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# Evacuation Shelter Deficits for Socially Vulnerable Texas Residents During Hurricane Harvey

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## Abstract

**Background:** Socially vulnerable residents of US Gulf Coast counties have higher exposure to physical hazards and disaster-associated risks. Evacuation is one way to mitigate the consequences of disaster exposure among socially vulnerable populations. However, it is unknown whether existing evacuation shelter capacity and locations in designated hurricane evacuation zones of Texas are adequate to accommodate persons with housing and transportation needs. This study estimated the evacuation shelter deficit arising from demand from socially vulnerable residents of the Houston-Galveston area.

**Methods:** Spatial statistical methods including Global Moran's I and Getis-Ord (Gi*) were used to measure spatial autocorrelation and identify census tracts in the study area with high (hot spots) and low (cold spots) social vulnerability in both housing and transportation domains. The shelter deficit in each county within the study area was estimated as well as for the entire Houston-Galveston Metropolitan Statistical Area.

**Results:** Designated evacuation zones in the Houston-Galveston area have an overall shelter deficit of 163 317 persons. Shelters in the area can only accommodate 36% of evacuees with significant housing and transportation needs, while 3 of 4 counties had county-specific evacuation shelter deficits. The highest deficits were in Harris County, where Houston is located, and the lowest were in Matagorda County, a rural county southwest of Harris County.

**Conclusion:** Emergency managers and other authorities should consider data related to demand from socially vulnerable residents for public shelters during disasters and increase shelter capacity in certain locations to address evacuation shelter shortage for vulnerable persons in designated evacuation zones of Texas.



## Keywords

evacuation, hurricane, shelter capacity, social vulnerability, spatial statistics


## Background

Exposure to geophysical natural hazards, such as fault lines and flood plains, does not always result in disaster impacts. Disasters are not the "inevitable outcome of a hazards' impact"[1] but occur when proximity to natural hazards coincides with preexisting social vulnerabilities.[2,3] This interaction occurs frequently in a number of areas located along the US Gulf Coast, where high-risk, hazard-susceptible areas have high proportions of socially vulnerable residents.[4] In US Gulf Coast counties, higher social vulnerability has been positively associated with the amount of disaster damage, measured in total dollars per capita.[5] For example, in New Orleans, Louisiana, flooding associated with Hurricane Katrina and subsequent levee failures had the largest impacts on socially vulnerable residents who were more likely to live in poverty, be renters rather than homeowners, African American, female, and have poorer physical health.[6] While a larger total share of damage may have been borne by wealthier residents, the relative impacts of disasters such as Hurricane Katrina on residents with lower incomes mean that they are

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more likely to face challenges with response and also lack the resources necessary for recovery.[7]

After Hurricane Katrina, more than 70 000 socially vulnerable residents of New Orleans were stranded in flooded neighborhoods for days, unable to access evacuation shelter facilities and other response and recovery resources.[8] Inability to evacuate an impending storm has been shown to result in excess deaths from both direct causes, including drowning, trauma, and carbon monoxide poisoning, and indirectly through complications associated with exacerbation of chronic conditions such as diabetes or cardiovascular disease.[9-11]The health impacts of disasters on socially vulnerable populations are often greater in part due to their higher disaster-associated risks and expanded care needs. Poverty may leave socially vulnerable residents of hazard-prone areas unable to finance the costs associated with an evacuation.[12] Lack of access to a personal vehicle may prevent them from driving to shelters or higher ground,[13] while highly publicized traffic jams from prior storms, some leading to injury and death during evacuations, may further deter evacuation.[14-16] Disabilities and poor physical or mental health may limit socially vulnerable residents' ability to comply with evacuation orders or access shelters due to concerns about disruptions to routine medical care or access to durable medical equipment.[17,18]

In high hazard exposure states located along the US Gulf Coast, like Texas, other factors that could potentially magnify the impact of a disaster on socially vulnerable groups include poor adaptive capacity and resilience at the state, county, and community levels. In a study conducted by Ross[19] on the administrative perspective of disaster resilience, Texas was the least equipped for natural disasters, with coastal counties in the state having lower adaptive capacities for disaster resilience than coastal counties in Louisiana, Alabama, Mississippi, and Florida. According to the Baseline Resilience Indicators for Communities, measures of social, economic, housing, and infrastructure resilience in south Texas counties were among the lowest in the United States.[20] Similarly, research by Reams et al[21] on county-level adaptive capacity for resilience found that the most resilient counties in the US Gulf Coast were those that invested more in education, had higher per capita incomes, and more women in the workforce—4 of the 5 least resilient counties using this metric were located along the Texas Gulf Coast.[21]

