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Rescaling social dynamics in climate change: The implications of cumulative exposure, climate justice, and community resilience

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ABSTRACT

In this study, we explore cumulative exposure, climate justice, and flood risk with specific reference to community resilience, vulnerability, and social justice characteristics at the county-level within the U.S. Mississippi River basin from 1990 to 2009. Using a basic conceptual model of spatial resilience to climate risks, temporal lag effect of community capacity, urban and rural spatial classification, integrative cumulative exposure, and spatial clustering of risk, we examine spatial climate risk outcomes and the role of community resilience in reducing such risks. Our approach accounted for local social, economic, environmental, regulatory policy, and planning mitigation contexts. Results suggest that community social and ecological characteristics were influenced by flood losses and that social capital and climate justice characteristics combined with local proactive planning and policy measures lead to lower disaster losses and enhanced community resilience.

"… multiple inequalities defined by income, race and education were major factors that increased the exposure and vulnerability of people, predominantly low-income African Americans, to hurricanes."

(quote from a 2016 United Nations report examining New Orleans following Katrina)

1. Introduction

Rapid climate change and increasingly extreme climate events combined with inappropriately placed development and general lack of preparedness result in severe adverse impacts on communities. Additional contributors to these impacts or structural conditions include persistent poverty, social and political exclusion, chronic social vulnerability, deficient access to social services, and lack of life opportunities that confront multiple climate risks (Broto, 2017; Highfield et al., 2014; Kashem et al., 2016; Mavhura et al., 2017; Rivera and Kapucu, 2015).

In the context of climate change impacts, vulnerable populations are tied to a variety of community structures. Certainly, stage of development plays a role for people in less developed countries who are continually exposed to multiple stressors which are exacerbated by unstable political regimes and market volatility (Eakin et al., 2014). Several approaches to capturing community structure with respect to disaster risk exist; examples include the event-exposure-vulnerability model (Intergovernmental Panel on Climate Change, IPCC, 2012), models reflective of climate-security relationships (National Research Council, 2013), climate variability-human migration-land degradation (Hermans-Neumann et al., 2017), social vulnerability as the product of social inequalities and place inequalities (Cutter et al., 2003), and disaster vulnerability as modeled in the expected poverty approach (Mahanta and Das, 2017).

Social processes have been argued to "determine unequal access to opportunities and unequal exposure to hazards" (Wisner, 2004, p. 8). They represent "disproportionate burdens of disaster risk" (Cutter, 2017, p. 117), 'disproportionate exposure' (Mitchell and Chakraborty, 2015), and 'flood disadvantage' of affected communities (O'Hare and White, 2017). Further equity issues described by the 'climate gap' (Grineski et al., 2015; Shonkoff et al., 2009), 'climate justice' (Ambrey et al., 2017; Barrett, 2013; Bulkeley et al., 2013, 2014; Popke et al., 2016; Smith and Rhiney, 2016), burdens of flood impacts in informal settlement (Amoako and Inkoom, 2017), 'inclusive development' for urban climate adaptation (Chu et al., 2016), 'land use planning inequity' associated with urban climate change adaptation (Anguelovski et al., 2016), and 'climate disadvantage' (Lindley et al., 2011), focus on the rather simple fact that unequally distributed losses from climate risk transform social and economic conditions and can affect vulnerability to subsequent risks (Mendelsohn et al., 2006).

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Verchick (2012, p. 68) offers the term, 'disaster justice' through the link of political and moral implications with spatially-isolated and socially-uneven vulnerabilities to disaster. He demonstrated that a disaster justice framework can be regarded "as a way of mainstreaming social resilience into disaster policy." Closely related to this, Leichenko and O'Brien (2008, p. 35) adopted the 'double exposure' concept by uniting environmental change affected by climate change and (economic) globalization.

Previous research (e.g., Frazier et al., 2013; Highfield et al., 2014; Mavhura et al., 2017) has focused on social vulnerability to climate risk and change. In general, results have suggest significant regional differences (e.g., urban-rural) as measured by metrics central to associations with social justice. These involve social service assets, health and food insecurity, and income inequality. 'Climate justice' has been shown to be pivotal in illuminating the "intersection of climate change and human well-being, and to political systems at all levels" (Klinsky et al., 2017, p. 172), 'spatial and temporal social differentiation of impacts or resilience and adaptive capacity' (Adger, 2001b; Waters and Adger, 2017), the "relationship between social vulnerability and flood exposure" (Collins et al., 2017), and 'evaluation of climate adaptation, resilience, and vulnerability' of agriculture (Popke et al., 2016). Despite the prevalence of reported research, few studies have empirically examined the spatial interplay of climate justice, cumulative exposure, and community resilience from the local or community perspective.

In the research reported here, we contribute to a developing body of literature by integrating concepts of cumulative exposure, climate justice, and community resilience. Our empirical case study involves the U.S. Mississippi River Basin region over the course of the past 20 years. Extending previous research (e.g., Cutter et al., 2014; Davies et al., 2015; Highfield et al., 2014; Joerin et al., 2014; Kim and Marcouiller, 2016; Miles, 2015; Ross and Berkes, 2014), we incorporate spatial and temporal effects to include resilience to climate risks, the temporal lag effect associated with development of community capacity, urban and rural spatial differences, spatial clustering of risk outcomes, and cumulative exposure. As such, we have two research objectives. First, we will examine spatial heterogeneity of climate risk outcomes using a theoretically consistent model of spatial resilience to climate risks. Second, we will spatially investigate the role of combined community resilience attributes that comprise socio-economic and environmental components, policy regulation and planning mitigation with respect to climate risk reduction in the U.S. Mississippi River Basin region.

This manuscript is organized into five sections. Following this introduction, relevant literature is reviewed which provides theoretical connections, drivers, and research hypotheses for the empirical models employed for this study. Next, research methods and data sources used in this county-level examination of the U.S. Mississippi River Basin between 1990 and 2009 are outlined. This includes local resilience to climate risks, a temporal lag effect of non-climatic condition, urban and rural spatial classification, and measurement of integrative cumulative exposure and spatial clustering of risk. Finally, a conclusion summarizes our empirical findings, relevant policy implications, and caveats to the approach which lead to future research needs.

2. Cumulative exposure, climate (in)justice, and community resilience: connections, drivers, and hypotheses

Climate change has become an important community stressor. It is expected to pose increasingly severe natural disasters including increased flooding, storm events, wildfires, landslides, droughts, and rising sea levels (IPCC, 2014). Communities within the U.S. Mississippi River Basin region have experienced significant and complex impacts of recurring climate risks (e.g., 1993 Great Midwest flood, 2008 flood). These have created periodic stresses on social, economic, and ecological conditions including threats to human and ecosystem health, economic loss, physical damage to infrastructure, and weakness of community capacity and well-being.

In general, most vulnerable communities suffer from "deprivation, exclusion, and inequality" as they are impacted by climate change (Edward et al., 2013, p. 6). Those "observed and future climate change impacts are and will be spatially and socially differentiated" and contribute to injustice as witnessed through disproportionate impacts on poor, marginalized and vulnerable communities (Adger, 2001a; Edward et al., 2013, p. 6). For instance, examining (in)justice as it is compounded by climate change impacts uncovers evidence of structural inequalities and racialized environmental hazard areas. These exacerbate climate impacts on the poor while at the same time increasing community vulnerability (UNDP, 2007). Such structural issues of climate risk are consistent with Rivlin (2015)'s viewpoints that New Orleans' racial and social fabric issues resulted in unequal opportunities for recovery after hurricane Katrina. Also, structural issues of climate risk are in-line with the arguments of Knowles and Kunreuther (2014) that these inequalities extend to serve as political and technical obstacles to reforming the flood insurance problem.

