Social Vulnerability to Climate Change: A Neighborhood Analysis of the Northeast U.S. Megaregion

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Abstract

The Northeastern U.S Megaregion is the largest agglomeration of people (49 million), economic activity, and urbanized land in North America and one of the largest in the world. Population growth over the last fifty years was complimented by extensive and intensive urban spatial development and the corresponding increase in the total number of weather related societal impacts. The risk of exposure under climate change will likely be experienced differently than previous natural hazards. The objective of this paper was to use neighborhood level data from 2000 Census to construct a comparative megaregion index of social vulnerability to climate change. Use of a factor analysis method simplified our final 27 variables into clusters of six analogous components to explain 79 percent of the variability of the original variables. Utilizing the individual factor variances, weighting schema were attributed to each component before their incorporation into an index of social vulnerability. Mapping the individual factor components and the index of social vulnerability provided a foundation for analyzing spatial variation and the hot-spots of vulnerability. Highlighting four major cities as case studies (Boston, Hartford, New York – New Jersey, and Philadelphia) provided an opportunity for closer review of the data and allowed for demonstrating the presence of spatial heterogeneity within counties, states, and metropolitan regions. Neighborhood variability demonstrates that different variable combinations actually generate the social vulnerability profiles. Greater understanding of neighborhoods' social vulnerability will potentially shape policy interventions, foster opportunities for interdisciplinary research, and progress towards the reduction of societal impacts.

Keywords

Social Vulnerability, Climate Change, Urban Areas, Neighborhood, Northeast, megaregion

Introduction

Vulnerability has been researched at length in the geography and hazards research communities. Recently an extensive analysis of vulnerability has flourished across many disciplines including: climate science, risk assessment, environmental management, the sustainable development communities (Thomalla et al., 2006), and urban planning (Stone, 2006). Each discipline however offers their perspectives, methods, interpretations and distinct languages towards the conceptualization and identification of vulnerability and its dimensions.

Of great concern to all fields is the successful reduction of economic losses and mortality rates (Thomalla et al., 2006). Meanwhile, increases in total lives lost, injuries, and economic costs have been observed (NCDC, 2006) signaling reorganization of social vulnerability of neighborhoods, regions, and nations to climate change and extreme events. Social vulnerability can be defined as the interplay of social, economic, and demographic characteristics that determine the resiliency of individuals and communities to climate change.

This research investigates social vulnerability of the Northeast U.S. Megaregion using 2000 neighborhood level social, economic, and demographic census data in order to compare relative sensitivity to climate change and extreme events. Neighborhood analysis will provide a critical foundation for depicting the hot-spots of social vulnerability; which is evermore important as climate change increasing the potential for social impacts.

Background

The exposure to hazards in the U.S. Northeast megaregion has been amplified by the two factors of continued urban spatial development and growing impacts of climate change (RPA, 2006; Stone, 2006). Amplification of both social and biophysical vulnerability has increased the total losses. This research is particularly interested in opportunities to mitigate social vulnerability through sustainable development policy. To demonstrate these opportunities we examine neighborhood social vulnerability assuming that social vulnerability is shaped by the conditions which are established through people's daily lives, such as their access to critical resources like money, information, or experience in overcoming potential hazards and disasters (Blaikie et al, 1994; Hewitt, 1997).

The geography and hazards communities commonly use Cutter's (1996) definition of vulnerability, which is the combination of biophysical and social vulnerability. The global environmental change community (Liverman, 1986; Dow, 1992) and more recently cited in the climate change community literature (Adger, 1999; Downing et al., 2001; Brooks, 2003; Downing and Patwardhan, 2003; O'Brien et al., 2004; and Brooks et al 2006) has further developed the conceptualization of vulnerability to allow for a dynamic feedback component. Brooks et al (2006) provides the most recent application of vulnerability and adaptive capacity assessment, intimately relating mortality risk with proxies for social vulnerability, in addition to determinants of adaptive capacity. Brooks et al (2006) introduces mechanisms that provide for fluctuations in risk and vulnerability, but particularly for adaptive spatial and temporal capacity.

For this paper we conceptualize vulnerability through the IPCC 2001 definition. The IPCC's definition of vulnerability serves as a conceptual framework for which a formulation of regional vulnerability can be applied in this article. The IPCC (2001) defines vulnerability as…

> "… the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity."

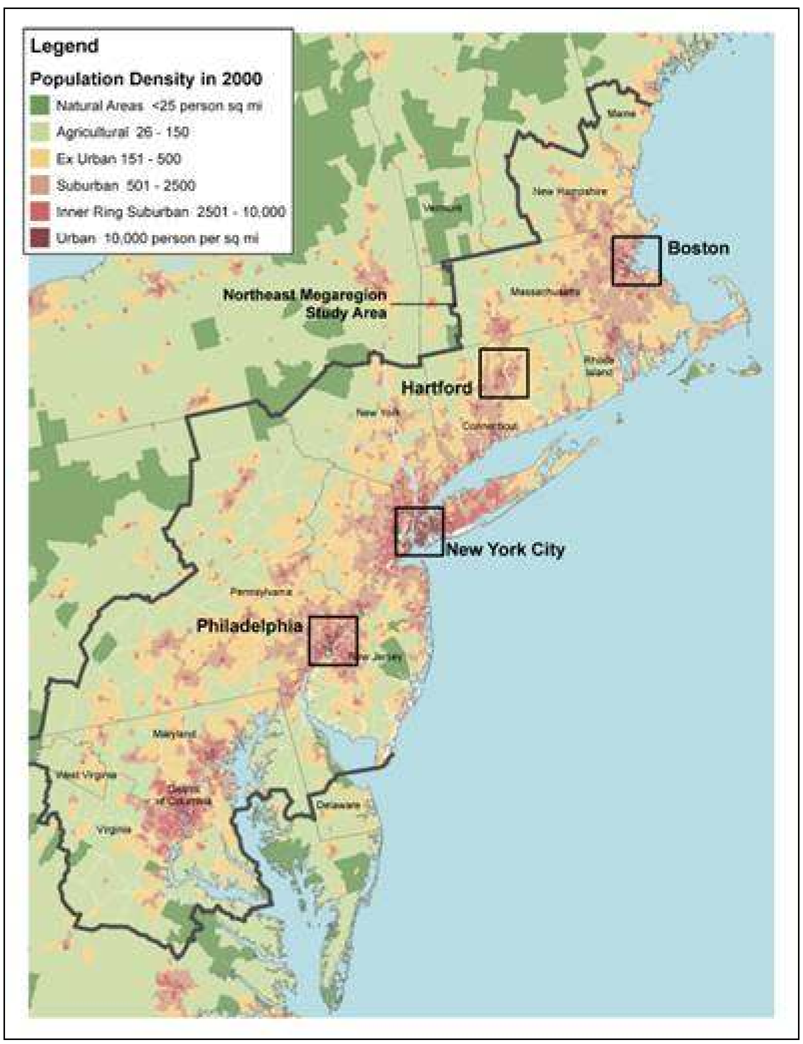
This definition can be translated into a conceptual framework for vulnerability to climate change using the three critical components of risk, vulnerability, and adaptation. Throughout the literature, these three components are most commonly referred to as biophysical vulnerability (or natural hazards/risk of exposure), social vulnerability (or a populations sensitivity to overcoming/adapting to hazards), and adaptive capacity (or the ability of a group to change over time to hazards (Brooks, 2003; Füssel, 2005;

Füssel and Klein, 2006). For a critique of the definitions and framework of vulnerability to climate change, see Füssel and Klein (2006).

The conceptualization of vulnerability has largely changed; however, examination of the social vulnerability aspect has remained consistent. The assessment of social vulnerability is usually conducted through the utilization of proxies or vulnerability indicators (Brooks, 2003; Brooks et al, 2006). In terms of policy making, these indicators should be thought of as meaningful, transferable, comparable and transparent in order to shape the analysis that enables successful climate change policy interventions (Bell and Morse, 1999), and to this accord we only employ Census derived variables. The variables we have chosen reflect current social, economic, and demographic conditions in the megaregion to shape our understanding of the geography of social vulnerability.

