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Climate Change, Heat Waves, and Environmental Justice: Advancing Knowledge and Action

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ABSTRACT

Knowledge about climate change and the increasing number of heat waves in the United States has caused researchers and public health officials to recognize the need for new methods and tools to evaluate the effects of heat waves to better prepare communities. Vulnerable populations include senior citizens, people with certain chronic illnesses, and those who live in urban centers. Researchers have embarked on investigating new methods to evaluate, on a local scale, the negative impact of heat waves on health and what intervention mechanisms can be put in place to prevent such health effects. One intervention tool currently being tested in some U.S. cities is a heat health warning system (HHWS), a location-specific program based on local weather conditions. Such systems are intended to trigger alerts on extreme heat days that might cause illness or death. The purpose of this article is to provide a focused literature review on heat waves and environmental justice, as well as present a specific example of a multi-disciplinary approach to evaluating heat wave preparedness, intervention tools (such as HHWS) and sustainability issues in Wayne County, Michigan. The methods in this study involve using secondary data sources such as census tract level data, and land cover and land use data in order to highlight potential areas of vulnerability to heat, as well as show how primary data collection of spatially variant temperatures in an urban setting can validate the need for location specific heat warning systems. The results of this study will provide guidance on new approaches for understanding heat wave preparedness, including transferable lessons and tools for other cities and communities, and will highlight the importance of collaboration among academic institutions, government and the community to help mitigate the public health effects of heat wave events.

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INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body whose mandate is to provide decision makers and others interested in climate change with an objective source of information reflecting scientific consensus about climate change. The fourth Assessment Report of the IPCC's findings, completed in 2007, suggests that North American cities which currently experience heat waves are expected to be further challenged by an increased number, intensity, and duration of heat waves during the course of the twenty-first century.[1]

Heat waves are defined by the Centers for Disease Control and Prevention (CDC) as "temperatures that hover 10 degrees or more above the average high temperature for the region and last for several weeks."[2]

Well-studied heat waves include the French heat wave of August 2003 that resulted in 15,000 excess deaths—the number of deaths over the average number of deaths during a particular time—and the Chicago heat wave of 1995 that resulted in 739 excess deaths.[3] As useful as these studies are, evidence is limited on the most effective ways to prevent heat-related mortality, particularly in urban settings.[4]

Despite the limited literature on preventing heat-related mortality, various studies have looked at the characteristics of populations in certain urban settings that are more vulnerable to heat-related mortality. A study of neighborhood microclimates in Phoenix examined heat-related health inequalities by looking at population, community, and biophysical characteristics to simulate the measure of a person's exposure to conditions that cause heat-related mortality or morbidity. This study found that the vulnerability of warmer neighborhoods was exacerbated by a resident's lack of adequate social and material resources to cope with extreme heat.[4] The Phoenix study also suggested a number of positive correlations between heat stress exposure and percentages of poor and minority inhabitants. The correlation between unequal burdens of exposure and poor, and/or minority communities is defined as environmental inequality or environmental justice (EJ). EJ research has historically focused on a variety of environmental hazards including hazardous waste sites, manufacturing facilities, and Superfund Sites as the exposure burden.[5] To date, studies of microclimates and heat-related inequalities, using an EJ model, have not been conducted in poor and/or urban communities such as Wayne County, Michigan.

Examining the relationship between EJ and climate change, or climate justice, is the subject of a report by The Congressional Black Caucus. This report on African Americans and climate change suggests that heat waves will be more deadly in urban areas like Detroit, New York, and Chicago. [6] This study extends this work by applying qualitative and quantitative approaches to heat and health research as a tool to assess preparedness for public health action during extreme heat events in the communities of Wayne County, Michigan. In this article, we will explain a prototype tool that can be used to determine what locations and populations might be more vulnerable to the negative effects of heat waves. Preliminary analysis from the tool will demonstrate how to use satellite ground cover images and socioeconomic variables for Wayne County, Michigan to help address concerns of EJ and climate change.