Synergies between high social vulnerability and poor adaptive capacity like those present in coastal Texas can compound disaster-associated risks for residents. One potential way to minimize disaster impacts from tropical storms and hurricanes for socially vulnerable residents of this region is to ensure that hurricane evacuation shelters have adequate capacity and are accessible to socially vulnerable populations. For example, based on data related to hurricane evacuation behavior in Florida, officials have eliminated shelter deficits, ensuring accessibility to a shelter with adequate space in evacuees home counties, since in the event of a storm, residents are more likely to evacuate to shelters near their homes.[22] However, no study has been conducted to quantify the potential shelter deficit for socially vulnerable residents of designated hurricane evacuation zones in the highly vulnerable Houston-Galveston area of Texas. Using a "county-boundary sheltering" model similar to the State of Florida's, this study estimated the shelter deficit for socially vulnerable residents of this area. In the context of this study, socially vulnerable populations refer to residents of hurricane evacuation zip-zones of Texas who have significantly high housing and transportation needs. To our knowledge, this is the first study to quantify shelter deficit for socially vulnerable populations in Texas. Findings could inform emergency management and other public health preparedness and response officials about potential approaches to eliminate shelter shortages, especially for socially vulnerable residents living in highly physically vulnerable locations.

## Methods

### Study Area and Population

The Houston-Galveston Area Council has designated 4 hurricane evacuation zip-zones in the Houston-Galveston Metropolitan Statistical Area (MSA); zip-zone Coastal, zip-zone A, zip-zone B, and zip-zone B[23,24] (Figure 1). The zip-zones include zip codes in 6 coastal Texas counties: Matagorda, Chambers, Brazoria, Galveston, Harris, and Liberty. The total population of the 4 evacuation zip-zones is 1.78 million.[25] Although other areas of the MSA are also highly vulnerable to the impacts of tropical storms and hurricanes, including inland flooding, we assume for this study that evacuation shelter demand would arise only from the population living in the designated zip-zones, since residents who live outside the zip-zones are considered to be at low risk of storm-surge associated flooding. For this reason, this study was only restricted to the population that reside in the evacuation zip-zones.

### Data Sources and Software

Data to calculate the Social Vulnerability Index (SVI) were obtained from the Center for Disease Control and Prevention (CDC).[26] Shapefiles for evacuation shelters in the Houston-Galveston MSA were obtained from Federal Emergency Management Agency (FEMA) and Homeland Infrastructure Foundation-Level Data.[27] Regional boundary data on counties and zip codes were downloaded from the Houston-Galveston Area Council.[28] ArcMap 10.4.2 (Redlands, California) was used for the analysis.

### Social Vulnerability Index

The SVI was developed by the Agency for Toxic Substances and Disease Registry (ATSDR) and CDC to enable public health officials and other relevant authorities to spatially identify populations that would likely need support before, during, and after disasters of all types.[29] The SVI is calculated by ranking census tracts on 15 variables in 4 domains including socioeconomic status, household composition and disability, minority status and language, and housing and

