber & McGeehin, 2008). Most of these heat-health effects are concentrated in geographic areas where certain socioeconomic factors and physical exposure increase a population's vulnerability to heat-related morbidity or mortality. Adverse health effects from heat are preventable through basic hydration or relocating to a cooler environment; therefore, public health interventions are a key component in reducing these effects (Luber & McGeehin, 2008). However, establishing which populations are at greatest risk is a complex issue involving a combination of environmental, cultural, and social conditions.

Numerous studies have identified individual-specific risk factors for heat-related mortality, with age, income, and social isolation being the most important (Jones et al., 1982; Kilbourne, Choi, Jones, & Thacker, 1982; Naughton et al., 2002; Semenza et al., 1996, 1999). Certain living conditions, including the type of building, floor level, the presence of an air conditioning unit, and the number of rooms, are also important determinants of heat-related mortality (Semenza et al., 1996). Research assessing the impact of heat on *morbidity* is more limited, owing partly to the availability of hospitalization or emergency department (ED) data. Despite this limitation, increases in morbidities, such as heat-related illness (HRI), have been noted in heat waves in Chicago, IL in 1995 and St. Louis and Kansas City, MO in 1980 (Jones et al., 1982; Semenza, McCullough, Flanders, McGeehin, & Lumpkin, 1999). Most of these morbidities befall the elderly (65 years and older) and individuals with underlying medical conditions (Jones et al., 1982; Knowlton et al., 2009; Semenza et al., 1996, 1999).

The majority of heat-health research has been conducted in urban areas, which are generally warmer than surrounding rural areas due to the urban heat island effect (Oke, 1997, 1982). Additionally, since urban areas display high population densities, the number of deaths and morbidities attributable to extreme heat can

* Corresponding author. Department of Geography, University of North Carolina at Chapel Hill, Saunders Hall, Campus Box 3220, Chapel Hill, NC 27599-3220, USA. Tel.: +1 (919) 962 8901.
E-mail address: mkovach@email.unc.edu (M.M. Kovach).

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be very high (Luber & McGeehin, 2008). Less research has been conducted in rural regions. Some examples include Gabriel and Endlicher (2011), who found higher mortality rates in urban locations compared to rural locations during extreme heat events in Germany. Similar results were noted in and around St. Louis and Kansas City, MO during the 1980 heat wave (Jones et al., 1982). In contrast, both Sheridan and Dolney (2003) and Henderson, Wan, and Kosatsky (2013) found higher mortality rates in rural and suburban regions compared to urban regions in Ohio, USA and British Columbia, Canada, while Lippmann, Fuhrmann, Waller, and Richardson (2013) found a similar pattern in North Carolina, USA using ED visit data for HRI.

Heat-health researchers have also attempted to address heat vulnerability at a local level by aggregating previous established area-level risk factors for heat mortality into heat vulnerability indexes. Often, these studies identify vulnerable locations, by examining the collocation of areas of greater physical exposure to extreme heat (e.g. urban surfaces) with locations displaying high social vulnerability (e.g. living below the poverty line, minorities) (Chow, Chuang, & Gober, 2012; Harlan, Declet-Barreto, Stefanov, & Petitti, 2013; Johnson, Stanforth, Lulla, & Luber, 2012; Reid et al., 2009; Wolf and Gregor, 2013). Reid et al. (2009), provides a useful example of this approach; they incorporated several physical, socioeconomic, and environmental area–level factors at the metropolitan level through the creation of a heat vulnerability index (HVI). Using principal components analysis, their index reduces 10 variables into four representative factors including social and environmental vulnerability, social isolation, prevalence of air conditioning, and proportion of the population that are elderly or with diabetes. Using the HVI, they contrast differences in vulnerability across different metropolitan regions of the United States, particularly downtown metropolitan areas, which have some of the highest HVI values.