PROJECT BACKGROUND

During the summer of 2008, a multidisciplinary team from the University of Michigan's School of Public Health, College of Engineering, and School of Natural Resources and Environment received funding from the University of Michigan's Graham Environmental Sustainability Institute to conduct a three part case study to evaluate heat-wave preparedness and sustainability issues in communities of Wayne County. The original three aims of this two-year case study, entitled, "Climate change, heatwaves, and health: Local tools for sustainability, equity, and prevention," are to:

- conduct an interview-based needs assessment of heat-wave preparedness and sustainability among residents and government officials in Wayne County.
- design a simple prototype, inexpensive heat health warning system (HHWS) that could be implemented in Detroit (none currently exists) and validate the system using historical health outcome data (morbidity and mortality).
- develop a heat vulnerability spatial decision support tool that will map several layers of neighborhood-scale information sources, such as: temperature data; satellite images of land-cover relevant to heat exposure (green space, built environment characteristics); satellite images to determine surface radiation; and demographic vulnerability indicators derived from the U.S. Census (including percent poverty, race/ethnic composition, elderly residents, and single-person households).

We added a fourth aim of gathering temperature data to examine microclimate temperatures in the backyards of 17 residences in different areas of Wayne County, Michigan. This additional aim would validate the use of satellite measures of surface radiation we had proposed in our mapping aim to document temperature differences throughout Wayne County. We hypothesized that these temperature differences would reflect the urban heat island effect, which is the concept that "as cities replace natural land cover with pavement, buildings, and other infrastructure, urban areas experience higher temperatures in a number of ways, up to 10 degrees [Fahrenheit] higher in urban versus rural settings."[7]

Literature review

We conducted a search using PubMed to find relevant peer-reviewed literature on EJ and heat and health issues in United States communities. We used a combination of the following keyword searches: neighborhood, climate change, environmental justice, microclimates, cities, adaptation, social justice, remote sensing, tools, urban, and heat stress. The criteria we used to limit the number of articles were publication date (no earlier than 2003), studies related to an urban environment in the U.S., and some mention of heat stress or extreme heat events and social justice issues. Two studies in Phoenix, Arizona provided examples for studying the microclimate (the local climate of a small neighborhood) as it relates to heat.[4, 8] A total of eight studies were found of Wayne County, Michigan that provided insights into heat-related mortality and potential effect modifiers of mortality and morbidity among different racial groups.[9–16] However, none of the Michigan studies investigated the effects of neighborhood or microclimate temperatures and potential tools to assess heat-wave preparedness as we propose to do. Next, we discuss the preliminary work accomplished for our study.

Table 1. Census Variables Used in Statistical Analysis

Variable	*Definition*
% Non-white	Percent of the total population that do not identify themselves as white, as defined in the census
% Below the poverty line	Percentage of the population with income in 1999 below the poverty level total
% Go outside disability	Percentage of the population 16 years of age and older that reported having an individual physical, mental, or emotional condition for 6 months or more that made it difficult to go outside the home alone to shop or go to a doctor's visit
% No college education	Percentage of total population over 25 years of age that have less than a college education and have not completed a BS, BA, MS, professional degree, or PhD
% Linguistically isolated	Percentage of total population that are 14 years or older, speak a non-English language, and also speak English less than very well
% Non-American citizens	Percentage of census respondents who indicated they are not U.S. citizens
% Living alone and over 65 years of age	Percentage of persons over 65 years of age living alone

Data collection and methods

We used data from three different sources, described in the following sections.

Land cover data sources. Using land cover and land use data compiled by the United States Geological Survey (USGS) as a part of the U.S. National Land Cover Database 2001 (NLCD 2001), our study of the urban heat island effect in Wayne County began with quantifying the amount of impervious surface. These data are relevant to heat because impervious surfaces are covered with natural or human-made materials (e.g., rock formations, buildings, roads, sidewalks, parking lots) that prevent water from entering the soil and also may contribute to heat build-up in a way that vegetated areas will not. NLCD 2001 provides data layers with percentage of imperviousness data. We used Zone 8 of the NCLD dataset which includes all Michigan land cover data, at 30 meter spatial resolution, and independent per-pixel estimates of imperviousness. These percentage estimates were derived from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and high resolution images obtained from the USGS. Spatial analysis tools from the ArcGIS version 9.3 geographic information system software (ESRI, Redlands, CA) calculated average percent imperviousness for each census tract in Wayne County.