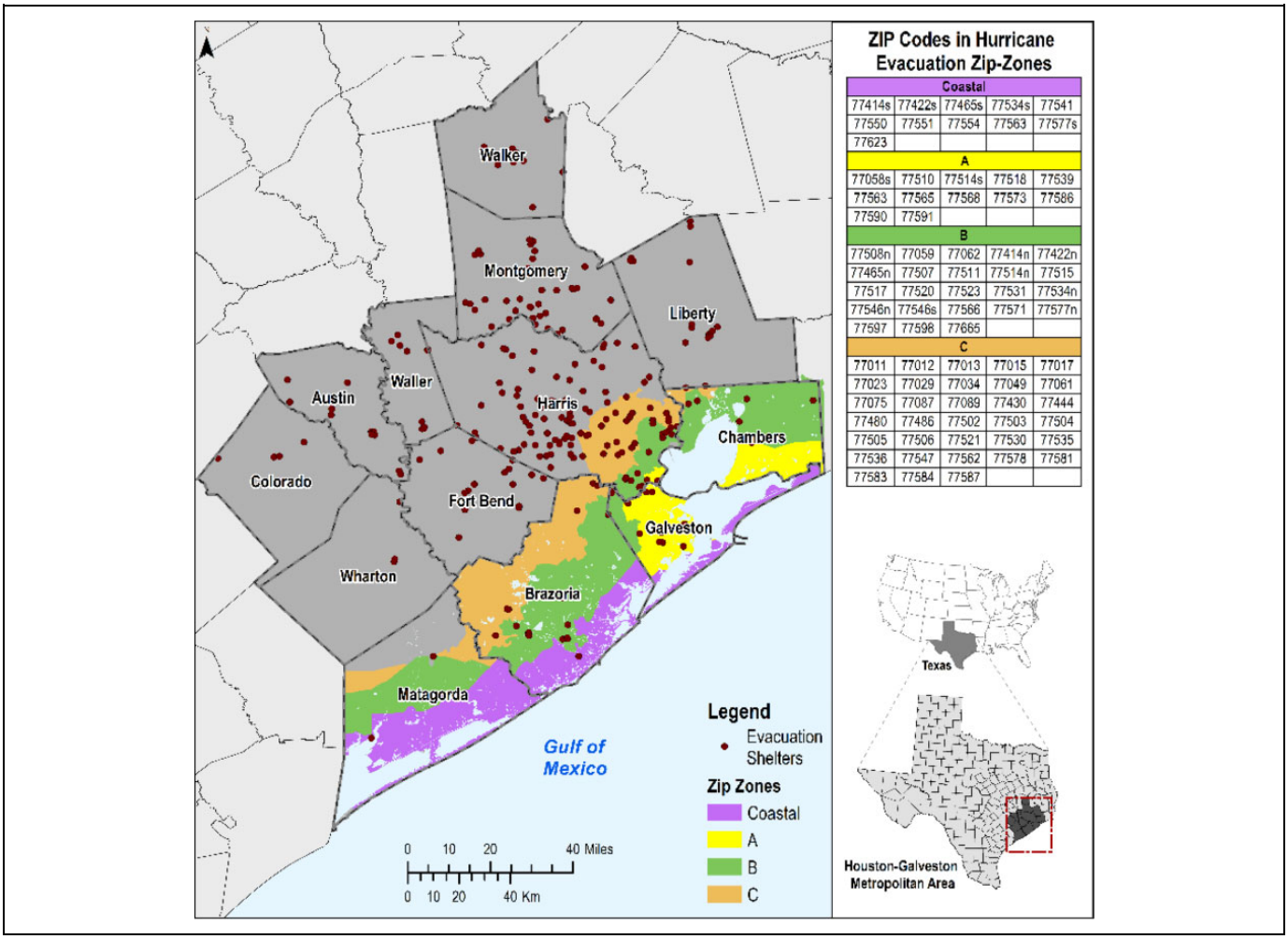


**Figure 1.** Hurricane evacuation zip-zones in the Houston-Galveston Metropolitan Statistical Area (MSA).

transportation.[29] Although information on the 4 themes were available in the comprehensive data set, for this study, we focused on the index for housing and transportation (HTI), which is made up of housing structure, crowding, and vehicle access variables. The HTI was estimated for census tracts located in the hurricane evacuation zip-zones of the Houston-Galveston MSA. Additional details on the methods for estimation of SVI is available elsewhere.[29]

## Spatial Analysis

*Moran's I statistic.* Moran's I statistic is a global measure of spatial dependence used to estimate spatial correlation based on feature locations and attribute values and determine if the feature locations are clustered, dispersed, or random.[30] The null hypothesis assumes that no spatial dependence exists in the study area, meaning that feature locations are random. Moran's I statistic ranges from $-1$ to $+1$ with statistically significantly negative values indicating dispersion, positive values indicating clustering, and a zero value indicating complete spatial randomness (no autocorrelation).

*Hot spot analysis.* The Getis-Ord statistic (Gi*) was used to identify HTI hotspots. A high value of the Gi* statistic denotes a cluster of high-index values (ie, hot spots), while a low value of the statistic represents a cluster of low-index values (ie, cold spots). The statistical significance of the hotspots was determined based on 90%, 95%, and 99% confidence intervals.

