Spatiotemporal Flood Exposure Changes in the CONUS from 2001 - 2016

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Introduction

Flood hazards are one of America's most frequent and expensive natural hazards. The average economic loss brought by floods in the United States per year is estimated at around $6 billion (Sarmiento & Miller, 2006). Thus, to reduce potential economic loss, evaluating flood exposure and tracking its trend over time is of significance. Novel socioeconomic data have been utilized in flood exposure research (Ho et al., 2018; Khajehei et al., 2020) and it becomes feasible to monitor the change in vulnerable population groups. Previous studies (Qiang, 2019; Qiang et al., 2017) have presented national assessments of population flood exposure at the county level in the United States and analyzed socioeconomic disparities associated with the exposure. To monitor the temporal change in flood exposure and the disparities, this study aims to analyze the changes in flood exposure in the contiguous United States (CONUS) from both spatial and temporal scales. This study tries to answer the following research questions: 1) how responsive are local communities to flood hazards and how is the responsiveness related to socioeconomic conditions? 2) what is the temporal change in urban flood exposure from 2001 to 2016 and how the changes are related to socioeconomic conditions? 3) what are socioeconomic disparities between people living in and out of flood zones, and have disparities changed between 2001 and 2016?

Method

Data acquisition and processing

Three types of data were collected in this study: flood maps, land use data, and socioeconomic data. First, flood maps were acquired from FEMA Flood Map Service Center in 2019 (https://msc.fema.gov/portal). Counties that have a local conflict in flood zone delineation or have fewer areas covered by flood maps were excluded from the dataset, resulting in the coverage of 2385 counties within the CONUS (76.7% of all counties in the CONUS). Second, land use data used in this study is the U.S. Geological Survey (USGS) National Land Cover Database (NLCD) dataset, which was retrieved from the Multi-Resolution Land Characteristics (MRLC) Consortium (https://www.mrlc.gov/). Four developed land cover classes in NLCD datasets were extracted, reclassified, and mosaiced as urban development areas. The urban growth was calculated by subtracting developed lands from the previous year to the latter year, while unchanged lands and urban shrinkages were omitted. The developed land represents population distribution and will be used in dasymetric population mapping to estimate population exposure to flooding hazards. Third, socioeconomic data from the 2000 and 2010 U.S. census and 2006, 2011, and 2016 American Community Surveys (ACS) were collected using the National Historical Geographic Information System (NHGIS) platform (https://www.nhgis.org/). Examples of socioeconomic variables include population below poverty level, unemployed, and without insurance.

Spatiotemporal analysis of flood exposure

Four analyses are carried out. First, the proportion of urban areas in flood zones to total urban areas (U_i) and the proportion of total land in flood zones to total areas (L) are calculated at the county level. D_i is the difference between U_i and L, indicating the deviation of flood exposure from the expected value.

$$U_i = \frac{Urban\ in\ flood\ zones\ in\ year\ i}{Total\ urban\ land\ in\ year\ i}$$

$$L = \frac{Land\ in\ flood\ zones}{Total\ land}$$

$$D_i = U_i - L$$

A positive D implies that people are more responsive to flooding hazards and restrict urban development in flood zones, and vice versa. Thus, the spatial variation of D can help understand the responsiveness to flood hazards. Choropleth maps of D in 2001, 2006, 2011, and 2016 are made in Figure 1(a) – (d). Regression analysis is conducted to analyze the relations between D and socioeconomic variables.

Second, the proportion of urban growth in flood zones to total urban growth (UG_i) is calculated in three time periods: 2001-2006, 2006-2011,2011-2016. The temporal trend of UG_i is analyzed at the county level. An increasing UG_i indicates an increasing exposure ratio in newly developed urban, and a decreasing UG_i indicates the opposite.

$$UG_i = \frac{Urban\ growth\ in\ flood\ zones\ between\ year\ (i+5)\ and\ year\ i}{Total\ urban\ growth\ between\ year\ (i+5)\ and\ year\ i} = \frac{Urban\ in\ flood\ zones\ in\ year\ (i+5) -\ Urban\ in\ flood\ zones\ in\ year\ i}{Urban\ in\ year\ (i+5) -\ Urban\ in\ year\ i}$$

Bivariate color maps are made between D_i and UG_i to analyze the proneness of urban growth in flood zones from 2001 to 2006, 2006 to 2011, and 2011 to 2016 (Figure 2 (a) – (c)). Univariate regression will be applied to analyze relations between UG_i and local socioeconomic variables in 2001, 2006, and 2011. The regression analyses will attempt to explain the underlying factors that caused the spatial variation of UG_i.

