COULD HOUSTON BE EVACUATED? ASSESSING EVACUATION CAPACITY AND DECISION MAKING RELATED TO HURRICANE HARVEY

A Dissertation

by

IBRAHEEM MUSTAPHA KARAYE

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PUBLIC HEALTH

Chair of Committee,	Jennifer A. Horney
Committee Members,	Courtney Thompson
	Maria Perez-Patron
	Nicholas Taylor
Head of Department,	Xiaohui Xu

December 2018

Major Subject: Epidemiology and Environmental Health

ABSTRACT

Background: Hurricane Harvey made landfall as a Category 4 storm on the Texas Gulf Coast on August 26, 2017. In this study, we assessed the feasibility of evacuating the Houston-Galveston region of the U.S. Gulf Coast.

Methods: First, we explored the spatial distribution of evacuation shelters in the Houston-Galveston MSA and estimated the shelter deficits in the region. Second, we conducted a statistical meta-analysis of 36 studies and identified the factors associated with hurricane evacuation decisions. Finally, we used an SF-12 instrument to assess the self-rated mental and physical health of residents in the Texas Gulf-Coast after hurricane Harvey. We also identified the factors associated with variations in self-rated health among the population.

Results: There was a disproportionate distribution of evacuation shelters in the Houston-Galveston MSA with high-capacity shelters clustered farther away (more than 120 miles) from the Coastal Zip-Zone, and low-capacity shelters clustered nearer (less than 50 miles) the Coastal Zip-Zone. In addition, the MSA had a prevailing aggregate shelter deficit for 353,713 persons. The factors significantly associated with hurricane evacuation were mobile home residence (r= 0.31; 95% CI: 0.21, 0.41), perception of risk (r= 0.18; 95% CI: 0.10, 0.26), Hispanic race (r= 0.08; 95% CI: 0.01, 0.14), and female gender (r= 0.05; 95% CI: 0.00, 0.09). Finally, the self-rated mental and physical health scores of residents in the Texas Gulf-Coast were 36.69 and 39.87 respectively, which were statistically significantly lower than national average.

Discussion: To improve the efficiency of evacuating the Houston-Galveston MSA in the face of hurricane, relevant authorities should make efforts towards eliminating prevailing shelter deficits. Second, information on factors associated with evacuation may enable the identification

of specific sub-population groups for evacuation interventions. Third, in the design of policy guidelines on disaster recovery, mental health services should be integrated with economic and educational empowerment programs and directed towards younger women with less than graduate level of education, who live in mobile homes with little children. Likewise, physical health rehabilitation programs after hurricanes should target evacuees at least 25 years of age who perceive medium to high risk of storm surge.

DEDICATION

To my late mother, Hauwa Maijidda Aliyu.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Jennifer Horney, for her effective mentorship and supervision throughout my graduate program. Her intelligence, initiative, and inspiration contributed to the seamless completion of my graduate program, and by extension, this research project. I would also like to extend my sincere gratitude to my committee members, Dr. Courtney Thompson, Dr. Maria Perez-Patron, and Dr. Nicholas Taylor for their expertise, encouragement, and patience in the supervision of this research project. This project would not have been possible without collaboration from Dr. Ashley Ross of the Department of Marine Sciences at Texas A&M University, Galveston, who generously shared the data set on Texas Gulf-Coast Survey. My heartfelt appreciation also goes to Dr. Tanya Garcia for the support and encouragement she provided me throughout my graduate studies at Texas A&M University.

Finally, my deepest gratitude goes to my lovely and caring wife, Maryam, and my parents, family, friends, and colleagues for their support and encouragement that have sustained me over the years.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Professors Jennifer Horney, Maria Perez-Patron, and Nicholas Taylor of the Department of Epidemiology and Biostatistics, and Professor Courtney Thompson of the Department of Geography.

The data set analyzed for Chapter 4 was provided by Professor Ashley D. Ross of the Department of Marine Sciences, Texas A&M University at Galveston.

Funding Sources

No external funding was received to support the research and compilation of this document. However, graduate study was supported by a scholarship from Kano State Government, Nigeria, and a tuition award from the Department of Epidemiology and Biostatistics at Texas A&M University.

NOMENCLATURE

HGAC	Houston-Galveston Area Council
MSA	Metropolitan Statistical Area

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

1. INTRODUCTION

Hurricane Harvey made landfall as a Category 4 storm on the Texas Gulf Coast on August 26, 2017. According to the National Oceanic and Atmospheric Agency (NOAA), Hurricane Harvey was the wettest tropical cyclone on record, with up to 56 inches of rain falling over the Houston metropolitan area over the next several days (Di Liberto, 2017). Estimated economic losses from Hurricane Harvey are more than $180 billion, with more than 200,000 homes, and 1 million cars completely flooded. Over 700,000 persons sought federal assistance of some kind after the hurricane. Hurricane Harvey resulted in at least 103 deaths in Texas; 68 due to direct causes, such as drowning and 35 due to indirect causes including fires, electrocution, and vehicle accidents due to flooded roads. This made Hurricane Harvey the deadliest hurricane to make landfall in Texas since 1919 (Blake & Zelinsky, 2018).

1.1 Background

1.1.1. Harvey & Evacuation

Hurricanes are a disaster to the extent that they affect people and properties. Increased population density around coastal cities increases the propensity of substantial damage due to disaster. Famously, a major hurricane made landfall in Galveston, Texas in 1900 that resulted in the death of over 8000 residents and changed the trajectory of the city's development as a port and economic center. More recently, significantly fewer deaths have been recorded during hurricanes, in part due to improved forecast and warning systems which alert residents to evacuate to prevent catastrophic consequences.

Hurricane Harvey rapidly gained strength as it approached the Gulf Coast of Texas in late August 2017, becoming a Category 4 storm on the Saffir-Simpson scale with sustained winds of 135 – 150 miles per hour. As the storm strengthened, authorities in several coastal counties issued mandatory evacuation orders (WFAA, 2017). However, officials in Harris County and the City of Houston – a metropolitan area larger than New Jersey with more than 6 million residents did not issue evacuation orders. Reasons given for not issuing evacuation orders included the uncertainty of the storm's path, the prediction that the storm would primarily be a rain (and not wind) event, and the short time available to move millions of people (Andone, 2017; Malewitz, 2017; Domonoske, 2017; Wang et al., 2017). The city's failed evacuation from Hurricane Rita in 2005, which resulted in 107 evacuation-related fatalities, likely also played a role in the decision not to order evacuations from Hurricane Harvey.

Although mandatory evacuation orders were not issued in most of the counties in the Houston-Galveston Metropolitan Statistical Area (MSA), more than 30,000 residents sought a place to stay at local evacuation shelters (Dwyer, 2017). According to media reports, many evacuation shelters in the Houston MSA were filled beyond capacity (Kelly, 2017; O'Donnell, 2017), while other shelters were themselves impacted by flooding that submerged cots and forced evacuees to relocate to other shelters that were not impacted (Mail Foreign Service (MFS), 2017). Although evacuation shelters were provided for Houston-Galveston MSA residents in Dallas, Austin, and San Antonio, most of these facilities were under-utilized due to the inability of Houston residents to travel due to flooded roads (Jankowski, 2017). For instance, a shelter with a capacity of 7,000 was opened by the City of Austin, but only accommodated 700 evacuees (10% of capacity) (Jankowski, 2017).

If an evacuation order were to be issued in the Houston MSA, many factors could impede compliance. First, as evident from the shelter strain experienced after Hurricane Harvey, there might not be enough evacuation shelter capacity in the MSA to accommodate the number of residents seeking a safer location to ride out the storm. Second, residents may not evacuate due to the cost and logistic concerns associated with the process. Many previous evacuation studies (Peacock et al., 2012; Howell, 1998; Elder et. al., 2007; Smith & McCarthy, 2009) have found a positive association between higher income and willingness to evacuate. Successful evacuation typically requires access to reliable transportation and access to an adequate amount of money for gas and hotels (Elder et al., 2007; Landy, 2007). However, 69% of U.S residents report having less than $1,000 of savings that could be used to facilitate evacuation (Huddleston, 2016). Therefore, many would-be evacuees would rely on regular income to finance an evacuation. Unfortunately, this means that an end-of-month evacuation, required due to the timing of Hurricane Harvey, may be financially infeasible for many residents.

In addition to the costs of evacuation borne by residents, evacuations are estimated to cost governments $1 million per mile of coastline (Davies, 2017). Because Hurricane Harvey-associated flooding was predominantly due to inland precipitation, rather than storm-surge, established evacuation zones may not have accurately delineated the exposed groups as much as the floodplains. However, in a survey conducted in the Houston-Galveston region in 2017, Brody et al. (2017) showed that most residents do not know if they live in floodplains. Finally, regardless of financial and logistical constraints, some residents simply refuse to evacuate, no matter the circumstances, even when mandatory evacuation orders are issued (Baker, 1991). Social and cultural factors, observation of peers evacuating, educational level, geographical ties with the area of residence, and many other factors also play a role in resident's compliance to evacuation orders.

In this project, we attempted to answer the question, "Could Houston be Evacuated?" To do this, we objectively measured the shelter capacity of the region and identified the factors that predict resident evacuation decisions.

1.2 Evacuation Shelter Capacity

In the event of severe hurricanes, most residents evacuate low-lying and vulnerable coastal areas, traveling to the homes of friends and family, or staying in paid accommodations. A small proportion of residents living in evacuation zones – typically estimated to be between 10% and 25% - utilize available public shelters (Baker, 2000; Connecticut Hurricane Evacuation Study, 1994). Low-income residents and those living in multi-family homes are more likely to utilize public shelters during a hurricane emergency (Perkins, 1996). Despite the relatively low percent of residents that utilize public shelters, demand can impose a severe strain on the limited number of available facilities and pose challenges to local governments and the American Red Cross (ARC), which typically manages shelter operations. Public shelter locations are limited in part due to American Red Cross specifications for the types and locations of facilities that can serve as public shelters, which were introduced in 1992 after a flood in McClellan Ville, South Carolina, submerged a shelter facility to a depth of five feet while occupied with evacuees.

After a very active 2005 hurricane season - 5 hurricanes made landfall in the U.S. Gulf of Mexico (Cindy, Dennis, Katrina, Rita, and Wilma) – the highly visible strains to the evacuation and response systems prompted the Governor of Texas to establish a 14-member task force to recommend ways of improving evacuation and sheltering. While the task force made recommendations related to improvement needed in command and control and emergency operations during hurricanes (Harris County Office of Homeland Security & Emergency Management (HCOHSEM), 2006), little attention was paid by the task force to the prevailing shelter space deficits in the state. The extent to which the shelter designs conform to ARC guidelines was also not addressed by the task force. Most of the spatial studies on evacuation capacity estimate the total number of people each individual evacuation shelter could hold (per square meter) rather than the proportion (absolute or relative) of population that could be accommodated (Xu et al., 2008).

Florida has been cited as one of the states that attained a significant milestone in improving evacuation shelter deficits. In 2006, the state estimated a statewide shelter space deficit of 386,379 persons for category 5 hurricanes. It also identified deficits in seven of its 11 planning regions and in 49 of its 67 counties (Florida Technical Report (FTR), 2018). By 2018, the state has eliminated its statewide deficit of the general population evacuation shelter space, at the aggregate level, with deficits observed in only three of ten planning regions and 24 of its 67 counties. Assuming no additional shelter spaces are introduced in the state, seven out of 10 general shelter spaces would continue to be sufficient through 2023 (FTR, 2018). For example, ahead of hurricane Irma in 2017, nearly all 67 counties in Florida and over 6 million vulnerable residents were issued evacuation orders, and about 200,000 citizens were sheltered across the state (FTR, 2018). As of January 1, 2018, a total of 1,002,757 shelter spaces are available. An estimated 1,039,468 spaces are projected to be available by the hurricane season of 2018 (FTR, 2018).

1.3 Factors Associated with Hurricane Evacuation

Factors that predict hurricane evacuation have been studied extensively (Baker, 1991; Peacock et al., 2012; Dow & Cutter, 1998). Results have shown that individuals make decisions in the context of actual and perceived risks as well as social and economic constraints. While some of these predictors are consistent across studies, others had conflicting, mixed, or no effects on predicting evacuation.

In the first major review of evacuation studies, Quarantelli (1980) developed a model of evacuation that included community context, threat conditions, social processes, patterns of behavior, and community preparedness based on about a dozen large scale, random-sample population surveys of communities impacted by floods, tropical storms, hurricanes, tornados, and manmade accidents. The next review (Baker, 1991) demonstrated through analysis of a large database constructed from surveys conducted following 12 hurricanes that made landfall in the US between 1961 and 1989 that there were not consistent associations between demographic factors and evacuation. However, Peacock et al. (2012), using data from Hurricane Andrew found that race had mixed results in predicting evacuation behavior. When demographic and household variables were included in the model, and indicators of 'risk' excluded, blacks and Hispanics were less likely to evacuate than whites. However, when risk indicators were included in the model, no significant differences in evacuation behavior were observed by race. In addition, the authors found that household size, presence of children or elderly negatively impacted evacuation behavior. The inconsistency in the association of demographic factors and evacuation was explored by Horney et al. (2012) who found that social factors could be acting as modifiers of in the relationship between the demographic variables and evacuation.

The effect of mobile home residence has been more consistent across studies. Many authors related that mobile home residence predicted evacuation. For example, Dow & Cutter (1998) found that the greatest determinant of hurricane evacuation behavior is personal perception of risk. Thus, individuals that live in mobile homes are more likely to evacuate since they know their homes are typically not sturdy enough to withstand hurricane impacts. In addition, families that reside in multi-unit buildings were more likely to evacuate than those who lived in single-family dwellings, who often remain to protect their homes (Dow & Cutter, 1998). In contrast to this observation, Horney et al. (2010) found no association between individual actual or perceived property flood risk and evacuation behavior from Hurricane Isabel in 2003 or from Hurricane Irene in 2011 (Wallace et al., 2016). Although the authors found statistically significant correlations between individual perceived risk and actual risk, neither was associated with evacuation.

The assessment of the association between income and evacuation has also yielded mixed results in the literature, with some authors reporting a positive relationship (Peacock et al., 2012) and others, an inverse association (Whitehead, 2003; Smith, 1999). The justification for the latter finding has been that wealthy families may own higher risk coastal property subject to waves and surge, that they may perceive their homes to be of higher quality and therefore able to withstand a strong storm, or that they may be more likely to remain in their homes to protect valuables. In the converse, a positive association between income with evacuation might be due to the relative ease that higher income residents have in financing the expenses associated with evacuation. Baker (1991) also demonstrated that the dissemination of information predicts evacuation. People are more likely to evacuate when they receive evacuation information from non-media sources like public officials, the government, or family and friends. They are also more likely to evacuate when public officials are proactive about issuing evacuation orders. Peacock et al. (2012) also made similar observations about the evacuation from Hurricane Andrew in Florida.

Mixed results have been published related to the effect of length of residence in a hurricane prone area and evacuation behavior. While some authors found a positive association (Baker, 1991), others found a negative or no association with evacuation behavior (Peacock et al., 2012). Logically, the length of residence could impact evacuation decision making both positively or negatively. New residents in an area could decide to evacuate because of their heightened perceived risk, but they could also decide not to evacuate because of their inexperience with risk in the area. On the other hand, long-term residents could decide to evacuate because of prior experience with hurricane landfalls in the area, or decide not to, because of their perceived safety of the area.

Overall, the hurricane evacuation literature reports many mixed or inconclusive findings related to factors that may impact evacuation behavior. Although numerous studies have identified associations of these factors with evacuation, the direction and magnitude of these associations vary widely. Except for mobile home residence and the means of information dissemination, which were found to positively inform evacuation, most variables do not have a clearly defined association with evacuation behavior.

1.4 Application of Short Form-12 (SF-12) to Disaster Studies

Short Form-12 (SF-12), the abbreviated version of SF-36, is a multipurpose short-form instrument that serves as a generic measure of self-rated health status. Although SF-36 has been shown to be valid for assessing the health outcomes of populations, psychometrically sound, and free of charge, many surveys do not incorporate the form because of its length and interview time burden (Ware et al., 2005). To overcome this limitation and increase the utility of the instrument, a subset of SF-36 was created, SF-12, which measures physical and mental health scores with accuracy of at least 90% (Ware et al., 1996). SF-12 has proven to be of high quality and can be administered in two minutes or less (Ware et al., 1996).

SF-12 includes 12 items (derived from SF-36) that are part of eight health concepts, including physical functioning, role limitations due to physical health problems, bodily pain, general health, vitality (energy/fatigue), social functioning, role limitations due to emotional problems, and mental health (psychological distress and psychological wellbeing). Each health concept is represented by one or two items as illustrated in Table 1.1.

Mental Component Summary Score (MCS) and Physical Component Summary Score (PCS) are normalized to the U.S standard population with a standard deviation of 10 and mean of 50. Higher scores signify better perceived health status. More information on SF-12 can be found in Ware et al. (1996).

Table 1.1. Number of SF-12 Health Survey Items per Concept.

Concept	SF-12
Physical Functioning	2
Role-Physical	2
Bodily Pain	1
General Health	1
Energy/Fatigue	1
Social Functioning	1
Role-Emotional	2
Mental Health	2

In addition to the immediate health impacts of hurricanes, they are often associated with secondary health effects. Secondary effects could be a consequence of long-term displacement or extended recovery (Quarantelli, 1997). The resilience of individuals and communities in the face of disaster has been measured by the ability of this population to adapt to the accompanying shock and major stresses. Mental health outcome may serve as a marker for such adaptation. Schwartz et al., (2018) investigated the prevalence of PTSD in residents exposed to Harvey in the greater Houston area. The results indicated PTSD in 46% of the study participants and higher odds of developing the disease with exposure to hurricane Harvey (OR=1.42; 95% CI: 1.06-2.05). Similar results were obtained by Taioli et al., (2018) among Hurricane Harvey residents displaced to temporary evacuation shelters. In another study conducted by Abramson et al. (2008) to measure the mental health outcomes of 1,077 displaced residents post-Katrina, high prevalence of poor self-rated mental health was observed among the study participants. Also, higher numbers of children in a household and lower self-efficacy were associated with poor mental health outcomes after hurricanes, while informal social support networks were associated with better mental health outcomes among the participants.

Hyre et al. (2008) measured the psychosocial status of hemodialysis patients one year after Katrina. Results showed that the 391 study participants had a mean (SD) PCS of 37.1 (10.9) and MCS of 46.7 (12.7). Evacuating less than 2 days prior to landfall and reporting a high level of fear of dying were associated with lower MCS scores. Also, patients who were displaced longer in evacuation shelters had poorer MCS status. Lower PCS was associated with fear of dying, evacuation to a hotel, and hospitalization a month before Katrina made landfall. In general, the MCS scores of the participants were lower than their PCS scores, pointing to poorer perceived mental health outcomes post-disaster.

1.5 Hurricane Evacuation Zip-Zones

Officials of the Houston-Galveston area identified Zip-Zones that would be triggered for evacuation as hurricane moves towards the coast. These Zip-Zones are delineated by ZIP codes and evacuation orders are issued to residents of each zone depending upon the predicted wind speed and surge height. About 20 to 25% of the population of Houston is estimated to live in evacuation zones (Houston Public Media (HPM), 2018). The proposition is that residents in coastal Zip-Zone and Zip-Zone A would be evacuated first, followed by evacuation Zip-Zones B and C (Blackburn, 2017).

The hurricane evacuation Zip-Zone map was designed primarily to respond to the threat of wind and surge (HPM, 2018; Blackburn, 2017). Although Hurricane Harvey was predominantly characterized by inland precipitation rather than surge, this study will utilize the evacuation Zip-Zone map to estimate evacuation shelter space deficit in the region. This is because the floodplain map in Houston is outdated, and with rapid development and increases in the proportion of impervious surfaces, may not reflect areas of actual risk (Blackburn, 2017). For example, many neighborhoods not located in flood zones (as shown by the floodplain map) were flooded by Harvey (Citylab, 2017). Another reason for using the Zip-Zone is overall resident lack of awareness about residency in a floodplain. In a survey conducted by Brody et al. (2007), most Houstonians do not know they live in floodplains, so the use of floodplain maps to calculate shelter demand may bias the estimation of shelter demand for the study. Finally, the State of Florida, which eliminated its general shelter space deficit through 2023, also utilized evacuation zones to estimate shelter demand.