The objective is to generate a set of generic neighborhood level indicators to allow for a comparative analysis of the social vulnerability among cities within the Northeast U.S. Megaregion (figure 1). An analysis of this nature will provide a foundation for determining the population that is currently at the highest risk. The Northeastern U.S Megaregion is the largest agglomeration of people, economic activity, and urbanized land in North America and one of the largest in the world. The Northeast has become America's foremost example of the megaregion, an emerging urban ecology that consists of a group of interconnected metropolitan regions and the natural landscapes on which they depend.

Figure 1: Northeast Megaregion



Many observers consider the Northeast the original megaregion, originally defined by geographer Jean Gottman, in his influential 1961 book *Megalopolis: The Urbanized Northeastern Seaboard of the United States*. The Northeast megaregion covers only two percent of the total land area of the United States. 49 million people, or almost 18 percent of the U.S. population, live in the Northeast megaregion and its metro areas, which generate one-fifth of the nation's gross domestic product (GDP) (U.S. Conference of Mayors, 2006).

Our approach to understanding social vulnerability is through an empirical analysis of the current landscape. Additionally we assume that the most vulnerable populations for the most part have not contributed to climate change, while they often reside in marginal areas in which the risk to the associated societal impacts is greatest. This paper uses a widely accepted set of generic vulnerability indicators derived from social, economic, and demographic variables established in Clark et al (1998) and Cutter (2003). The vulnerability indicators are prepared for use in a data reduction model that will reduce the variable into several components. Those factors can be multiplied by the percentage they contribute towards understanding social vulnerability through the results of the factor analysis. That equation is used to derive a comparative index of social vulnerability for further study of individual neighborhoods in the Northeast U.S. Megaregion. The index will focus on a population's relative vulnerability or resilience to climate hazards. This approach is not hazard-specific due to use of generic variables. Instead this research identifies the multi-dimensions and geographies that lead to social vulnerability within a megaregion.

Social vulnerability has not been investigated at the neighborhood-level for a megaregion, although Cutter (2003) provides methods to conceptualize a county-level comparative study of environmental hazards for the United States. While Clark et al (1998) provides a block-level vulnerability analysis to climate change, it is conducted for a single location in Massachusetts.

Identifying Social Vulnerability

An assessment of social vulnerability most often utilizes indicators or proxies to describe a place's social vulnerability. The most common proxy for vulnerability is poverty or the presence of low-income households which lack the financial resources or insurance coverage for post event/recovery efforts (Bolin and Stanford, 1998). Poverty in the Northeast U.S. megaregion is most pronounced in the inner cities of urban areas. According to some studies (Morrow, 1999) vulnerability is not limited to the poorest households.

The literature presents several demographic, social, and economic factors that are important proxies of vulnerability. The demographic variables cited most often throughout the literature include race and ethnicity (Bolin, 1994; Bolin and Stanford, 1998; Morrow, 1999), age (Hewitt, 1997), and gender (Blaike et al 1994; Hewitt, 1997). Race, ethnicity, and gender all play a role in how quickly households are able to recover (Bolin and Bolton, 1986; Morrow, 1999; Enarson and Scanlon, 1999), and may also result in amplified mortality rates (Klinenberg, 2002; O'Neil, 2003). Social or cultural vulnerability factors are also driven by family structure or social networks (Blaike et al 1994; Morrow, 1999). These social variables include the presence of a large number of dependents, either the young or elderly, and female headed households. The presence of both of these variables slows recovery from disasters (Bolin and Bolton, 1986; Enarson and Morrow, 1997; Cutter et al., 2000). There are several additional vulnerability factors associated with personal limitations and special needs populations. Those vulnerability proxies include restrictions in mobility, the ability to care for oneself, and the ability to work, and the persons usually affected by these variables are those with disabilities, transients, homeless or the institutionalized (Morrow, 1999). Further, language and literacy barriers may also prevent households from taking advantage of available aid or prevent them from safe evacuation (Bolin, 1994; Enarson and Morrow, 1997; Seirup, 2004). Lastly, there are a number of economic factors that can also increase vulnerability, such as education level, (Cutter, 1996), occupation and employment type (Cutter, 1996; Hewitt, 1997, Mileti, 1999), and income (Burton et al 1993; Blaike et al 1994; Hewitt, 1997).

Measures of the built environment (i.e. building stock and infrastructure) are increasingly used to identify places with high potential vulnerability, and to prevent further development in disaster-prone urban and coastal areas.

Table I

Common Themes / Influence on Sensitivity of Population

Theme	Variables	Variables Analyzed	Literature that Sited	
Lack of Material Resources and Personal Limitations	**Income allows individuals and families to spend money on prevention before a disaster and resilience thereafter.**			
	Percent Less than High School Education	Y	Cutter	Clark
	Percent in Poverty	Y	Cutter, Seirup	Clark
	Percent that are Renters	Y	Cutter, Seirup	
	Percent of Large Households (More than 7)	Y	Cutter, Seirup	Clark
	Percent Female Headed Households	Y	Cutter, Seirup	Clark
	Percent Two Working Parents	Y	Cutter, Seirup	
	Percent People over 30 living with Grandchildren	N	Seirup	
	Percent that receive Public Assistance	Y	Cutter, Seirup	
	Average Household Income	Y	Cutter, Seirup	Clark
	Mortgages more tan 35% Income	N	Seirup	Clark
	Median Rent	N	Seirup	Clark
	Percent Unemployed	N	Cutter, Seirup	
	Percent Self-Employed	N	Cutter, Seirup	Clark
	Percent with Less than High School Diploma	Y	Cutter, Seirup	
	Percent with Self Care Disability	Y	Cutter, Seirup	Clark
	Percent with Mobility Disability	Y	Cutter, Seirup	Clark
	Percent with a Work Related Disability	Y	Cutter, Seirup	Clark
	Percent Elderly with Self Care Disability	Y	Cutter, Seirup	Clark
	Percent Elderly with Mobility Disability	Y	Cutter, Seirup	Clark
	Percent Living in Nursing Homes/Group Quarters	N		Clark
Lifelines	**People without cars or telephones lack basic lifelines to leave places under conditions of impending disaster.**			
	Percent Housing with No to Telephone	Y	Cutter	Clark
	Percent that Use Public Transportation	Y	Cutter, Seirup	Clark
	Average Vehicles per Housing Unit	Y	Cutter, Seirup	Clark
	Average Travel Time to Work		Seirup	Clark
Lack of Information/ knowledge	**Populations that do not speak English; people who have recently moved to a region may not have adequate knowledge of regional hazards and methods of evacuation.**			
	Percent in Linguistic Isolation	Y	Cutter, Seirup	Clark
	Percent non U.S. Citizen	Y	Cutter, Seirup	Clark
	Percent New to Region		Seirup	Clark
	Percent New to U.S.	Y	Cutter, Seirup	Clark
Race, Ethnicity, and Gender	**Minority populations have been known to be misrepresented and disengaged in the political process, which may affect exposure, sensitivity, and resilience to hazards**			
	Percent Asian	Y	Cutter, Seirup	Clark
	Percent African American	Y	Cutter, Seirup	Clark
	Percent Hispanic	Y	Cutter, Seirup	Clark
	Percent Non-Hispanic	Y	Cutter	Clark
	Percent Other	Y	Cutter	Clark
	Percent Female	N	Cutter, Seirup	Clark
Built Environment	**Heat islands, housing stock, and urban population density increase impediments when coping with hazards**			
	Population Density (in Sq Miles)	Y	Cutter, Seirup	Clark
	Housing Density (in Sq Miles)	Y	Cutter, Seirup	
	City (Dummy Variable)	Y	Cutter	
	Housing Built Prior to 1939	N	Seirup	Clark
	Mobile Homes	N	Cutter	Clark
	Percent Urban/ Rural	N	Cutter	
	Population Growth	N	Cutter	
Age	**Both young and old are susceptible to lack to wealth and coping skills for hazards**			
	Percent Under Age 5	Y	Cutter, Seirup	
	Percent Under Age 18	Y	Cutter, Seirup	Clark
	Percent Over Age 65	Y	Cutter, Seirup	Clark
	Percent Elderly Living Alone	Y	Cutter, Seirup	

There are a host of environmental context factors in the literature such as infrastructure, lifelines, public transportation (Cutter, 1996), urban/rural density (Mitchell, 1999), and population growth (Morrow, 1999). Due to their age and structural type, the buildings themselves have been identified as important factors in affecting vulnerability. However, identical building stocks in different communities may have very different resiliencies. For example, a low-income household often lacks the financial resources or insurance coverage necessary for recovery efforts, while middle or high income households may have sufficient insurance coverage (Bolin and Stanford, 1998). Renters have little control over maintenance, and this includes protective measures that are taken (i.e. air conditioners used during extreme heat waves). Additionally, even if renters are supplied with units such as air conditioners, they may have limited financial resources to pay for the extra energy costs associated with running them (Klinenberg 2002). In the recovery phase, low-income renters may have trouble finding affordable replacement housing (Bolin, 1994; Bolin and Bolton, 1986; Morrow, 1997; Enarson and Morrow, 1997).