Third, the differences between the ratios of disadvantaged population groups living in and out of flood zone (D_{dis}) are compared using the following equation. Considering the uneven distribution of population in each county, it is arbitrary to calculate D_{dis} using the product of the population of the whole county and the area ratio of flood zones. Thus, the number of disadvantaged populations is first estimated at the census tract level (fine-scale) and later aggregated at the county level to avoid biases. The expected value of D_{dis} is 0, indicating socioeconomic conditions in and out of flood zones are the same or similar. Deviations from 0 indicate socioeconomic disparities.

$$D_{dis,\ i} = \frac{Disadv.population\ in\ flood\ zones\ in\ Year\ i}{Total\ population\ in\ flood\ zones\ in\ Year\ i} - \frac{Disadv.population\ outside\ flood\ zones\ in\ Year\ i}{Total\ population\ outside\ flood\ zones\ in\ Year\ i}$$

Then, the earliest and latest years (i.e., 2001 and 2016) are selected to calculate the long-term change in the proportion of the disadvantaged population in flood zones ($D'_{dis,\ 2001-2016}$) using the equation below. Local clusters of $D_{dis,\ 2001}$ and $D_{dis,\ 2016}$ will be analyzed by the Getis-Ord Gi* statistics. The comparison between $D'_{dis,\ 2001-2016}$ and $D_{dis,\ 2001}$ will be used to explain changes in socioeconomic disparities.

$$D'_{dis,\ 2001-2016} = D_{dis,\ 2016} - D_{dis,\ 2001}$$

Preliminary Results

As this work is still in progress, only preliminary results from the first two research questions are discussed. Figure 1 (a) shows the spatial distribution of responsiveness to flood exposure in 2001. As there are too few changes in D_i between 2001 and 2006, 2011, and 2016, only differences between 2001 and the latter years are visualized (Figure 1 (b) – (d)). Most counties with negative D_{2001} locate near rivers and coastal areas, such as Gulf Coast and lower East Coast, while the inland regions in the east have a higher value of D_{2001}. The differences in Figure 1 (b) – (d) show an overall increasing trend in D_i in the latter years, whereas coastal areas in the east and southern boarders show a decreasing pattern.

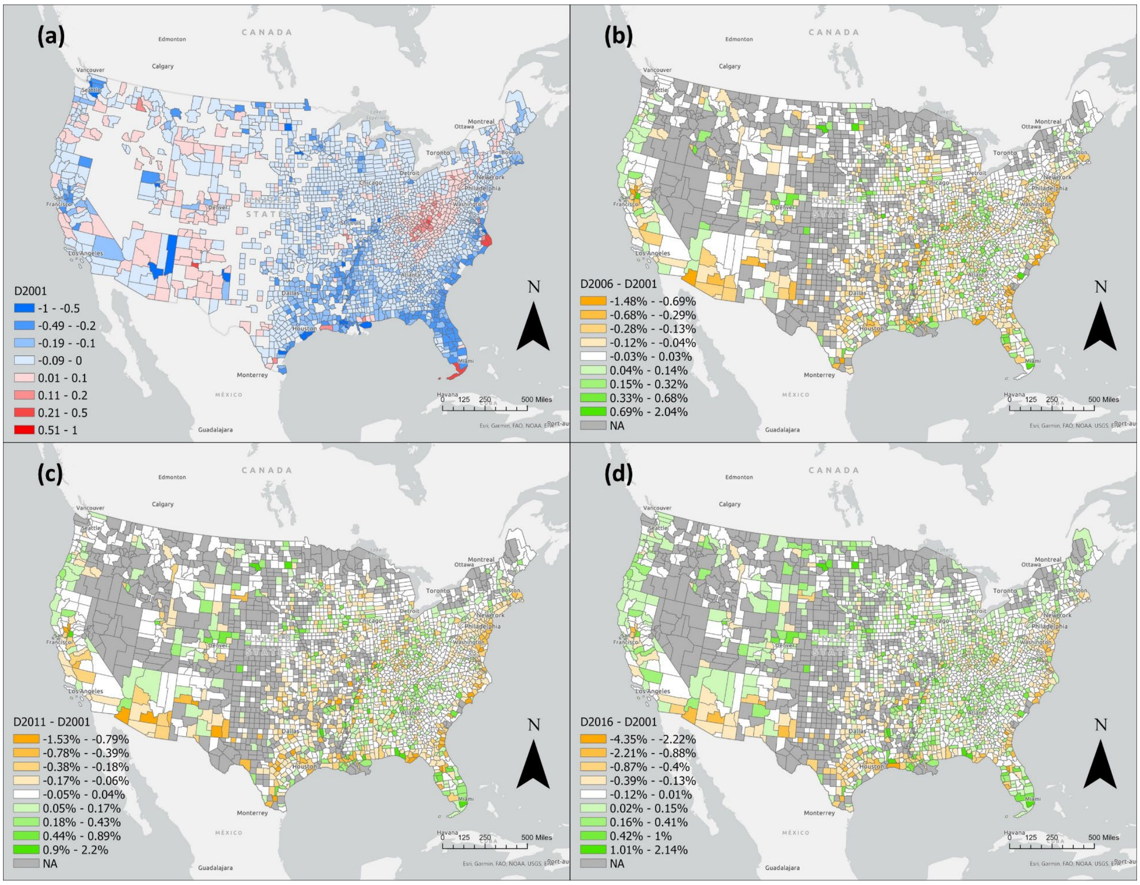

Figure 1. (a) The difference between the proportion of urban land in flood zones and the proportion of total land in flood zones in 2001 (D_{2001}) (b) $D_{2006} - D_{2001}$ (c) $D_{2011} - D_{2001}$ (d) $D_{2016} - D_{2001}$