1.6 Specific Aims

Aim 1: Spatially describe the hurricane evacuation shelter space deficit in the Houston-Galveston region.

Objective 1.1: Describe the spatial distribution of evacuation shelters in the region.

Objective 1.2: Estimate the evacuation shelter space deficit in the region.

Rationale: Estimating shelter distribution and space deficit is essential to improving evacuation shelter capacity in the Houston region.

Aim 2: Using a statistical meta-analysis, investigate the factors associated with hurricane evacuation.

Objective 2.1: Investigate the factors associated with hurricane evacuation.

Objective 2.2: Identify the factors that explain the heterogeneity across hurricane evacuation studies.

Rationale: The enumeration of factors that predict evacuation may help authorities provide targeted interventions to vulnerable groups and increase the efficiency of evacuation in hurricane emergencies.

Aim 3: Calculate the self-rated mental and physical health scores (SF-12) for Texas residents (N=1,086) living in counties at-risk from hurricanes and flooding; Identify the factors associated with self-rated health

Objective 3.1: Assess the self-rated health (both physical and mental) of residents of the Texas Gulf Coast after hurricane Harvey.

Objective 3.2: Identify the factors associated with variations in self-rated health.

Rationale: To adequately inform disaster preparedness, mitigation, and recovery plans and policies, a better understanding of the prevalence of mental health morbidity in the population impacted by Hurricane Harvey is needed, along with the identification of factors that predict mental health wellness in this population.

2. A SPATIAL ANALYSIS OF HURRICANE EVACUATION SHELTER CAPACITY IN THE HOUSTON-GALVESTON METROPOLITAN STATISTICAL AREA OF TEXAS

2.1. Introduction

The coastal regions of the U.S. Atlantic and Gulf of Mexico are attractive places to live and work but are increasingly exposed to some of the most powerful storms on earth. Since 1980, hurricanes and tropical storms causing more than $1 billion in damages have increased from an average of 0.4 per year to more than 1 per year (National Research Council, 2014). According to Hanson et al. (2011), eight of the twenty cities most at risk from flood losses from coastal storms in the world are located along the U.S. Atlantic and Gulf Coast. Population growth rates in Southeastern Atlantic (20.8%) and U.S. Gulf Coast (17.8%) regions was been nearly double the national average (11.4%) between 2000 and 2012, and much of this growth has been among vulnerable populations such as the elderly, the working poor, and racial and ethnic minorities (NRC, 2014; Cutter & Emrich, 2006). The persistent movement of people and economic development to coastal regions has dominated the growth in disaster losses for much of the past century (Pielke et al., 2008). Since 1960, despite large national efforts to reduce the impacts and costs of disasters, average annual federal expenditures to fund rebuilding from catastrophic losses in the U.S. have been rising faster than either overall population or gross national product (Cutter & Emrich, 2006).

In late August 2017, Hurricane Harvey was observed to approach the Gulf Coast of Texas. It rapidly gained strength and became a Category 4 storm on the Saffir-Simpson scale with sustained winds of 135 – 150 miles per hour. As the storm strengthened, authorities in several coastal counties issued mandatory evacuation orders (WFAA, 2017). However, officials in Harris County and the City of Houston – a metropolitan area larger than New Jersey with more than 6 million residents – did not issue evacuation orders. Reasons given for not issuing evacuation orders included the uncertainty of the storm's path, the prediction that the storm would primarily be a rain (not wind) event, and the short time available to move millions of people (Andone, 2017; Malewitz, 2017; Domonoske, 2017; Wang et al., 2017). The city's failed evacuation from Hurricane Rita in 2008, which resulted in 107 evacuation-related fatalities, likely also played a role in the decision not to order evacuations as Hurricane Harvey approached (Domonoske, 2017).

Although mandatory evacuation orders were not issued in most of the counties in the Houston-Galveston Metropolitan Statistical Area (MSA), more than 30,000 residents sought a place to stay at local evacuation shelters (Dwyer, 2017). According to media reports, many evacuation shelters in the Houston MSA were filled beyond capacity (Kelly, 2017; O'Donnell, 2017), while other shelters were themselves impacted by flooding that submerged cots and forced evacuees to relocate to other shelters that were not impacted (MFS, 2017). Although evacuation shelters were provided for Houston-Galveston MSA residents in Dallas, Austin, and San Antonio, most of these facilities were under-utilized due to the inability of Houston residents to travel due to flooded roads (Jankowski, 2017). For instance, a shelter with a capacity of 7,000 was opened by the City of Austin, but only accommodated 700 evacuees (10% of capacity) (Jankowski, 2017).

If an evacuation order were to be issued in the Houston MSA, many factors could impede compliance. First, as evident from the shelter strain experienced after Hurricane Harvey, there might not be enough evacuation shelter capacity in the MSA to accommodate the number of residents seeking a safer location to ride out the storm. Second, residents may not evacuate due to the cost and logistic concerns associated with the process. Many previous evacuation studies (Peacock et al., 2012; Howell, 1998; Elder et. al., 2007; Smith & McCarthy, 2009) have found a positive association between higher income and willingness to evacuate. Successful evacuation typically requires access to reliable transportation and access to an adequate amount of money for gas and hotels (Elder et al., 2007; Landy, 2007). However, 69% of U.S residents report having less than $1,000 of savings that could be used to facilitate evacuation (Huddleston, 2016). Therefore, many would-be evacuees would rely on regular income to finance an evacuation. Unfortunately, this means that an end-of-month evacuation, required due to the timing of Hurricane Harvey, may be financially infeasible for many residents.

In addition to the costs to residents, evacuations are estimated to cost governments $1 million per mile of coastline (Whitehead, 2003). Because flooding associated with Hurricane Harvey was predominantly due to inland precipitation rather than storm-surge, established evacuation zones based on predicted storm surge may not have accurately described the groups most likely to be exposed to flooding. However, while Federal Emergency Management Agency (FEMA) National Flood Insurance Program's designated floodplains may be more appropriate for identifying those likely to be exposed to flooding because of inland precipitation, most residents of the Houston-Galveston MSA do not know if they live in floodplains (Brody et al., 2017).

2.1.1. Evacuation Shelter Capacity

In the event of severe hurricanes, most residents evacuate low-lying and vulnerable coastal areas, traveling to the homes of friends and family or staying in paid accommodations (Dash & Gladwin, 2007). A small proportion of residents living in evacuation zones – typically estimated to be between 10% and 25% - utilize available public shelters (Baker, 2000; U.S Army Corps of Engineers, 1994). Low-income residents and those living in mobile homes and multi-family homes are more likely to utilize public shelters during a hurricane emergency (Perkins, 1996). Despite the relatively low proportion of residents that utilize public shelters, demand for shelters can impose a severe strain on the limited number of facilities. For example, facilities are required to meet American Red Cross (ARC) specifications related to the types and locations of facilities that can serve as public shelters. These regulations were introduced in 1992 after a flood in McClellanville, South Carolina, submerged a shelter facility to a depth of five feet while occupied with evacuees (Coch et al., 1991).

After a very active 2005 hurricane season – five hurricanes made landfall in the U.S. Gulf of Mexico, including Cindy, Dennis, Katrina, Rita, and Wilma – the highly visible strains to the evacuation and response systems prompted the Governor of Texas to establish a 14-member task force to recommend ways of improving evacuation and sheltering. While the task force made recommendations related to improvements needed in command and control and emergency operations during hurricanes (HCOHSEM, 2006), little attention was paid to the prevailing shelter space deficits in the state or the extent to which shelter designs conform to ARC guidelines.

The State of Florida is one model that Texas could follow with regard to addressing shelter deficit, having attained the milestone of eliminating evacuation shelter deficits in 2018 (FTR, 2018). After a 1995 assessment of existing evacuation shelters, the State of Florida enacted a statute that mandated district schools serve a dual-purpose role as evacuation shelters. Existing shelters were retrofitted, with school-based shelters being remodeled to meet ARC shelter design guidelines. By 2006, the State of Florida estimated that it had a statewide shelter space deficit of 386,379 persons for a Category 5 hurricane. It also identified deficits in seven of its 11 planning regions and in 49 of its 67 counties (FTR, 2018). By 2018, the state has eliminated its statewide deficit of the general population evacuation shelter space, at the aggregate level, with sufficient general shelter space based on population growth estimates through 2023 (FTR, 2018). As of January 1, 2018, a total of 1,002,757 shelter spaces are available. An estimated 1,039,468 spaces are projected to be available by the hurricane season of 2018 (FTR, 2018). For example, ahead of Hurricane Irma in 2017, nearly all 67 counties in Florida and over 6 million vulnerable residents were issued evacuation orders, and about 200,000 citizens were sheltered across the state (FTR, 2018).

To attain sufficient evacuation shelter capacity in the Houston MSA, an initial appraisal of the existing shelter deficit is required, similar to the investigation conducted by the State of Florida in 1995 (FTR, 2018).

In response to current planning gaps and limitations in evacuation and shelter capacity, this study employed spatial statistics to describe the geospatial distribution of evacuation shelters in the Houston-Galveston MSA and estimate the evacuation shelter space deficit in the area. Specifically, we examined and analyzed the spatial distribution of the shelters (assessing for clustering and dispersion within the area) and estimated existing shelter deficits. Shelter deficits were estimated in four ways– the aggregate deficit in the Houston-Galveston MSA; deficit by evacuation Zip-Zone, deficit by county, and deficit by distance or radii of evacuation Zip-Zone. Estimating shelter space deficits is critical to allowing relevant authorities plan for and improve Texas' shelter system for optimal hurricane evacuation.

2.2. Methods

2.2.1. Study Area

The Houston-Galveston MSA of Texas (Fig 2.1) comprises 13 counties including Austin, Colorado, Wharton, Fort Bend, Waller, Brazoria, Chambers, Galveston, Harris, Matagorda, Montgomery, Walker and Liberty (HGAC 2018). Evacuation shelters are spread across the MSA (Fig 2.2). However, six counties contribute to the formation of the evacuation Zip-Zones: Matagorda, Chambers, Brazoria, Galveston, Harris & Liberty. The total population of the Houston-Galveston MSA is 7,064,712 (HGAC, 2018; U.S. Census Bureau, 2017).

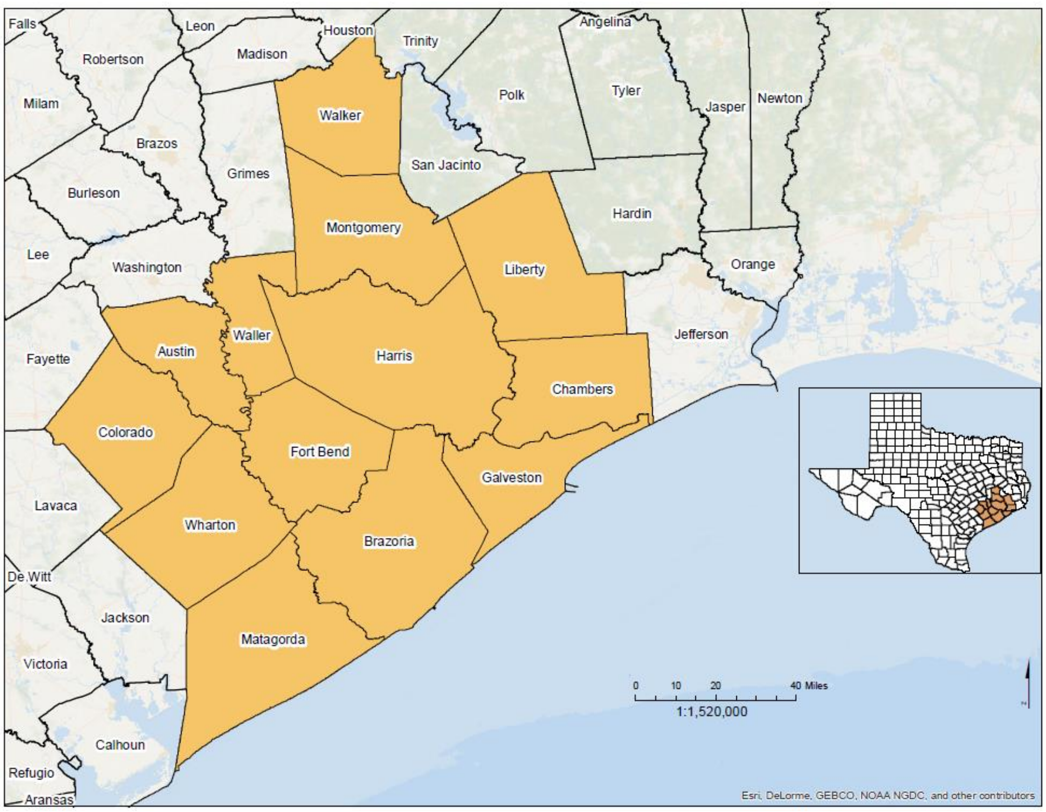

Figure 2.1. The Houston-Galveston MSA of Texas.

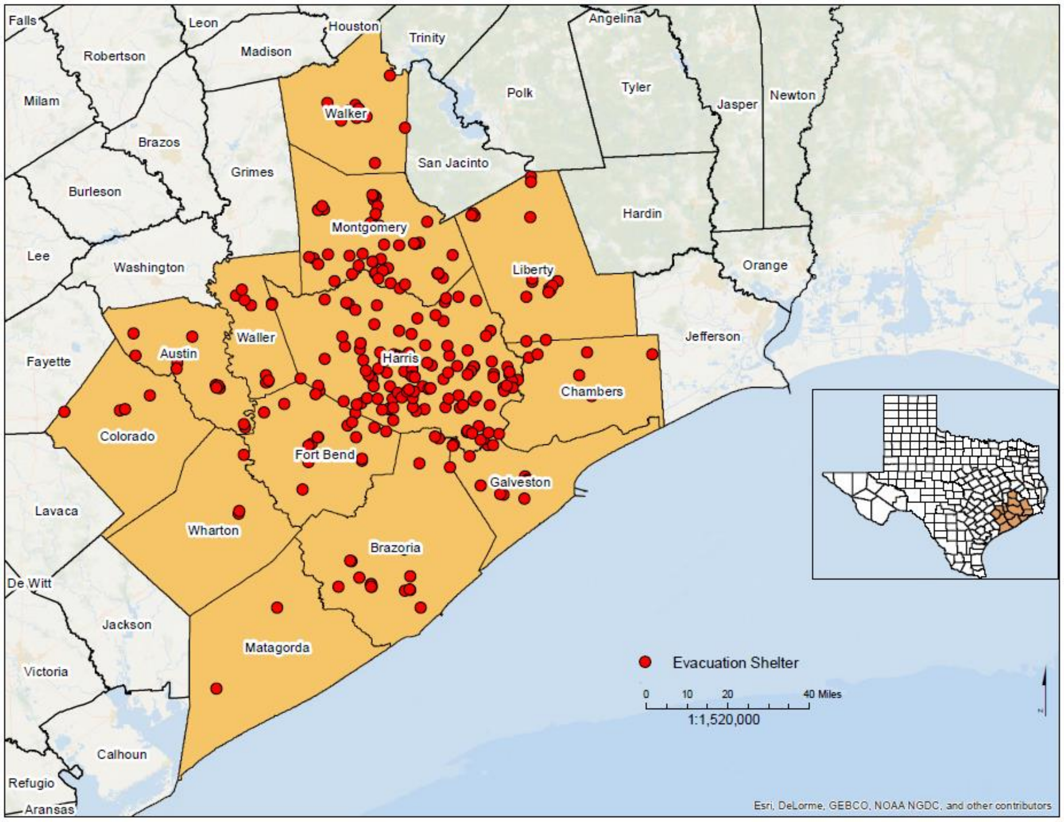

Figure 2.2. Evacuation Shelters in the Houston-Galveston MSA of Texas.

2.2.2. Hurricane Evacuation Zip-Zones

As part of hurricane disaster planning, Houston-Galveston area officials identified Zip-Zones along the coast and some inland areas that could be triggered for evacuation orders as a hurricane moves towards the Texas Gulf Coast. These Zip-Zones are delineated by ZIP Codes and evacuation orders are issued to residents of each zone depending upon the predicted wind speed and surge height. About 20 to 25% of the population of Houston is estimated to live in an evacuation zone (HPM, 2018). In hurricanes predominantly characterized by storm-surge, emergency plans indicate that residents in the Coastal Zip-Zone and Zip-Zone A would be evacuated first, followed by evacuation Zip-Zones B and C (Blackburn, 2017).

The hurricane evacuation Zip-Zone map was designed primarily to respond to the threat of wind and surge (HPM, 2018; Blackburn, 2017). While Hurricane Harvey was predominantly characterized by inland precipitation rather than surge, this study will utilize the evacuation Zip-Zone map to estimate evacuation shelter space deficit in the MSA. This is because the floodplain map in Houston is outdated, due to rapid development and increases in the proportion of impervious surfaces and may not reflect areas of actual risk (Blackburn, 2017). For example, many neighborhoods not located in flood zones, as designated by the Flood Insurance Rate Maps, were flooded by Harvey (Texas Natural Resources Information System, 2018; Citylab, 2017). Another reason for using the Zip-Zone is overall resident lack of awareness about whether or not their residence is located in a designated floodplain. In general, a majority of residents underestimate the flood zone in which their home is located (Horney et al., 2010; Wallace et al., 2016), an underestimation that may or may not impact their decision to evacuate (Horney et al., 2010). In the Houston-Galveston MSA specifically, most residents surveyed in 2017 did not know they lived in floodplains (Brody et al., 2017), so the use of floodplain maps to calculate shelter demand in Houston may bias the estimation of shelter demand for the study. Third, because Hurricane Harvey was primarily a rain event, the amount of localized precipitation may have been more predictive of flooding than residence in a floodplain or evacuation zone (King, 2017). Florida also utilized evacuation zones to estimate shelter demand in its successful effort to eliminate shelter deficit.

2.2.3. Data Sources & Software

Data on evacuation shelters in the Houston-Galveston MSA were obtained from Federal Emergency Management Agency (FEMA). Regional boundary data on counties and ZIP Codes were obtained from the Houston-Galveston Area Council (HGAC) (2018). Demographic information was obtained from SimplyAnalytics (New York, 2017).

ArcMap 10.4.2 (Redlands, California) was used for the analysis.

2.2.4. Spatial Analysis

2.2.4.1. Cluster Analysis

Spatial clustering occurs when the distribution of a variable of interest (e.g. evacuation shelter, crime) exhibits a systematic or non-random distribution in space (Anseline & Griffith, 1988). The phenomenon is often identified using measures of spatial autocorrelation. Positive spatial autocorrelation occurs when similar responses cluster together, while negative spatial autocorrelation refers to the clustering of dissimilar responses. Although, in multivariate models, spatial autocorrelation of residuals may result in biased parameter estimates and invalid significance levels (Can, 1990; Ding, 2001), the phenomenon has found considerable utility in the natural sciences, including public health. For example, Ahmadkhani and colleagues (2018) used spatial autocorrelation to describe the spatial distribution of Crimean Congo Hemorrhagic Fever in Iran. The authors also employed spatial statistics to identify areas with clusters (hotspots) of the disease. The phenomenon has also been used to describe the spatial distribution of Dengue Hemorrhagic Fever in Ecuador (Castillo et al., 2001); the gender difference in the distribution of alcohol-related mortality in Scotland (Emslie & Mitchell, 2009); and the geographic areas with high risk of infant mortality in Mexico (Alvarez et al., 2009). Social scientists also employ spatial autocorrelation to improve understanding of socio-economic trends. For example, the effect of housing price on development policies (Baumont, 2004); and the association between fringe banking and neighborhood crime rates (Kubrin et al., 2011; Van Zandt et al., 2013).