Commonly suggested vulnerability themes used in assessments have been compiled by Clark et al. (1998) and Cutter (2003). Theses assessments serve to establish a list of generic vulnerability variables. Table 1 depicts the major themes from the literature and their corresponding variables or proxies.

Data and Methods

To define vulnerability within urban areas of the Northeast, we use variables derived from the 2000 US Decennial Census. Census data is widely accessible, transferable, and familiar among multiple disciplines. More than 40 tract-level variables (Seirup, 2004; Cutter et al, 2003; Clark et al, 1998) from SF1 and SF3 of the 2000 census were selected for the analysis. Tract-level data was chosen to ensure that future research on temporal trends could be employed easily using the GeoLytic's Neighborhood Change Database. The database provides long form data from decennial census starting in 1970 and normalized to 2000 tract geographies. To overcome problems of extremely populated census tracts we used the Seirup (2004) normalization method instead of the Cutter et al (2003) method, which divides by the total population of the tract. With the Seirup (2004) normalization method, for example, percent elderly living alone is normalized by the total elderly population by tract.

Due to certain factors, several census tracts were initially removed. These included tracts with no data, tracts with populations less than 100, and tracts with a large proportion of the population living together, such as in a nursing home. Tracts with populations of less than 100 often contain large parks, airports or industrial areas (i.e. Central Park, Kennedy Airport). Tracts with less than 100 persons skew the results, amplifying concentrations of vulnerability due to the lack of population living there. Tracts where 50% or more of the population is living together, such as in nursing homes, hospitals, and prisons, are beyond the scope of this paper. It is recognized, however, that these facilities can potentially be more vulnerable to heat-related or other types of disasters, as was evident during the 2003 heat wave in Europe and during Hurricane Katrina in 2005.

Understanding and comparing neighborhood social vulnerability across the megaregion can best be done using a principal component or factor analysis. Factor analysis is used to simplify the multivariate dataset in order to understand the trends and associations more clearly. Factor analysis clusters variables into similar terms, generating fewer variables (called components or factors) that explain a large percentage of the variability of the original variables. Factor analysis also removes multi-collinearity between variables and combines those that are highly correlated (positively or negatively) to reduce redundancy in the variables. For example, many variables in this analysis are measuring poverty or the presence of financial resources, and are combined into a single component in our factor analysis called *'Material/ Resources/Lifelines'* (See Table III). The component factors are more suitable for creating an additive index of social vulnerability. For the neighborhood level analysis of coping ability, the reduction of redundancy reveals relationships between the variables suggested in the vulnerability literature of Cutter (2003) and Seirup (2004).

Specifically, the Varimax rotation method enables the highest variance to be calculated for each component. The first component is calculated by minimizing the sum of squares of the perpendicular distance from each point to the component. This maximizes the amount of variance explained by that component. The second principal component is orthogonal to the first and explains the largest amount of the remaining variance. This process is repeated until there are as many components as there are variables and all of the variance is explained. The Eigen value of the component is a measure of the amount of variance explained by that component. In this factor analysis, Eigen values greater than 1.0 are considered in a model to explain its variance. (REF)

Using a Varimax rotated factor analysis, a limited set of variables (n=27) were used in the final rotated analysis, as shown in table II. Variables in the final analysis attributed the greatest contribution to the factor analysis maintained communalities over 0.5. Notice the variable 'City' is a dummy variable created to group tracts in the core central cities of New York City, Philadelphia and Suffolk (Boston) Counties. The removal of variables from the final factor analysis was done to reduce conflicting assumptions of vulnerability. Variables included self-employment due to high correlation with high income neighborhoods. We removed the year built variable because of the low contribution to the analysis. The year built variable is not a good indicator of resiliency in the built environment since older buildings in New York City and Boston are often well maintained as compared to dilapidated buildings in low income areas built just a decade ago.

Mapping Social Vulnerability

The rotated factor analysis generated six components, shown in Table III which account for approximately 79% of the total cumulative variance for the socio-economic vulnerability of the Northeast (or our measure of the ability to cope with a disaster). Factor analysis is an effective tool for understanding which variables are strongly correlated and represent similar conditions. The factor that accounts for the largest variance (27.99%) includes variables related to material resources needed to cope with disasters such as income, lifelines, and education levels. Based on evidence that all these variables are all driven by income per capita we called this factor '*Material resources/ Lifelines'.*

The next two factors represent 14% and 13% percent of the variance. The second component, '*Built Environment',* includes variables that refer to the density of development, specifically housing density and population density and the city dummy variable. The third component contains variables related to the tenure and integration into the community, and includes linguistic isolation, percentage of residents recently arrived to the United States, and percentage of non-citizens. This factor we call *'Access to Information'* because it is related to the ability to obtain knowledge and information regarding regional hazards and to communicate that knowledge to others.

Table III

Results of Factor Analysis

Literature Themes	**Census Variables**		**Component Name**	**Percent Variance**
	Positively Weighted	Negatively Weighted		
Lack of Material Resources/ Lifelines	Below Poverty, Renters, (Moderately on Hispanic), Receiving Public Assistant, Female-headed Households, Large Households over 7, No Telephones, and Less than high school education	Non-Hispanic White, Average Household Income, Two Working Parents, Number of Vehicles per Household	1: Material Resources/ Lifelines	27.99%
Built Environment	Population Density, (Moderately on Hispanic), Housing Density, Core City Binary, Percentage Relying on Public Transportation		2: Built Environment	14.47%
Access to Information and Knowledge	Asian, Ability to Speak English, New to US, Not US Citizen		3: Access to Information and Knowledge	13.56%
Children and the Disabled	Children Under 18, Moderately with Persons with Disabilities		4: Children	8.60%
Elderly and Elderly Living Alone	Elderly Living Alone, Over 65		5: Elderly	8.22%
African American	African American		6: Race	5.79%

*Total Cumulative % Variance = 78.675%

The next two factors both focus on age, with each contributing approximately 8 percent of the variance, respectively. The fourth factor, '*Children and the Disabled*' reflects the concentration of children under 18 as well as persons that are disabled. The fifth factor, *'Elderly and Elderly Living Alone*', represents percentage elderly and more specifically percentage elderly living alone.

The sixth factor represents African-American concentrations in the study area. Although it only represents 5.79% of the variance in the model, the sixth factor is included in the analysis because it signifies the last of the variables representing race and ethnicity, which are well defined as an environmental justice characteristic. The other race and ethnicity variables are contained within different factors as described in table III.

The factor analysis illustrates the underlying complexity and dimensionality that characterizes the region's ability to cope with environmental hazards. As Seirup (2004) demonstrates, the true complexity of social vulnerability cannot be mapped with a single variable (e.g. poverty). Alternatively, mapping of dozens of individual variables masks the cumulative quality of the variables.

Mapping social vulnerability for the Northeast megaregion and four case studies illustrates spatial variability existing among neighborhoods (census tracts) of each individual factor component. In addition, each individual factor demonstrates that spatial heterogeneity between the factors does indeed exist among the neighborhoods. This confirms that different neighborhoods have different factors driving social vulnerability. In that case, development of neighborhoods typologies and policy assumptions can be formulated regarding future climate change interventions. The kinds of interventions and follow-up research would be based on the social vulnerability profiles of each neighborhood.