Social, economic, and political stress resulting from climate risks exert direct and indirect impacts at local and regional scales over time. Relevant studies have examined notable stressors (e.g., Adger, 2010; Alexander et al., 2017; Bergstrand et al., 2015; Cutter, 2017; Fritze and Wiseman, 2009; Gallopín, 2006; Highfield et al., 2014; Leichenko and O'Brien, 2008; National Research Council, 2013; O'Hare and White, 2017; Otto et al., 2017; Paterson et al., 2017; Rivera and Kapucu, 2015; Shively, 2017; Wisner, 2004). These stressors include the fiduciary sustainability of risk-based policies such as the national flood insurance program, the legitimacy of climate risk governance, organizational form and function, representative deliberation, and the ability to build adaptive capacity and enhance resilience to further disruptive climate risks. In the work reported here, a definition of vulnerability in the context of climate change is adopted from the IPCC (2007, Appendix I). As a function of character, magnitude, and rate of climate change, vulnerability refers to "the degree to which a system is susceptible to and unable to cope with adverse effects of climate change" (p.883).

Climate change impact and adaptation studies to date (e.g., Bolin et al., 2013; Bunce et al., 2010; Chakraborty et al., 2014; Collins et al., 2017; Colten et al., 2017; Dow et al., 2006; Leichenko and O'Brien, 2008; Okereke and Schroeder, 2009; Shively, 2017) have employed a variety of contextual factors to explain multiple exposures on issues related to social justice. Bennett et al. (2016, p.909) argued that the incorporation of dynamic approaches "… with the complexities of local experiences of multiple exposures" can be helpful in "lead[ing] to more effective vulnerability research and adaptation policy." Based on this work, the concept of (double) exposure by Leichenko and O'Brien (2008, p. 35) is adopted for this paper, stating that the concept is "… a function of the magnitude and intensity of the stress or shock, as well as of the contextual conditions present within the exposure frame that make each unit of analysis more prone or sensitive to a particular change."

Contextual factors associated with exposure, climate justice, and vulnerability involve a variety of indicators. These include poverty rates, social safety nets, effectiveness of public institutions, income distribution, migration, employment outcomes, health care, and food/water accessibility (Holden et al., 2014). Further, in the context of local equity, analysis needs to include cultural diversity, social and political exclusion, racial segregation, uneven social outcomes, and disproportionate disaster risk outcomes for women, children, and populations with lower capabilities (e.g., Anguelovski and Roberts, 2011). Other contextual factors require accounting for high levels of reliance on climate-sensitive business sectors and realistic expectations for flood insurance programs.

Incorporating spatial justice and climate change, Anguelovski and Roberts (2011) defined climate injustice as "the inequalities that exist between countries and regions in their climate responsibility, vulnerability, and mitigation." Dow et al. (2006) and Paavola et al. (2006) followed a multifaceted justice concept that incorporated both distributive and procedural justice; claiming that social vulnerability attributes were clearly associated with climate justice. Dow et al. (2006, p. 79) addressed climate justice attributes and incorporated "… issues of how climate change is associated with other broad inequalities in wealth and well-being." Likewise, connecting urban risk management and resilience with social justice theories, Ziervogel et al. (2017, p. 124) conceptualized justice as "the fair distribution of social and material advantages, meaningful participation in decision-making processes, acknowledgement of social, cultural and political differences, and the right to minimum levels of capabilities and opportunities to achieve livelihood and well-being goals." In this vein, the work reported here examined social or spatial justice within the context of climate change adaptation. Normatively, we accept that "socially valued resources, such as jobs, income, political voice and power, cultural acceptance, social services and environmental goods, as well as the opportunities to make use of these resources, should be equitably allocated across space" (Shi et al., 2016, p. 132). This extends to "the distribution of, access to, and control over resources" (Routledge et al., 2018, p. 85).

Further, the concepts of exposure, climate justice, and vulnerability under climate change can be linked with resiliency attributes. Noted as "… the capacity to adapt and to thrive in the face of challenge" (Evans and Reid, 2013, p. 93; UNDP, 2007), resilience to climate risk is analytically complex due to the interdependency of social, economic, and environmental attributes. Resilience is "… a process that links a network of adaptive capacities (resources with dynamic attributes) to adaptation after a disturbance or adversity" (Norris et al., 2008, p. 127).

According to the World Resources Institute's roots of resilience (2008) and work by Evans and Reid (2013), if the poor are successfully involved in ecosystem-based enterprises, they can become more economically resilient. Their communities can become more socially resilient, and ecosystems can become more biologically resilient. In the context of structural production of vulnerability and alternative forms of resilience, Derickson and MacKinnon (2015) regarded resourcefulness as a capacity of marginalized communities. The existing empirical literature (e.g., Kim and Marcouiller, 2016) suggests a variety of related variables specific to social and economic resilience. These contextual variables involve social networks, community value cohesion, employment, health and wellness, and quality of life. Similarly, Miles (2015) connected diverse components of well-being, identity, services, and capitals (WISC) with community resilience. Of the WISC, Miles (2015, p. 108) described identity attributes that included equity, esteem, empowerment, diversity, continuity, efficacy, distinctiveness, and adaptability. Further, capital attributes involved cultural, social, political, human, built, economic, and natural components. Knutsson and Ostwald (2006) pointed out that these types of capital can be used as a tool for understanding vulnerability, adaptation, and resilience within a process-oriented sustainable livelihoods approach.

Minority populations are often disproportionately impacted by disasters reflecting underlying issues of social and environmental justice. Examining African American communities vulnerable to flooding from sea-level rise on the Chesepeake Bay, Hesed and Ostergren (2017) underscored problems associated with the lack of key climate justice elements. These include flood response resources, preparedness, social capital, transparency, representation in governance, information, and utilization of community knowledge. Such elements are identified as seven barriers that could be addressed in efforts to increase climate justice.

In this sense, we can formulate theoretical connections along three distinct and unique ideas: (1) cumulative exposure, (2) climate (in) justice, and (3) community resilience. Such connections have been considered by a host of researchers, focusing on broad climate policy (e.g., Bolin et al., 2013; Leichenko and O'Brien, 2008; Lennox, 2015; Meerow, 2017; Roberts and Parks, 2007; Silva et al., 2010; Walker and Burningham, 2011). Findings from such work provide important windows of opportunities to address social dimensions of climate change and environmental sustainability at the local level.

Drawing attention to the combined and interactive effects of cumulative exposure and climate stress, recent studies (e.g., Bunce et al., 2010; Eriksen et al., 2011; Ferdinand et al., 2012; Gaillard, 2010; Kelman et al., 2015; Lennox, 2015; Lim et al., 2017; McDowell and Hess, 2012; Mercer, 2010; Okpara et al., 2017; Silva et al., 2010) have emphasized that integrative perspectives play a pivotal role in dealing with complex social and environmental security components. Such viewpoints can be important for developing solutions that manage climate risks and integrate social vulnerability within the context of community resilience and climate adaptation. For instance, based on the concept of 'double bind,' comprised of distinct desired and actual pathways, Ferdinand et al. (2012) argued that community poverty can produce barriers to resilience that increase vulnerability to disaster risk. This is even though poorer communities potentially have strong strategies to manage disasters. As noted by Ferdinand et al. (2012), a desired pathway can be obtained through reducing poverty and managing the causal relationships among vulnerability reduction, adaptation enhancement, and disaster risk mitigation. On the other hand, in an actual pathway, alleviating persistent poverty may be viewed as a necessary but insufficient mechanism to minimize vulnerability to disaster risk.

