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A method for creating high resolution maps of social vulnerability in the context of environmental hazards

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ABSTRACT

The availability of demographic information from census data has enabled the development of indices that describe the relative social vulnerability of populations at different locations. These indices are often used in conjunction with models of physical exposure to environmental hazards, such as flooding and hazardous waste emission, to identify populations at greatest risk. However, using standard census areal units to calculate social vulnerability can lead to significant underestimation of vulnerable populations as environmental hazards typically occur on a finer spatial scale than census units such as block groups. This paper describes and illustrates a hybrid method for creating a social vulnerability index (SVI) at a tax parcel level by utilizing supplementary information about tax parcels to link cadastral dasymetric mapping techniques and established social vulnerability indexing methods. This high resolution social vulnerability index may be used for planning at the municipal level to address existing or potential environmental justice issues.

1. Introduction

1.1. Motivation

In May of 2010, Middle Tennessee and more specifically, the greater Nashville area (Davidson County), experienced catastrophic flooding following a record setting rainfall event in which more than 13 inches (330 mm) of rain fell within a 48 h period (NOAA, 2011). At least eleven fatalities occurred due to flash flooding of streams and tributaries of the Cumberland River, many of them senior citizens, and more than 11,000 buildings were damaged at an estimated cost of at least $2 billion (NOAA, 2011).

As with many natural hazards, the 2010 flood prompted inquiries into social vulnerability (i.e., the ability of individuals to cope with and rebound from physical, emotional, and economic burdens) induced by the flood (Burton, 2010; Cutter, Boruff, & Lynn Shirley, 2003; Maantay & Maroko, 2009; Myers, Slack, & Singelmann, 2008). A study of social vulnerability, flood inundation, and locations of emergency response shelters in Davidson County conducted at a spatial scale of census tracts suggested that areas with higher social vulnerability were more likely to be flooded and had disproportionately limited access to emergency services (Padgett, 2013). While this study addressed issues relevant to social vulnerability and the distribution of harms produced by an environmental hazard by offering a social vulnerability index (SVI) as a measure for addressing environmental justice issues, the use of census tracts for the analyses provided a level of precision insufficient for identification of significant disparities in flood exposure and emergency shelter access for high and low vulnerability populations.

The study described herein attempts to overcome these spatial mismatches between identification of environmental hazards and socially vulnerable populations that can hinder identification of environmental justice issues by developing a methodology, using Davidson County as a test bed, which allows for assessment of social vulnerability at high spatial resolution. The approach taken in this study combines a social vulnerability indexing method and a dasymetric population mapping method via disaggregation logic based on supplementary information within a cadastral dataset. The result is an SVI at the tax parcel spatial scale (to be referred to as parcel level in the remainder of the paper) that can be overlaid with environmental hazard boundaries for precise identification of spatial coincidence between socially vulnerable populations and exposure to harm from environmental hazards. While

Abbreviations: SVI, Social Vulnerability Index; BGSVI, Block Group Level Social Vulnerability Index; PSVI, Parcel Level Social Vulnerability Index.

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development of the methodology was motivated by the Nashville flood case, the parcel level SVI produced is broadly applicable to many environmental hazards that affect the built human environment.

1.2. Social vulnerability in the context of environmental hazards

The concept of social vulnerability to environmental hazards has gained increasing interest with many studies proposing composite indices for comparative analysis of vulnerability across spatial extents (Chakraborty, Tobin, & Montz, 2005; Cutter et al., 2003; Krishnamurthy & Krishnamurthy, 2012; Shepard et al., 2012). The social vulnerability indices often utilize a hazards-of-place framework, which implies that only human environments, spaces containing human populations, are considered vulnerable, and are often mapped to show spatial relationships between social vulnerability and biophysical vulnerability to environmental hazards such as flooding (Azar & Rain, 2007; Cutter, 1996). These indices have been created as planning tools and metrics that can be used to inform policy development, funding allocations and educational efforts, to assist municipal and emergency planners in identifying populations at risk during evacuation scenarios, and to identify potential or existing environmental justice concerns (Burton, 2010; Chakraborty et al., 2005; Cutter et al., 2003).