In this analysis we highlight four major city case studies: Boston, Hartford, New York – New Jersey, and Philadelphia. Mapping the four cases studies at higher resolution (1:500,000 instead of 1:3,000,000) provides an opportunity to demonstrate the utility of choosing a neighborhood or census tract as a unit of analysis. Particularly, the analysis illustrated the benefit of shifting from county-level unit of analysis to census tract due to the high level of heterogeneity among a county and a major case study city. The megaregion as a study area worked well to validate commonalities between neighborhoods and depicted clusters throughout the study area.

To map the six individual components from the Varimax rotated factor analysis we first standardize the loadings for each tract in the analysis. A standardization method was used to combine individual maps into a scalar composite map. To standardize the individual components, shown in formula 1, we divided an individual component's factor loading values by the maximum value for each component.

Formula 1

Each Component = Value of factor loading / Max Value of factor loading

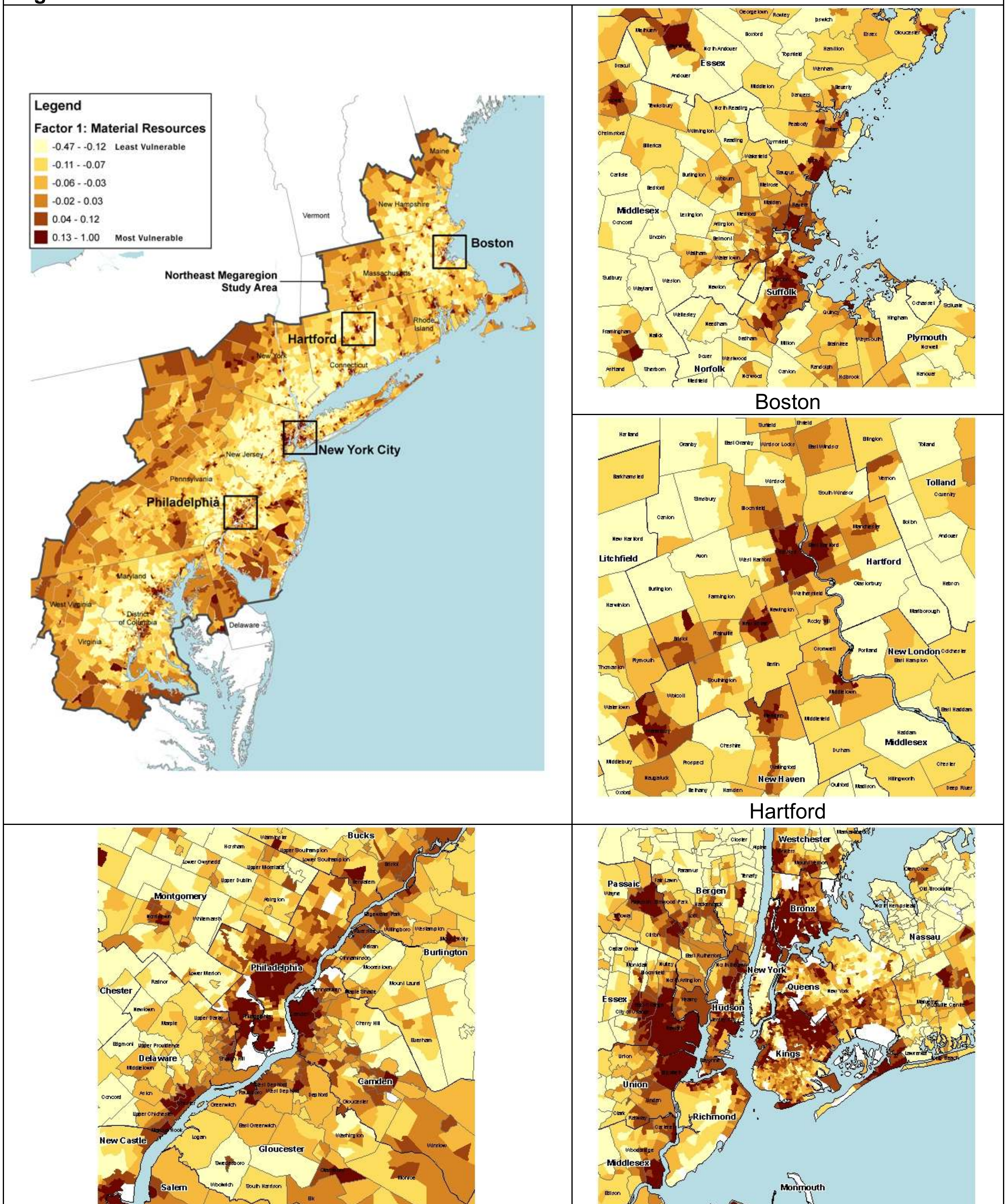
For example '*Material Resources/Lifelines'* is a map of component 1 which consists of a mathematical combination of census variables depicting the ability to cope based on existing household material resources. Our city case studies present the spatiality of components that depict vulnerability conditions.

Factor One: Material Resources / Lifelines

Factor One: Material Resources and Lifelines map depicted in figure 2, represents variables related to financial resources and necessary lifelines to prepare for or recover from a disaster. The component loads positively with several variables including the percent below poverty, large households, female head of household, percent on public assistance, percent no telephone, and percent without a high school degree. This component loads negatively with the percent of households with two working parents, percent non-Hispanic white and average household income.

The megaregion map demonstrates a distinct clustering of neighborhoods within all the central cities of this analysis (Boston, New Hartford, New York – New Jersey, Philadelphia), suggesting that highly populated central cities lack the material resources to overcome an extreme event. At the fringes of the megaregion increasing vulnerability due to lack of material resources in rural areas becomes more evident.

Figure 2 Factor 1 : Material Resources / Lifelines



Boston

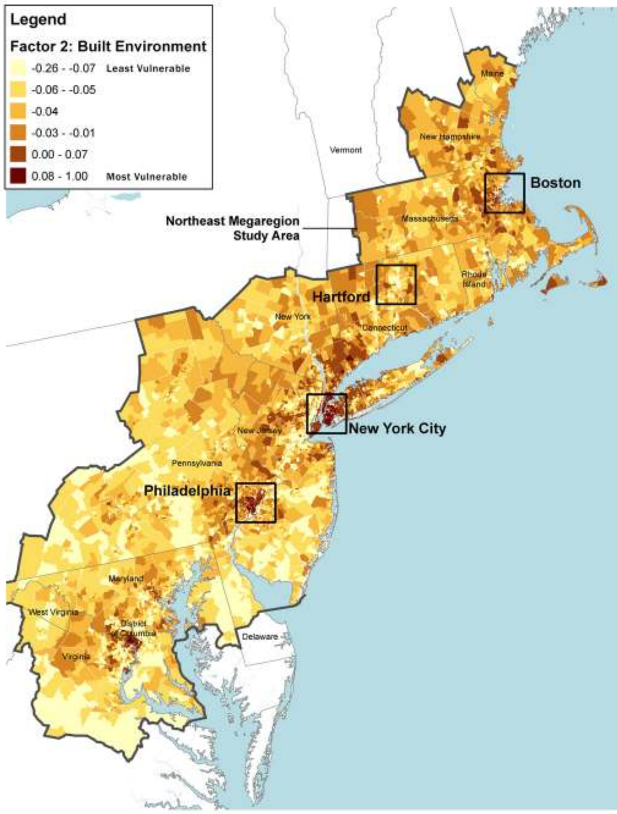
Hartford

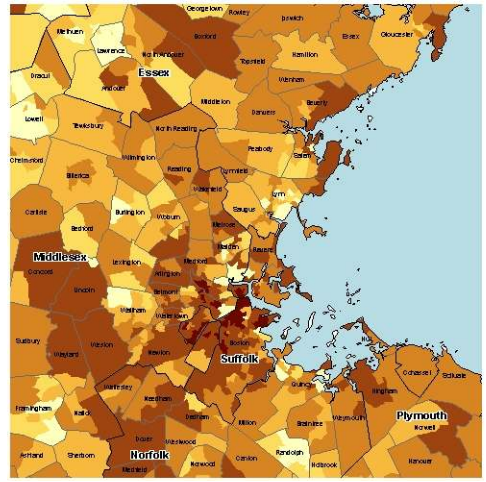
Philadelphia

New York – New Jersey

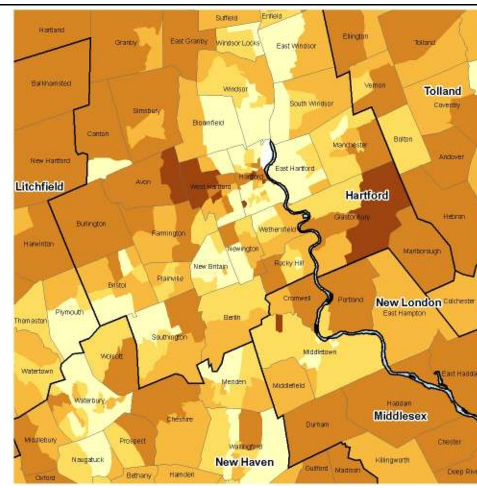
The Boston map depicts a large concentration of most vulnerable valued neighborhoods within the City of Boston, Revere, and Lynn. We can see that within the City of Boston there are some neighborhoods that have extremely low vulnerability values and others that have are extremely high vulnerability, as depicted by map of material resources and lifelines. Farther from the City of Boston, towards Middlesex, Essex and Plymouth Counties, there is an increase in material wealth and resources which are needed to cope with hazardous events, and this correlates to decreasing sensitivities.