Functional drivers of cumulative exposure have been shown to include a variety of social and economic elements. In an assessment of small farm impacts in Peru, Lennox (2015) suggested functional drivers that included poverty, inequality, rapidly changing climate, and globalized market forces. Similarly, Meerow (2017) extended cumulative exposure and globalization (Leichenko and O'Brien, 2008) to a coastal megacity (Manila) and argued that decentralized and privatized urban governance regimes cause fragmentation and inequality thus further weakening urban resilience to climate change impacts.

Adaptation in vulnerable communities with respect to social and environmental stressors is a growing area of research interest. McDowell and Hess (2012) identified multiple stressors that involved land scarcity, market uncertainties, institutional marginalization, water shortages, rising temperature, extreme events, reduced access, expenditure of household assets, and lack of capital (natural, human, financial, physical, and social). In addition, Lim et al. (2017) investigated the relationships between and among relevant variables that included income disparity, housing quality, and tornado impacts and found that counties with greater income disparity were more vulnerable to climate risk. Further, adopting the concept of cumulative exposure disproportionately affecting poorer communities, Grineski et al. (2015, p. 180) identified triple exposures with conjoined effects of the global recession, drug war violence, and extreme heat in the border city of Juárez, Mexico. Such approaches were consistent with Bunce et al. (2010, p. 407) who claimed that "sources of [multiple] stress and impacts were mixed in time and space, complicating objective identification of causal chains." Given this basis in the literature, two research hypotheses are proposed that account for the interactions of justice, vulnerability, resilience, and flood risk as follows:

Hypothesis 1. Community capacities vulnerable to climate change impacts are associated with climate injustice.

Hypothesis 2. Positive relationships will exist between lower cumulative exposure to climate risk, justice combined with adaptation planning, and climate adaptation and resilience.

From the literature outlined above, we adopted 'cumulative' to involve social vulnerability and climate-related risks with the interchangeable terms 'exposure', 'danger,' and 'bind.' This interaction among terms can be worthwhile to capture the relationship between complex social frameworks and climate risks. In this empirical study we incorporate concepts associated with cumulative exposure, climate (in) justice, and community resilience. This approach can be supported by van der Voorn et al. (2012)'s adaptation as a process of climate adaptation planning under uncertainty. Further, our work can be a step toward accomplishing successful adaptation in following the work of Moser and Boykoff (2013, p. 16) who highlight that adaptation should "… typically not just [be] to one climate risk, but to multiple interacting ones (unfolding across geographic scales, spatial and sectoral boundaries, ecological systems, and social strata) against a backdrop of non-climatic stresses and conditions."

3. Research design and methods

3.1. Analytical framework and data collection

Our two research hypotheses involve the nexus of cumulative exposure, climate justice, and community resilience under climate change. This leads us to choose two analytical procedures for this empirical research. These include (1) the development and application of indexed measures for climate risk, social equity, cumulative exposure, spatial clustering of climate risk, and spatial clustering of cumulative exposure and (2) the examination of the role that community capacity and planning effort play in reducing climate risk within the flood risk prone areas over the last 20 years. In this second phase, quantitative methods are employed with spatial clustering effects, spatial and temporal effects through urban-rural spatial classification, and temporal lag effects of community capacity attributes.

Indices that capture these concepts are summarized in Fig. 1. To measure climate risk, we added a vulnerability index and an exposure index following the proposition that "exposure and vulnerability are major factors in disaster risk" (Wallace, 2017, p. 153). In measuring the vulnerability index, we followed a min-max transformation procedure that employed an equally weighted normalized scaling method (Hahn et al., 2009; Okpara et al., 2017, pp. 354–355) with 25 variables (see Table 1) to "capture the actual score of an indicator relative to the maximum and minimum spread of the entire range of values for that indicator." Selected variables were based on 16 socio-economic characteristic components composed of five demographic sub-components, four housing sub-components, four economic sub-components and three social capital sub-components. Further, three environmental and geographical characteristic components were identified. Finally, six policy regulation and planning mitigation characteristic components consisting of four non-structural mitigation sub-components and two structural mitigation sub-components were identified.

To measure the exposure index, we used the *Flood duration* and *Flood severity* variables from flood losses within climate risk component variables. *Flood duration* was determined by flood-affected days during the study period and *Flood severity* was measured by the severity levels by each county's flood losses divided by total flood losses. We measured spatial clustering of climate risk to identify spatial associations among the climate risk index using Local Moran's *I*. This method was used to represent spatial clustering with positive autocorrelation of high values (called High-High) and low values (called Low-Low) in the index. We

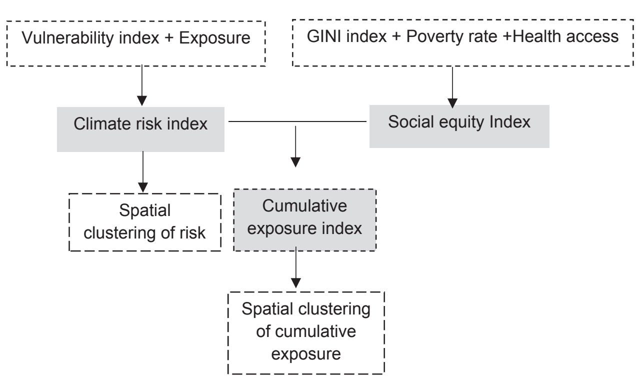


Fig. 1. Measurement flow of cumulative exposure index. Note: min-max transformation in dash, local Moran's I in long dash.

measured an index of social equity using three variables that included *GINI*, *Health access*, and *Poverty*. Gini coefficients (*GINI*) were calculated at the household income level and used to address the effects of economic inequality (as a social equity component) in the study area. By adding a climate risk index to the social equity index, we obtained the cumulative exposure index and then calculated the spatial clustering of cumulative exposure index using Local Moran's *I*.

The second phase followed the assumption that a time lag existed with respect to the effect of community capacity in responding to climate risk. We used secondary data from 1990 to 1999 for community capacity characteristic variables. To reflect the ten-year time lag effect on flood losses, we applied "1" to reflect increasing trends in flood losses during the 2000s compared to 1990s whereas "0" was applied for geographies that experienced decreasing trends during the 2000s. Such a time lag effect approach can be useful in identifying a time gap with the role of community capacity (varied socio-economic, environmental and geographical, and policy and planning attributes) in disaster risk reduction within the context of community resilience.

3.2. Data collection, study area, and urban and rural spatial classification

Data supporting the two research phases were collected from public and freely accessible datasets as summarized in Table 1. These sources included the U.S. Census Bureau (USCB), U.S. County Business Pattern (USCBP), Dave Leip's Atlas of U.S. Presidential Elections (DLAP), the Federal Emergency Management Agency (FEMA), National Levee Database (NLD) and National Inventory of Dams (NID) from U.S. Army Corps of Engineers, PRISM Climate Group (PRISM), NASA's Moderate Resolution Imaging Spectroradiometer classification (MODIS), Economic Research Service (ERS), May's (2013) state regulation provisions (SRP), and the Spatial Hazard Events and Losses Database for the United States (SHELDUS) at the Hazard Research Lab at the University of South Carolina. Data on damage and/or loss after flooding (including property damage and crop damage at the county level) were obtained from SHELDUS.