Figure 2 compared the local responsiveness to floods with the developing trend of urban growth in flood zones. Most counties in the Atlantic coastal plain have a high UG_i and low D_i, indicating the trend of increasing urban development in flood zones while people living in these places are not responsive to flood hazards. There are a few exceptions with high responsiveness, such as areas near Miami (Florida), New Orleans (Lousiana), and Houston (Texas). The purple cluster (high responsive and fast urban growth in flood zones) in the northeast US is decreasing to blue (high responsiveness and slow urban growth in flood zones) over time. In the west, counties tend to have a deeper color over time, turning from light blue to purple, representing an increasing UG_i.

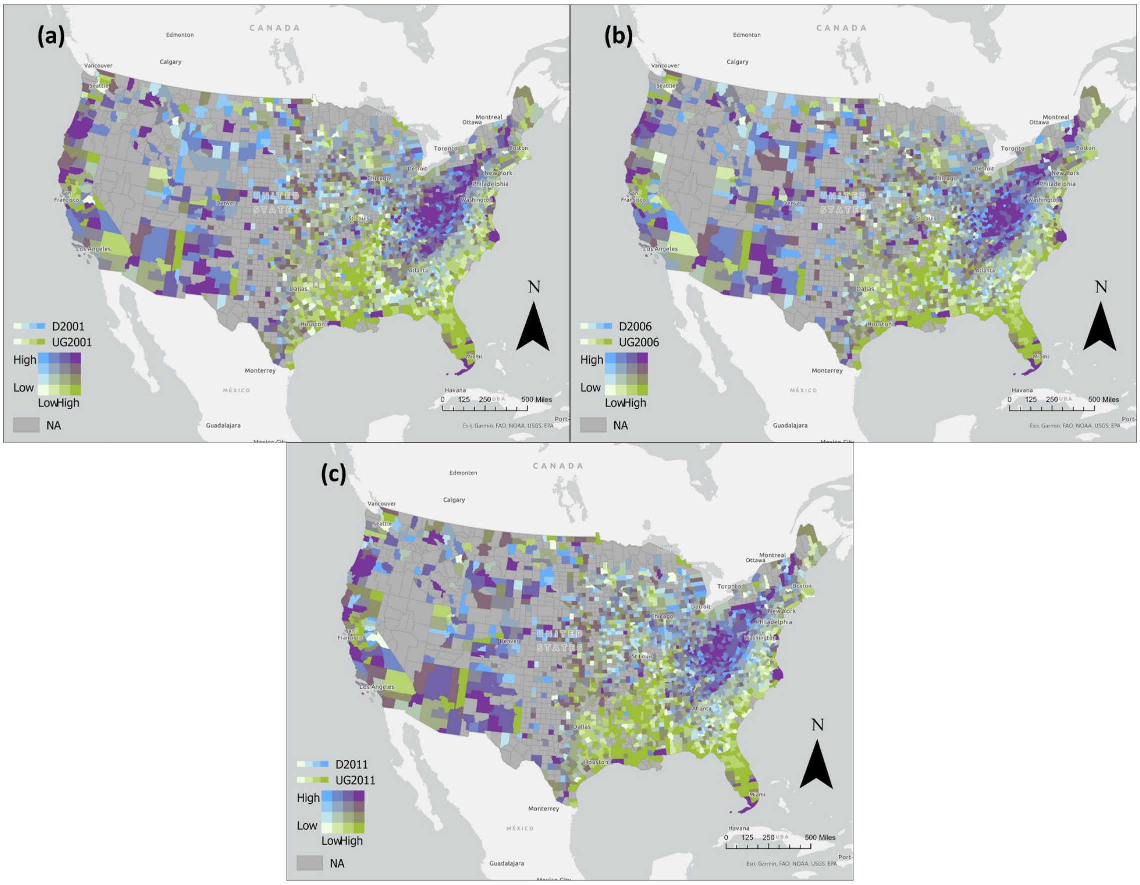

Figure 2. Bivariate color maps between flood responsiveness (D_i) and the proneness of urban growth in flood zones (UG_i) in (a) 2001, (b) 2006, (c) 2011

Discussion and Conclusion

The comparison of D_i (Figure 1) shows that the proportion of urban lands in flood zones to total urban lands is slightly increasing in CONUS over the 2001 – 2016 period. The bivariate color maps (Figure 2) show the trend of increasing urban lands in flood zones in the southeast while other places, such as inland northeast regions, avoid further development in flood-prone areas. In future studies, socioeconomic factors will be associated with these changes. The impact on the vulnerable population to flood hazards will be analyzed and the environmental justice issue will be addressed.

The outcomes of this study reveal mitigation and responsiveness to flooding hazards and social-environmental justice related to the exposure. The understanding of flood exposure over time and its driving factors will be enhanced by this study, which calls for policy-making at the federal level to be adjusted and help disadvantaged populations accordingly.

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