Census data sources. Demographic and social variables from the U.S. Census of 2000 were used to evaluate potential heat-related inequalities in the communities of Wayne County. Census data were obtained from the Geolytics 2000 Census dataset software package. Demographic variables identified as risk factors associated with heat-related mortality include those individuals who are living alone and aged (those over 65 years of age) and those of lower socioeconomic status.[9, 10, 17] We also hypothesized that linguistic isolation, non-American citizen, and presence of a disability that would prevent leaving home would be associated with higher heat-related mortality. Individuals who are linguistically isolated may be less likely to receive news about impending high temperatures, individuals who are not American citizens may be unfamiliar with U.S. climate, and disabled individuals may be unable to take action to cool themselves during heat waves. All these census variables are listed and defined in Table 1.

Statistical analysis

To facilitate the mapping of the census and imperviousness variables, we calculated quintiles of each of them across the 620 Wayne County census tracts using SAS Statistical Software, version 9.1 (SAS Institute, Inc., Cary, NC).

The statistical package SPSS version 15.0 (SPSS Inc, Chicago, IL) was used to calculate bivariate associations between all census tract variables used in the analysis and the mean imperviousness of each census tract. Spearman rank correlation coefficients were used to quantify these correlations because the frequency distribution of some of the key variables were not normal (i.e., produced a skewed histogram). Using Spearman coefficients is more conservative than Pearson's correlation as it does not assume normal distribution of the variables being evaluated. Correlations were calculated using SAS version 9.

RESULTS

Land cover mapping analysis

Wayne County has a total of 620 census tracts that cover an area of 618 square miles in Southeastern Michigan. The areas with over 50% imperviousness are mostly found inside the city of Detroit boundaries, as depicted in Figure 1.

The four maps of Wayne County in Figure 2 show the spatial distribution of the census tract variables (a) % below the poverty line, (b) % non-white, (c) % go-outside disability, and (d)% no college education.

Figures 2A through 2C indicate that the highest percentages of poverty, non-white, and go-outside disability are located within or near the city of Detroit boundaries. In contrast, the highest percentage of those with no college education is concentrated in the northeastern and southwestern section of the county.