Along with the trend of growing disaster losses over time, the increased frequency and severity of flooding along the Mississippi River basin areas have put a large number of people and resources at risk. According to Peterson et al. (2013), between 1990 and 2009, the Mississippi River basin (shown in Fig. 2) experienced 40% of all flood events occurring in the U.S. which have caused at least $50,000 in damages to property and crops. During this period, the 1993 floods within the Missouri and Mississippi River systems caused an "estimated US $16 billion in damage and cost the federal government about US $5.5 billion" (Daniels, 2014, p. 389). Flooding in the Mississippi River basin is an increasingly significant issue of community disaster planning.

The basin involves 24 states and about 1600 counties throughout the Central US. From these counties, we focused on 1266 counties in 22 states that were designated as part of presidential disaster declarations based on flood losses over the last 20 years as defined by the Federal Emergency Management Agency (FEMA). Given their comparatively long history of flooding, the selected 1266 counties were useful for investigating flood risk on social and economic condition, environmental and geographical status, policy regulation, and planning mitigation characteristics.

Spatial clustering of risk and cumulative exposure was estimated by incorporating county coding along the urban-rural continuum. This was done using Beale Codes that classified all U.S. counties into nine categories based on county size and proximity to a metropolitan area (ERS). We reorganized the spatial classifications into urban (codes 0–3), suburban-exurban (4, 6, and 8), and rural (5, 7, and 9). Following this procedure, the 1266 counties were broken down into 373 urban, 428 suburban-exurban, and 465 rural counties. Such spatial comparisons were devised to examine the flood risk that incorporated urban and rural spatial effects.

Table 1
Concept measurement and data source.

Variable name	Definition and measurement		All (n = 1266)		Urban (n = 373)		Suburban-exurban (n = 428)		Rural (n = 465)		Source
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Socio-economic characteristic variables											
Demographic sub-components											
Language	Language other than English	%	4.05	4.33	4.02	4.23	3.94	4.32	4.16	4.43	USCB
Bachelor	Bachelor degree and over	%	17.25	6.52	17.04	5.86	17.26	7.02	17.39	6.54	
White	White persons	%	91.58	13.68	92.24	12.41	91.46	13.37	91.17	14.89	
Age	65-year old and over	%	15.76	4.03	15.59	3.74	15.73	4.32	15.92	3.98	
Female	Female householder	%	11.90	5.23	11.77	5.29	11.80	4.81	12.08	5.56	
Housing sub-components											
Homeowner	Owner-occupied housing	%	73.85	6.38	73.97	6.32	74.08	6.50	73.55	6.31	
Housing age	Housing structure built	%	16.77	7.46	16.78	7.50	17.51	7.61	16.10	7.23	
Housing value	Median housing value	1000 US$	42.46	14.56	42.43	14.51	42.69	14.65	42.26	14.54	
Mobile home	Mobile home	%	12.00	6.59	12.28	6.62	12.27	6.60	11.54	6.54	
Economic sub-components											
Employment	Employment rate	%	42.50	5.72	42.49	5.66	42.47	5.75	42.55	5.76	USCB
Economic diversity	Farming, fishing, forestry industry	%	0.96	1.95	0.87	1.79	0.98	2.07	1.03	1.94	USCBP
Resilient industry	Disaster-resilient industry	%	11.98	3.91	12.15	5.24	11.96	3.34	11.86	3.07	
Business diversity	Small business establishments	%	96.07	1.59	96.05	1.66	96.10	1.59	96.05	1.59	
Social capital sub-components											
Civic	Civic organizations per 10,000 populations		14.93	5.79	14.84	5.66	14.94	5.86	15.00	5.85	USCBP
Voter	Voter turnout	%	42.15	6.34	42.10	6.03	42.14	6.45	42.21	6.49	DLAP
Residency length	Householder moved into units	%	55.32	6.86	55.28	6.51	55.54	7.32	55.14	6.70	USCB
Social equity sub-components											
GINI	Income inequality		0.43	0.03	0.43	0.03	0.43	0.03	0.43	0.03	USCB
Health access	Physicians per 10,000 populations		11.39	14.31	11.52	12.82	11.91	17.04	10.80	12.59	
Poverty	Poverty rate	%	16.75	8.16	16.67	7.75	16.90	8.08	16.69	8.57	
Environmental and geographical characteristic variables											
Residential	Residential area	%	15.48	17.44	15.63	17.18	16.18	17.16	14.71	17.90	MODIS
Precipitation	Number of times precipitation exceeded the 75 percentile		7.95	3.32	8.07	3.32	8.03	3.28	7.79	3.36	PRISM
Metro	1 = metro, 0 = non-metro		0.21	0.41	0.23	0.42	0.21	0.41	0.19	0.39	ERS
Policy regulation and planning mitigation characteristic variables											
Non-structural mitigation sub-components											
Building regulation	Building regulation (1 = minimalist, 2 = enabling, 3 = mandatory, 4 = energetic)		2.12	1.14	2.09	1.14	2.18	1.15	2.09	1.13	SRP
CRS class	Community rating system (1–10 class, 11: no class)		10.54	1.24	10.65	0.99	10.44	1.39	10.53	1.27	FEMA
Mitigation plan	Population covered by multi-hazard approved mitigation plan	1000 person	40.25	109.95	41.52	128.50	40.93	104.39	39.44	98.38	
Storm ready	Population in storm-ready counties	1000 person	25.34	99.43	28.28	120.03	22.39	86.07	25.69	92.57	
Structural mitigation sub-components											
Levee	Levee length	mile	14.68	425.60	2.98	11.27	37.60	731.86	2.98	9.79	NLD
Dam	Dams storage	1000 acre-feet	8.13	58.58	8.56	62.24	8.18	51.28	7.74	61.89	NID
Cumulative exposure, climate justice, and vulnerability index variables											
Cumulative exposure	Normalized index including inequality index and risk index		0.04	0.09	0.03	0.08	0.04	0.09	0.03	0.09	Authors' calculation
Vulnerability	Normalized vulnerability index		0.04	0.07	0.03	0.08	0.03	0.06	0.03	0.06	
Risk	Index including normalized vulnerability index and *Flood severity* * *Flood duration*		74.50	273.75	61.35	141.94	89.05	384.10	68.93	228.10	
Inequality	Normalized index including income inequality, health access, and poverty rate		0.08	0.05	0.07	0.05	0.08	0.07	0.07	0.05	
Climate risk characteristic variables											
Flood losses	Per capita property and crop losses by flood damage in 2000s	US$	594.23	7683	1250	20,249	280.33	892.41	252.37	1909	SHELDUS
Flood severity	Categorized severity level by flood losses (1–11)		1.44	1.43	1.55	1.57	1.47	1.57	1.30	1.14	
Flood duration	Length of flooding	days	36.59	53.75	33.26	48.94	36.53	59.93	40.00	52.39	
Income losses	Per capita income losses by flood damage in 2000s	US$	446.40	4325	770.46	11,271	222.60	622.09	346.14	1084	Authors' calculation