2.2.4.2. Investigating for Global Clustering (Global Moran's I)

The current study employed Global Moran's I to determine if clustering of evacuation shelters (by capacity) existed in the Houston-Galveston MSA. The Global Moran's I statistic measures the spatial autocorrelation of the shelters (by capacity) using a null hypothesis that assumes a 'complete spatial randomness (CSR)' of the evacuation shelters (by capacity). Therefore, statistically significant point estimate (Z-statistic) would result in the rejection of the null hypothesis and conclusion of a possible non-random distribution (clustering) of the shelters. Although the Global Moran's I statistic is helpful in identifying the presence of spatial clustering in the overall data, it does not describe the specific locations where the clustering occurs.

2.2.4.3. Investigating for Local Clustering (using Getis-Ord Gi*)

Because Global Moran's I statistic did not identify the specific clustering locations in the Houston-Galveston MSA, Local Indicators of Spatial Association (LISA) were used to identify these locations. Specifically, the Getis-Ord (Gi*) spatial statistic tool was used to identify areas with local spatial clustering of evacuation shelters (by capacity). Like the Global Moran's I, Gi* statistic also provided a z-score and precision estimates to determine the rejection or otherwise of the null hypothesis.

2.2.4.4. Estimation of Evacuation Shelter Space Deficit

To investigate evacuation shelter space deficit, the multiple ring buffer tool was used to map areas within 20, 30 and 40-mile radii of each of the evacuation Zip-Zones, as illustrated in Fig. 2.3. Subsequently, the ‘Select by Location’ function was used to choose only shelters that fall within each of the listed radii, and the total shelter space capacity, estimated.

The county-level shelter space deficit was estimated by first excluding the seven counties in the MSA that fall outside of the evacuation zones (Walker, Montgomery, Waller, Austin, Colorado, Wharton, and Fort Bend). Subsequently, the ZIP Codes comprising each of the counties were screened and only those that intersect with evacuation zone boundaries were included for the analysis. The population from these ZIP Codes was used to estimate the shelter demand for each county. Finally, to estimate ‘sufficient shelter capacity’, the shelters that fall within each of the counties were selected using the ‘select by location’ feature, and their total capacity estimated.

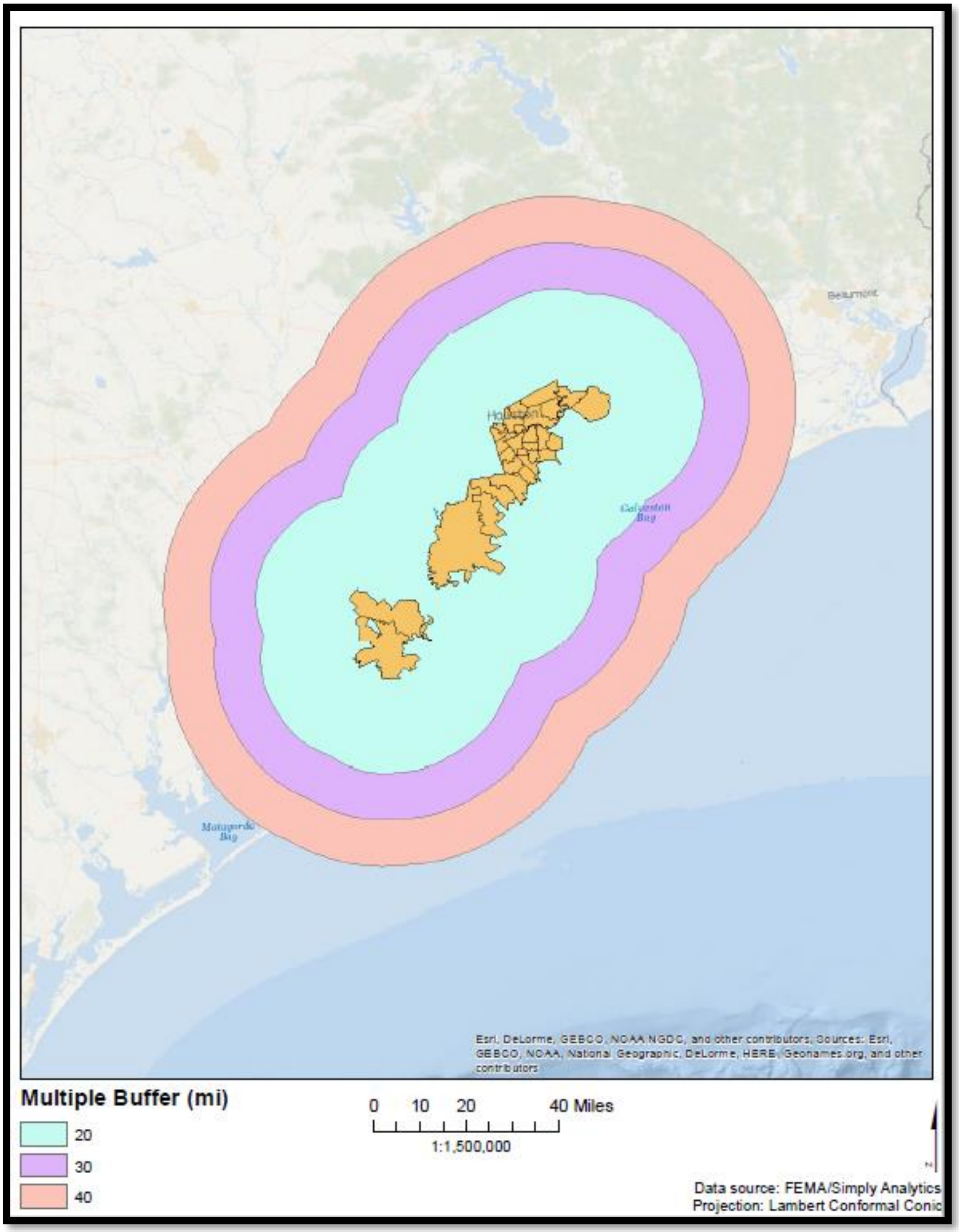

Figure 2.3. Multiple Ring Buffer (20, 30 & 40 mi) around Evacuation Zone C.

2.3. Results

There were 280 evacuation shelters in the Houston-Galveston MSA with a total capacity of 91,600 persons. Churches constituted about 56% of the shelters (Table 2.1).

Table 2.1. Evacuation Shelter Categories in the Houston-Galveston MSA.

Shelter Category	Frequency	Proportion (%)
Church	157	56.07
School	56	20.00
Community center	49	17.50
*Others	18	6.43
Total	**280**	**100.0**
*Courthouse, car dealership, convention center, veteran center, vacant building, mall, elderly home, library, and bar		

The four evacuation zones (Coastal, A, B, and C) had a total population of 1.78 million people- equivalent to 25.2% of the total population in the Houston-Galveston MSA (Table 2.2). Evacuation Zone C had the highest population of 995,409 people while the Coastal Zone had the lowest population (Table 2.2).

Table 2.2. Population Distribution in the Evacuation Zones in the Houston-Galveston MSA.

Evacuation Zone	**Population**	**Number of ZIP Codes**
Coastal	104,697	11
A	261,839	12
B	419,306	23
C	995,409	33
Total	1,781,251	79

2.3.1. Shelter Distribution

The overall data were interrogated to determine if spatial clustering of evacuation shelters existed by capacity. Global Moran's I statistic was estimated (Moran's Index=0.165; *Z* Score=2.45; P-value=0.01) which showed statistically significant clustering patterns of shelters in the Houston-Galveston MSA. To specifically identify areas of clustering, the Getis-Ord (Gi*) statistic was estimated. Results showed that shelters with higher capacity were clustered around Montgomery and Walker counties (farther away from the evacuation zones), while shelters with lower capacity were clustered around Harris, Fort Bend, Waller, and Austin counties, nearer the evacuation zones (Fig. 2.4).

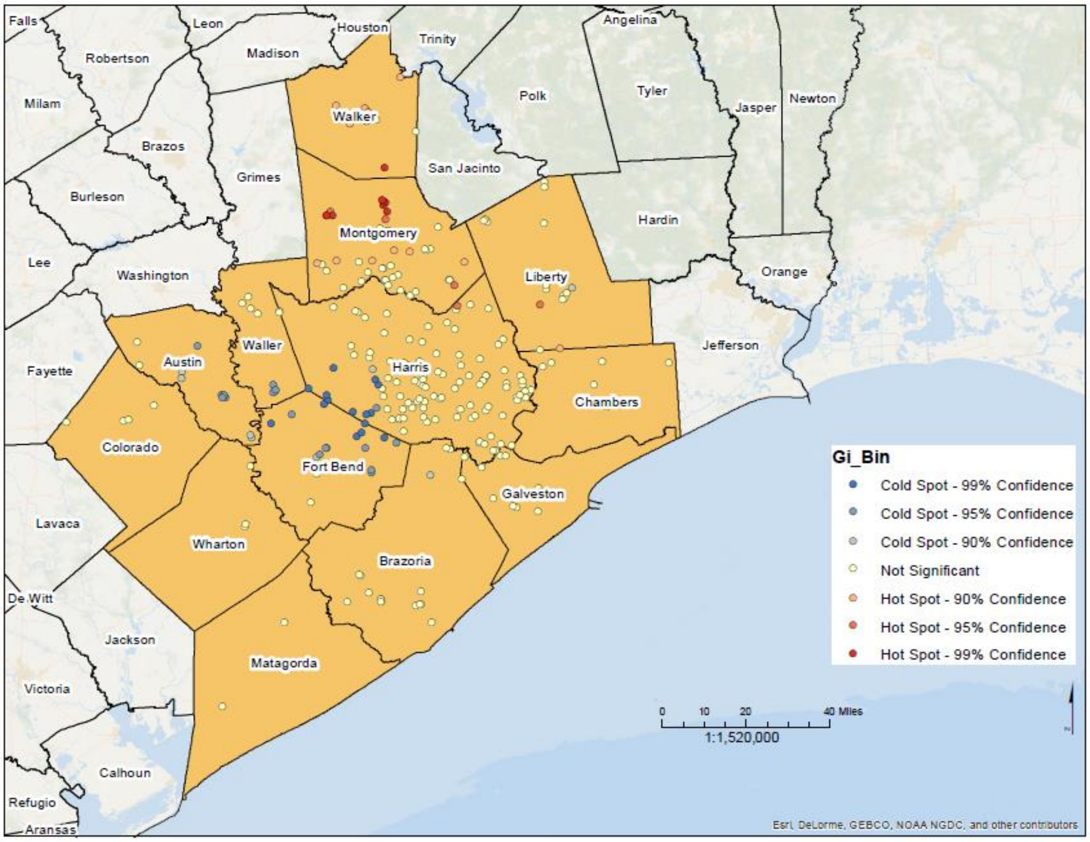

Figure 2.4. Map of the Houston-Galveston MSA Illustrating the Spatial Clustering of Evacuation Shelters by their Capacity.

2.3.2. Shelter Deficit

We investigated shelter deficits in four dimensions – aggregate (regional) deficit, deficit by evacuation zone, deficit by distance and deficit by county. Table 2.3 describes the shelter space deficit by evacuation Zip-Zones in the Houston-Galveston MSA. At the regional level, the absolute shelter space deficit is 353,713 persons, while the relative deficit is 21%. To eliminate shelter deficit in the MSA, additional shelter space for 353,713 persons would be needed. Only 21% of the population in the four designated evacuation zones can be accommodated in the available shelters in the MSA. If evacuations were ordered only for the Coastal Zone or Zone A, there would be no deficits. However, deficits would exist if the population in Zone B or Zone C is evacuated since only 37% of the population in Evacuation Zone C could be accommodated.

Table 2.3. Evacuation Shelter Space Deficits by Evacuation Zones in the Houston-Galveston MSA.

Evacuation Zone	Population (persons)	Shelter Demand (0.25*Tot. Pop.)	Shelter Capacity (persons)	Absolute Shelter Deficits (persons)	Relative Shelter Deficit (*91,600/Demand)
Coastal	104,697	26,174	91,600	65,426	3.50
A	261,839	65,460	91,600	26,140	1.40
B	419,306	104,827	91,600	13,227	0.87
C	995,409	248,852	91,600	157,252	0.37
Total	1,781,251	445,313	91,600	353,713	0.21

The illustration of shelter deficit by distance/radius of evacuation is shown in Table 2.4. Deficit exists across shelters located within 20, 30 and 40 miles of the evacuation zones, except for the Coastal Zone, within a 40-mile radius. Thus, assuming the residents in the Coastal Zone can only afford a gallon of gas to evacuate into shelters within a 20-mile radius, only about 44% of them can be accommodated. In addition, a space for an additional 14,545 people would be required to accommodate all the Coastal Zone evacuees in shelters within the 20-mile radius.

Table 2.4. Evacuation Shelter Space Deficit by Radius (Distance) of Evacuation.

Evacuation Zip-Zone	Population (persons)	Estimated Demand (25%)	Shelter Capacity (20mi)	Absolute Deficit 20 mi	Relative Deficit 20 mi (Shelter cap./Demand)	Shelter Capacity (30mi)	Absolute Deficit 30mi	Relative Deficit 30 mi (Shelter cap./Demand)	Shelter Capacity (40mi)	Absolute Deficit 40mi	Relative Deficit 40 mi (Shelter cap./Demand)
Coastal	104,697	26,174	11,629	14,545	0.44	20,831	5,343	0.80	38,614	12,440	1.48
A	261,839	65,460	31,115	34,345	0.48	43,356	22,104	0.66	56643	8,817	0.87
B	419,306	104,827	45,434	59,393	0.43	55,833	48,994	0.53	67,783	37,044	0.65
C	995,409	248,852	52,679	196,173	0.21	63,780	185,072	0.26	73,552	175,300	0.30

Table 2.5. Evacuation Shelter Space Deficit by County in the Houston-Galveston MSA of Texas.

County	Total # of ZIP Codes in evacuation zone	Total # of Shelters	Total Population (Exposed)	Shelter Demand (0.25*Tot. Pop.)	Shelter Capacity	Absolute Shelter Space Deficit	Relative Shelter Space Deficit
Brazoria	18	18	369,736	92,434	6,450	85,984	0.07
Chambers	7	9	87,739	21,935	3,152	18,783	0.14
Liberty	1	16	33,386	8,347	4,149	4198	0.50
Galveston	15	13	345,835	86,459	4,530	81,929	0.05
Matagorda	3	3	38,380	9,595	918	8,677	0.10
Harris	34	118	1,069,996	267,499	36,303	231,196	0.14

All the six counties included in the evacuation zones are deficient in shelter spaces (Table 2.5). The highest deficit is in Harris County, while the lowest is in Liberty County. An additional shelter space capacity of 4,198 persons is required to eliminate the shelter deficit in Liberty County. While 50% of the evacuees from Liberty County can be accommodated in shelters within the county, only about 14% of the evacuees from Harris County can be accommodated in its shelters.

2.4. Discussion

This study investigated the spatial distribution and capacity of evacuation shelters in the Houston-Galveston MSA. Results revealed that most of the large capacity shelters are clustered in Montgomery County, more than 120 miles from the Coastal Zone, while lower capacity shelters are clustered in Harris, Fort Bend, Waller and Austin Counties, about 50 miles from the Coastal Zone. Because the tool utilized for the analysis adjusts for population and county size, we assume that this observation is not confounded by either of these factors. Because of cost and other logistical factors associated with the decision to evacuate, residents are more likely to evacuate to a shelter closest to their residence (FTR, 2018). The inverse spatial relationship observed in this study, with larger capacity clusters located farther away from the evacuation zones, may therefore discourage residents from evacuating.

More than a quarter (25.20%) of the total population of the Houston-Galveston MSA, or approximately 1,781,251 people, live in one of four designated evacuation zones; however, the MSA has a shelter space deficit of 353,713. In other words, only 21% of the residents from the evacuation zones that seek public shelters can be accommodated. A similar study conducted in Florida in 2018 showed that Florida had met its goal of eliminating shelter deficits through 2023, partly through enacting a statute that mandates all district schools conform with ARC guidelines in the design and construction of their facilities. In the Houston-Galveston MSA, a majority of shelters are churches- institutions which are not under the direct jurisdiction of the government and can therefore not be required to be built to meet guidelines required to be designated as a hurricane evacuation shelter.

If all the ZIP Codes in the Coastal Zone or Zone A are triggered for evacuation, there will be enough evacuation shelter beds to accommodate all residents seeking shelter. This is an important observation because areas closer to the coast are at a higher risk of flooding than areas farther inland during storm-surge-predominant hurricane events. Therefore, the Coastal Zone is often evacuated first and evacuation Zone C, last. The sufficient evacuation capacity in the Coastal Zone and Zone A is due to the relatively smaller size of the population residing in these zones and hence, the lower demand.

Because evacuees can only reasonably be expected to travel a certain distance to seek public shelter accommodation during hurricanes, evacuation capacity was also investigated within 20, 30 and 40 miles of each of the evacuation zones. Except for the 40-mile radius of the Coastal Zone, all evacuation zones within the set radii are associated with shelter space deficits. For example, if residents in evacuation Zip-Zone C, are cash-strapped and can only afford a gallon of gas (20 miles) to ride out the storm, only 21% of these residents who are likely to seek public shelters can be accommodated. Alternatively, 196,173 additional shelter spaces would be required to accommodate the residents from zone C within this radius.

This study has substantive implications for local emergency managers and county officials. Results inform clustering of higher capacity shelters in counties farther away from designated evacuation zones. This requires evacuees to travel longer distances to reach shelters of high enough capacity to accommodate them. Efforts should be made by relevant authorities to increase the number of large-capacity shelters in counties more proximal to the evacuation zones. Overall, the Houston-Galveston MSA has a shelter space deficit of 353,713 persons, a 79% shortfall. Deficits in shelter space also exist in all 6 counties that constitute the evacuation zones, as well as in areas within 20, 30 and 40-mile radii of each of these zones. Therefore, improving the shelter capacity in the Houston-Galveston MSA will require a plan for strategic construction of these facilities in areas of higher demand.

While this study describes the spatial distribution of evacuation shelters and prevailing shelter deficit in the Houston MSA, it also has several limitations. First, Hurricane Harvey was predominantly characterized by inland precipitation rather than storm-surge and because the evacuation zone map was mainly designed for storm-surge hurricanes, the spatial analysis conducted in this study would be more valid for storm-surge hurricanes like Hurricane Ike and less relevant for Hurricane Harvey. However, we used the evacuation zones because the floodplain maps in Houston are likely outdated, and with rapid development and increase in the proportion of impervious surfaces, these maps may not reflect areas of actual risk (Blackburn, 2017). For example, many neighborhoods not located in designated flood zones in Flood Insurance Rate Maps were flooded by Harvey (Citylab, 2017). Another reason for using the Zip-Zone is overall lack of awareness about residency in a floodplain, so the use of floodplain maps to calculate shelter demand may bias the estimation of shelter demand for the study. Because the evacuation Zip-Zone do not fully coincide with postal designated ZIP Codes, the estimation of the populations in each of the zones may be affected by approximations. For example, evacuation Zip-Zones including a ZIP Code designated as north and south does not coincide with postal designated ZIP Codes. As such, we divided the population equally among two Zip-Zones.

While this might have affected the estimation of population in each of the Zip-Zones, it would not affect the aggregate population in all the zones.

Second, not all evacuees choose to use public shelters. Based on the literature, we estimated 25% of residents might choose to evacuate to a public shelter. However, actual shelter demand may be higher or lower than this estimate, and this could affect the estimated shortages in capacity. In Florida, regional behavioral surveys are regularly conducted to estimate shelter demand. Based on these surveys and the demographic characteristics of the region (e.g., income), shelter demand can be more accurately estimated (HCOHSEM, 2018). Similar surveys could be implemented in the Houston-Galveston MSA to provide more precise estimates for shelter demand.