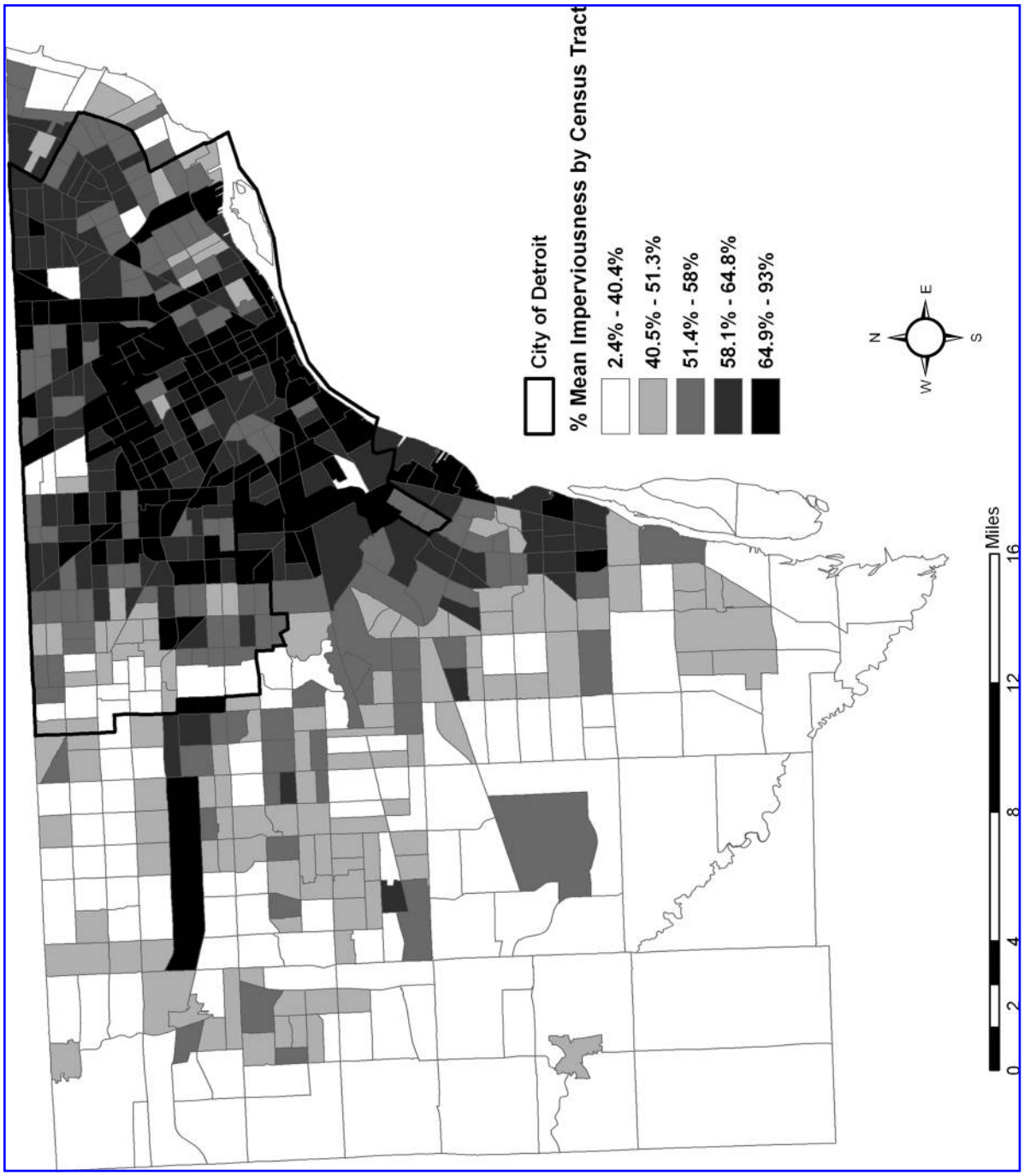

FIG. 1. % Mean imperviousness by census tract.