*Estimation of evacuation shelter space deficit.* The "Select by Location" tool was used to restrict the analysis to the HTI hotspots contained in the hurricane evacuation zip-zones. For each county, the population of vulnerable persons was determined by estimating the total hotspot population within the county boundary. Because previous studies have estimated potential shelter demand at 25% of the total population,[31,32] a similar threshold was used to estimate potential shelter demand in this study. Shelter supply was calculated as the total number of shelter spaces in a county. Using a supply and demand relationship, shelter deficit was then estimated. Absolute county deficit was obtained by calculating the difference between shelter capacity and shelter demand in a county, while relative county shelter capacity was obtained by computing a ratio between the 2 variables. The aggregate absolute deficit for

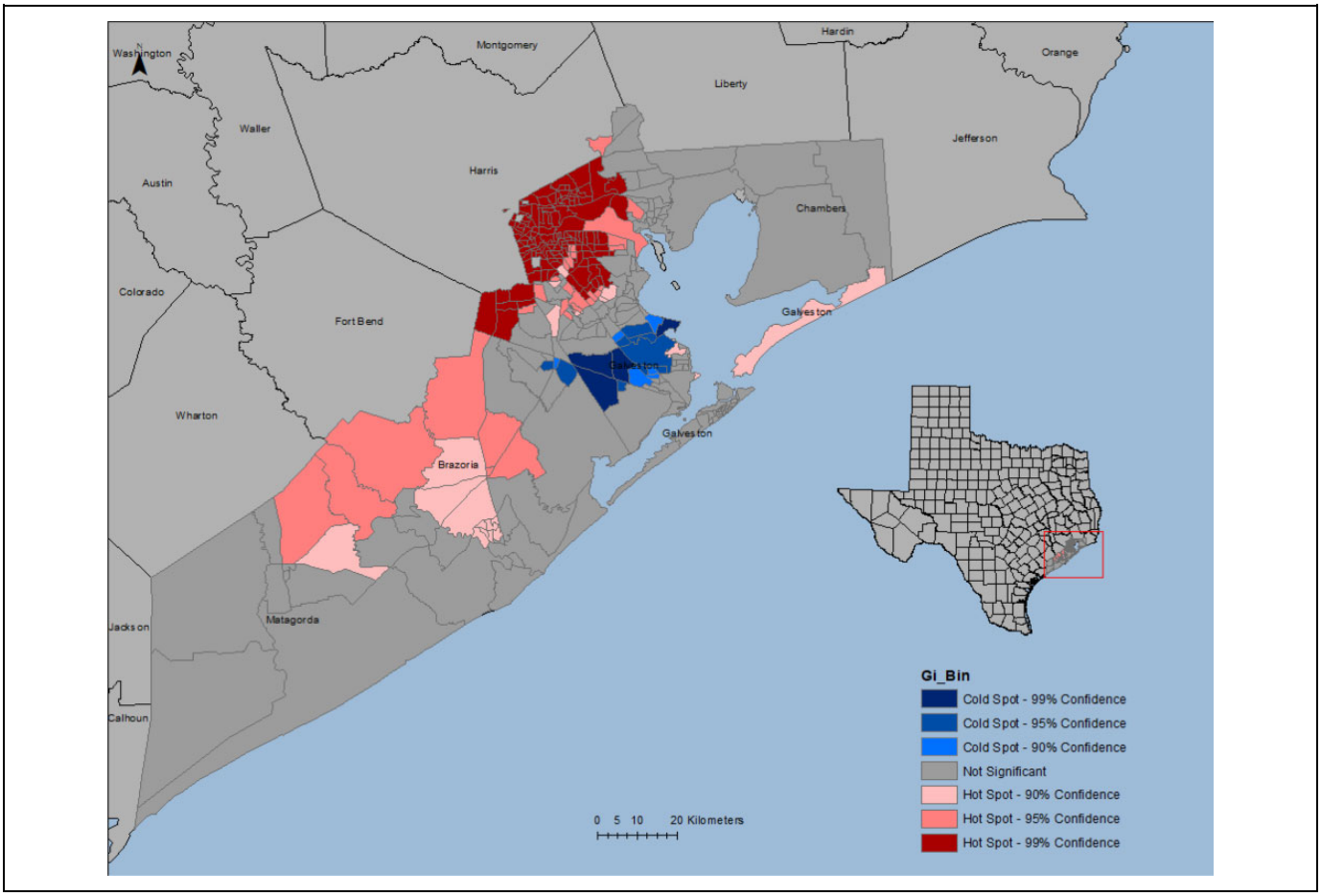


**Figure 2.** Housing and transportation vulnerability hot spots.

the Houston-Galveston MSA was estimated by computing the difference between the total shelter spaces in the 13-county MSA (N = 91 600) and the total shelter demand for vulnerable persons living in evacuation zip-zones. Similarly, the aggregate relative capacity was estimated by computing the ratio between the 2 variables.

