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Vulnerability to extreme heat by socio-demographic characteristics and area green space among the elderly in Michigan, 1990–2007

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ABSTRACT

Objectives: We examined how individual and area socio-demographic characteristics independently modified the extreme heat (EH)-mortality association among elderly residents of 8 Michigan cities, May–September, 1990–2007.

Methods: In a time-stratified case-crossover design, we regressed cause-specific mortality against EH (indicator for 4-day mean, minimum, maximum or apparent temperature above 97th or 99th percentiles). We examined effect modification with interactions between EH and personal marital status, age, race, sex and education and ZIP-code percent "non-green space" (National Land Cover Dataset), age, race, income, education, living alone, and housing age (U.S. Census).

Results: In models including multiple effect modifiers, the odds of cardiovascular mortality during EH (99th percentile threshold) vs. non-EH were higher among non-married individuals (1.21, 95% CI = 1.14–1.28 vs. 0.98, 95% CI = 0.90–1.07 among married individuals) and individuals in ZIP codes with high (91%) non-green space (1.17, 95% CI = 1.06–1.29 vs. 0.98, 95% CI = 0.89–1.07 among individuals in ZIP codes with low (39%) non-green space). Results suggested that housing age may also be an effect modifier. For the EH-respiratory mortality association, the results were inconsistent between temperature metrics and percentile thresholds of EH but largely insignificant.

Conclusions: Green space, housing and social isolation may independently enhance elderly peoples' heat-related cardiovascular mortality vulnerability. Local adaptation efforts should target areas and populations at greater risk.

1. Introduction

In the U.S., the association between hot weather and mortality, especially cardiovascular and respiratory mortality, is well established (Anderson and Bell, 2009; Braga et al., 2002; Curriero et al., 2002; Medina-Ramon and Schwartz, 2007). With climate change and an aging population, heat-related mortality is of increasing concern. Public health measures to protect vulnerable populations from the effects of heat and heat waves are being adopted in many cities in the U.S. and around the world. Previously identified characteristics of vulnerability to heat-related morbidity and mortality include: advanced age, nonwhite race, poverty, lack of air conditioning or the financial resources to operate an air conditioner, social isolation, lack of green space (which provides shade and reduces ambient temperature) and low educational attainment (Reid et al., 2009; Sampson et al., 2013; Zanobetti et al., 2013). These characteristics have been used to construct vulnerability maps that can help communities determine where to focus resources during extreme heat (EH) (Harlan et al., 2013; Johnson et al., 2012; Reid et al., 2009).

However, in a validation study of one such vulnerability map, Reid et al. (2012) showed that their map reflected vulnerability to mortality in general but not vulnerability to heat-associated mortality. Some previously constructed vulnerability maps have been limited by using data that identify the characteristics of

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vulnerability or the health outcome of interest at a spatial resolution no finer than city- or county-level. Additionally, some of the area-level characteristics evaluated, such as percent of people living in poverty, percent of people with lower education, and percent green-space can be highly correlated with each other. For example, in the Detroit metropolitan area, census tracts with lower percent of vegetative cover are often the same census tracts with the highest percent of residents in poverty (White-Newsome et al., 2009). Finally, it is likely that socio-demographic characteristics of heat vulnerability such as race, income and education are mediated by more downstream mechanisms of heat vulnerability, such as cultural and social isolation, poor housing or utility poverty (Gronlund, 2014). This situation makes evaluation of the independent and relative contributions of these factors to heat vulnerability challenging. In other words, the relative influence of each of these potential effect modifiers, as well as the extent to which these effect modifiers confound each other, is poorly understood.

Cities in Michigan, a state with a temperate, 4-season climate and relatively low air conditioning prevalence, have been shown to have high vulnerability to heat (Anderson and Bell, 2009; Zanobetti and Schwartz, 2008). We aimed to determine the relative influence of individual and ZIP-code characteristics in modifying the short-term association between EH and cardiovascular and respiratory mortality in Michigan using death, land cover, temperature and socio-demographic data from 1990 to 2007.