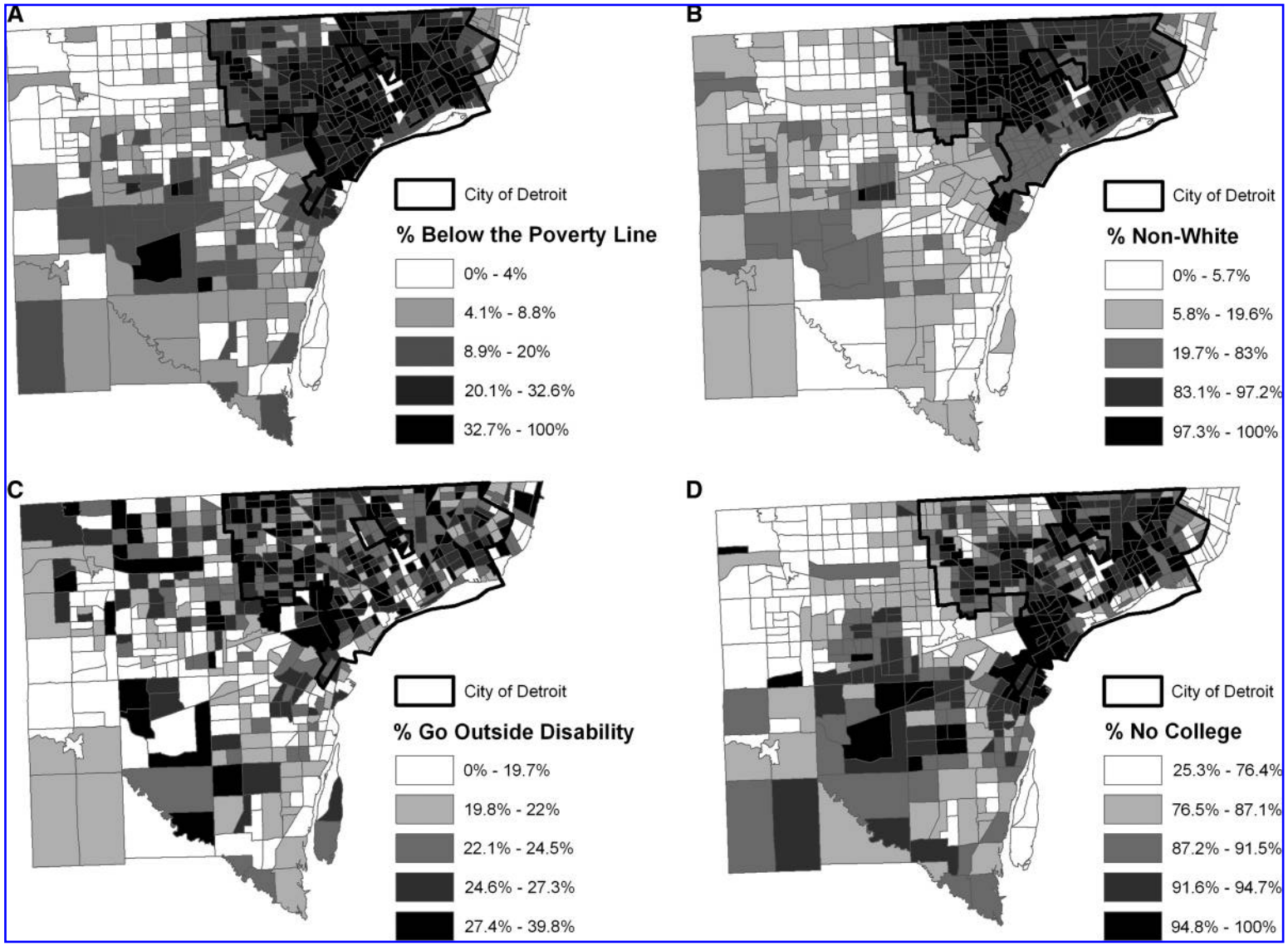

FIG. 2. Spatial distribution of census tract variables in Wayne County, MI showing quintiles (with categories for variables going from lowest to highest levels) indicated by the lightest color to the darkest. All data based on 2000 Census. City of Detroit boundary shown with dark outline. **A.** Percentage below the poverty line. **B.** Percentage non-white. **C.** Percentage with go outside disability. **D.** Percentage no college.