## Results

The Moran's I index was 0.17 with an Z score of 62.49 and an *P* value of .00. Therefore, there was a significant spatial dependence of housing and transportation vulnerability in the study area. Figure 2 illustrates census tracts with statically significant housing and transportation vulnerability in the study area (hot spots = red; cold spots = blue).

Four of the 6 counties in the hurricane evacuation zip-zones have populations with significantly high vulnerability for housing and transportation. The total population of vulnerable persons in these counties was 1 019 667. No housing and transportation hot spots were identified in Liberty or Chambers Counties. The Houston-Galveston MSA (including counties outside of the evacuation zip-zones) has a total shelter capacity of 91 600 persons (Table 1).

Three of the 4 counties with the highest social vulnerability in HTI—Brazoria, Harris, and Matagorda—were deficient in evacuation shelter space (Table 1). Harris County had the highest absolute shelter deficit (161 504) while Matagorda had the lowest (1 576). In addition, Harris County can only meet 18% (35 303 of 196 807) of the shelter demand arising from highly vulnerable populations, and additional shelter space for 161 504 persons would be required to eliminate the deficit in Harris County. Overall, the hurricane evacuation zip-zones have a shelter deficit for 163 317 persons and only 36% (91 600 of 254 917) of the highly vulnerable housing and transportation population in these zones could be sheltered in the facilities within the entire Houston-Galveston MSA (Table 1).

## Discussion

The Houston-Galveston region's hurricane evacuation zip-zones have relatively large shelter deficits for populations with high transportation and housing vulnerability as defined by the SVI. In the advent of a severe tropical storm or hurricane with significant storm surge, more than 160 000 vulnerable persons in evacuation zip-zones may be left stranded without shelter space in the entire 13-county MSA. Because these residents also have housing and transportation needs, they are likely

**Table 1.** Evacuation Shelter Deficit in the Evacuation Zip-Zones of Texas.

| County | Total Population (est. 2017) | Vulnerable Population | Shelter Demand (0.25*Vul. Pop.) | Shelter Capacity | Absolute Shelter Space Deficit | Relative Shelter Capacity |
|---|---|---|---|---|---|---|
| Brazoria | 362 457 | 214 086 | 53 522 | 6450 | 47 072[a] | 0.12 |
| Galveston | 335 036 | 9976 | 2494 | 4530 | 2036 | 1.82 |
| Harris | 4 652 980 | 787 229 | 196 807 | 35 303 | 161 504[a] | 0.18 |
| Matagorda | 36 840 | 8376 | 2094 | 518 | 1576[a] | 0.25 |
| Houston-Galveston MSA | 7 064 712 | 1 019 667 | 254 917 | 91 600 | 163 317[a] | 0.36 |

Abbreviation: MSA, Metropolitan Statistical Area.
[a]denotes evacuation shelter space deficit.

unable to travel longer distances beyond their county of residence to access evacuation shelters in other counties or regions of Texas.

After Hurricane Katrina, a survey of residents who did not evacuate reported that 55% attributed their nonevacuation to not owning a car or having access to another means of transportation.[33] In addition, most evacuation decisions in Hurricane Katrina were shaped by social vulnerabilities like poverty, preexisting medical conditions, and minority status.[6] If a similar storm were to make landfall along the Texas Gulf Coast, the shelter shortage in the hurricane evacuation zip-zones may expose disaster-susceptible residents not only to the immediate impacts of the storm, such as surge and flooding, but also to acute and longer term consequences such as physical and mental health morbidity and mortality.[6] For example, drowning was the leading cause of death due to Hurricane Katrina,[9] while a majority of the 117 deaths that occurred following Hurricane Sandy were attributed to drowning of nonevacuees in their homes.[9] Nonevacuees are also more likely to die of trauma, carbon monoxide poisoning, and other illnesses such as heart failure.[10,11]