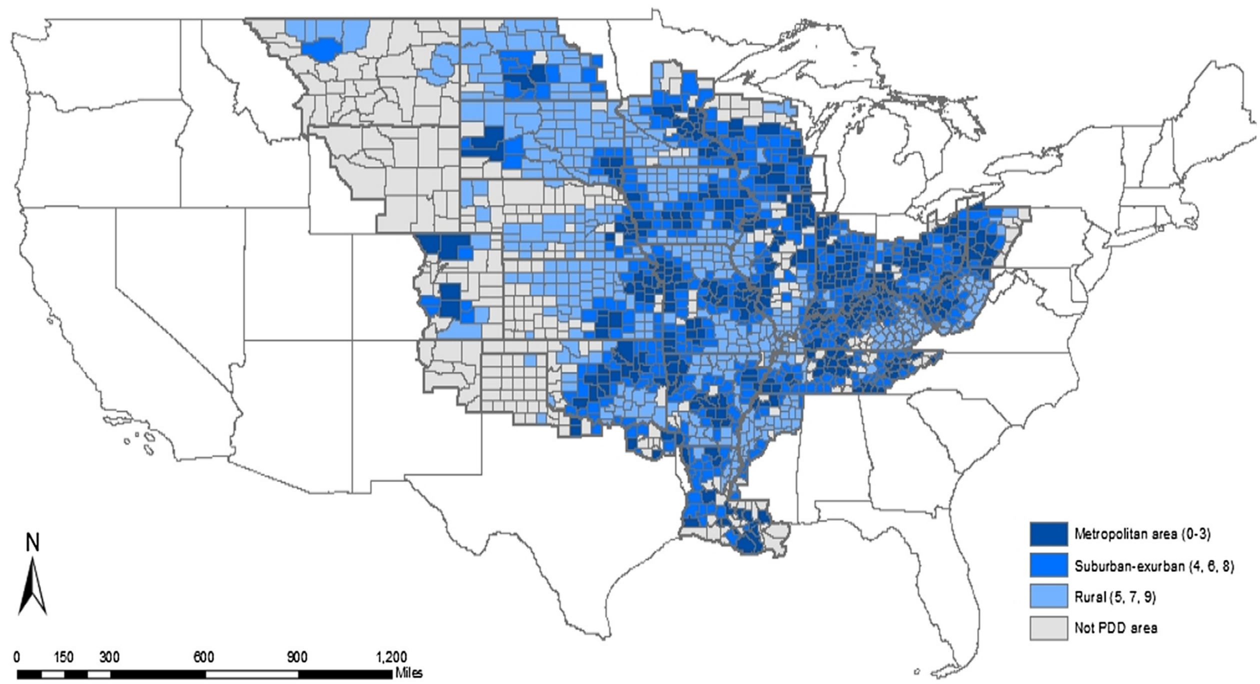


Fig. 2. Study area and urban-rural spatial classification. Source: Authors' configuration based on urban and rural continuum from the Economic Research Service.

4. Results

4.1. Spatial heterogeneity of climate risk outcomes

Spatial clustering effects for indices reflective of climate risk, social equity, cumulative exposure, social clustering of climate risk, and social clustering of cumulative exposure were calculated. Counties were ranked for flood vulnerability and risk using the vulnerability index and climate risk index. Further, we compared counties with indices reflective of vulnerability, social equity, and cumulative exposure under the spatial classification of urban, suburban-exurban, and rural areas. Then the cumulative exposure index, social clustering of cumulative exposure index, and social clustering of climate risk index were mapped. Relying on multiple data sources, visual narratives could be contextually based and triangulated to investigate the effect of spatial differentials and associations of climate risks. The ranked counties calculated by the vulnerability index (ranging from 0.024 to 1 among the 1266 counties) and the climate risk index (ranging from 0 to 663.04) between 2000 and 2009 were assessed based upon urban and rural classifications as described above.

Among the counties with a higher vulnerability index, Franklin County, Missouri (urban area, 1.000), Green County, Missouri (urban area, 0.9377), Vernon County, Missouri (rural area, 0.9023), Lawrence County, Kentucky (suburban-exurban area, 0.7969), and Renville County, Nebraska (rural area, 0.7776) were ranked as the top five within 90th percentiles. Among the counties with a higher flood risk (higher climate risk index within 90th percentiles), Hancock County, Illinois (rural area, 663.04), La Crosse County, Wisconsin (urban area, 616.03), Randolph County, Illinois (suburban-exurban area, 594.06), Brown County, Illinois (rural area, 583.07), and Jersey County, Illinois (urban area, 570.09) were ranked as the top five. Pair-wise correlations between the vulnerability index, the climate risk index, and urban and rural classifications revealed that the vulnerability index was positively associated with the climate risk index ($r = 0.1517$), while both the vulnerability index and the climate risk index were negatively related to rural areas among the spatial classifications ($r = -0.108$ and -0.174).

As depicted in Fig. 3, we compared the three indices (vulnerability, social equity, and cumulative exposure) to identify if urban fringe regions (suburbs and exurbs) were more exposed to climate risk and were more apt to exhibit climate (in)justice than urban areas. Differences were found between the cumulative exposure index and the social equity index. In particular, both cumulative exposure and social (in) equality in suburban-exurban areas exhibited higher levels than other areas within the study area. This result is consistent with the findings of Wilson and Chakraborty (2018) on the spatial concentration of urban heat vulnerability.

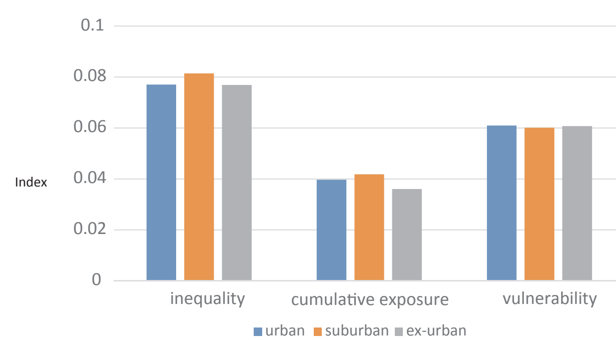
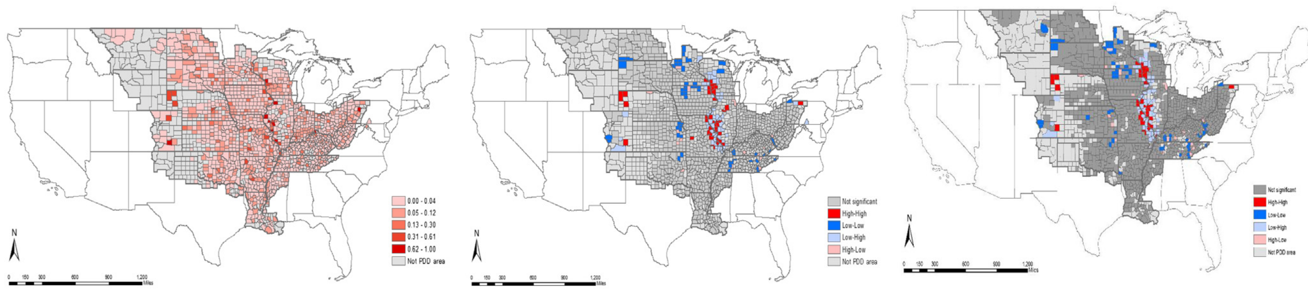


Fig. 3. Cumulative exposure, vulnerability, social inequality, and urban and rural spatial classification. Source: Authors' calculation, Index is measured by min-max transformation.