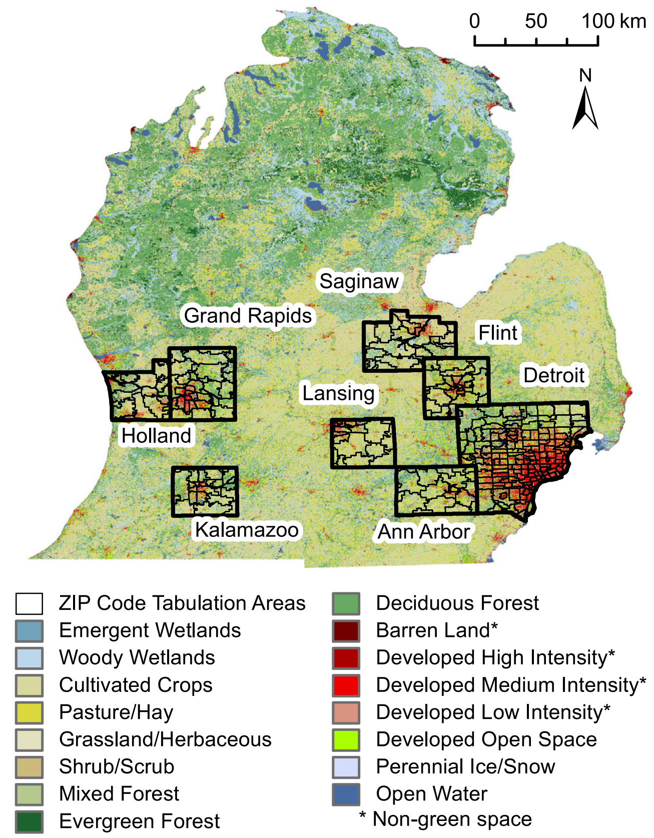

Fig. 1. Land cover in Michigan's lower Peninsula in 2001 (U.S. Department of the Interior, 2012).

2. Methods

2.1. Data

The 10 counties in Michigan with populations greater than 200,000 were aggregated into 8 "cities" according to the county's corresponding Metropolitan Statistical Area: Ann Arbor (Washtenaw County), Detroit (Wayne, Oakland and Macomb Counties), Flint (Genesee County), Grand Rapids (Kent County), Holland (Ottawa County), Kalamazoo (Kalamazoo County), Lansing (Ingham County) and Saginaw (Saginaw County) (Fig. 1). Within these cities, we used ZIP codes, i.e., U.S. postal codes, as area units.

Michigan death records from 1990 to 2007 were obtained from the Michigan Department of Community Health. These records included date of death, ZIP code of residence, marital status, race, age, sex and educational level. We restricted our data set to decedents 65 years and older and further classified the decedents as unmarried vs. married or separated, black vs. nonblack (other race/ethnicities were too few to allow analysis), age 79 years or older vs. age 65–78 years, male vs. female and no high school degree vs. high school degree or higher. Primary causes of death were classified using the International Classification of Diseases codes from versions 9 and 10 (ICD-9 and ICD-10) as all-natural cause (ICD-9 <800, 992 and E900.0; ICD-10A R, T67 and X30), heat-related (ICD-9 992 and E900.0; ICD-10 T67 and X30), cardiovascular (ICD-9 390-429; ICD-10 I0-I52) and respiratory (ICD-9 460–466, 480–487, 490–492, 494–496; ICD-10 J9–J18, J40–J44, J47).

Daily mean (TMEAN), minimum (TMIN) and maximum (TMAX) temperature and dew point (means of at least 18 hourly observations) were obtained from the National Climatic Data Center (2012) for the airport weather station nearest to each city with the most complete time series. Daily mean apparent temperature (AT, °C), a measure which incorporates both temperature and humidity, was calculated as

$$AT = -2.653 + (0.994 \times \text{ambient temperature}) + (0.0153 \times (\text{dew point temperature})^2)$$

(O'Neill et al., 2005)

For 4 of the study cities, Detroit, Grand Rapids, Flint and Lansing, ozone data from the U.S. Environmental Protection Agency's Air Quality System (U.S. EPA, 2007) were available from monitors in the corresponding counties. Daily 8-hour averages were calculated and standardized as described previously (Medina–Ramón et al., 2006).

We obtained area-level socio-demographic characteristics from 2 sources: Decennial Census Long Form data in 2000 ZIP Code Tabulation Areas (ZCTAs, polygons constructed by the U.S. Census Bureau approximating ZIP codes, which are not true polygons), for 1990 and 2000 (Geolytics, Inc., 2006) and 5-year average (2006–2010) estimates in 2010 ZCTA boundaries from the American Community Survey (2012). We extracted the following characteristics for each study ZIP code: percent 65 years or older and living alone; percent black; percent aged 75 years and older; percent without a high school degree; percent of households at or below the poverty level; and percent of homes built before 1940, 1940–1959, 1960–1979 and after 1979. We also obtained ZIP-code population-weighted centroids for 2000 and 2010 ZIP codes (MABLE/Geocorr, 2012).

Land cover classifications at a resolution of $30 \times 30\ m^2$ were obtained from the Multi-Resolution Land Characteristics Consortium for 1992, 2001 and 2006 (U.S. Department of the Interior, 2012). We further classified these data as "green space" vs. "non-green space" (Fig. 1) and calculated the percent area non-green space in each ZIP