After the devastating impacts of Hurricane Andrew in Florida, state officials began a process of assessing evacuation shelter capacity. To our knowledge, no such data is available for Texas. To the best of our knowledge, this is the first study in Texas and the Houston-Galveston MSA to investigate the spatial distribution and capacity of evacuation shelters. The results of this study could inform authorities in Harris County and the surrounding MSA about current shelter capacity and appropriate steps that could be taken to improve shelter capacity in the Houston-Galveston MSA.

3. FACTORS ASSOCIATED WITH HURRICANE EVACUATION- A STATISTICAL META-ANALYSIS OF STUDIES PUBLISHED BETWEEN 1999-2017

3.1. Introduction

Increased population density and development in coastal cities increases the likelihood of substantial damage due to disasters. Since the 1900 hurricane that killed more than 8,000 in Galveston, Texas, and changed the trajectory of the city's development as a port and economic center, the number of deaths associated with hurricanes and tropical storms has declined due in part to improved forecast and warning systems which alert residents to evacuate to prevent catastrophic consequences. Factors that predict hurricane evacuation have been studied extensively (Baker, 1991; Peacock et al., 2012; Dow & Cutter, 1998). Results have shown that individuals make decisions in the context of actual and perceived risks as well as social and economic constraints. While some of these predictors are consistent across studies, others had conflicting, mixed, or no effects on predicting evacuation.

In the first major review of evacuation studies, Quarantelli (1980) developed a model of evacuation decision-making that included community context, threat conditions, social processes, patterns of behavior, and community preparedness based on about a dozen large scale, random-sample population surveys of communities impacted by floods, tropical storms, hurricanes, tornados, and manmade accidents. In the next review, Baker (1991) demonstrated through analysis of a large database constructed from surveys conducted following 12 hurricanes that made landfall in the US between 1961 and 1989 that there were no consistent associations between demographic factors and evacuation. Peacock et al. (2012) used data from Hurricane Andrew, which impacted Florida in 1992, and found mixed results when assessing the association between race and evacuation behavior. When demographic and household variables were included in their models, and indicators of 'risk' excluded, blacks and Hispanics were less likely to evacuate than whites. However, when risk indicators were included in their models, no significant differences in evacuation behavior were observed by race. In addition, household size and the presence of children or elderly negatively impacted evacuation behavior. The inconsistency in the association of demographic factors and evacuation was explored by Horney et al. (2012) who found that social factors could be acting as modifiers in the relationship between demographic variables and evacuation.

The effect of mobile home residence has been more consistently positively associated with evacuation across multiple studies. For example, Dow & Cutter (1998) found that the greatest determinant of hurricane evacuation behavior is personal perception of risk. Thus, individuals that live in mobile homes are more likely to evacuate since they know their homes are typically not sturdy enough to withstand hurricane impacts. In addition, families that reside in multi-unit buildings were more likely to evacuate than those who lived in single-family dwellings, who often remain to protect their homes from flooding through the use of sandbags or pumps (Buckland & Rahman, 1999) or from looting or extended evacuation (Dow & Cutter, 1998). In contrast, Horney et al. (2010) found no association between individual actual or perceived property flood risk and evacuation from Hurricane Isabel in 2003 or from Hurricane Irene in 2011 (Wallace et al., 2016). Although the authors found statistically significant correlations between individual perceived risk and actual risk, neither was associated with evacuation.

The assessment of the association between income and evacuation has also yielded mixed results in the literature, with some authors reporting a positive relationship (Peacock et al., 2012) and others, an inverse association (Whitehead, 2003; Smith, 1999). The justification for the latter finding has been that they may perceive their homes to be of higher quality and therefore able to withstand a strong storm or that they may be more likely to remain in their homes to protect valuables. In the converse, a positive association between income with evacuation might be due to the fact that wealthier residents may own higher risk coastal property subject to waves and surge and may also evacuate relatively more easily due to their ability to finance the expenses associated with evacuation.

Baker (1991) also demonstrated that dissemination of information predicts evacuation. People are more likely to evacuate when they receive evacuation information from non-media sources like public officials, the government, or family and friends. They are also more likely to evacuate when public officials are proactive about issuing evacuation orders. Peacock et al. (2012) also made similar observations about the evacuation from Hurricane Andrew in Florida. On the other hand, other studies have reported that media sources exerted significant influence on hurricane evacuation decisions (Stein et al., 2010; Arif et al., 2017).

It has been hypothesized that racial and ethnic minorities are less likely to evacuate because of differences in social and family networks, risk perceptions, language and communication difficulties and inadequate resources required for evacuation (Fothergill et al., 1999). However, empirical evidence suggests mixed associations. Therefore, some studies reported lower evacuation rates in minorities (Peacock et al., 2012), some have found lower rates in select minorities but not in others (Riad et al., 1999), while some have found no significant difference (Bateman & Edwards, 2002).

Stein and colleagues (2010) studied the determinants of hurricane evacuation for Houston residents following Hurricane Rita and observed that heterogeneity in evacuation decision was explained by area of residence. Therefore, individuals that lived in evacuation zones were more likely to evacuate due to the influence of the media than those who lived outside of the zones. Another study also found that residents who live in officially designated evacuation areas respond differently to a set of information cues, incentives and risk factors than evacuees who live outside of these areas (Peacock et al., 2004).

Mixed results have been published related to the effect of length of residence in a hurricane prone area and evacuation behavior. While some authors found a positive association (Baker, 1991; Horney, 2003), others found a negative or no association with evacuation behavior (Peacock et al., 2012). Logically, the length of residence could impact evacuation decision making both positively or negatively. New residents in an area could decide to evacuate because of their heightened perceived risk, but they could also decide not to evacuate because of their inexperience with risk in the area. On the other hand, long-term residents could decide to evacuate because of prior experience with hurricane landfalls in the area, or decide not to, because of their perception that the area is safe (false expectations paradox) (Baker, 1991).

Overall, numerous studies across different fields have been published assessing associations between demographic and other factors and evacuation in response to approaching hurricanes. Except for a few of these factors, associations with evacuation reported in the literature are highly variable, with studies reporting positive, negative, or null associations. A statistical meta-analysis could provide a summary measure of this association. In response to the fact that the last literature review of hurricane evacuation behavior was published in 1991, Huang et al., (2016) conducted a meta-analysis using both real and hypothetical hurricane evacuation scenarios. However, because results obtained through simulation may differ from actual decision making during a hurricane event, this study aims to improve on the Huang et al.,

(2016) study by including only real hurricane evacuation studies and utilizing additional meta-analytical methods (exploratory analysis of effects using forest plots, moderator analysis including meta-regression, and assessment for publication bias). The enumeration of factors that predict evacuation may help authorities provide targeted interventions to vulnerable groups and increase the efficiency of evacuation in hurricane emergencies.

Based on the previously described literature, it is also reasonable to conclude that determinants of hurricane evacuation are not similar across disaster events. Therefore, study results may differ by region impacted (e.g., Atlantic or Gulf Coast), severity of hurricane, analytic method employed, and evacuation zone (Stein et al., 2010). To identify the factors that explain heterogeneity of evacuation decisions in hurricane conditions, this study aims to investigate the moderators of evacuation decisions across studies. The isolation of such moderators may enhance disaster planning by emphasizing specific at-risk groups that could be targeted for evacuation communications.

3.2. Methods

3.2.1. Search Strategy

A systematic literature search was conducted for English language articles published from 1999 to 2018 using Google Scholar, Web of Science and SCOPUS data bases. The key words searched were “HURRICANE” and “EVACUATION FACTORS”. An article was included in the study if it was published in English, was based on an actual (not hypothetical) hurricane, and provided sufficient information to calculate relevant effect sizes (of hurricane evacuation on predictor variables). For this reason, articles that reported correlation coefficients, odds ratios, or regression coefficients were included in the study. References cited in original and review papers were also examined until no further articles were identified. Upon the completion of this search, a total of 39 studies, derived from 27 journal articles, dissertations, and conference papers were included in the study.

3.2.2. Effect Size Conversions

Some studies reported Pearson's correlation coefficients while others reported regression coefficients (β), odds ratios, or both. To obtain a common index of effect size, we used the formulae proposed by Field and Gillet (2010) to convert regression coefficients and odds ratios to correlation coefficients.

$$r = \frac{\sqrt{OR}-1}{\sqrt{OR}+1}$$

Further, to account for the differential precision of effect estimate associated with sample size variation between studies, we used Fisher's Z_r transformation to weight the sample correlation coefficients by their degrees of freedom (n-3).

$Z_r = \sqrt{[Ln(1+r) - (Ln(1-r)]}$

$SE_{Zr} = 1/(\sqrt{(n-3)})$

Where r- correlation coefficient; Z_r- Fisher's transformed r; SE_{Zr}- Std. Error of Z_r; n- sample size

Finally, to obtain the weighted average effect size for each predictive factor, Stata 14 (College Station, Texas) was used to reconvert the pooled Fisher's Zr estimate to correlation coefficient. The summary of the steps in effect size conversions is illustrated in Figure 3.1.

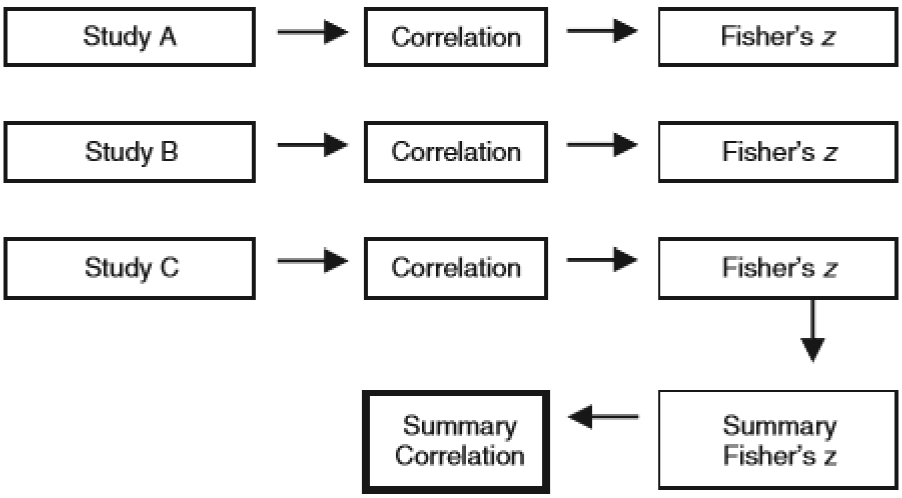

Figure 3.1. An Illustration of Conversion between Effect Sizes.

3.2.3. Statistical Analysis

Because of potential heterogeneity in populations, study designs, hurricane category, and hurricane regions, we assumed that the true effect would vary between studies in addition to the usual sampling variation within studies. To account for both sources of variation, we fitted a random effect meta-analytic model which provided more conservative estimates and larger standard errors. Heterogeneity across studies was checked using the Q statistic and I^2 statistic. To further identify the potential cause of heterogeneity, we conducted a moderator analysis using meta-regression to test if any of the study characteristics modified the relationship between evacuation and any of the predictor variables. The potential effect modifiers tested in the study were year of publication, analytic method, severity of hurricane, and hurricane region. Stratum-specific estimates were presented for every effect modifier identified. Finally, publication bias was investigated in two ways. First, by observing visual asymmetry in funnel plots i.e. plots of effect estimates against their estimated precision (reciprocal of the variance) and second, by estimating the degree of asymmetry using Egger's unweighted regression asymmetry test. Whenever publication bias was identified, sensitivity analysis using the Trim-and-Fill Method was conducted to compare adjusted and unadjusted results.

3.3. Results

3.3.1. Characteristics of the Articles

The search strategy revealed a total of 24 articles (published from 1999 to 2018) that reported an association between evacuation and predictor variables (Table 3.1). These articles published data from 36 studies including 28 journal papers, five dissertations, five conference papers, and one unpublished manuscript. All the articles were published in English and were based on 'actual' (rather than hypothetical) hurricane scenarios. The total sample size for all the articles was 33,858 (Range: 97 to 3,390). In terms of statistical measures, 28 studies reported odds ratios or regression coefficients, while 8 studies reported both (regression and correlation coefficients) statistical estimates.

Table 3.1. Characteristics of Published Studies on Factors that Predict Hurricane Evacuation.

First Author	Year	Sample Size (N)	Location	Hurricane	[1]Analytic Method
Sadri	2017	863	NY, NJ	Sandy	Both
Hasan	2011	1,995	FL, AL, MS, LA	Ivan	Both
Huang	2012	562	TX	Ike	Both
Riad	1999	376	FL, SC, NC, GA	Andrew	Regress
Smith	2009	1881	FL	Jeanne, Charley, Frances, Ivan	Regress
Whitehead	2000	895	NC	Bonnie	Regress
Zhang	2004	312	TX	Bret	Both
Bateman	2002	1,008	NC	Bonnie	Regress
Brackenridge	2012	120	TX	Ike	Regress
*Fu	2004	428	LA	Andrew	Regress
Fu	2004	1,688	SC	Floyd	Regress
Huang	2014	1,277	LA, TX	Katrina, Rita	Regress
Noltenius	2008	287	FL	Wilma	Regress
*Solis	2009	1,355	FL	Katrina, Wilma, Dennis	Regress
Solis	2009	360	FL (SE)	Katrina	Regress
Solis	2009	506	FL	Wilma	Regress
Solis	2009	305	FL (NW)	Dennis	Regress
Solis	2009	184	FL (NW)	Katrina	Regress
*Stein	2010	223	TX (Inside Evac. Zone)	Rita	Both
Stein	2010	318	TX (Outside Evac. Zone)	Rita	Both
Wilmot	2004	466	LA	Andrew	Regress
*Willigen	2005	309	NC (Community Residence)	Floyd	Regress
Willigen	2005	852	NC (School Residence)	Floyd	Regress
*Smith	2009	1,711	FL (Central)	Charley, Frances, Ivan, Jeanne	Regress
Smith	2009	2,739	FL (SE)	Jeanne, Ivan, Charley, Frances	Regress
Smith	2009	2,105	FL (SW)	Frances, Jeanne, Ivan, Charley	Regress
Smith	2009	568	FL (Charlotte)	Jeanne, Frances, Ivan, Charley	Regress
Smith	2009	1,925	FL (NW)	Jeanne, Frances, Ivan, Charley	Regress
Fu	2003	3,390	LA	Andrew	Regress
Brezina	2008	680	LA	Katrina	Regress
Dixon	2017	586	TX	Ike	Both
Rosenkoetter	2007	97	GA	Katrina	Regress
Horney	2018	1,086	TX	Harvey	Regress
Sadri	2017	1,109	NY, NJ	Sandy	Regress
*Elliot	2006	962	LA	Katrina	Regress
Elliot	2006	330	LA (New Orleans)	Katrina	Regress

[1] Analytical method included regression coefficient, or both regression and correlation coefficients
*Study conducted on different sub-populations

The predictive factors included in this study were mobile home residence, perception of risk, child(ren) in home, marital status, home ownership, peer or neighbor evacuation, social cues, mandatory (official) evacuation orders, previous hurricane exposure, media, education, length of time in residence, race/ethnicity (black, white, and Hispanic), and female gender.

3.3.2. Risk Factor Estimates

Random effect pooling identified statistically significant positive correlation between evacuation and four variables, including mobile home residence (r= 0.31; 95% CI: 0.21, 0.41), perception of risk (r= 0.18; 95% CI: 0.10, 0.26), Hispanic race (r= 0.08; 95% CI: 0.01, 0.14), and female gender (r= 0.05; 95% CI: 0.00, 0.09) (Table 3.2). Results also showed statistically significant heterogeneity between studies for all the pooled effect estimates except length of time in residence. In other words, majority of the effect sizes were not uniform but varied considerably across studies. Such variability may be random or systemic and we investigated if study characteristics explained this variability between studies. The only significant predictor to demonstrate a relatively uniform (homogenous) effect was the length of time in residence (X^2=8.48, P-value>0.05; I^2=5.70).

Table 3.2. Pooled (Summary) and Heterogeneity Estimates of Factors that Predict Hurricane Evacuation.

		Summary Estimate		Heterogeneity Estimates	
Predictive Factors	No of studies (K)	Pooled *r*	95% CI	X^2	I^2
Mobile Home	20	*0.31	0.21, 0.41	*1236.33	*98.50
Perception of Risk	9	*0.18	0.10, 0.26	*86.21	*90.70
Child(ren) in Home	14	0.07	-0.01, 0.14	*128.21	*89.90
Married	8	-0.02	-0.14, 0.09	*136.54	*94.90
Own Home	18	-0.03	-0.12, 0.06	*596.12	*97.10
Peer/Neighbor Evacuation	12	-0.07	-0.17, 0.03	*224.45	*95.10
Social Cues	6	0.04	-0.06, 0.14	*67.11	*92.50
Mandatory/Official Evacuation Order	13	0.18	-0.02, 0.37	*1568.56	*99.20
Previous Hurricane Exposure	10	0.02	-0.01, 0.05	*17.36	*48.10
Media	5	-0.10	-0.25, 0.05	*46.83	*91.50
Education (at least High School)	15	0.01	-0.02, 0.03	*29.49	52.50*
Length of Time in Residence	9	-0.01	-0.03, 0.01	8.48	5.70
Black	12	0.06	-0.14, 0.26	*1465.92	*99.20
Hispanic	10	*0.08	0.01, 0.14	*109.63	*91.80
White	10	0.05	-0.05, 0.15	*127.33	*92.90
Female	17	*0.05	0.00, 0.09	*116.05	*86.20
*P-value<0.05					

3.3.3. Moderator Analysis

To explore reasons for the observed heterogeneity between studies, we examined (by meta-regression analysis) the relationship between evacuation and predictor variables according to hurricane severity, hurricane region, and publication year (Table 3.3). Results showed that hurricane region modified the relationship between Hispanic race and evacuation (Coef. = 0.23; 95% CI:0.04,0.42) and publication year modified the relationship between educational level and evacuation decisions (Coef. = 0.06; 95% CI: 0.01, 0.12). Of the remaining variables (13 of 15), no specific reason for the heterogeneity could be found (Table 3.3).

Table 3.3. Meta-regression Analysis of Potential Moderators on Predictive Factors.

	Hurricane Category		Hurricane Region		Publication Year	
Predictive Factors	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI
Mobile Home	0.04	-0.09, 0.16	-0.05	-0.28, 0.18	-0.23	-0.46, 0.00
Perception of Risk	0.06	-0.09, 0.21	-0.06	-0.27, 0.15	0.06	-0.15, 0.27
Child(ren) in Home	0.08	-0.09, 0.24	-0.07	-0.32, 0.18	-0.04	-0.28, 0.19
Married	-0.06	-0.22, 0.11	0.07	-0.23,0.36	0.10	-0.18, 0.38
Own Home	0.09	-0.14, 0.31	-0.15	-0.46,0.16	-0.03	-0.30, 0.24
Peer/Neighbor Evacuation	-0.06	-0.30, 0.17	-0.15	-0.55,0.25	-0.09	-0.39, 0.20
Social Cues	0.06	-0.15, 0.27	-0.08	-0.43,0.27	-0.10	-0.58, 0.38
Mandatory/Official Evacuation Order	0.03	-0.26, 0.33	-0.26	-0.76, 0.23	-0.11	-0.59, 0.37
Previous Hurricane Exposure	-0.06	-0.16, 0.03	-0.06	-0.21, 0.08	-0.02	-0.10, 0.05
Media Influence	-0.17	-0.35, 0.00	0.08	-0.51, 0.66	0.15	-0.58, 0.88
Education (at least High School)	-0.01	-0.05, 0.03	0.00	-0.07, 0.06	*0.06	0.01, 0.12
Hispanic	-0.05	-0.27, 0.17	0.23*	0.04, 0.42	0.07	-0.27, 0.40
White	0.11	-0.06, 0.27	-0.02	-0.34, 0.30	-0.17	-0.43, 0.09
Female	0.01	-0.07, 0.09	0.07	-0.07, 0.21	-0.08	-0.20, 0.04

When the effect of Hispanic race on evacuation decisions was stratified by hurricane region (Table 3.4), it was observed that Hispanics in the Atlantic Coast were more likely to evacuate compared to their counterparts in the Gulf Coast (who demonstrated no significant association with evacuation decisions).