The main limitation of these studies is that their results (i.e. identification of areas with high and low heat vulnerability) are not validated with actual counts of morbidity or mortality. Recent research has evaluated some of these indices, including the HVI, to assess whether they indeed demarcate areas of high heat vulnerability. Reid et al. (2012) evaluated the utility of the HVI with hospitalization and mortality data and found that it correctly identified locations with an overall high health burden. However, the performance of the HVI varied when comparing the health burden on days with high temperatures across different locations. Harlan et al. (2013) evaluated the HVI in Phoenix, Arizona, United States and found that certain HVI factors, such as social and environmental vulnerability and elderly, accompanied with land surface temperatures, most accurately predicted heat mortality. Maier et al. (2014) evaluated the HVI across the state of Georgia and found increases in all-cause mortality during extreme heat for counties with high HVI values. Most recently, Wolf, McGregor, and Analitis (2014) validated a separate heat vulnerability index they created for London, United Kingdom with daily mortality and ambulance dispatch data. Their analysis demonstrated that HVI predicted ambulance calls better than mortality.

Unlike the HVI approach, we assessed the spatial variability of heat vulnerability using an ecological study design, where spatially explicit, area-level risk factors are associated with heat morbidity (i.e. HRI). We determine these area-level risk factors from fine-scaled spatial variations in the incidence of HRI using ED visit data, rather than from previously established individual-level risk factors. Additionally, we examine HRI incidence across rural and urban landscapes and populations. Thus, previously unexamined risk factors common to rural locations are included in the analysis (e.g. mobile homes, non-citizens, and labor requirements for agriculture production). By identifying the risk factors for HRI and the locations of vulnerable populations within North Carolina, more targeted public health interventions and strategies for resource allocation can be developed to help mitigate the health effects of heat.

Materials and methods

Study region

This study was conducted in North Carolina, a state within the southeastern United States. North Carolina displays a humid subtropical climate, large population, and significant topographic variability (Fig. 1). While the urbanized areas of the state are growing rapidly, roughly one-third of its population still resides in rural areas, according to the 2010 Census. Temperature variability is maximized in the western mountainous portion of the state due to varying topography (Figs. 1 and 2). The eastern two-thirds part of the state, which encompasses the largest metropolitan locations (i.e. Charlotte, Raleigh, and Fayetteville), has less temperature variability, with mean temperatures ranging from 20.8 to 24.6 °C. The study was focused on this region, where the greatest number of HRI ED visits were especially high.

Health data

The incidence of HRI in North Carolina was determined using emergency department (ED) visit data from the North Carolina Disease Event Tracking and Epidemiologic Tool (NC DETECT), a statewide, public health surveillance system developed by the University of North Carolina and the North Carolina Division of Public Health (Lippmann et al., 2013). NC DETECT provides information on the age, sex, county of residence, and ZIP code of residence of the patient, as well as the date and time of the ED visit, and up to 11 diagnoses at discharge coded using the 9th revision of the International Classification of Disease (ICD-9-CM). It is estimated that NC DETECT included ED visit data for 92% of the population in 2007 and 99.5% by 2008, allowing for statewide coverage of HRI incidence rates (Rhea et al., 2012). NC DETECT does not include ED data from federally run military hospitals (Womach Army Hospital at Fort Bragg near Fayetteville and Naval Hospital at Camp Lejune near Jacksonville) or Indian Health Services hospital (Cherokee Indian Hospital) located on the Qualla Boundary. ED visits containing at least one heat-related code (ICD-9-CM code 992.xx) in any of the 11 diagnostic fields were used in this study to calculate the incidence of HRI. This code accounts for the effects of heat and light and includes diagnostic codes, such as heat stroke (992.0), heat syncope (992.1), heat cramps (992.2), heat exhaustion (992.3–992.5), heat fatigue (992.6), heat edema (992.7) and other specified and unspecified heat effects (992.8–992.9). Due to few HRI ED admissions (i.e. $\leq$10 ED visits for HRI), the mountainous western quarter of the state, which rarely experiences temperatures above 35 °C, was excluded from the analysis. The resulting dataset contains a total of 13,095 ED visits for HRI covering the warm season months (May–September) from 2007 to 2012.

Demographic and socioeconomic data

Information on the demographic and socioeconomic characteristics of North Carolina was gathered from the 2010 Census and the 2008–2012 American Community Survey (ACS) at the ZIP code level (i.e. ZIP code tabulation area, or ZCTA). Similar to the HVI (Reid et al., 2009), we gathered data on age, poverty, educational attainment, those living alone, and non-white population. Information on diabetes prevalence and air conditioning were not included, since these variables were not available at the ZIP code