Figure 3 Factor 2 : The Built Environment

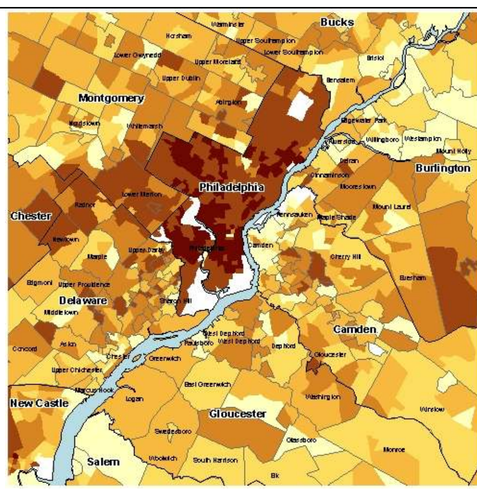




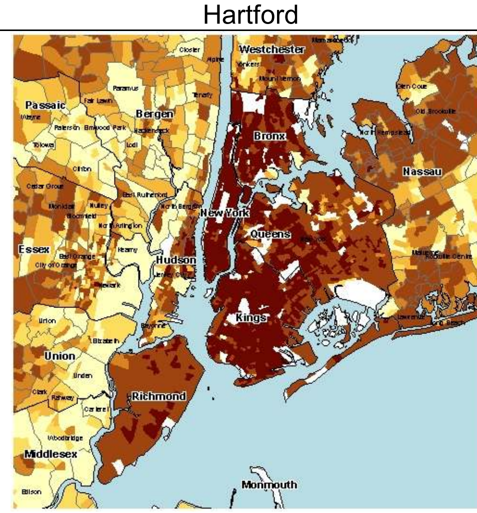
Boston



Hartford



Philadelphia



New York – New Jersey

The Hartford map depicts concentrations of the most vulnerable neighborhoods in the central city of Hartford, as well as in East Hartford and New Britain. The county of Hartford encompasses the majority of the towns, unlike Boston, where Suffolk County makes up the entire city. The greater Hartford area has a mix of low and high vulnerability neighborhoods. In low vulnerability neighborhoods, there is a low amount of spatial variability within the municipalities themselves.

The New York Map depicts high vulnerability neighborhoods clustered in the South Bronx, northern Manhattan, northern Brooklyn, eastern Queens, and clusters of extreme vulnerability in Yonkers, Mount Vernon, and Hempstead in Nassau County. Across the river there is an extreme level of vulnerability associated with poverty and lack of material resources in Newark and Paterson, New Jersey. Additionally there is a cluster of extreme vulnerability in Jersey City. In the thirty-one county metropolitan area, there is an enormous amount of spatial variability at the county and municipality level.

The Philadelphia Map depicts several clusters of extremely vulnerable neighborhoods throughout the city. The City and the County are a common jurisdiction compact like Boston, and New York City. Camden, New Jersey presents itself as another large clustered area that is lacking the material resources and lifelines to deal with a disaster. Other small clusters of extremely vulnerable populations are in Bucks County, Pennsylvania, and Montgomery County, New Jersey. Camden and Gloucester Counties in New Jersey have a mixture of vulnerabilities related to lack of resources and lifelines.

Factor 2: The Built Environment

The Built Environment component represents the density of development, as displayed in figure 3. One of the biggest drivers of hazards conditions is the density of development and its current impacts on the environment, which are exacerbated during an extreme event. In the Northeast, two such events include heavy precipitation and heat waves. The effects of both of these events are intensified by the capacity and constraints of storm water management facilities, or the existence of urban heat islands which facilitate a greater demand for energy.

The built environment component loads positively with population density, housing density, public transportation, and the core city dummy variable; and loads moderately with the proportion of Hispanic population. It is assumed that areas with high positive values of this component may need additional or specialized hazard response planning as a result of intense resource demands which could occur during and after a disaster.

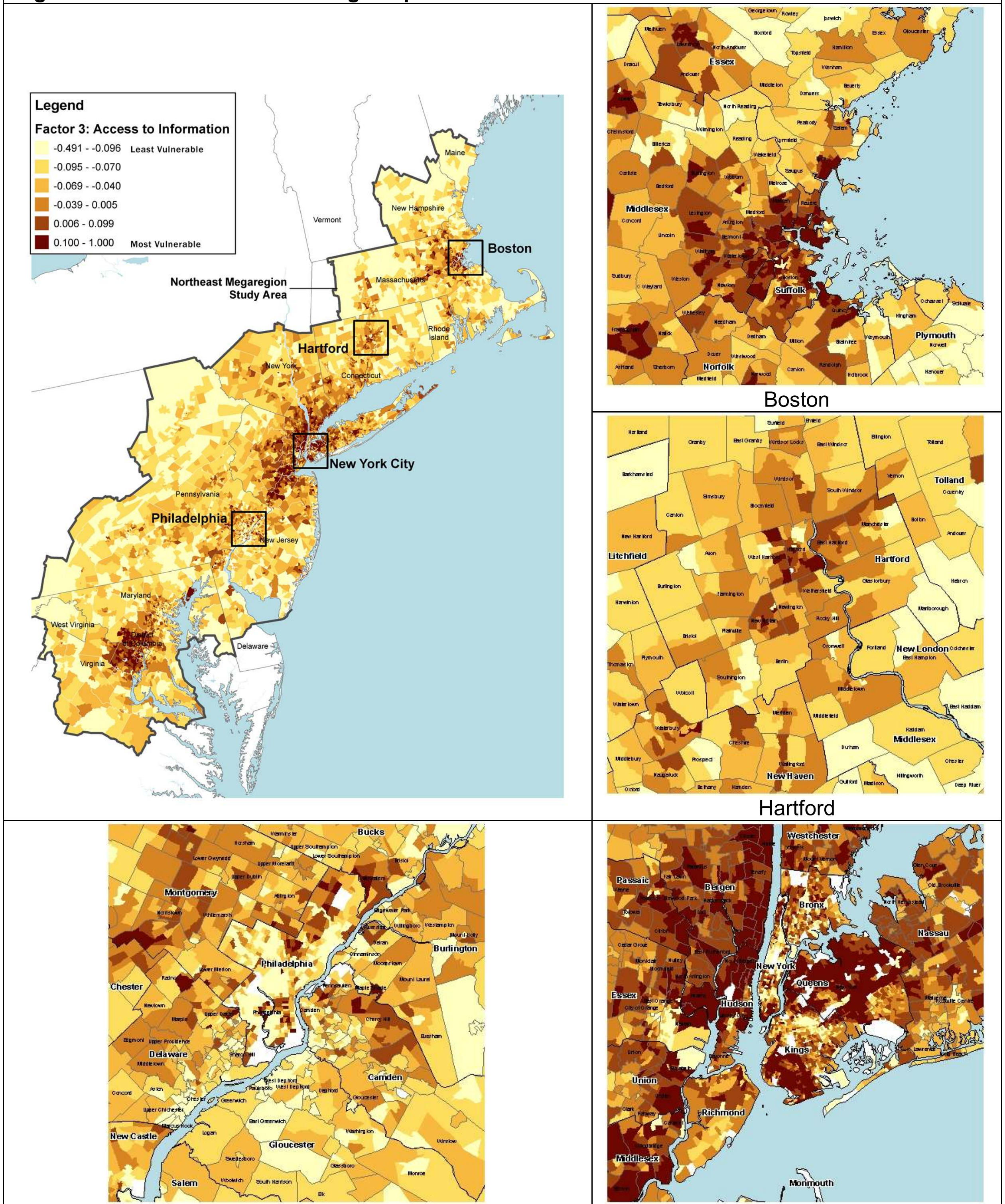
The megaregion map demonstrates some high vulnerability clustering of neighborhoods within all the central cities of this analysis (Boston, New Hartford, New York – New Jersey, Philadelphia); suggesting additional considerations may be needed to overcome an extreme event. The region as a whole is extremely built, with the highest valued places being in the central cities. However, moderate values stretch across most of the region until we head south of Pennsylvania, where increasing presence of low density suburban settlement patterns flourish.