We investigated whether distinct characteristics of spatial distribution existed using the cumulative exposure index. As illustrated in Fig. 4(a), several counties (e.g., Hancock County, Illinois; La Crosse County, Wisconsin; Randolph County, Illinois; Brown County, Illinois; Jersey County, Illinois) ranked as the top five, exhibiting higher levels of cumulative exposure index with values ranging from 1 to 0.859. These counties were closely related to the lists of higher flood risk counties as described before. On the other hand, Carroll County in Illinois, Van Buren County in Iowa, Spink County in South Dakota, Fayette County in Tennessee, and Howard County in Nebraska were ranked as the bottom five with values below 0.1.

Along with the estimated spatial distribution of the cumulative exposure index, we mapped the social clustering of the cumulative



(a) Spatial distribution of cumulative exposure (b) Spatial clustering of cumulative exposure (c) Spatial clustering of risk

Fig. 4. Spatial distribution and spatial clustering of cumulative exposure and risk. Source: Authors' calculation, (a) is based on min-max transformation, (b) and (c) are based on Local Moran's I.

exposure index to identify whether spatial associations existed for the cumulative exposure index by using Local Moran's *I*. As depicted in Fig. 4(b), the red color indicates High-High and the blue color reflect Low-Low associations. Several counties along the Mississippi River were spatially correlated with hotspots for social clustering of cumulative exposure index with higher values. In a similar way, using Local Moran's *I*, we mapped the social clustering of climate risk index with the estimated climate risk index to examine whether spatial associations existed for the climate risk index and correlations between social clustering of the cumulative exposure index and the social clustering of climate risk index. As described in Fig. 4(c), higher values were largely concentrated along the Mississippi River.

Focusing on the 80 selected flood prone counties with social clustering of the climate risk index, as described in Table 2, can also highlight important centers of particular vulnerability to flooding. We re-ranked counties based on the vulnerability index (ranging from 0.024 to 1 in the entire study areas) and the climate risk index (ranging from 0 to 663.04) between 2000 and 2009 while noting county urban and rural classification. Among the top ten counties with highest flood vulnerability, Scott County, Iowa (0.7026), St. James Parrish, Louisiana (0.4498), Jackson County, Iowa (0.2405), Buffalo County, Wisconsin (0.2132), and Perry County, Missouri (0.2086) were ranked as the top five. With respect to counties that exhibited a higher flood risk index, Hancock County, Illinois (663.04), La Crosse County, Wisconsin (616.03), Randolph County, Illinois (594.04), Jersey County, Illinois (570.09), and Whiteside County, Illinois (548.20) were ranked as the top five among 1266 counties within the US Mississippi River basin. Also, of note, Jackson County in Iowa exhibited a higher level of vulnerability as well as a higher level of flood risk.

4.2. The role of combined community resilience attributes in disaster risk reduction

To incorporate the potential relationships of cumulative exposure, climate justice, and community resilience, we analyzed the 1266 counties using a generalized linear model with a binary outcome. The time lag effects of community capacity on climate risks (or temporal dimensions of resilience) were tracked using the dependent variable coded as a binary outcome derived from the gap of flood losses. Losses involved both property and crop damage between 1990 and 1999 and 2000 to 2009. Explanatory variables included three component characteristics with seven sub-component variables that captured community capacity characteristics in the 1990s.

Spatial clustering of risk (Model 2) and urban and rural spatial

Table 2
Spatial comparison of vulnerability and risk.

	Rank	Vulnerability comparison			Risk comparison		
		Counties	Index**	Urban and rural classification	Counties	Index***	Urban and rural classification
Top 10 vulnerable and risk communities	1	Scott, IA	0.7026	Urban	Hancock, IL	663.04	Rural
	2	St. James, LA	0.4498	Suburban-exurban	La Crosse, WI	616.03	Urban
	3	Jackson, IA	0.2405	Suburban-exurban	Randolph, IL	594.06	Suburban-exurban
	4	Buffalo, WI	0.2132	Suburban-exurban	Jersey, IL	570.09	Urban
	5	Perry, MO	0.2086	Rural	Whiteside, IL	548.20	Suburban-exurban
	6	St. Charles, LA	0.2048	Urban	Mississippi, MO	363.11	Rural
	7	Whiteside, IL	0.2046	Suburban-exurban	Ramsey, MN	355.01	Urban
	8	Tensas, LA	0.1198	Rural	Jackson, IA	285.24	Suburban-exurban
	9	Morrison, MN	0.1162	Suburban-exurban	Vernon, WI	275.08	Suburban-exurban
	10	Ralls, MO	0.1126	Rural	Jackson, IL	266.09	Rural
Bottom 10 vulnerable and risk communities	1	Rock Island, IL	0.0095	Urban	Alexander, IL	1.0394	Rural
	2	Ramsey, MN	0.0119	Urban	Ralls, MO	1.1126	Rural
	3	Phillips, AR	0.0148	Rural	Jo Daviess, IL	2.0255	Suburban-exurban
	4	Crittenden, AR	0.0152	Urban	Carlisle, KY	2.0362	Rural
	5	Wilkinson, MS	0.0211	Suburban-exurban	Goodhue, MN	2.0532	Suburban-exurban
	6	Anoka, MN	0.0214	Urban	Ballard, KY	3.0226	Rural
	7	Shelby, TN	0.0222	Urban	Tunica, MS	3.0232	Urban
	8	Coahoma, MS	0.0222	Rural	Lake, TN	3.0343	Rural
	9	Cape Girardeau, MO	0.0224	Rural	Cape Girardeau, MO	4.0224	Rural
	10	Ballard, KY	0.0226	Rural	Mercer, IL	4.0231	Urban

Note:
** Min-max transformation method.
*** Vulnerability index + Exposure (flood severity * flooding duration).

Table 3
Climate risk resilience, spatial clustering, and temporal lag effect of capacity.