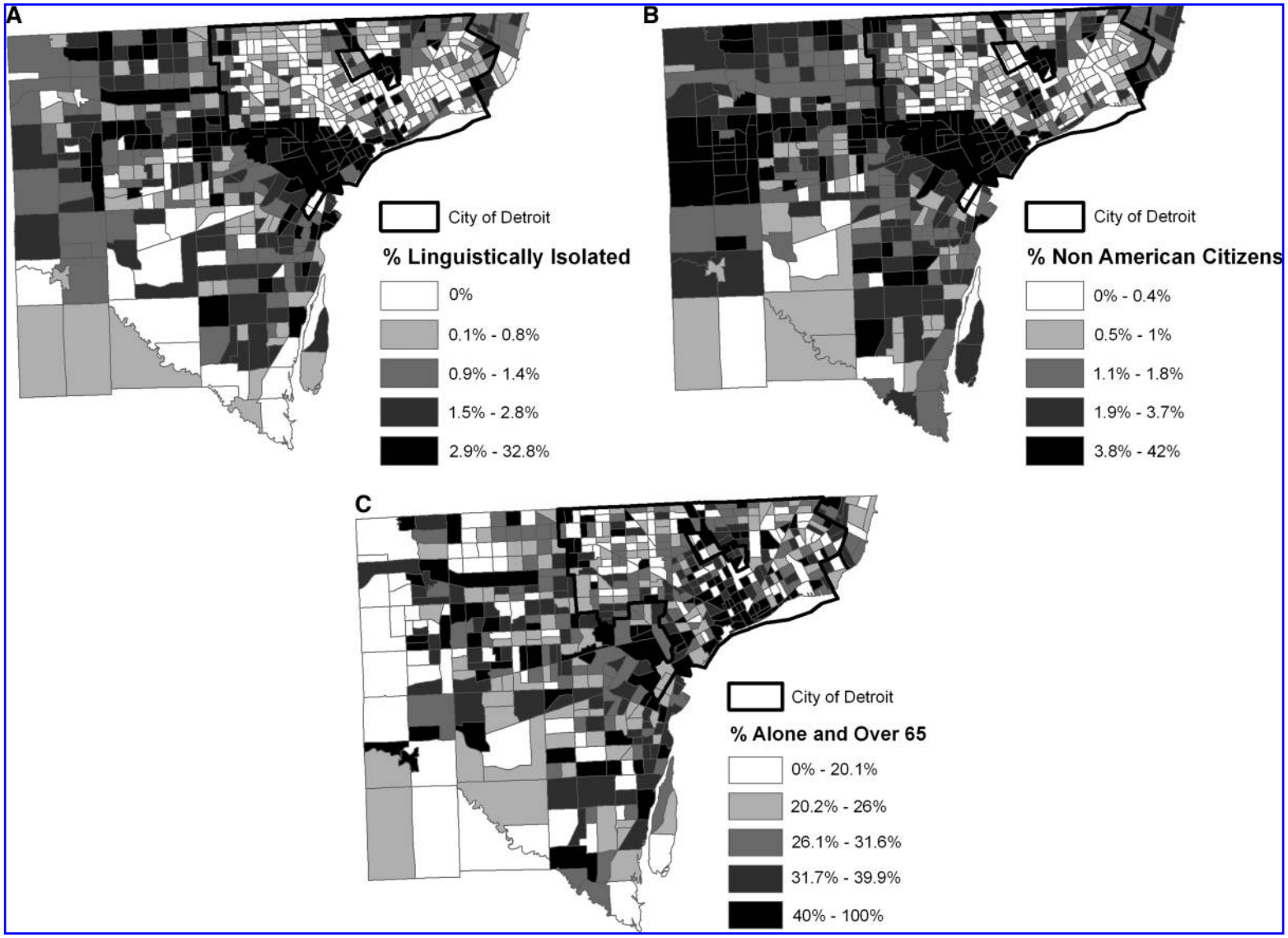

FIG. 3. Spatial distribution of census tract variables in Wayne County, MI showing quintiles (with categories for variables going from lowest to highest levels) indicated by the lightest color to the darkest. All data based on 2000 Census. City of Detroit boundary shown with dark outline. **A.** Percentage of population linguistically isolated. **B.** Percentage not American citizen. **C.** Percentage living alone and over 65 years of age.

However, for the categories of linguistic isolation, non-American citizen, and alone and over 65, the higher percentages of the population in these categories are not concentrated in the northeastern area of Wayne County, but are more dispersed as shown in Figure 3.

Correlation analysis

Table 2 shows the correlations between the geographical variables used for the maps. For variables that were normally distributed or were normally distributed after a logarithmic transformation, Pearson correlation coefficients were similar to Spearman rank correlation coefficients. Therefore the Spearman correlations among untransformed variables are presented. The strongest correlations were between the following variables: poverty and non-white ($r = 0.75$); no college education and poverty ($r = 0.69$); non-American citizen and linguistic isolation ($r = 0.66$); poverty and mean imperviousness ($r = 0.59$); non-white and no college education ($r = 0.47$); and non-white and non-American citizen ($r = -0.47$). Looking specifically at the correlation between mean imperviousness—an indicator of higher potential for heat exposure—and the census tract variables, the highest correlations were between percentage non-white, percentage living below the poverty, and percentage with no college education.

DISCUSSION

The goal of our study was to introduce a prototype tool that can be used to determine what locations and populations might be more vulnerable to negative effects from a heat wave. Preliminary analysis showed that for Wayne County, Michigan, the area within the city limits of Detroit could experience higher temperatures on average than the surrounding region due to the high percentage of impervious surface. Based on the land cover and census tract maps, the section of Wayne County with the highest imperviousness also corresponds to the highest percentage of poverty, non-white, and go-outside disability in that population. These socio-demographic variables have been found in other studies to be associated with increased vulnerability to heat. These other studies did not control for impervious surface in their analyses, so the associations could merely be confounded by impervious surface. However, if these socio-demographic risk factors are associated with vulnerability to heat independent of impervious surface, the combination of these risk factors and impervious surfaces in a neighborhood could further increase that neighborhood's vulnerability to heat. This suggests that, from a climate justice perspective, the Detroit location is an area of greater vulnerability and these populations would be important to target for heat-related public health interventions.