Philadelphia and New York - New Jersey maps depict the largest numbers of neighborhoods with extreme densities that extend to their jurisdictional boundaries. The Hartford map depicts places with low vulnerability to the built environment to have low population and housing densities. The Boston map depicts moderate sensitivity to the built environment; and this vulnerability extends throughout Middlesex, Essex, and Norfolk Counties. This signals the need for multi-jurisdiction management and planning efforts.

Factor 3: Access to Information and Regional Experience

Access to information and regional experience represents a community's ability to gain and share hazards information. This component depicts areas of high percentages of Asian populations, percentages of households which do not speak English, large amounts of new residents, and non U.S. citizens, which are grouped into a single component. In figure 4, the megaregion map depicts Washington DC and the New York – New Jersey Metropolitan Areas with extreme clusters of high sensitivity to regional experience and information access. At a smaller spatial scale Boston, Hartford, and Philadelphia exhibit clusters of moderate to high vulnerability neighborhoods. Language and literacy can be potential barriers which prevent households from taking advantage of available aid or prevent them from safe evacuation (Bolin, 1994; Enarson and Morrow, 1997; Seirup, 2004).

Figure 4 Factor 3 : Knowledge/Experience



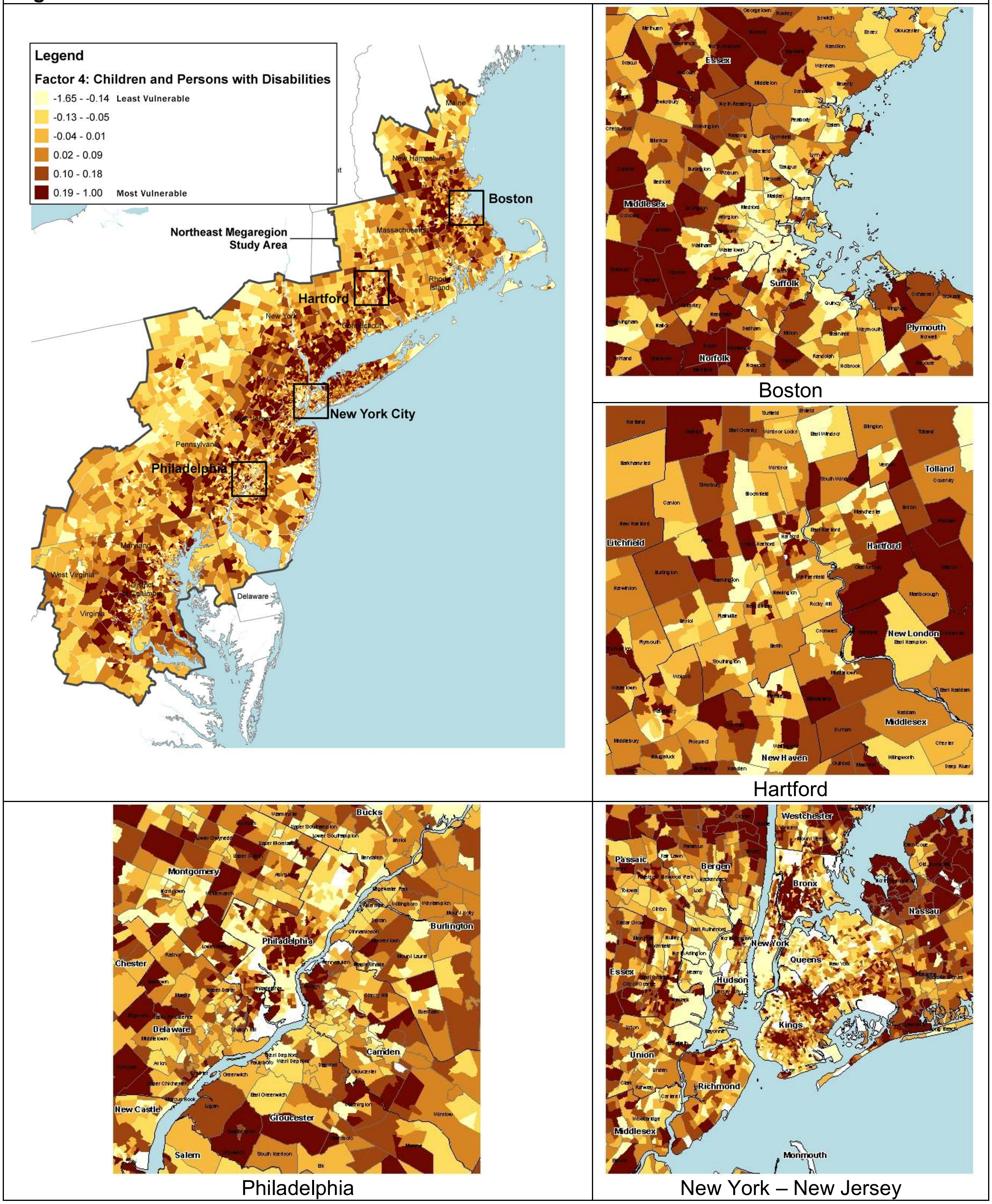
Boston

Hartford

Philadelphia

New York – New Jersey

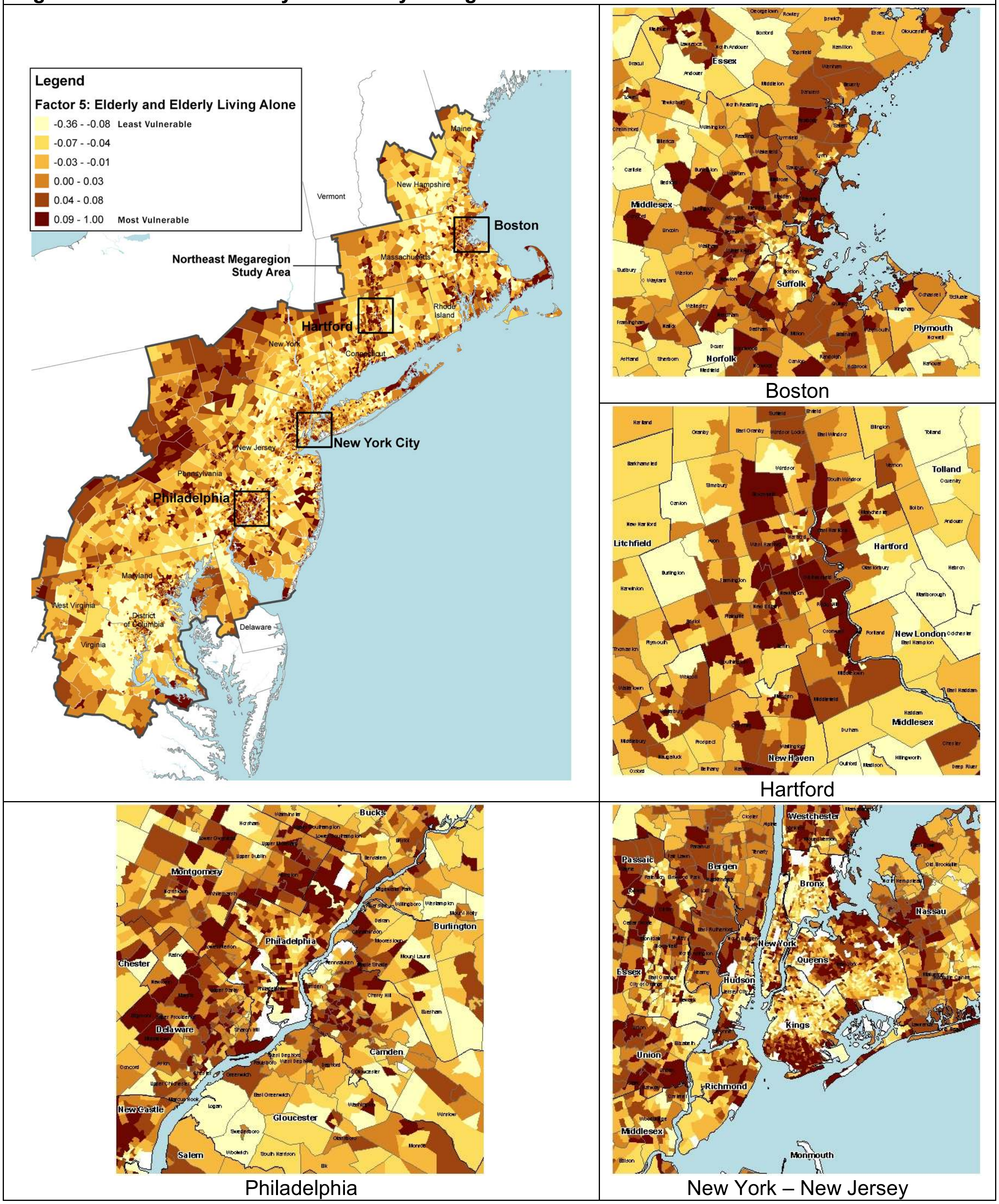
Figure 5 Factor 4: Children and Persons with Disabilities