	Model 1 All	Model 2 All	Model 3 Urban	Model 4 Suburban-exurban	Model 5 Rural
Intercept	−4.463 (6.590)	83.666* (44.859)	−6.818 (12.843)	−6.368 (12.072)	−10.150 (11.231)
Socio-economic characteristics					
Demographic sub-components					
Language	0.011 (0.020)	0.212 (0.205)	0.016 (0.032)	0.018 (0.038)	0.002 (0.026)
Bachelor	−0.059** (0.021)	−0.333** (0.156)	−0.055 (0.046)	−0.025 (0.034)	−0.094** (0.038)
White	0.010 (0.009)	0.037 (0.077)	0.003 (0.017)	0.005 (0.017)	0.046** (0.018)
Age	0.021 (0.030)	0.026 (0.194)	0.045 (0.068)	0.027 (0.046)	0.019 (0.054)
Female	0.012 (0.029)	0.186 (0.246)	0.017 (0.030)	0.037 (0.055)	0.091* (0.054)
Housing sub-components					
Homeowner	−0.043* (0.021)	−0.298 (0.219)	−0.067 (0.044)	−0.033 (0.037)	−0.064* (0.036)
Housing age	0.066** (0.019)	0.178 (0.134)	0.097** (0.044)	0.056 * (0.032)	0.064* (0.036)
Housing value	5.33e−06 (0.00001)	4.24e−06 (0.00005)	0.00003* (0.00002)	0.00001 (0.00001)	0.00002 (0.00001)
Mobile home	0.028* (0.016)	0.063 (0.104)	0.021 (0.035)	0.057* (0.030)	0.029 (0.027)
Economic sub-components					
Employment	−0.064** (0.022)	−0.155 (0.187)	−0.039 (0.046)	−0.097** (0.038)	−0.047 (0.040)
Economic diversity	−0.113 (0.035)	−0.061 (0.136)	−0.231** (0.102)	−0.152** (0.055)	−0.033 (0.080)
Resilient industry	−0.014 (0.015)	−0.618** (0.287)	−0.016 (0.020)	−0.005 (0.037)	−0.034 (0.043)
Business diversity	−0.046 (0.051)	−0.140 (0.292)	−0.026 (0.102)	−0.123 (0.094)	−0.033 (0.088)
Social capital sub-components					
Civic	−0.022 (0.014)	−0.041 (0.092)	−0.048* (0.028)	−0.011 (0.026)	−0.014 (0.026)
Voter	−0.002 (0.016)	−0.436* (0.223)	−0.019 (0.036)	−0.005 (0.029)	−0.020 (0.028)
Residency length	−0.059** (0.023)	−0.111 (0.144)	−0.097** (0.046)	−0.081** (0.041)	−0.028 (0.039)
Social equity sub-components					
GINI	0.019* (0.030)	0.737** (0.301)	0.029* (0.057)	0.121* (0.065)	0.068* (0.042)
Health access	−0.003 (0.005)	−0.023 (0.032)	−0.013 (0.015)	−0.0004 (0.006)	−0.005 (0.012)
Poverty	0.032 (0.022)	0.318* (0.177)	0.007 (0.049)	0.044 (0.040)	0.039 (0.041)
Environmental and geographical characteristics					
Residential	−0.009 (0.006)	−0.017 (0.041)	−0.006 (0.012)	−0.004 (0.010)	−0.011 (0.009)
Precipitation	0.197*** (0.030)	0.110 (0.199)	0.214** (0.068)	0.169** (0.055)	0.222*** (0.050)
Metro	0.366* (0.216)				
Spatial Clustering of risk effect	No	Yes	No	No	No
Number of observations	1266	84	373	428	465
Policy regulation and planning mitigation characteristics					
Non-structural mitigation sub-components					
Building regulation	−0.052 (0.070)	−0.286 (0.566)	−0.154 (0.149)	−0.057 (0.128)	−0.017 (0.120)
CRS class	−0.090 (0.058)	−0.392 (0.329)	−0.190 (0.144)	−0.058 (0.085)	−0.165 (0.104)
Mitigation plan	−1.14e−06 (9.45e−07)	−0.00001** (8.90e−06)	−0.132 (0.267)	−2.65e−06* (1.59e−06)	−1.19e−06 (2.12e−06)
Storm ready	−1.28e−06 (9.67e−07)	−0.00001 (7.24e−06)	−2.07e−06 (1.32e−06)	−1.71e−06 (1.59e−06)	−1.34e−06 (2.17e−06)
Structural mitigation sub-components					
Levee	−0.0002 (0.0001)	−0.017 (0.057)	−0.0006 (0.011)	−0.015 (0.011)	−0.013 (0.011)
Dam	−6.44e−08 (1.07e−06)	−0.00006 (0.00005)	−2.76e−06 (3.01e−06)	−1.11e−06 (2.07e−06)	−1.91e−06* (1.14e−06)
Spatial Clustering of risk effect	No	Yes	No	No	No
Number of observations	1266	84	373	428	465
Log pseudolikelihood	−764.043	−34.484	−205.177	−255.703	−276.542
AIC	1.254	1.487	1.253	1.328	1.309
BIC	−7292.32	−179.15	−1625.74	−1905.25	−2130.98

Note: Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

classification (Models 3 to 5) were analyzed; a summary of which is included in Table 3. Using a Local Moran's *I* among risk index values reflects reselected spatial association effects from flood risks. In addition, we analyzed models that were specific to spatial category; including urban (Model 3), suburban-exurban (Model 4), and rural (Model 5). Prior to estimating the association between flood risk and community capacity, we examined the potential for multicollinearity among the explanatory variables. Using the standard rule-of-thumb and a VIF = 4.74, we determined that serious multicollinearity was not problematic within the empirical model.

Several community capacity variables as resilience factors played a crucial role in mitigating flood risks after accounting for spatial effects and differentials. Results suggested that *Bachelor*, *Homeowner*, *Housing age*, *Employment*, *Civic, Residency length*, and *GINI* variables were statistically significant in explaining flood risks. This was consistent with findings of prior research (Kim and Marcouiller, 2016). Except for *Housing age* and *GINI* variables, these drivers exhibited positive associations with reducing climate risk and enhancing community resilience under climate change. The *Civic* variable as a proxy factor for social capital characteristics was negatively associated with flood losses. Representing community resilience or hazard mitigation drivers (e.g., Kim and Marcouiller, 2016), social capital attributes lead to lower climate risk. As predicted, housing functions and economic inequality variables (*Housing age* and *GINI*) were positively associated with climate risks without the spatial effects. Supported by Highfield et al. (2014), Ibarraŕn and Ruth (2009), and Kapucu and Özerdem (2013), our