It is important to note that the conclusions from this correlation analysis are specific to Wayne County, MI. For example, linguistic isolation and non-citizenship are not strongly correlated with impervious surface in this analysis, but in cities where a larger percentage of the population is foreign born, these characteristics may be more strongly correlated with impervious surface.

The variables we evaluated are not the only ones that may denote higher vulnerability to heat, or higher potential exposure to heat. Additionally, some of the variables we included (linguistic isolation, citizenship, and disability) have not yet been shown to be risk factors for heat vulnerability. However, visually showing the overlap between areas of higher population vulnerability and higher environmental exposure using maps may be a useful tool for drawing attention to the EJ aspects of climate change, heat, and health in cities throughout the U.S. As additional risk factors for heat vulnerability are found, they may easily be added to an analysis such as this one.

CONCLUSION AND FUTURE DIRECTIONS

We have demonstrated preliminary results that show that heat waves, which are increasing with climate change,

Table 2. Spearman Rank Correlation Coefficients for all Variables in Analysis. Coefficients Were Calculated over 620 Census Tracts in Wayne County, Michigan

	% Non-White	*% Living alone and over 65 years of age*	*% Living Below the Poverty Line*	*% No College Education*	*% Linguistically Isolated*	*% Non-American Citizens*	*% Go Outside Disability*	*% Mean Imperviousness*
% Non-white	1.00	0.01	0.75*	0.47*	−0.36*	−0.47*	0.39*	0.50*
% Living alone and over 65 years of age		1.00	0.21*	0.05	0.25*	0.16*	0.00	0.22*
% Living below the poverty line			1.00	0.69*	−0.09	−0.27*	0.33*	0.59*
% No college education				1.00	−0.15*	−0.34*	0.16*	0.40*
% Linguistically isolated					1.00	0.66*	0.03	0.06
% Non-american citizens						1.00	−0.06*	−0.12
% Go outside disability							1.00	0.25*
% Mean imperviousness								1.00

*Statistically significant at the $p < 0.05$ level.

may be an important climate justice issue in Wayne County, Michigan, which encompasses the Detroit metropolitan area. According to a report on ethnic diversity and neighborhood integration from the 1980s to 2000, Detroit has been reported to be the most segregated city among the 50 largest metropolitan regions with the highest black population.[18] This demographic suggests an unfair burden that should be remedied. Our intention was to bring together several data sources at the census tract scale of resolution as a first step in a larger project intended to apply quantitative and qualitative methods to the issue of heat, health, and equity in the Detroit area. We plan to pursue several additional avenues of inquiry as our project continues.

While using imperviousness data was helpful in mapping potential for heat exposure, a next step in this analysis would be to use thermal images of Wayne County captured by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Data from ASTER, an imaging instrument on the National Aeronautic and Space Administration's Terra Satellite, can be used to generate maps of land surface temperature and reflectance. ASTER images have been commonly used to "explore intra-urban temperature variations and surface land cover."[19] ASTER has multiple data products that can be used to characterize thermal emissivity at the earth's surface. Since the ASTER satellite only passes over Southeastern Michigan a limited number of times during the year, we would be limited to a small number of satellite scenes to choose from during our study period. However, this ASTER analysis would be useful to certify the target areas that might be vulnerable to extreme heat based on our preliminary analysis described above.

In addition to exploring ASTER and other potential data sources for our mapping, we intend to interview community leaders, residents and public officials in the Detroit area to learn how the prototype tools we have developed can be integrated into heat wave preparedness programs to better direct resources and inform the public about potential health risks during hot weather, and specific steps to prevent them while improving environmental sustainability.

We hope this work will provide a template for application in other communities in addressing the health and social justice implications of climate change.

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