Although counties predominantly located in evacuation zip-zones would be expected to have nonsufficient shelter space because of their geographic locations, alternative ways exist by which shelter deficit could still be eliminated in these areas. These include (but are not limited to) the retrofitting of existing shelters, mandating district schools to serve a dual-purpose function, creating new shelter spaces that conform to American Red Cross (ARC) guidelines, and transporting vulnerable persons to shelters in other counties (inland). For example, Texas could follow the model applied by the State of Florida[22] in addressing shelter deficit, having attained the milestone of eliminating shelter deficits through 2023. In 1995, Florida conducted an appraisal of existing evacuation shelters and enacted a statute that mandated district schools in the state to serve a dual-purpose role. Existing shelters were retrofitted with school-based shelters overhauled to meet ARC shelter design guidelines. By 2006, Florida estimated a statewide shelter deficit of 386 379 persons for category 5 hurricanes, and by 2018 the state has eliminated its aggregate shelter deficit for the general population, with shelter spaces projected to be sufficient (based on population growth estimates) through 2023.[22] Regardless of the method chosen by authorities in Texas to eliminate shelter deficit, the findings in this study would assist in estimating the burden of shelter support that is required for the vulnerable population. This study has several important limitations. Based on a long-standing evidence from both disaster research and data collected by first responders,[31,32,22] shelter demand was estimated to be 25% for the socially vulnerable population residing in the hurricane evacuation zip-zones. In other words, it was assumed that 25% of socially vulnerable population living in high-hazard areas would use public shelters in the case of an evacuation. The use of 25% for shelter demand in this study assumes that shelter needs are similar in both general and vulnerable populations. However, actual shelter demand would likely be higher for the socially vulnerable, and our result may be an underestimate. Shelter deficit was also estimated in both absolute and relative terms—the former to enable emergency managers and county officials to quantify the shelters required to eliminate shortage, and the latter to permit comparison between shelter capacity and shelter demand for each county. County-shelter deficits were estimated assuming that socially vulnerable residents would evacuate to shelters in the same county as their residence, and aggregate deficit was estimated assuming that vulnerable residents would evacuate to shelters in other counties within the MSA. If authorities are able to provide transportation to shelters in other counties or regions across the state respectively, then our deficit estimates would overestimate the true demand. We used county-level analysis because it was employed in previous studies conducted by Florida and New England states.[22,34] County governments are also known to play significant roles in emergency management activities and often serve as intermediaries between municipalities and state governments.[35-37]

Shelter demand was estimated based on the US Center for Disease Control and Prevention's SVI. The hierarchical model of CDC's SVI has been shown to have a lower precision and weaker internal validity compared to deductive and inductive models,[38,39] and the precision of the model has been found to be sensitive to the weighting scheme chosen.[39] However, some studies have shown that CDC's SVI has a higher accuracy than other models and compares well to other indices of social vulnerability.[39,40] The CDC SVI was also chosen for this study because it is publicly available and has been cited more than 180 times in the literature (see https://www.researchgate.net/

publication/274439003_A_Social_Vulnerability_Index_for_-Disaster_Management). Finally, the data source for evacuation shelters used in the study is synchronized with FEMA and ARC databases in real time and therefore subjected to frequent updates. While such updates may provide the most currently relevant information, they may also impact the ability of readers to replicate the study results. The findings obtained from this study were based on data collected on April 8, 2019.

This study also has several important strengths. To our knowledge, it is the first to estimate shelter deficits specifically for socially vulnerable residents of designated hurricane evacuation zip-zones in Texas. Second, it employed spatial statistical methods to identify highly vulnerable groups and corresponding shelter capacity. Finally, it relied on publically available data from the US Census and FEMA, as well as a validated measure of social vulnerability developed by ATSDR and CDC.

## Conclusion

This study employed spatial statistical methods to estimate shelter deficits for socially vulnerable residents of designated hurricane evacuation zones in Texas. In addition to social vulnerability, this region is frequently exposed to physical hazards, including major hurricane landfalls every 6 years on average.[41] This study focused on vulnerability related to housing and transportation, which are likely to be related to both the decision and the ability to evacuate when ordered by local officials in the event of a disaster. While Hurricane Harvey was primarily an inland flooding event in the Houston-Galveston area, the next major tropical storm or hurricane will likely include more severe storm surge and coastal flooding, which may be exacerbated by sea-level rise,[42] subsidence,[43] and rapid population growth and development in the region.[44] In the event of a major tropical storm or hurricane, more than 160 000 socially vulnerable residents of Harris, Brazoria, and Matagorda counties could be left without needed space in an evacuation shelter. To protect the public's health and safety, emergency management and other local authorities should consider approaches to eliminating the shelter deficit (like creating new shelters, retrofitting existing shelters, or providing transportation to shelters in other counties), particularly for socially vulnerable residents.

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