Factor 4: Children and Persons with Disabilities

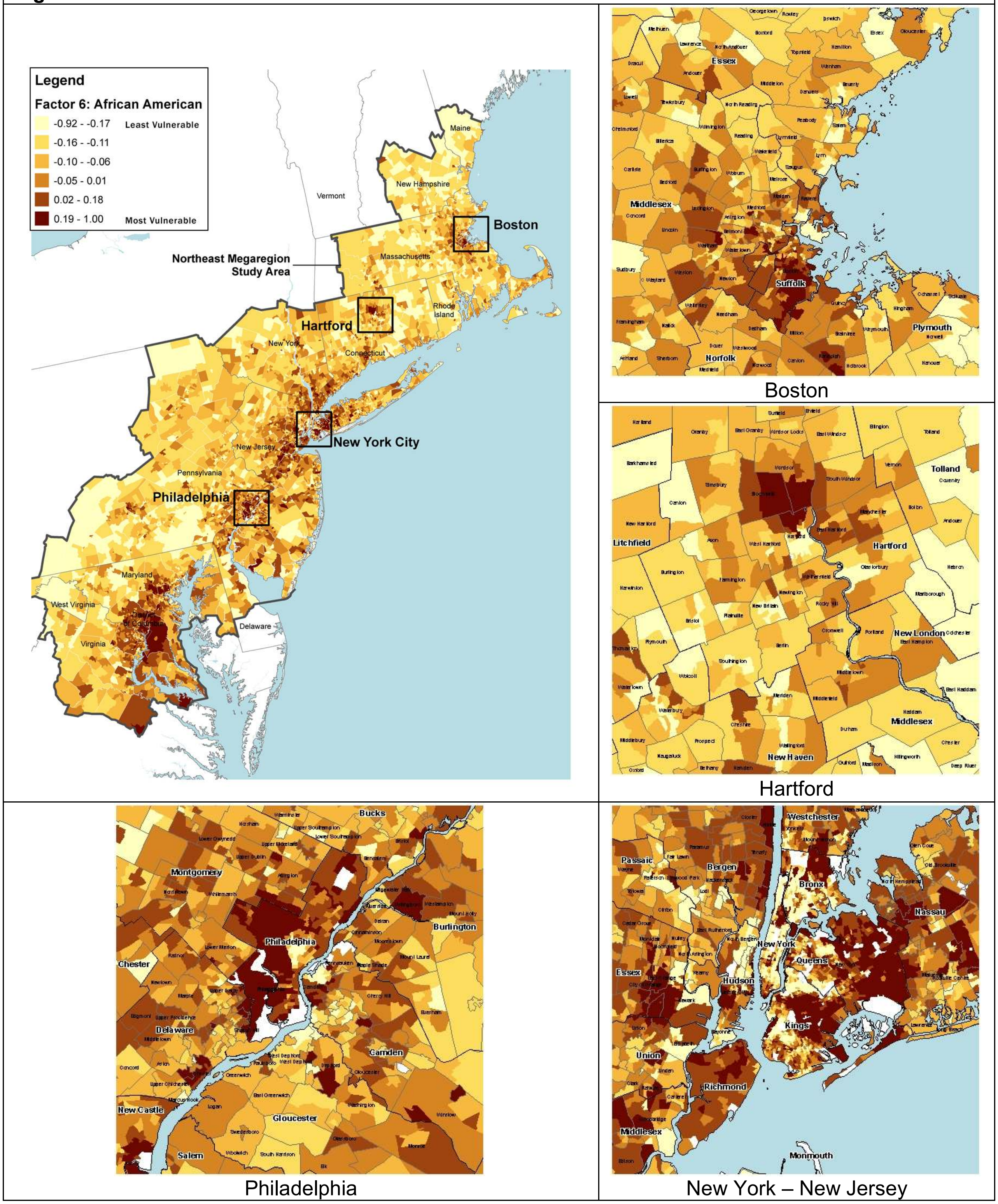
Children and Persons with Disabilities (figure 5) loads positively with percentage of population under 18 (strongly) and percentage of population with a disability (moderately). Across the megaregion, the children and persons with disabilities interestingly correspond (not entirety) to locations just outside the central cities.

Figure 6 Factor 5 : Elderly and Elderly Living Alone



In factor one this area had very low vulnerability scores due to wealth, education, and other factors not limiting financial resources. Across each of the four case studies there is the presence of high spatial heterogeneity in this component. Neighboring communities may have completely opposite sensitivities to coping with an extreme event. In the New York - New Jersey map, several clusters of very low vulnerability dominate the map in Midtown and Lower Manhattan, portions of Brooklyn, much of Queens, and wealthy suburbs of New Jersey. In Boston, similar trends exist within the city itself, with increasing sensitivity moving away from the city.

Figure 7 Factor 6 : African America



Factor 5: Elderly and Elderly Living Alone

The fifth factor of Elderly and Elderly Living Alone loads positively with high percentage of elderly persons and elderly persons living alone. In figure 6 on the megaregion map, two interesting spatial trends emerge. The first is a high amount of sensitivity in the first tier suburbs just outside the central cities of Boston, New York-New Jersey, Philadelphia, and Hartford. The second spatial trend is the emergence of high sensitivity areas at the periphery or the megaregion. There are also pockets of highly sensitivity communities along the coast (i.e. Cape Cod and the North folk on Long Island).

Looking into the four case studies one can discern some smaller highly sensitive areas in Revere in Massachusetts, locations along the Connecticut River in New London and Hartford Counties, and along the southern coastal areas of Brooklyn and Rockaway in New York.

Factor 6: African American

The sixth component of African American loads positively with a single variable, percentage African-American. The other race and ethnicity variables that aligned themselves in the other five components signify some differentiation of what drives vulnerability among race and ethnic groups. It has been revealed that African-Americans have high individual vulnerability. Klingenberg (2002) reviews death rates during the Chicago 1995 heat wave and in O'Neill's (2004) reviews heat-related mortality rates in seven northeast cities.

The megaregion map in figure 7 depicts relatively low to moderate vulnerability in rural and exurban communities throughout the Northeast. There is a distinct clustering of African American populations in central cities and older cities across the Northeast. In Boston, the greatest sensitivity is within southern Suffolk County and moderate sensitivity in Middlesex County. In the Hartford map, a hot-spot is located in northern portions of the city of Hartford and communities directly to the north. The New York – New Jersey map reveals an extremely high percentage of African American clustered in northeastern Brooklyn, eastern Queens to the Nassau County line, and patches in Nassau County, New York, and Essex County, New Jersey. The Philadelphia map illustrates high percentages of African Americans in southern portions of the city of Philadelphia.