In the natural hazards literature social vulnerability indices are typically based on a definition of vulnerability that posits that social stratification and local infrastructure factors are the primary contributors to the vulnerability or resilience of a population (Chakraborty et al., 2005; Cutter, 1996; Cutter et al., 2003; Rygel, O'Sullivan, & Yarnal, 2006). The vulnerability indicators (such as age, gender, socioeconomic status, living arrangements, access to medical care, and race/ethnicity) used in construction of most social vulnerability indices are heavily based on socio-demographic information measured in census data and are generally consistent from one study to another (Azar & Rain, 2007; Cutter et al., 2003; Rygel et al., 2006). However, choice of which specific census variable to use to represent a vulnerability indicator and the number of indicators and variables used for an index varies widely, with the number of variables used ranging from less than ten to more than fifty depending on the type of analysis and the index construction method (Chakraborty et al., 2005; Cutter et al., 2003; Fekete, 2009; Krishnamurthy & Krishnamurthy, 2012; Rygel et al., 2006; Shepard et al., 2012; Wilhelmi & Morss, 2013).

One widely accepted method for creating an SVI is the SoVI® [1] analysis method, in which principal components analysis (exploratory factor analysis) is used to reduce a large number of demographic variables to a smaller subset of vulnerability factors (Cutter et al., 2003). The vulnerability factors produced in the principal components analysis are linear combinations of variables that are highly correlated with each other, while the factors themselves are orthogonal to each other. In this way, each factor can be generally described as representing a certain unique characteristic of vulnerability. This methodology was recently adopted by the United States Army Corps of Engineers (USACE) for use in water resources planning (Dunning & Durden, 2013).

1.3. Environmental justice and associated analytical challenges and advances

Related to the concept of social vulnerability to environmental hazards is the idea of environmental justice. Derived from the idea of environmental racism, which was focused on discrimination against people of color in environmental policy-making, environmental justice has been generally described as a type of distributive justice concerned in particular with the distribution of benefits and burdens among a population that is affected by decisions and actions made in relation to the environment (Cutter, 2012; Wenz, 1988). As a form of distributive justice, environmental justice analysis involves an assessment of the geographical distribution of environmental hazard burdens among the population. Therefore, it is an inherently spatial problem, and one where scalar mismatches between populations of interest and environmental hazards often hamper precise characterization of the at-risk population (Chakraborty, Maantay, & Brender, 2011; Mennis, 2003).

The analytical problems associated with coincidence analysis of hazards and populations have been well documented to show that scale does matter, particularly when examining the intersection of two or more areal units of different scales and spatial extents (Chakraborty et al., 2011; Mennis, 2003). Different interpretations of intersection or overlap of census units with hazard zones have been shown to have a large influence on the results of hazard risk analysis, leading to both overestimation and underestimation of at-risk populations, an issue referred to as the Modifiable Areal Unit Problem (MAUP) (Maantay, Maroko, & Herrmann, 2007; Mennis, 2002). In particular, the use of census data, which is heavily relied upon for social vulnerability and environmental justice studies, restricts spatial interpretation of socio-demographic data to areal units (e.g., census tracts) that may not correlate well with the spatial scale of the hazard of interest (e.g., floodplains), or with the actual boundaries of spaces in which people are located (e.g., residences).

Dasymetric mapping techniques have recently received attention as a valuable tool for environmental justice analyses as they provide a way to disaggregate socio-demographic data to a finer scale which may be more representative of the area affected by a hazard (Chakraborty et al., 2011; Maantay et al., 2007; Mennis, 2003). Dasymetric mapping is a form of areal interpolation that utilizes an ancillary dataset containing supplementary information that can be used to redistribute data to smaller areal units. Land use classification raster data sets are commonly used as an ancillary dataset for this purpose, allowing census data to be redistributed to raster grids of 30 m–100 m in edge length by attributing a population density to different land use classifications (Mennis, 2002, 2003). An alternative to land use classification rasters as a supplementary dataset is cadastral (tax parcel) data (Maantay et al., 2007; Tapp, 2010). Using cadastral data as an ancillary dataset allows population data to be redistributed to individual parcels, a spatial unit highly relevant to municipal planning.

Dasymetric mapping techniques that make use of density of development categories in land-use classification rasters as a proxy measure of population density were utilized by Mennis (2002) for analysis of environmental justice risk. In an analysis of the proximity of ‘disadvantaged’ populations (minorities and those living below the poverty line) to a hazardous facility, Mennis found that the percentage of the population that could be considered ‘disadvantaged’ peaked at a distance from the hazardous facility that is several times smaller than the length of many block groups and census tracts. Without disaggregation of the population to higher resolution sub-units, the relative increase in the percent of the population residing near hazardous facilities that are ‘disadvantaged’, and the environmental justice risk associated with this disproportionate population distribution, would likely not be recognizable.

Cadastral-based dasymetric mapping techniques have also been applied to analysis of environmental justice issues. Maantay and

[1] The SoVI social vulnerability index is a product of the Hazards and Vulnerability Research Institute and a registered trademark of the University of South Carolina.