Table 3.4. Stratified Result of Hispanic Ethnicity by Hurricane Region.

	Hispanic	
	Pooled Estimate	95% CI
Hurricane Region		
Atlantic Coast	*0.26	0.19, 0.33
Gulf Coast	0.04	-0.02, 0.09

3.3.4. Publication Bias

Both visual control (see Fig. 3.2) and statistical significance (see Table 3.5) identified the presence of publication bias in peer/neighbor evacuation (Bias= -6.50; 95% CI: -12.57, -0.44), length of time in residence (Bias= -2.63; 95% CI: -4.65, -0.60), and media (Bias= -6.83; 95% CI: -13.30, -0.35) (Table 5). Correcting for these biases with Trim and Fill method did not significantly change the results (not shown). We did not identify publication bias in studies of other predictor variables (Table 3.5).

Table 3.5. Egger's Regression Test for Publication Bias in Studies on Hurricane Evacuation.

Predictive Factors	Bias	95% CI
Mobile Home	-0.61	-11.52, 10.31
Perception of Risk	5.48	-2.59, 13.55
Child(ren) in Home	1.63	-1.62, 4.87
Married	-7.98	-22.86, 6.91
Own Home	2.89	-5.30, 11.07
Peer/Neighbor Evacuation	-6.50*	-12.57, -0.44
Social Cues	12.28	-3.98, 28.54
Mandatory/Official Evacuation Order	3.86	-16.41, 24.12
Previous Hurricane Exposure	1.95	-0.23, 4.14
Media	-6.83*	-13.30, -0.35
Education (at least High School)	-1.02	-3.05, 1.02
Length of Time in Residence	-2.63*	-4.65, -0.60
Black	6.35	-14.36, 27.05
Hispanic	5.02	-1.01, 11.04
White	6.06	-2.28, 14.40
Female	-1.64	-5.70, 2.42
*P-value<0.05		

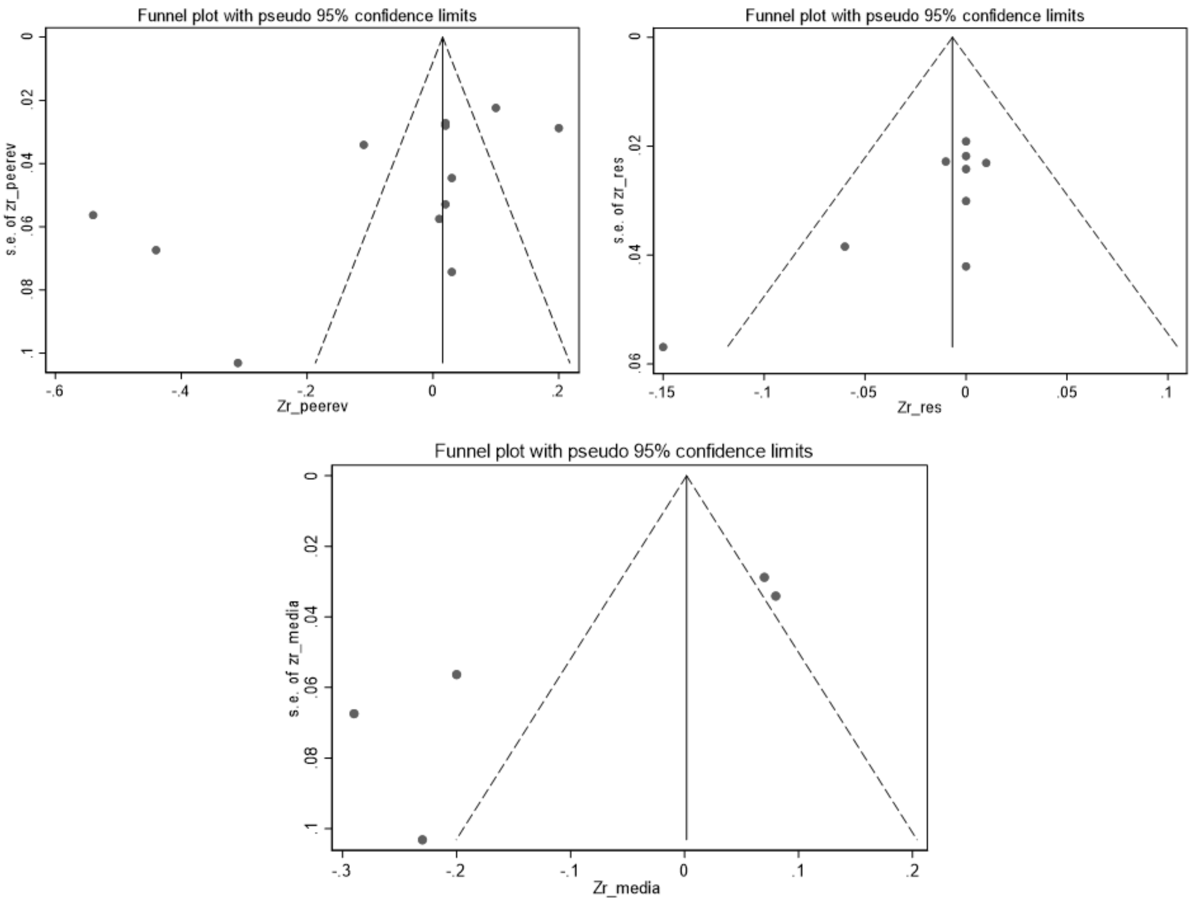

Figure 3.2. Funnel Plots Illustrating Asymmetry (Publication Bias) for the Length of Time in Residence, Peer/Neighbor Evacuation, and Mobile Home Residence.

3.4. Discussion

This meta-analytic study combined results from 36 studies with sample sizes ranging from 97 to 3,390 (total sample size of 33,858 participants). Results indicated that across studies, evacuation was significantly and positively correlated with mobile home residence (r= 0.31; 95% CI: 0.21, 0.41), perception of risk (r= 0.18; 95% CI: 0.10, 0.26), Hispanic race (r= 0.08; 95% CI: 0.01, 0.14), and female gender (r= 0.05; 95% CI: 0.00, 0.09).

The correlation between mobile home residence and evacuation ((r= 0.31; 95% CI: 0.21, 0.41) may be explained by increased perception of structural vulnerability by the residents and therefore, the decision to evacuate an impending storm. A similar observation was made in the meta-analysis of Huang et al., (2016) and the systemic review of Baker (1991). Issuance of a mandatory (official) evacuation order was also found to be significantly positively correlated with evacuation decisions. This is probably because residents perceive officials issuing orders have a high knowledge of hazards but also believe that officials have the responsibility to warn and protect households by disseminating accurate information on impending risks. This positive reputation of local officials such as emergency managers likely influences residents' evacuation decisions (Huang et al., 2016).

Perception of risk was also positively correlated with evacuation decisions. This finding is well documented in previous studies (Mileti & Peek, 2000; Mileti & Sorensen, 1990; Sorensen, 2000; Sorensen & Sorensen, 2007). Because perception of risk estimates the self-rated threat of hurricane to individuals, their families and properties, it is reasonable to anticipate a positive relationship between this variable and the decision to evacuate.

The significantly positive correlation between female gender and evacuation may be due to the women's social vulnerabilities and caregiving roles in households. Such conditions often heighten their risk perceptions to hurricane threats and increase their likelihood of evacuation (Bateman & Edwards, 2002). Fothergill et al. (1999) also asserted that females have greater likelihood of perceiving disaster as serious and risky.

3.4.1. Moderator Analysis

In many cases, effects were not uniform across studies. To understand the factors that significantly predict evacuation, it will be appropriate to ascertain if the heterogeneity is substantive or attributable to methodological differences between studies. This meta-analysis has made a useful contribution to this process by investigating the moderating effects of hurricane severity (by category), year of publication, and region of hurricane occurrence.

The moderating effect of hurricane region on Hispanic race and evacuation decisions was examined. Hispanics were more likely to make positive evacuation decisions when faced with hurricanes in the Atlantic Coast compared with the Gulf Coast. On the other hand, no significant relationship was observed in the Gulf Coast between Hispanic race and evacuation. The explanation behind this observation is unclear and warrants further research. However, it could be attributed to differences between Hispanics in the two regions in education, English language comprehension, size of social network, risk perception, and economic resources to finance evacuation. Such factors were hypothesized by Fothergill and colleagues (1999) as contributing to evacuation non-compliance among minority ethnic groups.

This study has several strengths. First, it improved on a previous meta-analysis conducted by Huang and colleagues (2016) by including more recent articles and analyzing only actual (rather than hypothetical) hurricane studies. Second, the study employed moderator analysis including meta-regression to explore the possible sources of heterogeneity across studies. Through this method, this study isolated significant moderators within which predictor variables were stratified. Third, publication bias was assessed using visual (funnel plots) and statistical (Egger’s regression) methods. Sensitivity analysis was also conducted to investigate any significant difference between biased and adjusted results.

Although we have made a comprehensive summary of the factors that predict hurricane evacuation, there are still limitations that merit discussion. First, the pooled estimates were presented in the form of correlation coefficients rather than odds ratios. Because the latter often adjust for putative confounding covariates, their results are preferred. However, we could not present the summary odds ratios because most of the primary studies did not provide sufficient sample size information (between evacuated and non-evacuated groups) to calculate inverse-variance weighted pooled estimates. Second, some of the stratified estimates (on moderators) were associated with sparse number of studies (K<6) across sub-sets of the predictor variables. These might have accounted for the non-statistically significant findings obtained in some strata (e.g. Hispanics in the Gulf-Coast). Although a meta-analysis could be conducted on a minimum of two published studies, Sanchez-Meca and Marin-Martinez's (1997) Monte Carlo simulation recommended that tentative conclusions be drawn on meta-analysis for which number of studies is less than six.

Finally, this study identified significant heterogeneity in majority of the predictor variables (except the length of time in residence), but only explained the possible causes of this phenomenon in 13% (2 of 15) of the randomly defined effect sizes. Because the isolation of specific effect modifiers may enable the targeting of specific at-risk groups during hazard planning, it is imperative for future primary studies to explore heterogeneity to explain the factors that moderate evacuation decisions.

4. FACTORS ASSOCIATED WITH THE SELF-RATED HEALTH OF RESIDENTS IN THE TEXAS GULF COAST AFTER HURRICANE HARVEY

4.1. Introduction

The number and severity of natural disasters are increasing while populations living in areas that are physically vulnerable to disasters are growing both in the U.S. and around the world (Neumann et al., 2015; Tuthill, 2014). Quantifying the overall direct and indirect physical (Greenough et al., 2001; Noji, 2005; Du et al., 2010) and mental health impacts of disasters can be difficult (Norris et al., 2002; Fergusson et al., 2014). Most disaster research focuses on a single event, with case studies and relatively small sample sizes making it difficult to generalize findings to disasters of another type, severity or location (Peacock et al., 2011). Typical epidemiologic study designs frequently must be adapted for implementation in a disaster-impacted population (Dominici et al., 2005) while baseline data on the health status of disaster affected populations is typically not available. These and other factors mean that most post-disaster health research is cross-sectional in nature, comparing populations – sometimes longitudinally – with all data collection time points in the post-disaster period (Norris, 2006).

Both individual characteristics and experiences before, during, and after a disaster may contribute to mental health outcomes and psychopathologies post-disaster (Goldmann & Galea 2014). After a hurricane, those most severely impacted individuals report anxiety, depression, and Post Traumatic Stress Disorder (PTSD) at rates higher than unimpacted populations (Briere & Elliott, 2000; Benedek et al., 2007; Norris et al., 2002; Adams et al., 2014; Van Griensven et al., 2006). Increases in depression and anxiety have been linked to the occurrence of hurricanes in general, and in the U.S. Gulf Coast specifically (Weisler et al., 2006; Larrance et al., 2007).

Hurricane Harvey made landfall on the Texas Gulf Coast on August 26, 2017. Catastrophic flooding associated with Hurricane Harvey displaced more than 30,000 people to evacuation shelters and flooded more than 135,000 homes, making the storm both physically devastating and emotionally traumatizing (Ferreras, 2017; Huber et al., 2017; McCarthy, 2017; Takahashi, 2017). Impacts to physical safety are often an immediate source of concern for those affected by high winds and heavy rains associated with a hurricane (Bourque et al., 2006). Damage to transportation and other infrastructure from hurricanes and flooding often result in fatal or non-fatal injuries like electric shock, falls, lacerations, and crush injuries. For example, a study conducted by the Centers for Disease Control and Prevention (CDC, 2005) on the physical health impacts of Hurricane Katrina showed that a total of 2,018 non-fatal injuries occurred. Out of a total of 971 deaths attributed to Hurricane Katrina, 25% were because of injury and trauma, while 40% were from drowning (Brunkard et al., 2008).

Mental health morbidity may be associated with a hurricane's impacts in the weeks and months after the disaster. In a study conducted by Rhodes and colleagues (2010) on the prevalence of mental health outcomes of residents exposed to Hurricane Katrina, results showed that almost half of the survivors suffered from PTSD. A rapid needs assessment conducted by the CDC in New Orleans, Louisiana, revealed that almost 50% of residents suffered from some type of mental illness after Hurricane Katrina (CDC 2006; Weissler et al., 2006) A study of residents exposed to Hurricane Sandy also showed that majority of survivors suffered some form of psychopathology (20% PTSD, 46% anxiety and 33% depression) (Schwartz et al., 2017).

Therefore, to adequately inform disaster preparedness, mitigation, and recovery plans and policies, a better understanding of the prevalence of mental health morbidity in the population impacted by Hurricane Harvey is needed, along with the identification of factors that predict mental health wellness in this population.

Exposure to natural disasters including hurricanes is associated with poor mental health, partly due to the disruption of the pre-existing social cohesion that accompany these events (Heid et al., 2017; Schwartz et al., 2018; Schwartz et al., 2018; Bokszczanin 2007; Thienkura et al., 2006; Hoven et al., 2005; Jaycox et al., 2010). In addition, residents who evacuate during major disasters have been shown to suffer poorer mental health outcomes than non-evacuees (Gittelman, 2003; Bourque 2006). These findings have been attributed to several factors. First, evacuation is a tedious and exhausting task that requires careful planning and demands resources like money, transportation, and physical assistance, which may be associated with emotional distress. Second, residents who evacuate to designated public evacuation shelters may lack social support - an important buffer against stress that reduces the risk of PTSD (Galea et al., 2008; Kaniasty & Norris, 2008; Ozer & Weiss, 2004; Weems et al., 2007). Third, evacuees in shelters are more likely to experience disruptions in their daily pre-disaster routines (e.g. physical activity, jobs, and access to hospital or clinic appointments and prescription medications) (Abramson et al., 2008). Because of these reasons, the prevalence of mental health illness increases with duration of displacement (Kessler et al., 2008; Paxson et al., 2012; Sabin et al., 2003; Norris et al., 1999) and increased rates of PTSD have been observed among evacuees who have lived in shelters for extended periods (Hyre et al., 2008; Gittelman, 2003). For example, the prevalence of PTSD in victims of Hurricane Katrina rose from 15% a few months after the disaster to about 21% a year later (Kessler et al., 2008). Similarly, the proportion of people that experienced suicidal thoughts increased from 2.8% to 6.4% (Kessler et al., 2008).

Disaster often reinforces pre-existing social inequalities (Kaniasty & Norris 1995; Norris et al., 2002; Tierney, 2000). For example, growing evidence suggests that young adults, women, parents of small children, and those with lower incomes suffer higher rates of PTSD and other mental disorders after disasters (Bolin & Bolton, 1986; Galea et al., 2007; Kessler et al., 2008; Jones-DeWeever, 2008). In addition, the mental health of those exposed to hurricanes has been shown to differ by educational level; individuals with graduate or professional-level degrees are more likely to have better mental health than their counterparts with lower educational attainment (Li et al., 2008; Baral & Bhagwati, 2018). After a disaster, women are more likely to suffer from poorer mental health than men (Harville et al., 2010; Norris et al., 2002; Zhang & Ho, 2011; Baral & Bhagwati, 2018), while the middle-aged and elderly manifest better mental health than younger individuals (Galea et al., 2007; Kessler et al., 2006; Sastry & VanLandingham, 2009).

Using the SF-12 psychometric instrument, which is derived from the Medical Outcomes Study, we assessed the self-rated mental and physical health of residents of the Texas Gulf Coast after Hurricane Harvey. We also identified the factors (e.g. evacuation, sociodemographic variables) associated with variations in self-rated health.

4.2. Methods

4.2.1. Data Sources

In December 2017, data were collected from respondents living in coastal counties located along the Texas Gulf Coast. A total of 1,086 residents were surveyed using interviewer-administered questionnaires. The survey consisted 21 questions and was organized into two sections. The first section included questions about demographic characteristics of the participants, their knowledge about hurricanes, and their perceptions about climate change and coastal hazards, risk perception, and evacuation decisions. The second section included questions about self-rated physical and mental health from the SF-12 (Ware et al., 1996; Jenkinson et al., 1997). The SF-12 is a validated measure of General Health Function comprised of 12 questions across 8 domains that include physical functioning, role limitations due to physical health problems, bodily pain, general health, vitality (energy/fatigue), social functioning, role limitations due to emotional problems, and mental health (psychological distress and psychological wellbeing). These questions were used to derive two summary scores: a physical and a mental health component.

4.2.2. Data Analysis

Responses were recorded on paper and transferred into a Microsoft Excel 2016 data base (Redmond, Washington). Double-data entry was conducted from which a concordance of 95% was noted. Descriptive statistics, including frequencies, counts, and 95% confidence intervals for each item in the questionnaire were calculated. The SF-12 instrument was then scored using the code provided by Hays (2018) and described by Ware (2005). By design, the items in the SF-12 instrument were standardized such that MCS and PCS were normally distributed. However, the distribution of the health scores was still re-evaluated using a histogram/kernel density plot and confirmed to meet the normality assumption. One sample T-test and Two-tailed T-tests for unequal variances were conducted using Welch’s approximations. Further, a multivariate linear regression model was fitted with mental composite score as the response variable and evacuation, age, race, gender, education, home type and surge risk as the independent variables. All data analyses were conducted using Stata 14 (College Station, Texas).

4.3. Results

A total of 1,086 participants who reported a home address in Texas completed the survey. Most of the Texas respondents (1089 of 1209, 89.30 %) reported being affected by Hurricane Harvey (Table 4.1). The mean age of respondents was 40.67 years (Range: 18 – 84). Females comprised 56.99% (689 of 1209) of the respondents. Nearly 40% of the respondents were Hispanic (470 of 1209, 38.88%).

Self-rated physical and mental health scores of the respondents were 36.69 and 39.87 respectively, both of which were statistically significantly lower than the national average (Table 4.2). There were no statistically significant differences in self-rated health scores by hurricane exposure (Table 4.3). However, self-rated health scores were significantly different by gender, with higher self-rated physical health score in males and higher mental health score in females (Table 4.3).

Table 4.1. Descriptive Statistics of Select Variables for Study Participants.

Characteristic	**(N=1,086) (%)**
Evacuated	
Yes	371 (34.16)
No	715 (65.84)
Race	
White	268 (24.68)
Hispanic or Latino	411 (37.85)
African American/Other	407 (37.48)
Age in Years	
Mean (SD)	40.49 (16.45)
Age in Groups	
18-24 years	198 (18.23)
25-44 years	504 (46.41)
45-64 years	240 (22.10)
65 years and older	144 (13.26)
Home Type	
Mobile Home/Trailer	56 (5.16)
Single family	778 (71.64)
Apartment	252 (23.20)
Educational Status	
High School	266 (24.49)
Some College	301 (27.72)
Associate/ Bachelor's Degree	343 (31.58)
Graduate/Professional degree	176 (16.21)
SF-12 Measure	
Physical Component Summary Score (PCS)	45.20 (9.26)
Mental Component Summary Score (MCS)	34.58 (8.89)

Table 4.2. Two-Tailed T-Tests of Average Values of Physical & Mental Component Summary Scores against National Mean Values.