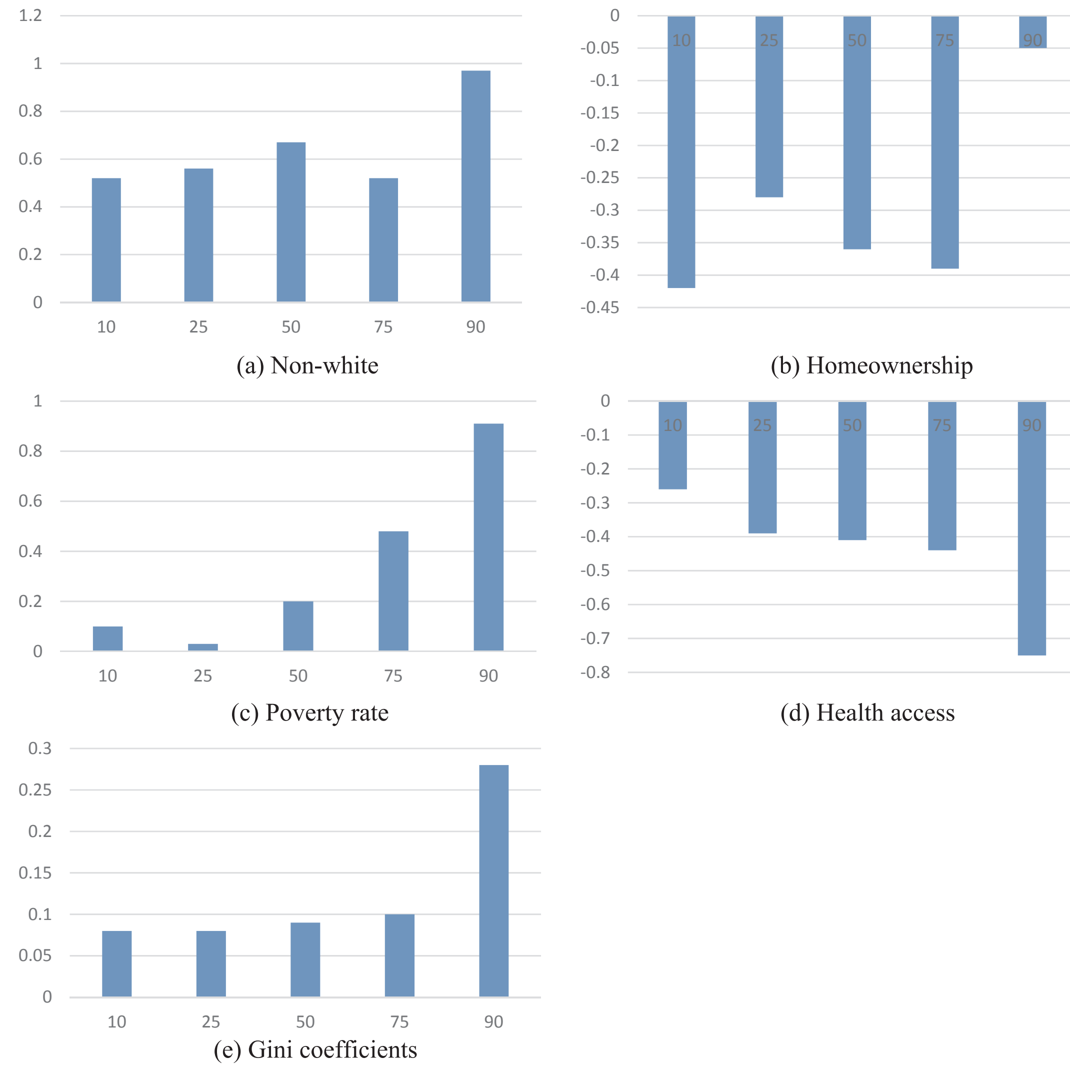


Fig. 5. Relationships between climate (in)justice and climate change impacts. Note: Y-axis indicates standard coefficients of predicted climate change risks and X –axis indicates percentiles.

findings suggested a significant role of enhanced housing structural facilities and social equity in mitigating climate risk and reducing vulnerability.

From environmental and geographic perspectives, *Precipitation* and *Metro* variables were positively and significantly association with flood losses. Urban physical characteristics including impervious surface and urbanization level were linked with increased flood losses. This result was consistent with the findings of Brody et al. (2014). From a policy regulation and planning mitigation perspective, most variables revealed the expected correlation with the outcome variable regardless of the spatial effects considered. Among the six sub-component variables, only the *Mitigation plan* variable as a non-structural mitigation approach had a significant influence on reducing flood loss.

Further, to identify how race (*Non-white*), social service assets (*Health access*), and economic conditions (*Poverty*, *Homeownership*, and *GINI*) were disproportionately impacted by climate risk as proxies for climate justice effects and structural vulnerability, we examined the relationship between predicted climate risks and climate justice effects by the levels of each variable. In Fig. 5, each bar shows standard coefficients generated from Model 1 in Table 3 by the degree of percentile of 10, 25, 50, 75, and 90 for each climate justice proxies. As predicted, higher percentiles of *Non-white*, *Poverty*, and *GINI* lead to higher likelihoods of climate risks. Conversely, the probabilities of climate risks decreased in accordance with the increase of percentiles of *Homeownership* and *Health access*. The results suggested positive relationships exist between climate (in)justice characteristics and climate change.

5. Conclusions and discussion

In this work, we explored community resilience, vulnerability, and flood risk with specific reference to cumulative exposure and climate justice characteristics at the county-level within the U.S. Mississippi River basin from 1990 to 2009. A basic conceptual model of spatial resilience to climate risks, temporal lag effect of community capacity, urban and rural spatial classification, integrative cumulative exposure and spatial clustering of risk allowed us to examine spatial climate risk outcomes and the role of community resilience in reducing such risks. Our approach accounted for local social, economic, environmental, regulatory policy, and planning mitigation contexts by employing a temporal lag effect of community capacity, urban and rural spatial classifications, integrative cumulative exposure, and spatial clustering of risks.

Our empirical results are confirmatory and suggest that climate change-induced flood losses were indeed inversely related to community social and ecological attributes. Local proactive planning and policy can affect social capital and climate justice characteristics that, as we have demonstrated, lead to lower disaster losses and enhanced community resilience.

Ultimately, efforts to enhance community resilience in the context of climate risks and climate change lead to sustainable community development. For this reason, lessons learned from past climate risk experience can help community residents, community organizations, planners, and policy makers predict problems, prepare for future climate risk and provide "an opportunity to influence public policy focused on disaster risk" (Cutter et al., 2014, p. 65). Further, our empirical results are consistent with O'Hare and White's (2017, p. 6) justice and decision-making in the context of flood disadvantage:

"The broader, often cumulative, factors underwriting how and why certain sectors of society are exposed to flood risk and differentials in their capacity to respond to and recover from flooding are emphasized."

Despite providing empirical insights and confirmation of attributes that explain community resilience to climate risks, this work is still quite preliminary and contains important limitations. In this study, we attempted to account for justice in the context of climate risk with empirical models and visualizations that show geographically uneven injustice. However, rather than considering justice as a dynamic concept, our secondary data approach only allowed us a somewhat static concept of justice. Justice is dynamically produced over time and space. Future research needs to address the following questions: Why do we have (in)justice in certain locations/regions? What accounts for the spatial variability? How and where are these (in)justices produced?

As with numerous studies using secondary data sources, we were constrained by the limited number of analytical variables associated with community attributes. We acknowledge the difficulty in using existing regional data and proxies to address individual-level perceptions or behavioral responses of diverse social and ecological variables that are influenced by climate risks. These involve perceptions of social equity and social capital that evade simple metrics and quantitative analysis. As suggested by Mortreux and Barnett (2017) and Ambrey et al. (2017), by using survey-based approaches, future research needs to include psycho-social factors or awareness of climate change impacts at the individual level to provide context to the variety of regional capacity components. This can more effectively explain relationships between justice, vulnerability, resilience, and climate risk. These include attitudes concerning risk, personal experience, trust and expectations of authorities, place attachment, competing concerns, household composition and demographic dynamics.

In this study, we attempted to extend and respond to the work of Desouza and Flanery (2013, p. 89) concerning resilience and complex adaptive systems whereby they state that "[resilience is] the capacity to address various structuring of components and their interactions with the ultimate goal of achieving resilience." Our work complements previous work by advancing theoretically-sound empirical models that incorporate developmental dynamics, climate change adaptation planning effort, social capital, social justice, and distributional elements that speak to social and economic inequity. However, the research reported here is limited in that it does not address the fact that complex adaptive systems are unpredictable in their behavior particularly in their nonlinear response to human intervention (e.g., van der Voorn et al., 2012). Future research needs to examine adaptation strategies as a process like climate adaptation planning with backcasting-adaptive management methods (e.g., van der Voorn et al., 2017). Such work could address how a normative planning method for climate change adaptation is useful in accounting for less tangible aspects that need to be considered in climate change adaptation.

In addition, this study is limited by its inability to reflect intergovernmental or interorganizational networks that exist among local, regional, state, and federal agencies in terms of climate policy efforts to enhance resilience and adapt to climate change. More work is needed to understand intergovernmental coordination of disaster planning and public policy. This could take the form of mixed qualitative and quantitative methods that incorporate content analysis of planning documents matched with secondary data resources as suggested by Kapucu and Hu (2016).

That said, our work supports the notion that planning does indeed matter in reducing climate risk and increasing community resilience to future disasters. Future research that applies van der Voorn et al. (2017)'s backcasting-adaptive management method for climate adaptation planning (which includes six dimensions such as inputs and resources, vision development, stakeholder engagement, pathway development, methodological aspects, and impact) can provide a better understanding of local vulnerabilities and pro-active climate adaptation planning. This important set of response elements provide important topics to address in community and regional planning and related public policies required to proactively address increasingly severe climate events.

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