Individual factor maps illustrate spatial variation of neighborhoods within each of the six components. Significant spatial variability in the individual component maps suggest no two neighborhoods have the same ability to cope with hazards. Individual component maps reveal different social and economic drivers that affect a household's or a community's sensitivities to hazards and extreme events. However, using a weighted index of vulnerability will illustrate a more comprehensive picture of social vulnerability hot-spots.

The component factor map only portrays hot-spots in the megaregion. To establish climate adaptation policies one should review the lifelines and material resource variables carefully and at the lowest geographic level (such as the census tract). This will enhance the understanding of total number of low income families in an area, or households with no vehicles.

Index of Social Vulnerability

The index of socio-economic vulnerability provides a relative measure of social vulnerability per neighborhood. The index is generated though an additive formula (Formula 2) of all six components; each component is weighted using the percent variance observed in the factor analysis (Table III). We assume using weightings from the factor analysis will appropriately weight the components for each neighborhood instead of assuming all components have the same contribution to the neighborhood's vulnerability. The maps are separated into quintiles, so that each class contains equal number of neighborhoods.

Formula 2

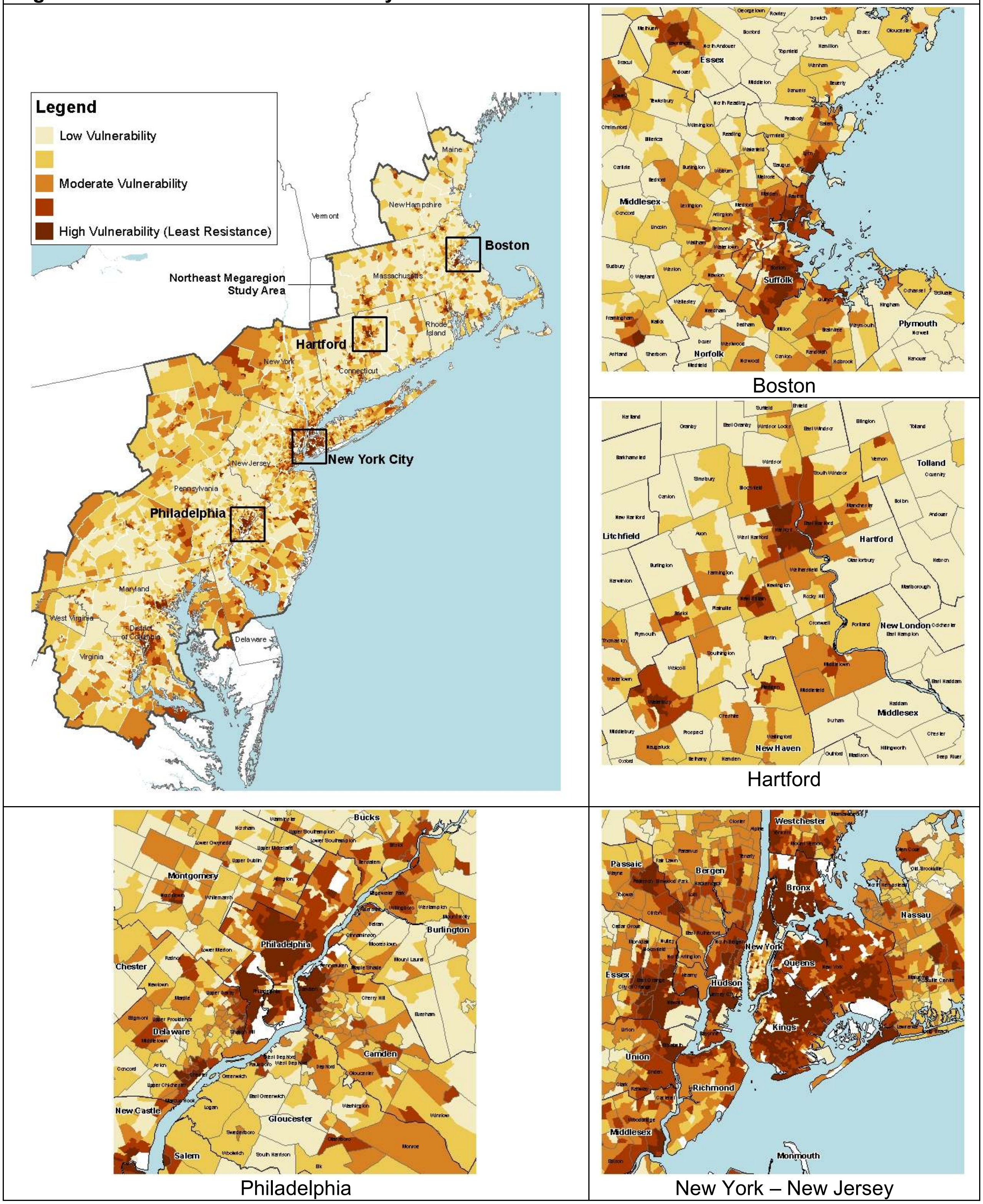
Socio-economic Vulnerability = (FACTOR 1 * 27.986) + (FACTOR 2 *14.468) + (FACTOR 3 * 13.558) + (FACTOR 4 * 8.626) + (FACTOR 5 * 8.222 + (FACTOR 6 * 5.794)

We expected to see a wider range of vulnerability instead of moderate levels directly due to the unit of geographic analysis we chose versus Cutter (2003) county level geography. On par with Clark et al (1998), which reveals that the usage of neighborhood level data shows greatest spatial details of a place, our study of the Northeast enabled broad comparisons to be made about vulnerability in a megaregion.

Figure 8 of our index of social vulnerability provides evidence of spatial clustering. Several large clusters of highly vulnerable census tracts are identified in the densest urban areas across the

Northeast. The presence of these high value clusters also occur in smaller cities and towns across the region which should receive attention during sustainable hazards management and planning. This result is consistent with other vulnerability studies (Seirup, 2004; Cutter, 2001; Clark et al 1998).

Figure 8 Index of Social Vulnerability



Conclusions

Mapping socio-economic vulnerability and exposure to future hazards identifies the opportunities for robust, regional initiatives as well as potential programmatic and community-based initiatives. The urban vulnerability study lends itself to policy analysis that seeks methods for reducing exposure through improvement of the urban environment (e.g. tree planting programs that provide shading and reduce UHI conditions in urban areas) or reform energy pricing structures (e.g. similar concept as water pricing reform) (Asad et al, 1999).

The vulnerability maps may be used as a reactive (e.g. emergency response) tool or as proactive (e.g., land use planning) tool. As an urban planning tool, the urban vulnerability index is a sophisticated model that could be used to mitigate heat impacts as adaptation to projected climate scenarios. Urban areas are already susceptible to extreme heat conditions and the UHI effect due to their lack of vegetation, high absorptive capacity, and high energy consumption rates. The implementation of mitigation strategies can greatly reduce health impacts due to the UHI effect. For example, increasing the amount of vegetative cover and higher albedo surface materials can reduce temperatures and air pollution, consequently reducing negative health effects. This was demonstrated in studies done in Newark and Camden, New Jersey, by Solecki et al. (2005) and for New York City (Rosenzweig and Solecki, 2006)

Vulnerability maps also could be used as a response tool. The creation of a heat wave warning systems is one such example. Other sustainable hazards programs might include contingency plans for establishing community cooling stations in public buildings. In the case of immigrants and those with lack of information regarding hazards, community or state resources can be allocated to promote the use of interpreters, victim advocates, and media outlets to raise awareness.

In sum, the maps of urban vulnerability feature areas in need of hazards assistance. Based on our factor analysis, individual components specifically present the spatial and temporal distribution of vulnerability to climate change in general and heat-related hazards. Government leaders can better allocate funds to areas of highest socio-economic vulnerability. By identifying highly vulnerable communities, our results will enable decision and policy makers to focus their attention on at-risk communities. As future hazards become exacerbated by climate change, these individuals now have better information to aid in understanding issues of equity and social justice, and to facilitate prompt action, even during this period of heightened climate variability and change.

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