	Study Participants N=1,086 (%) *	Standardized Mean (SD) Score					
		MCS	95% CI	P-value	PCS	95% CI	P-value
Evacuated							
Yes	282 (23.33)	34.52 (7.89)	33.60-35.45	<0.05	42.48 (9.25)	41.40-43.57	<0.05
No	469 (38.79)	34.62 (9.45)	33.76-35.47	<0.05	46.84 (8.89)	46.03-47.65	<0.05
Gender (Evacuated)							
Male	125 (10.34)	36.10 (6.41)	34.96-37.23	<0.05	39.86 (9.16)	38.24-41.48	<0.05
Female	157 (12.99)	33.27 (8.71)	31.90-34.65	<0.05	44.57 (8.80)	43.18-45.96	<0.05

Table 4.3. Two-Sample T-Tests of Physical & Mental Component Summary Scores between Categories of Select Variables.

	Study Participants N=1,086] (%)	Standardized Mean (SD) Score					
		MCS	95% CI	P-value	PCS	95% CI	P-value
Evacuated							
Yes	282 (23.33)	34.52 (7.89)	33.60-35.45	0.89	42.48 (9.25)	41.40-43.57	<0.05
No	469 (38.79)	34.62 (9.45)	33.76-35.47		46.84 (8.89)	46.03-47.65	
Gender (Evacuated)							
Male	125 (10.34)	36.10 (6.41)	34.96-37.23	<0.05	39.86 (9.16)	38.24-41.48	<0.05
Female	157 (12.99)	33.27 (8.71)	31.90-34.65		44.57 (8.80)	43.18-45.96	

4.3.1. Evacuation After Harvey

Of the 1,086 study participants, 30.69% (371 of 1209) reported evacuating due to Hurricane Harvey (Table 4.4). Evacuees were younger than non-evacuees, with a mean age of 35.75 years, as compared to 42.96 years. Being middle-aged or elderly was significantly associated with lower risk of evacuation (Table 4.5). Specifically, the middle-age group was associated with 16 less evacuees per 100 compared to the 18-24 age group, and the elderly were associated with 26 less evacuees per 100 compared to the 18-24 age group. Further, Hispanic or African-American ethnicity was associated with 10 additional evacuees per 100 compared to the whites (Table 4.5). Medium or high perception of surge risk was associated with increased risk of evacuation compared to low perception of risk, with 22 additional evacuees per 100 and 43 evacuees per 100 among residents with medium and high perception of risk (respectively), compared to residents with low perception of surge risk. The self-rated mental and physical health scores of the evacuees were 34.52 and 42.48 respectively which were both statistically significantly lower than national average (Table 4.3). However, while the self-rated mental health scores of the evacuees did not significantly differ by evacuation status, the self-rated physical health scores did - with evacuees reporting significantly lower physical health scores than non-evacuees (Table 4.4).

Both male and female evacuees reported statistically significantly lower health scores than the national average (Table 4.3). The self-rated health scores of the evacuees also differed by gender, with more males reporting higher self-rated mental health scores (Table 4.3).

Table 4.4. Distribution, Crude Risk Differences and 95% Confidence Intervals (95% CI) for Demographic Factors Potentially Associated with Evacuation from Hurricane Harvey, 2017 (N=1,086).

Variable Description	Evacuated (n=371)		Did not evacuate (n=715)		Risk differences (95% CI)
	n	%	n	%	
Home Type					
Single family	257	33.03	521	66.97	REF
Mobile Home/Trailer	27	48.21	29	51.79	*0.15 (0.02, 0.29)
Apartment/Other	87	34.52	165	65.48	0.01 (-0.05, 0.08)
Gender					
Female	219	35.10	405	64.90	REF
Male	152	32.90	310	67.10	-0.02 (-0.08, 0.03)
Age					
18-24 years	77	38.89	121	61.11	REF
25-44 years	219	43.45	285	56.55	0.05 (-0.03, 0.13)
45-64 years	56	23.33	184	76.67	*-0.16 (-0.24, -0.07)
65 years and older	19	13.19	125	86.81	*-0.26 (-0.34, -0.17)
Race					
White	114	28.01	293	71.99	REF
Hispanic or Latino	155	37.71	256	62.29	*0.10 (0.03, 0.16)
African American/Other	102	38.06	166	61.94	*0.10 (0.03,0.17)
Educational Status					
High school	104	39.10	162	60.90	REF
Some college	96	31.89	205	68.11	-0.07 (-0.15, 0.01)
Associate/Bachelor' s degree	96	30.36	247	69.64	*-0.11 (-0.19, -0.04)
Graduate/Professional degree	75	42.61	101	57.39	0.04 (-0.06, 0.13)
Perception of Flood Risk					
Low	38	21.59	138	78.41	REF
Medium	109	27.74	284	72.26	0.06(-0.01,0.14)
High	224	43.33	293	56.67	*0.22(0.14,0.29)
Perception of Surge Risk					
Low	65	14.74	376	85.26	REF
Medium	122	37.20	206	62.80	*0.22(0.16,0.29)
High	184	58.04	133	41.96	*0.43(0.37,0.50)
*P-value<0.05					
Perception of Flood Risk					
Low	38	21.59	138	78.41	REF
Medium	109	27.74	284	72.26	0.06(-0.01,0.14)

In multivariate linear regression models assessing adjusted associations between self-rated mental health scores and evacuation, no statistically significant relationship was observed (coef. = 0.19; 95% CI: -1.19, 1.57) (Table 4.5). However, the middle-aged and elderly had significantly higher mental health scores than younger residents aged 18 to 24 years (Table 4.5). Also, females had lower self-rated mental health scores than males (Coef. = -2.10; 95% CI: -3.53, -0.67). In addition, the mental health scores in residents with graduate or professional-level degrees was about four times those with high school education only (Coef. =3.73; 95% CI: 1.68, 5.77). High perception of surge risk was associated with increased self-rated mental health scores compared to low perception of risk (Coef. = 1.75; 95% CI: 0.09, 3.40). Residents that lived in mobile homes had significantly lower self-rated mental health compared to residents that lived in single-family homes (Coef. = -2.66; 95% CI: -5.27, -0.04).

A second multivariate linear regression model was fitted with physical component summary score as the outcome variable and evacuation status as the predictor, while adjusting for age, sex, educational status, home type, and surge risk (Table 4.5). Results showed that self-rated physical health was negatively associated with evacuation (coef. = -3.51, 95% CI: -4.97, -2.06). Further, as the residents aged, their self-rated physical health declined - with the elderly experiencing almost a six-fold decrease in self-rated physical health compared to younger residents (aged 18 to 24 years) (Coef. = -6.14, 95% CI: -8.94, -3.33).

Table 4.5. Adjusted Associations between Self-Rated Health Scores and Evacuation.

N=751	Mental Component Summary (MCS) Score		Physical Component Summary (PCS) Score	
	Coef.	**95% CI**	**Coef.**	**95% CI**
Evacuation (Ref= "No")				
Yes	0.20	-1.17, 1.58	*-3.51	-4.97, -2.06
Age (Ref= "18-24 years")				
25-44 years	0.82	-0.84, 2.48	*-1.89	-3.64, -0.13
45-64 years	*4.40	2.35, 6.45	*-3.19	-5.36, -1.02
65 years and older	*8.15	5.51, 10.80	*-6.14	-8.94, -3.33
Gender (Ref= "Male")				
Female	*-2.10	-3.53, -0.67	0.38	-1.14, 1.89
Educational Status (Ref= "High School")				
Some college	0.21	-1.46, 1.88	0.66	-1.12, 2.43
Associate/ Bachelor's degree	1.34	-0.37, 3.05	0.02	-1.79, 1.83
Graduate/Professional degree	*3.73	1.68, 5.77	-1.26	-3.42, 0.91
Race (Ref.= "White")				
Hispanic or Latino	0.24	-1.47, 1.95	0.52	-1.29, 2.33
African American/Other	0.86	-0.95, 2.66	0.53	-1.38, 2.44
Home Type (Ref.= "Single Family")				
Mobile home	*-2.66	-5.27, -0.04	-0.01	-2.78, 2.75
Apartment/Other	0.16	-1.31, 1.62	0.59	-0.96, 2.14
Perception of Surge Risk (Ref.= "Low")				
Medium	0.06	-1.46, 1.58	*-2.11	-3.72, -0.51
High	*1.75	0.09, 3.40	*-3.90	-5.66, -2.15
*P-value<0.05				

4.4. Discussion

This cross-sectional survey, conducted among residents of Texas Gulf Coast counties shortly after Hurricane Harvey made landfall, allowed us to assess not only residents' perceptions of natural disasters and their evacuation behavior, but also to calculate their self-reported physical and mental health scores and potential associations between mental and physical health and evacuation. The overall self-rated physical and mental health scores of the respondents (39.87 & 36.69 respectively) were significantly lower than the national average, which is set at 50.0.

Living in a region of the U.S. that is highly physically vulnerable to natural disasters may contribute to respondents' relatively low self-rated physical and mental health. Since 2005, 13 major hurricanes have made landfall in the U.S Gulf of Mexico (Cindy, Dennis, Katrina, Rita, Wilma, Humberto, Dolly, Gustav, Ike, Isaac, Ingrid, Patricia and Harvey). Studies have shown that experiencing a major hurricane is significantly associated with increases in various types of mental health outcomes, both immediately following the hurricane and in the years after the disaster (Heid et al., 2017; Schwartz et al., 2018; Schwartz et al., 2018; Bokszczanin, 2007; Thienkura et al., 2006; Hoven et al., 2005; Jaycox et al., 2010). Experiencing multiple disasters, as many residents of the U.S. Gulf Coast have in the last two decades, has been associated with poorer mental health in both the general population (Harville et al., 2011) and among postpartum women effected by Hurricane Gustav after being affected by Hurricane Katrina (Harville et al., 2009).

When the respondents were stratified by evacuation status, those who evacuated were more likely to be Hispanic, aged 25 to 44 years, live in single-family home, and perceive a high risk of surge or flooding from Hurricane Harvey. This is similar to prior disaster research that has shown that personal perception of risk tends to be strongly associated with evacuation (Dow & Cutter, 1998). However, contrary to our findings, much of the hazards and disasters research reports that mobile home residents are more likely to evacuate than residents of stick-built homes because the latter often remain to protect their homes and properties. Our finding may be explained by a possible oversampling of residents in the study population who lived in single-family homes (777 of 1209, 64.27%). In adjusted models, this association between residence in a single-family home and evacuation was attenuated.

The mean self-rated physical health scores differed significantly by evacuation status of the respondents, with statistically significantly better self-rated physical health in non-evacuees than evacuees. This might be due to the physical injuries, pain and exhaustion that accompany evacuation (Bourque et al., 2006). The mean self-rated mental health scores did not significantly differ by evacuation status of the study participants. Further, the lack of association between the self-rated mental health of the individuals and their evacuation status remained after adjusting for covariates (gender, age, race, home type, perception of risk and educational status). This finding contradicts previous studies that found associations between evacuation and poor self-rated mental health (Gittelman, 2003; Bourque, 2006).

Mental health outcomes differed significantly by gender, educational status, age, home type and surge risk. Previous studies have shown that disasters may strengthen pre-existing socially structured inequalities (Kaniasty & Norris 1995; Norris et al., 2002; Tierney, 2000). For example, the association between gender and post-disaster mental health is well documented in previous studies, with women more likely to manifest symptoms of emotional distress (Harville 2010; Norris et al., 2002; Zhang & Ho, 2011; Baral & Bhagwati, 2018). This may be because women faced with a disaster are more likely to perceive the world as dangerous, blame themselves for the disaster, and portray a more negative self-image than men (Tolin & Foa, 2006). Previous studies have also found a negative association between educational attainment and mental health distress after disaster (Li et al., 2008; Baral & Bhagwati, 2018). This is because those with a higher level of education are more likely to develop coping strategies to deal with impending disaster, unlike individuals with lower educational attainment who are more likely to perceive the disaster negatively and not garner the requisite social and psychologic support. We also found that individuals who lived in single-family houses (unattached) were more likely to have better mental health scores than those who live in mobile homes. Perhaps, the relationship between home type and mental distress may be explained by income, with higher income-residents more likely to live in single family (unattached) houses than mobile homes. Previous studies have also found a positive association between income and mental health after disaster (Li et al., 2008; Baral & Bhagwati, 2018). Our finding of favorable post-disaster mental health outcomes in the middle-aged and elderly is backed by empirical literature (Galea et al., 2007; Kessler et al., 2006; Sastry & VanLandingham, 2009). Younger individuals are more likely to experience higher level of stress (e.g. displacement, family break-up, young children) and adverse economic outcomes (e.g. property loss, unemployment) than older individuals, since the latter are often more affluent and likely to have older children that will assist with their activities of daily living (Sastry & Gregory, 2013). In the current study, a high perception of surge risk was also found to be positively associated with mental well-being. This finding is surprising giving that favorable mental health outcomes are typically expected among individuals with lower perception of risk (Kim et al., 2011; Havenaar et al., 2003; Lima, 2004;

Bromet et al., 2002). Because our finding contradicts empirical evidence, this warrants further research.

The limitations of this study are acknowledged. First, being a cross-sectional study, no pre-hurricane data was available to permit a more objective comparison of self-rated health between the pre- and post-Harvey periods. Second, the survey was interviewer-administered and relied on self-report measures which might be prone to information bias. Third, missing data in SF-12 responses might have biased the result estimates. However, a sensitivity analysis using multiple imputation did not yield significantly different results. Despite these limitations, the current study has some noteworthy strengths. First, the SF-12 psychometric instrument used in the study is proven to be highly valid and reliable both in the U.S and international populations (Ware et al., 1996). To the best of our knowledge, this is the first study that employed this instrument in the assessment of self-rated mental and physical health outcomes from Hurricane Harvey.

4.4.1. Policy Implications

In the design of policy guidelines on disaster recovery, mental health services should be integrated with economic and educational empowerment programs and directed towards younger women with less than graduate level of education, who live in mobile homes with little children. Likewise, physical health rehabilitation programs after hurricanes should target evacuees at least 25 years of age who perceive medium to high risk of storm surge.

5. CONCLUSION

5.1. Summary

The purpose of this project was to assess evacuation capacity and decision making related to Hurricane Harvey. The study had three aims. First, to spatially describe the hurricane evacuation shelter space deficit in the Houston-Galveston Metropolitan Statistical Area (MSA). Second, to investigate by means of a statistical meta-analysis, factors associated with hurricane evacuation. Third, to assess the self-rated health (both physical and mental) of residents of the Texas Gulf Coast after Hurricane Harvey, and to identify the factors associated with variations in self-rated health. The summary of results and conclusions are presented in the following sections.

5.1.1. Spatial Distribution of Shelter Space Deficit in the Houston-Galveston MSA

A spatial analysis of hurricane evacuation shelters in the Houston-Galveston MSA indicated a total of 280 shelters with an aggregate capacity of 91,600 persons. About 25% (or 1.78 million people) of the total population of the Houston-Galveston MSA reside in evacuation Zip-Zones. Evacuation shelters were clustered by size, with high-capacity shelters located farther from the Coastal Zip-Zone (about 120 miles) and low-capacity shelters located nearer the Coastal Zip-Zone (about 50 miles). Specifically, high-capacity shelters were located around Montgomery and Walker counties while low-capacity shelters were located around Harris, Fort-Bend, Waller, and Austin counties.

Shelter deficits were estimated in four dimensions- by MSA, evacuation Zip-Zone, distance, and county. The entire Houston-Galveston MSA had an aggregate deficit of 353,713 persons. In other words, the available shelters in the MSA can accommodate only about 21% of the total shelter demand. Regarding Zip-Zone deficit, B and C had estimated deficits of 13,227 and 157,252 persons respectively (no deficit was found in other Zip-Zones). When deficit was estimated by distance, all the Zip-Zones (except the coastal Zip-Zone within 40 miles) had deficits within 20, 30, and 40 miles (Range: 5,343 to 196,173 persons). County deficit estimation showed that all six counties in the evacuation Zip-Zones have shelter deficiency- the highest being in Harris County (231,196 persons) and lowest in Liberty County (4000 persons).

5.1.2. Factors Associated with Hurricane Evacuation- a Statistical Meta-analysis of Studies Published from 1999-2018

In this study, a statistical meta-analysis investigated factors associated with hurricane evacuation. A total of 39 published journal articles, dissertations, and conference papers were systematically extracted from Google Scholar and SCOPUS data bases. Random effect pooling of estimates identified six factors to be statistically significantly associated with hurricane evacuation decisions. These include mobile home residence (0.31; 95% CI: 0.21, 0.41), perception of risk (0.18; 95% CI: 0.11, 0.23), children in home (0.06; 95% CI: 0.00, 0.12), mandatory evacuation (0.17; 95% CI: 0.00, 0.34), Hispanic race (0.08; 95% CI: 0.01, 0.14) and female gender (0.05; 95% CI: 0.02, 0.09). Residents in mobile homes were more likely to make evacuate decisions due to heightened risk perceptions related to the structural vulnerability of their homes (Huang, 2016). Females were shown to make evacuation decisions more than males because they are intrinsically more likely to perceive hurricane conditions as dangerous and risky (Fothergill et al., 1999). The presence of children in home likely increases perception of risk and therefore evacuation. Alternatively, the evacuation of children may be correlated with those of women, who are often their primary care givers. Mandatory (official) evacuation orders were correlated with evacuation decisions due to the belief that emergency officials have high knowledge of hazards and provide accurate information on impending risks (Huang, 2016).

Another important observation was the non-uniformity (heterogeneity) of effect sizes across studies. To isolate the specific causes of heterogeneity, a meta-regression analysis was conducted which identified analytical method, hurricane severity and geographic region as moderators of evacuation. Further stratification by these predictors indicated that studies with correlation coefficients were more likely to find positive correlation between peer/neighbor evacuation and evacuation decisions; Category 4 hurricane was associated with a positive correlation between reliance on media sources and evacuation decisions, while Category 5 hurricane demonstrated a negative association between the two variables. Regarding the moderation effect of region of hurricane occurrence, Hispanics who reside in the Atlantic Coast were significantly associated with evacuation decisions unlike their counterparts in the Gulf Coast who demonstrated no association with evacuation decisions.

Some explanations on the moderator analysis results are discussed. While multivariate regression analysis often adjusts for confounding effects of multiple covariates, correlation coefficient analysis measures the crude relationship between two variables. The theoretical difference between these two methods might have accounted for the variation in the results of peer/neighbor evacuation and evacuation decisions. The impact of the media on decision to evacuate may be explained by the anxiety provoked among residents by increasing risk perceptions (Stein et al., 2010). While residents exposed to Category 4 hurricanes may sense an immediate urge to evacuate (through media advisories), their counterparts exposed to Category 5 hurricanes may have already expected the worst, thereby developing tolerance by failing to comply with evacuation advisories aired via media. Finally, the differential inference on the evacuation behavior of Hispanics by region of hurricane occurrence was likely explained by variation in education, English language comprehension, and economic resources to finance evacuation, between Hispanics in the Gulf Coast and their counterparts in the Atlantic Coast.

5.1.3. Predictors of Self-Rated Health among Residents in the Texas Gulf-Coast after Hurricane Harvey

About four months after hurricane Harvey made landfall, primary data were collected from the residents of the Texas Gulf Coast using SF-12, which is a highly valid and reliable psychometric instrument for the estimation of the self-rated health of populations (Ware et al., 1996). Of the 1,086 study participants, about 371 (34.16%) evacuated due to hurricane Harvey. The self-rated mental and physical health of the respondents were significantly lower than national average (34.58 and 45.20 respectively). Also, evacuees had significantly lower self-rated physical health than non-evacuees, but no significant difference was found between the self-rated mental health of both groups. In terms of gender, males were found to have higher self-rated mental health and lower physical health than females.

Upon adjusted analysis with multivariate linear regression models, no statistically significant association was found between self-rated mental health and evacuation status of study participants (coef. =0.20; 95% CI: -1.17, 1.58). The middle-aged and elderly have significantly better self-rated mental health than younger respondents (aged 18-24 years) and females have lower self-rated mental health compared to males (coef. =-2.10; 95% CI: -3.53, -0.67). Respondents with graduate or professional degrees have better self-rated mental health than those with only high school education (coef. = 3.73; 95% CI: 1.68,5.77). Individuals that live in mobile homes have lower self-rated mental health than residents of single-family homes (coef. =-2.66; 95% CI: -5.27, -0.04). In addition, high perception of surge risk was associated with better self-rated mental health than low perception of surge risk (coef. =1.75; 95% CI:0.09,3.40). On the adjusted estimates of self-rated physical health, evacuation was significantly associated with poorer outcome (coef. = -3.51; 95% CI: -4.97, -2.06). The young, middle-aged, and elderly had poorer physical health than the 18-24 age group, and medium or high perception of surge risk was significantly associated with poorer physical health than low perception of surge risk.

The poorer self-rated health (physical and mental) of the study population (compared to the U.S national average) may be attributed to the higher rate of hurricane landfall in the Texas Gulf Coast. For example, more than 13 hurricanes made land fall in the Gulf Coast since 2005. The non-significant association between self-rated mental health and evacuation was surprising since we expected evacuees to have poorer self-rated mental health. However, the poorer physical health of the evacuees was ‘expected’, due to the physical injuries, pain and exhaustion that accompany the evacuation process. Disasters may strengthen pre-existing social inequalities and hence the possible explanation for the variation in mental health outcomes by gender, educational status, home type, and perception of surge risk (Kaniasty & Norris 1995; Norris et al., 2002; Tierney, 2000). The middle-aged and elderly demonstrated better self-rated mental health than younger individuals (the 18-24 age group) probably because the latter experienced more stress (e.g. displacement, family breakup) and adverse financial outcomes (e.g. loss of employment).

5.2. Future Study

5.2.1. Hurricane Evacuation Shelter Distribution and Deficit

Although this study investigated the prevailing shelter deficit in the Houston-Galveston MSA, shelter demand was estimated based on the hurricane evacuation Zip-Zone map. Unfortunately, the map was primarily designed to identify areas at risk of flooding from storm surge rather than inland precipitation. The results of this study are therefore more valid for storm-surge hurricanes like Ike, and less relevant for Harvey. For Harvey, a more accurate estimation of flood risk areas may be obtained with flood inundation maps for the Houston-Galveston MSA. However, because of rapid urban development and increase in impervious areas in the region, these maps are outdated, and need to be revised to reflect current risks (Blackburn, 2017). Future studies should therefore utilize updated flood inundation maps to enable a more accurate estimation of shelter demand (for rain-predominant storms like Harvey).

5.2.2. Factors that Predict Hurricane Evacuation

Some of the primary studies included in the statistical meta-analysis reported correlation coefficients, while others reported Odds Ratios or regression coefficients. To derive a pooled estimate, we converted all the effect sizes to correlation coefficients for final analysis. While Odds Ratios and regression coefficients (especially obtained from multivariate models) often adjust for the confounding effect of putative covariates, correlation coefficients only provide a crude measure of association between variables. Unfortunately, most of the primary studies did not provide sufficient sample size information to calculate variance-weighted pooled estimates for Odds Ratios, hence the use of correlation coefficient as summary estimate. To permit a statistical meta-analysis of Odds Ratios, future primary studies should provide sufficient sample size information to recalculate a 2x2 contingency table. For example, in the relationship between mobile home residence and evacuation, counts are required for mobile home residents that evacuated, mobile home residents that failed to evacuate, non-mobile home residents that evacuated, and non-mobile home residents that failed to evacuate.

Another important phenomenon that requires further exploration is statistical interaction. Although this study identified heterogeneity across multiple studies, only 20% (three of 15) of moderators were isolated. Therefore, future primary studies should explore statistical interactions to identify additional moderators of hurricane evacuation.

5.2.3. Self-rated Health of Residents after Hurricane Harvey

A cross-sectional data from this study was used to assess the self-rated health of residents in the Texas Gulf-Coast and factors associated with these scores. Being ‘cross-sectional’, the data only provided prevalent estimates rather than incidence rates. Therefore, future longitudinal studies may permit a more valid comparison of self-rated health between the periods preceding and superseding a hurricane landfall.

This study was also limited by missing data (70% response rate) in SF-12 estimates. Although multiple imputation did not significantly change the results, future studies may improve on this limitation by ensuring a higher response rate.

REFERENCES

Abramson, D., Stehling-Ariza, T., Garfield, R., & Redlener, I. (2008). Prevalence and Predictors of Mental Health Distress Post-Katrina: Findings from the Gulf Coast Child and Family Health Study. *Disaster Medicine and Public Health Preparedness*. 2(2), 77-86

Ahmadkhani, M., Alesheikh, A. A., Khakifirouz, S., & Salehi-Vaziri, M. (2018). Space-Time Epidemiology of Crimean-Congo Hemorrhagic Fever (CCHF) in Iran. *Ticks and Tick-borne Diseases*. 9(2), 207-216

Alvarez, G., Lara, F., Harlow, S. D., & Denman, C. (2009). Infant mortality and Urban Marginalization: A Spatial Analysis of their Relationship in a Medium-Sized City in Northwest Mexico. *Pan American Journal of Public Health*. 26(1), 31-38

Andone, D. (2017). Houston Knew it was at Risk of Flooding so Why Didn't the City Evacuate? *CNN*. Retrieved from: https://www.cnn.com/2017/08/27/us/houston-evacuation-hurricane-harvey/index.html

Anseline, L., Griffith, D.A., (1988). Do Spatial Effects Really Matter in Regression Analysis? *Pap. Reg. Sci. Assoc*. 65, 11–34

Baker, E. J. (1991). Hurricane Evacuation Behavior. *International Journal of Mass Emergencies and Disasters*. 9, 287-310

Baker, E. J. (2000). Hurricane Evacuation in the United States. *Storms*. 1, 306-319

Baral, M. I. & Bhagwati, K. C. (2018). Post-Traumatic Stress Disorder and Coping Strategies among Adult Survivors of Earthquake, Nepal. *International Journal of Health Sciences & Research*. ISSN:2249-9571

Bateman, J. M. & Edwards, B. (2002). Gender and Evacuation: A Closer Look at Why Women are More Likely to Evacuate for Hurricanes. *Natural Hazards Review*, 3(3), 107-117

Benedek, D. M., Carol, F., & Robert, J. U. (2007). First Responders: Mental Health Consequences of Natural and Human-Made Disasters for Public Health and Public Safety Workers. *Annual Review of Public Health* 28 (2007): 55–68

Blackburn, J. (2017). Hurricane/Tropical Storm Harvey: Policy Perspectives. Living with Houston Flooding. Retrieved from: https://www.bakerinstitute.org/media/files/research_document/03d3e4fe/BI-pub-Blackburn_Harvey-090617.pdf

Blake, E.S. & Zelinsky, D.A. (2018). Hurricane Harvey . *Tropical Cyclone Report* AL092017. Retrieved from https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf

Bokszczanin, A. (2007). PTSD Symptoms in Children and Adolescents 28 Months after a Food: Age and Gender Differences. *Journal of Traumatic Stress*, 20, 347–351

Bolin, R. & Bolton, P. (1986). Race, Religion, and Ethnicity in Disaster Recovery. *University of Colorado, Institute of Behavioral Science*. Retrieved from: https://scholarcommons.usf.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1087&context=fmhi_pub

Bourque, L. B., Siegel, J. M., Kano, M., & Wood, M. M. (2006). Weathering the Storm: The Impact of Hurricanes on Physical and Mental Health. *The Annals of the American Academy of Political and Social Science, 604*(1), 129-151

Brackenridge, S., Zottarelli, L. K., Rider, E., & Carlsen-Landy, B. (2012). Dimensions of the Human–Animal Bond and Evacuation Decisions among Pet Owners during Hurricane Ike. *Anthrozoös*. 25(2), 229-238

Brezina, T. (2008). What went Wrong in New Orleans? An Examination of the Welfare Dependency Explanation. *Social Problems*. 55(1), 23-42

Briere, J., & Elliott, D. (2000). Prevalence, Characteristics, and Long-Term Sequelae of Natural Disaster Exposure in the General Population. *Journal of Traumatic Stress.* 13, no. 4 (2000): 661–79

Brody, S. D., Lee, Y., & Highfield, W. E. (2017). Household Adjustment to Flood Risk: A Survey of Coastal Residents in Texas and Florida, United States. *Disasters*. 41(3), 566-586

Bromet, E. J., Gluzman, S., Schwartz, J. E., & Goldgaber, D. (2002). Somatic Symptoms in Women 11 years after the Chornobyl Accident: Prevalence and Risk Factors. *Environmental Health Perspectives*. 110 (Suppl. 4), 625

Brunkard, J., Namulanda, G., & Ratard, R. (2008). Hurricane Katrina Deaths, Louisiana, 2005. *Disaster Medicine and Public Health Preparedness.* 2(4), 215-223

Buckland, J., & Rahman, M. (1999). Community-Based Disaster Management during the 1997 Red River Flood in Canada. *Disasters*. 23(2), 174-191

Can, A. (1990). The Measurement of Neighborhood Dynamics in Urban House Prices. *Econ. Geography*. 66, 254–272

Castillo, K. C., Körbl, B., Stewart, A., Gonzalez, J. F., & Ponce, F. (2011). Application of Spatial Analysis to the Examination of Dengue Fever in Guayaquil, Ecuador. *Procedia Environ Sci*. 7, 188-193

Centers for Disease Control and Prevention (CDC) (2006). *MMWR Morb Mortal Wkly Rep*. 55(2):38-41

Centers for Disease Control and Prevention (CDC). (2005). Surveillance for Illness and Injury after Hurricane Katrina-New Orleans, Louisiana. *MMWR: Morbidity and Mortality Weekly Report*. 54(40), 1018-1021

Citylab. (2017). The Evacuation That Wasn't. Retrieved from: https://www.citylab.com/transportation/2017/08/the-evacuation-that-wasnt/538026/

Coch, N.K. & Wolff, M.P. (1991). Effects of Hurricane Hugo Storm Surge in Coastal South Carolina. *J Coast Res*. 201-226. Retrieved from: http://www.jstor.org/stable/25735416

Connecticut Hurricane Evacuation Study Technical Report. (1994). Retrieved from: https://www.hsdl.org/?abstract&did=768940

Cutter, S.L. & Emrich, C.T. (2006). Moral Hazard, Social Catastrophe: The Changing Face of Vulnerability along the Hurricane Coasts. *Ann Am Acad Pol Soc Sci*. 2006, 604(1):102-112

Dash, N., & Gladwin, H. (2007). Evacuation Decision Making and Behavioral Responses: Individual and Household. *Natural Hazards Review*, 8(3), 69-77

Davies, Alex. (2017). Harvey Wrecks up to a Million Cars in Car-Dependent Houston. Retrieved from: https://www.wired.com/story/harvey-houston-cars-ruined/

Di Liberto, T. (2017). Reviewing Hurricane Harvey's Catastrophic Rain and Flooding. Retrieved from: https://www.climate.gov/news-features/event-tracker/reviewing-hurricane-harveys-catastrophic-rain-and-flooding

Ding, C., 2001. An Empirical Model of an Urban Spatial Development Pattern. *Rev. Urban Reg. Dev. Stud.* 13 (3), 123–136

Dixon, D. S., Mozumder, P., Vasquez, W. F., & Gladwin, H. (2017). Heterogeneity Within and Across Households in Hurricane Evacuation Response. *Networks and Spatial Economics*. 17(2), 645-680

Dominici, F., Levy, J.I., Louis, T.A. (2005). Methodological Challenges and Contributions in Disaster Epidemiology. *Epidemiol Rev*. 27(1):9–12

Domonoske, C. (2017). Why Didn't Officials Order the Evacuation of Houston? *National Public Radio.* Retrieved from: https://www.npr.org/sections/thetwo-way/2017/08/28/546721363/why-didn-t-officials-order-the-evacuation-of-houston

Dow, K. & Cutter, S. L. (1998). Crying Wolf: Repeat Responses to Hurricane Evacuation Orders. *Coastal Management*. 26(4), 237-252

Dow, K. & Cutter, S.L. (2000). Public Orders and Personal Opinions: Household Strategies for Hurricane Risk Assessment. *Environmental Hazards.* 2:143-55

Du, W., FitzGerald, G. J., Clark, M., & Hou, X. Y. (2010). Health Impacts of Floods. *Pre-Hospital and Disaster Medicine.* 25(3), 265-272

Dwyer, C. (2017). The Goal is Rescue: The Massive Response to Harvey by the Numbers. *National Public Radio*. Retrieved from: https://www.npr.org/sections/thetwo-way/2017/08/28/546714612/-the-goal-is-rescue-harvey-s-historic-deluge-met-with-equally-massive-response

Elder, K., Xirasagar, S., Miller, N., Bowen, S. A., Glover, S., & Piper, C. (2007). African Americans' Decisions Not to Evacuate New Orleans Before Hurricane Katrina: A Qualitative Study. *American Journal of Public Health*. 97(Supplement_1), S124-S129.

Elliott, J. R. & Pais, J. (2006). Race, Class, And Hurricane Katrina: Social Differences in Human Responses to Disaster. *Social Science Research.* 35(2), 295-321

Emslie, C., & Mitchell, R. (2009). Are There Gender Differences in The Geography of Alcohol-Related Mortality in Scotland? An Ecological Study. *BMC Public Health*. 9(1), 58

Fergusson, D. M., Horwood, L. J., Boden, J. M., & Mulder, R. T. (2014). Impact of a Major Disaster on the Mental Health of a Well-Studied Cohort. *JAMA Psychiatry*. 71(9), 1025-1031

Ferreras, J. (2017). Hurricane Harvey has Affected 13 Million. South Asian Floods have Affected 41 Million. Retrieved from: https://globalnews.ca/news/3708870/hurricane-harvey-south-asian-floods/

Field, A. P., & Gillett, R. (2010). How to do a Meta-analysis. *British Journal of Mathematical and Statistical Psychology*. 63(3), 665-694

Florida Technical Report (FTR). (2018). Statewide Emergency Shelter Plan. Retrieved from: https://www.floridadisaster.org/globalassets/dem/response/sesp/2018/2018-sesp-a1-main-plan-text_final_1-30-18.pdf

Fothergill, A., Maestas, E. G., & Darlington, J.D. (1999). Race, Ethnicity and Disasters in the United States: A Review of the Literature. *Disasters*. 23:156–73

Fu, Haoqiang. (2004). Development of Dynamic Travel Demand Models for Hurricane Evacuation (Doctoral Dissertation). *L.S.U Doctoral Dissertations*. 1583. Retrieved from: https://digitalcommons.lsu.edu/gradschool_dissertations/1583

Galea, S., Brewin C.R., Gruber, M., Jones, R.T., King, D.W., King, L.A., McNally RJ, Ursano RJ, Petukhova M, Kessler RC. (2007). Exposure to Hurricane-Related Stressors and Mental Illness after Hurricane Katrina. *Arch Gen Psychiatry*. 2007 Dec; 64(12):1427-34

Galea, S., Tracy, M., Norris, F., & Coffey, S. F. (2008). Financial and Social Circumstances and the Incidence and Course of PTSD in Mississippi During the First Two Years after Hurricane Katrina. *Journal of Traumatic Stress: Official Publication of The International Society for Traumatic Stress Studies.* 21(4), 357-368

Gittelman, M. (2003). Disasters and Psychosocial Rehabilitation. *Int. J. Ment. Health.* 32: 51–69

Goldmann, E. & Galea, S. (2014). Mental Health Consequences of Disasters. *Annual Review of Public Health*. 35, 169-183

Greenough, G., McGeehin, M., Bernard, S. M., Trtanj, J., Riad, J., & Engelberg, D. (2001). The Potential Impacts of Climate Variability and Change on Health Impacts of Extreme Weather Events in the United States. *Environmental Health Perspectives*. 109(Suppl 2), 191

Harris County Office of Homeland Security and Emergency Management (HCOHSEM). (2016). Mass Shelter Plan. Retrieved from: https://www.documentcloud.org/documents/4375459-Mass-Shelter-Plan.html

Harville, E. W., Xiong, X., & Buekens, P. (2010). Disasters and Perinatal Health: A Systematic Review. *Obstetrical & Gynecological Survey*. 65(11), 713

Harville, E. W., Xiong, X., Pridjian, G., Elkind-Hirsch, K., & Buekens, P. (2009). Postpartum Mental Health after Hurricane Katrina: A Cohort Study. *BMC Pregnancy and Childbirth*. 9(1), 21

Harville, E.W., Xiong, X., Smith, B.W., Pridjian, G., Elkind-Hirsch, K., Buekens, P. (2011). Combined Effects of Hurricane Katrina and Hurricane Gustav on the Mental Health of Mothers of Small Children. *J. Psychiatr. Ment. Health Nurs*. 18: 288–296

Hasan, S., Ukkusuri, S., Gladwin, H., & Murray-Tuite, P. (2010). Behavioral Model to Understand Household-Level Hurricane Evacuation Decision Making. *Journal of Transportation Engineering*, 137(5), 341-348

Havenaar, J. M., De Wilde, E. J., Van Den Bout, J., Drottz-Sjöberg, B. M., & Van Den Brink, W. (2003). Perception of Risk and Subjective Health among Victims of the Chernobyl Disaster. *Social Science & Medicine*. 56(3), 569-572

Hays, R. (2018). Scoring the SF-12 Version 2.0. Retrieved from: http://gim.med.ucla.edu/FacultyPages/Hays/utils/

Heid, A. R., Pruchno, R., Cartwright, F. P., & Wilson-Genderson, M. (2017). Exposure to Hurricane Sandy, Neighborhood Collective Efficacy, and Post-Traumatic Stress Symptoms in Older Adults. *Aging and Mental Health*. 21(7), 742-750. doi:10.1080/13607863.2016.1154016

Horney, J. A., MacDonald, P. D., Van Willigen, M., Berke, P. R., & Kaufman, J. S. (2010). Individual Actual or Perceived Property Flood Risk: Did it Predict Evacuation from Hurricane Isabel in North Carolina, 2003? *Risk Analysis.* 30(3), 501-511

Horney, J. A., MacDonald, P. D., Van Willigen, M., & Kaufman, J. S. (2012). The Importance of Effect Measure Modification when Using Demographic Variables to Predict Evacuation. *Risk, Hazards & Crisis in Public Policy*, *3*(1), 1-19

Houston-Galveston Area Council (HGAC). (2018). H-GAC Counties. Retrieved from: http://www.h-gac.com/rds/government_links/counties.aspx

Houston Public Media (HPM). (2018). Many Houstonians may be Unaware they Live in Evacuation Zones. Retrieved from:

https://www.houstonpublicmedia.org/articles/news/2018/01/12/261131/many-houstonians-may-be-unaware-they-live-in-evacuation-zones/

Hoven, C.W., Duarte, C.S., Lucas, C.P., Wu, P., Mandell, D.J., Goodwin, R.D., et al. (2005). Psychopathology Among New York City Public School Children 6 Months after September 11. *Archives of General Psychiatry*. 62, 545–552

Howell, Susan E. (1998). Evacuation Behavior in Orleans and Jefferson Parishes - Hurricane Georges. *Survey Research Center Publications.* Paper 32. Retrieved from: https://scholarworks.uno.edu/src_pubs/32

Huang, S.K. (2014). Households' Evacuation Decisions in Response to Hurricanes Katrina & Rita (Doctoral Dissertation). Retrieved from: http://oaktrust.library.tamu.edu/bitstream/handle/1969.1/153425/HUANG-DISSERTATION-2014.pdf?sequence=1

Huang, S. K., Lindell, M. K., & Prater, C. S. (2016). Multistage Model of Hurricane Evacuation Decision: Empirical Study of Hurricanes Katrina and Rita. *Natural Hazards Review*, *18*(3), 05016008

Huang, S. K., Lindell, M. K., & Prater, C. S. (2016). Who leaves and Who Stays? A Review and Statistical Meta-analysis of Hurricane Evacuation Studies. *Environment and Behavior*. 48(8), 991-1029

Huang, S. K., Lindell, M. K., Prater, C. S., Wu, H. C., & Siebeneck, L. K. (2012). Household Evacuation Decision Making in Response to Hurricane Ike. *Natural Hazards Review*. *13*(4), 283-296

Huber, C., Klinger, H., O'Hara, K. (2017). Hurricane Harvey: Facts, FAQs and How to Help. Retrieved from: https://www.worldvision.org/disaster-relief-news-stories/hurricane-harvey-facts

Huddleston, C. (2016). 69% of Americans Have Less Than $1,000 in Savings. *GOBankingRates*. Retrieved from: https://www.gobankingrates.com/saving-money/savings-advice/data-americans-savings/

Hyre, A. D., Cohen, A. J., Kutner, N., Alper, A. B., Dreisbach, A. W., Kimmel, P. L., & Muntner, P. (2008). Psychosocial Status of Hemodialysis Patients One Year after Hurricane Katrina. *The American Journal of the Medical Sciences.* 336(2), 94-98

Jankowski, P. (2017). Hurricane Harvey: More Evacuees Leave Austin Shelters. *Statesman*. Retrieved from: https://www.statesman.com/news/local/hurricane-harvey-more-evacuees-leave-austin-shelters/f4zDL4UssDVClKI1E3092O/

Jaycox, L. H., Cohen, J. A., Mannarino, A. P., Walker, D. W., Langley, A. K., Gegenheimer, K. L., & Schonlau, M. (2010). Children's Mental Health Care following Hurricane Katrina: A field Trial of Trauma-Focused Psychotherapies. *Journal of Traumatic Stress: Official Publication of The International Society for Traumatic Stress Studies*. 23(2), 223-231

Jenkinson, C., Layte, R., Jenkinson, D., Lawrence, K., Petersen, S., Paice, C., & Stradling, J. (1997). A Shorter Form Health Survey: Can the SF-12 Replicate Results from the SF-36 in Longitudinal Studies? *Journal of Public Health*. 19(2), 179-186

Jones-DeWeever, A. (2008). Women in the Wake of the Storm: Examining the Post-Katrina Realities of the Women of New Orleans and the Gulf-Coast. *Institute for Women's Policy Research*. Retrieved from: https://iwpr.org/publications/women-in-the-wake-of-the-storm-examining-the-post-katrina-realities-of-the-women-of-new-orleans-and-the-gulf-coast-executive-summary/

Kaniasty, K. & Norris, F. H. (2008). Longitudinal Linkages between Perceived Social Support and Post-traumatic Stress Symptoms: Sequential Roles of Social Causation and Social Selection. *Journal of Traumatic Stress: Official Publication of The International Society for Traumatic Stress Studies.* 21(3), 274-281

Kelly, M. (2017). Houston Convention Center Already Thousands over Capacity. ABC News. Retrieved from: https://abcnews.go.com/US/30000-hurricane-harvey-victims-desperate-shelter-evacuation-centers/story?id=49466070

Kessler, R.C., Galea, S., Gruber, M.J., Sampson, N.A., Ursano, R.J., Wessely, S. (2008). Trends in Mental Illness and Suicidality after Hurricane Katrina. *Molecular Psychiatry*. 13:374–384

Kessler, R.C., Galea, S., Jones, R.T., Parker, H.A. (2006). Hurricane Katrina Community Advisory Group. *Bull World Health Organ*. 84(12):930-9

Kim, Y., Tsutsumi, A., Izutsu, T., Kawamura, N., Miyazaki, T., & Kikkawa, T. (2011). Persistent Distress After Psychological Exposure to the Nagasaki Atomic Bomb Explosion. *The British Journal of Psychiatry.* 199(5), 411-416

Kubrin, C. E., Squires, G. D., Graves, S. M., & Ousey, G. C. (2011). Does Fringe Banking Exacerbate Neighborhood Crime Rates? Investigating the Social Ecology of Payday Lending. *Criminology & Public Policy*. 10(2), 437-466

Landy, M. (2007). A Failure of Initiative: Final Report of the Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina. *The Journal of Federalism*. 38(1), 152-165

Larrance, R., Anastario, M., & Lawry, L. (2007). Health Status Among Internally Displaced Persons in Louisiana and Mississippi Travel Trailer Parks. *Annals of Emergency Medicine.* 49(5), 590-601

Li, Y., He D.J., Wu Y.Q., Yang N.B., Wang H.F., Cong X.Y. (2008). Post-Traumatic Stress Disorder and Risk Factors among Earthquake Survivors in Wenchuan, Sichuan. Chin. *J. Rehabil. Med*. 23: 868–871

Lima, M. L. (2004). On the Influence of Risk Perception on Mental Health: Living Near an Incinerator. *Journal of Environmental Psychology*. 24(1), 71-84

Mail Foreign Service (MFS). (2017). Now Even Rescue Shelters Succumb to Deluge. *Daily Mail [serial online] Newspaper Source Plus*, Ipswich, MA. ISSN: 0307-7578

Malewitz, J. (2017). Why not Evacuate before Harvey? *Texas Tribune*. Retrieved from: https://www.texastribune.org/2017/08/27/why-not-evacuate-harvey-houston-leaders-defend-their-calls-stay-put/

McCarthy, K. (2017). Houston Convention Center already Thousands over Capacity. Retrieved from: https://abcnews.go.com/US/30000-hurricane-harvey-victims-desperate-shelter-evacuation-centers/story?id=49466070

Mileti, D. S. & Peek, L. (2000). The Social Psychology of Public Response to Warnings of a Nuclear Power Plant Accident. *Journal of Hazardous Materials. 75*(2-3), 181-194

Mileti, D. S., & Sorensen, J. H. (1990). Communication of Emergency Public Warnings: A Social Science Perspective and State-of-the-Art Assessment (No. ORNL-6609). *Oak Ridge National Lab.*, TN (USA)

National Research Council (NRC). (2014). Reducing Coastal Risk on the East and Gulf Coasts. *The National Academies Press, Washington, DC.* Retrieved from: https://doi.org/10.17226/18811

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding- A Global Assessment. *PloS One.* 10(3), e0118571

Noji, E. K. (2005). Public Health Issues in Disasters. *Critical Care Medicine*. 33(1), S29-S33

Noltenius, M. S. (2008). Capturing Pre-evacuation Trips and Associative Delays: A Case Study of the Evacuation of Key West, Florida for Hurricane Wilma (Doctoral Dissertation). *University of Tennessee*. Retrieved from: https://trace.tennessee.edu/utk_graddiss/494

Norris, F.H. (2006). Disaster Research Methods: Past Progress and Future Directions. *J Trauma Stress*.19(2):173–84. PMID:16612819

Norris, F. H., Friedman, M. J., & Watson, P. J. (2002). 60,000 Disaster Victims Speak: Part II. Summary and Implications of the Disaster Mental Health Research. *Psychiatry: Interpersonal and Biological Processes.* 65(3), 240-260

Norris, F.H., Murphy, A.D., Baker, C.K., Perilla, J.L. (2004). Post-disaster PTSD over Four Waves of a Panel Study of Mexico's 1999 Flood. *J. Trauma. Stress*.17: 283–292

O'Donnell, N. (2017). Houston Flooding Evacuees Overwhelm Main Evacuation Center. *CBS News*. Retrieved from: https://www.cbsnews.com/news/houston-flooding-convention-center-overcrowded-sleeping-on-floor/

Ozer, E. J., & Weiss, D. S. (2004). Who Develops Post-Traumatic Stress Disorder? *Current Directions in Psychological Science.* 13(4), 169-172

Paxson, C., Fussell, E., Rhodes, J., Waters, M. (2012). Five Years Later: Recovery from Post-Traumatic Stress and Psychological Distress among Low-Income Mothers affected by Hurricane Katrina. *Social Science & Medicine*. 74:150–157

Peacock, W. G., Brody, S.D., & Highfield. W. (2004). Hurricane Risk Perceptions among Florida's Single-Family Homeowners. *Landscape and Urban Planning*. 83:120–35

Peacock, W.G., Morrow, B.H., Gladwin, H. (2012). Hurricane Andrew: Ethnicity, Gender and the Sociology of Disasters. *Routledge, London, New York*. ISBN: 1135108277

Peacock, W.G., Tripoli, G., & Wood, S., L. (2011). Creating a More Disaster Resilient America (CAMRA). *Hazard Reduction and Recovery Center*. Retrieved from: http://research-legacy.arch.tamu.edu/camra/report.pdf

Perkins, J. B. (1996). Shaken Awake! Estimates of Uninhabitable Dwelling Units and Peak Shelter Populations in Future Earthquakes affecting the San Francisco Bay Region. *Association of Bay Area Governments.* Publication Number: P96002EQK

Pielke, R.A., Gratz, J., Landsea, C.W., Collins, D., Saunders, M.A., Musulin, R. (2008). Normalized Hurricane Damage in the United States: 1900–2005. *Nat Hazards Rev*. 9(1):29-42.

Quarantelli, E. L. (1980). Evacuation Behavior and Problems: Findings and Implications from the Research Literature. *Ohio State Univ Columbus Disaster Research Center*. Retrieved from: udspace.udel.edu/bitstream/handle/19716/1283/MR27.pdf?sequence=1

Quarantelli, E. L. (1997). The Disaster Research Center (DRC) Field Studies of Organized Behavior in the Crisis Time Period of Disasters. In: Stallings RA, ed. *Methods of Disaster*

Research. Retrieved from: http://udspace.udel.edu/bitstream/handle/19716/198/PP254-DRC?sequence=1

Rhodes, J., Chan, C., Paxson, C., Rouse, C. E., Waters, M., & Fussell, E. (2010). The Impact of Hurricane Katrina on the Mental and Physical Health of Low-Income Parents in New Orleans. *American Journal of Orthopsychiatry*. 80(2), 237-247

Riad, J. K., Norris, F. H., & Ruback, R. B. (1999). Predicting Evacuation in Two Major Disasters: Risk Perception, Social Influence, and Access to Resources. *Journal of Applied Social Psychology*. 29(5), 918-934

Rosenkoetter, M. M., Covan, E. K., Cobb, B. K., Bunting, S., & Weinrich, M. (2007). Perceptions of Older Adults regarding Evacuation in the Event of a Natural Disaster. *Public Health Nursing*. 24(2), 160-168

Sadri, A. M., Ukkusuri, S. V., & Gladwin, H. (2017). Modeling Joint Evacuation Decisions in Social Networks: The case of Hurricane Sandy. *Journal of Choice Modelling*. 25, 50-60

Sastry, N. & Gregory, J. (2013). The Effect of Hurricane Katrina on the Prevalence of Health Impairments and Disability among Adults in New Orleans: Differences by Age, Race, and Sex. *Social Science & Medicine*. 80, 121-129

Sastry, N. & VanLandingham, M. (2009). One year later: Mental Illness Prevalence and Disparities among New Orleans Residents Displaced by Hurricane Katrina. *American Journal of Public Health*. 99(S3), S725-S731

Schwartz, R. M., Rasul, R., Kerath, S. M., Watson, A. R., Lieberman-Cribbin, W., Liu, B., & Taioli, E. (2018). Displacement During Hurricane Sandy: The Impact on Mental Health. *Journal of Emergency Management*. 16(1), 17-27. doi:10.5055/jem.2018.0350

Schwartz, R. M., Sison, C., Kerath, S. M., Murphy, L., Breil, T., Sikavi, D., & Taioli, E. (2017). The Impact of Hurricane Sandy on the Mental Health of New York Area Residents. *American Journal of Disaster Medicine*. 10(4), 339-346

Schwartz, R. M., Tuminello, S., Kerath, S. M., Rios, J., Lieberman-Cribbin, W., & Taioli, E. (2018). Preliminary Assessment of Hurricane Harvey Exposures and Mental Health Impact. *International Journal of Environmental Research and Public Health*. 15(5), 974

SimplyAnalytics. (2017). Census 2017 Current Estimates Data. *SimplyAnalytics.* Retrieved from: http://simplyanalytics.com/

Smith, K.T. (1999). Estimating the Cost of Hurricane Evacuation: A Study of Evacuation Behavior and Risk Interpretation using Combined Reveal and Stated Preferences Household Data. *Department of Economics, East Carolina Univ., Greenville, NC*. Retrieved from: https://www.cs.rice.edu/~devika/evac/papers/kevinsmith.pdf

Smith, S. K. & McCarty, C. (2009). Fleeing the Storm(s): An Examination of Evacuation Behavior during Florida's 2004 Hurricane Season. *Demography*. 46, 127-145

Solis, D., Thomas, M., & Letson, D. (2009). Determinants of Household Hurricane Evacuation Choice in Florida. In presentation at the Southern Agricultural Economics Association Annual Meeting (Vol. 31). Retrieved from: https://pdfs.semanticscholar.org/a1db/0dcb62cd1617060b1f7163780b620341cf11.pdf

Sorensen, J. H. (2000). Hazard Warning Systems: Review of 20 Years of Progress. *Natural Hazards Review*. *1*(2), 119-125

Sorensen, J. H. & Sorensen, B. V. (2007). Community Processes: Warning and Evacuation. *Handbook of Disaster Research* (pp. 183-199). Springer, New York, NY

Stein, R. M., Dueñas-Osorio, L., & Subramanian, D. (2010). Who Evacuates when Hurricanes Approach? The Role of Risk, Information, and Location. *Social Science Quarterly*. 91(3), 816-834

Taioli, E. (2018). Preliminary Assessment of Hurricane Harvey Exposures and Mental Health Impact. *International Journal of Environmental Research and Public Health. 15*(5) doi:10.3390/ijerph15050974

Taioli, E., Tuminello, S., Lieberman-Cribbin, W., Bevilacqua, K., Schneider, S., Guzman, M., & Van Griensven, F., Chakkraband, M.L., Thienkrua, W. (2006). Mental Health Problems among Adults in Tsunami-Affected Areas in Southern Thailand. *JAMA*. 2006; 296:537–548

Takahashi, P. (2017). This is How Many Homes were Damaged by Harvey in the Houston Area. Retrieved from: https://www.bizjournals.com/houston/news/2017/09/14/this-is-how-many-homes-were-damaged-by-harvey-in.html

King, B. (2017). Houston's Mayor was Right to not Evacuate. Retrieved from: https://www.nytimes.com/2017/08/28/opinion/harvey-flooding-mayor-evacuation.html

Texas Natural Resources Information System. (2018). *FEMA DFIRM*. Retrieved from: https://tnris.org/data-catalog/entry/federal-emergency-management-agency-d-firm/

Tolin, D.F. & Foa, E.B. (2006). Sex Differences in Trauma and Post-Traumatic Stress Disorder: A Quantitative Review of 25 Years of Research. *Psychol. Bull*. 2006; 132: 959–992

Tuthill, S. (2014). Hurricane Risks Rise as Coastal Populations Grow. Retrieved from: https://www.accuweather.com/en/weather-news/as-coastal-populations-grown-s/13927793

U.S. Army Corps of Engineers. (1994). Connecticut Hurricane Evacuation Study Technical Report. Retrieved from: https://www.hsdl.org/?view&did=24235

U.S. Census Bureau. (2017). Current Population Estimates. Retrieved from: https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

Van Griensven, F., Chakkraband, M. S., Thienkrua, W., Pengjuntr, W., Cardozo, B. L., Tantipiwatanaskul, P., & Sabin, M. (2006). Mental Health Problems among Adults in Tsunami-Affected Areas in Southern Thailand. *JAMA*. 296(5), 537-548

Van Zandt, S. S., & Mhatre, P. C. (2013). The Effect of Housing Choice Voucher Households on Neighborhood Crime: Longitudinal Evidence from Dallas. *Poverty & Public Policy*. 5(3), 229-249

Wallace, J. W., Poole, C., & Horney, J. A. (2016). The Association Between Actual and Perceived Flood Risk and Evacuation from Hurricane Irene, Beaufort County, North Carolina. *Journal of Flood Risk Management*. 9(2), 125-135

Wang, A., Wootson, C., O'Keefe. (2017). As Harvey Submerges Houston, Local Officials Defend their Calls not to Evacuate. Retrieved from: https://www.washingtonpost.com/news/post-nation/wp/2017/08/27/harvey-is-causing-epic-catastrophic-flooding-in-houston-why-wasnt-the-city-evacuated/?utm_term=.932887400d9e

Ware Jr, J. E., Kosinski, M., & Keller, S. D. (1996). A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Medical Care*. 34(3), 220-233

Ware, J. E., Kosinski, M., Turner-Bowker, D. M., & Gandek, B. (2005). How to Score Version 2 of the SF-12 Health Survey. *Lincoln, RI: QualityMetric Incorporated*. ISBN: 18918101039781891810107

Weems, C. F., Watts, S. E., Marsee, M. A., Taylor, L. K., Costa, N. M., Cannon, M. F., & Pina, A. A. (2007). The Psychosocial Impact of Hurricane Katrina: Contextual Differences in

Psychological Symptoms, Social Support, and Discrimination. *Behavior Research and Therapy*. 45(10), 2295-2306

Weisler, R. H., Barbee, J. G., & Townsend, M. H. (2006). Mental Health and Recovery in the Gulf Coast after Hurricanes Katrina & Rita. *JAMA*. 296(5), 585-588

WFAA. (2017). Mandatory Evacuations Order in Some Texas Coastal Cities Ahead of Harvey. Retrieved from: https://www.wfaa.com/article/weather/mandatory-evacuations-ordered-in-some-coastal-texas-cities-ahead-of-harvey/287-466984235

Whitehead. J. (2003). One Million Dollars per Mile? The Opportunity Costs of Hurricane Evacuation. *Ocean and Coastal Manage*. 46: 1069-1083

Whitehead, J. C., Edwards, B., Van Willigen, M., Maiolo, J. R., Wilson, K., & Smith, K. T. (2000). Heading for Higher Ground: Factors Affecting Real and Hypothetical Hurricane Evacuation Behavior. *Global Environmental Change Part B: Environmental Hazards*, 2(4), 133-142

Willigen, V. M., Edwards, B., Lormand, S., & Wilson, K. (2005). Comparative Assessment of Impacts and Recovery from Hurricane Floyd among Student and Community Households. *Natural Hazards Review*. 6(4), 180-190

Wilmot, C. G., & Mei, B. (2004). Comparison of Alternative Trip Generation Models for Hurricane Evacuation. *Natural Hazards Review*. 5(4), 170-178

Xu, W., Okada, N., Hatayama, M., & Takeuchi, Y. (2008). A Model Analysis Approach for Reassessment of the Public Shelter Plan Focusing both on Accessibility and Accommodation Capacity for Residents- Case Study of Nagata Ward in Kobe City, Japan. *Journal of Natural Disaster Science*. 28(2), 85-90

Zhang, Y. & Ho, S.M. (2011). Risk Factors of Posttraumatic Stress Disorder Among Survivors After the 512 Wenchuan Earthquake in China. *PLoS ONE*. 6: 1–6. doi: 10.1371/journal.pone.0022371

Zhang, Y., Prater, C. S., & Lindell, M. K. (2004). Risk Area Accuracy and Evacuation from Hurricane Bret. *Natural Hazards Review*. 5(3), 115-120