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Hurricane Harvey and Greater Houston households: comparing pre-event preparedness with post-event health effects, event exposures, and recovery

Sara E. Grineski, Aaron B. Flores, Timothy W. Collins, and Jayajit Chakraborty[1]

Most disaster studies rely on convenience sampling and 'after-only' designs to assess impacts. This paper, focusing on Hurricane Harvey (2017) and leveraging a pre-/post-event sample of Greater Houston households (n=71) in the United States, establishes baselines for disaster preparedness and home structure flood hazard mitigation, explores household-level ramifications, and examines how preparedness and mitigation relate to health effects, event exposures, and recovery. Between 70 and 80 per cent of participants instituted preparedness measures. Mitigation actions varied: six per cent had interior drainage systems and 83 per cent had elevated indoor heating/cooling components. Sixty per cent reported home damage. One-half highlighted allergies and two-thirds indicated some level of post-traumatic stress (PTS). Three-quarters worried about family members/friends. The results of generalised linear models revealed that greater pre-event mitigation was associated with fewer physical health problems and adverse experiences, lower PTS, and faster recovery. The study design exposed the broad benefits of home structure flood hazard mitigation for households after Harvey.

Keywords: disaster, flood, health, Hurricane Harvey, mitigation, social vulnerability

Introduction

Hurricane Harvey came ashore near Rockport, Texas, United States, on 25 August 2017. It was a Category 4 storm with winds in excess of 200 kilometres per hour. The storm lingered overland for an extended period of time owing to a combination of meteorological factors, including warm water in the Gulf of Mexico and a lack of wind in the upper atmosphere (Friedman and Schwartz, 2017), causing an extreme storm surge and leading to unprecedented rainfall totals (Risser and Wehner, 2017). In the six days after it made landfall, large portions of southeast Texas received more than one metre of rain (Jonkman et al., 2018). Among the approximately 13 million people directly affected by Harvey, some 22,000 were rescued from floodwaters, around 32,000 were temporarily housed in shelters, and at least 450,000 applied for Federal Emergency Management Agency (FEMA) disaster assistance. Only 17 per cent of those affected had flood insurance (Shultz and Galea, 2017).

The actual event and subsequent flooding caused severe damage in the nine-county Greater Houston metropolitan statistical area (MSA), which is the focus of this study. Creeks and bayous in this MSA witnessed water levels never before recorded. A record-

setting 76 centimetres of rain fell in parts of Houston. More than 156,000 homes were destroyed and at least 39 people died (Griffin, 2017). Most of the flooding receded within two days, but some areas remained flooded for weeks (Jonkman et al., 2018). To date, few studies have been published on the health and social impacts of Hurricane Harvey.

Leveraging a unique pre- and post-event survey sample of Greater Houston households, this paper establishes pre-event baselines for general disaster preparedness and home structure flood hazard mitigation and then reports on household-level health effects, event exposures, and recovery in the 90 days following the storm. Furthermore, it appraises how baseline preparedness and mitigation are related to post-Harvey health effects, event exposures, and recovery. The literature review that follows evaluates how households can prepare effectively for hurricanes and how they tend to be affected by them.

Preparing for hurricanes and hurricane-induced flooding

To prepare for a hurricane-induced flood disaster, householders can engage in home-site structural mitigation activities (such as installing an interior drainage system, elevating electrical components, building flood walls, or fitting hurricane shutters), as well as undertake general disaster preparedness measures (such as evacuation planning). How common pre-event mitigation and preparedness actions were among the average Greater Houston household prior to Hurricane Harvey is currently unknown. Structural mitigation is a widely used tool to protect residences against hurricane damage and has been promoted for decades (Sheaffer et al., 1967); it is an effective means of preventing losses (Kreibich et al., 2005; Poussin et al., 2012; de Moel, Van Vliet, and Aerts, 2014).

Households with higher home values and longer tenure were most likely to adopt structural mitigation strategies in coastal Florida and Texas as opposed to households at greatest risk or those with heightened risk perceptions (Brody, Lee, and Highfield, 2017). Despite the potential benefits of preventing losses, raising home values (Simmons, Kruse, and Smith, 2002), and protecting sensitive coastal habitats against the ecological harm caused by scattered waste (Burrus, Dumas, and Graham, 2011), hurricane mitigation actions can be expensive. Research has demonstrated that having flood insurance, even with high premiums, may undermine the desire of homeowners to protect their property via structural mitigation actions (Burrus, Dumas, and Graham, 2011).

In addition to employing mitigation strategies, householders can also protect themselves from hurricanes and floods by undertaking general disaster preparedness measures, such as developing an evacuation plan, preparing an emergency kit, and buying a fire extinguisher. Previous exposure to disasters can lead households to take these sorts of steps so as to be better prepared for the next event (Norris, Smith, and Kaniasty, 2010). When examining Greater Houston after Hurricane Rita in September 2005, researchers reported that 60 per cent of interviewed residents prepared their

home in the week before it came ashore by shuttering doors and windows and moving furniture and/or important items to safe locations, but they did not evaluate how this correlated with post-event impacts (Zhang et al., 2007).

Health effects of hurricanes and hurricane-induced flooding

Hurricanes and floods can affect households in various ways, including causing physical health problems and post-traumatic stress (PTS), presenting dangerous experiences with which they must cope, and damaging their home. Physical health problems are relatively common after hurricanes and floods. Following Hurricane Katrina in August 2005, one-third of evacuees to shelters in Houston reported suffering from an injury or health problem (Brodie et al., 2006). Among households who experienced home damage owing to a flood disaster in El Paso, Texas, in July 2006, 22 per cent suffered from allergies, 19 per cent from throat irritation, 17 per cent from headaches, 16 per cent from nasal irritation, 14 per cent from eye irritation, and 11 per cent from skin irritations in the four months afterwards (Collins, Jimenez, and Grineski, 2013).

While anxiety and depression affect people post disaster, post-traumatic stress disorder (PTSD) is the only psychopathology linked specifically to experiencing a traumatic event. It is one of the most commonly occurring and studied mental health maladies in the wake of disasters. One literature review estimated the prevalence of PTSD at 30–40 per cent among direct disaster victims, 10–20 per cent among rescue workers, and 5–10 per cent in the general population (Goldmann and Galea, 2014). Among 41 evacuees at the George R. Brown Convention Center in Houston, 46 per cent had probable PTSD three weeks after Harvey (Schwartz et al., 2018), exceeding slightly the average reported in Goldmann and Galea (2014). One year after Katrina, researchers found that 50 per cent of evacuees still in Louisville, Kentucky, were suffering from PTSD (LaJoie, Sprang, and McKinney, 2010). Post-Harvey mental health concerns were also evident in the statistics showing that 232 evacuees at the George R. Brown Convention Center sought mental health services during the two weeks that they were available at the shelter (Shah et al., 2018). Instead of focusing on direct victims, researchers surveying a random sample of residents of Chambers and Galveston Counties in Texas found that seven per cent met the criteria for PTSD between two and five months after Hurricane Ike struck in September 2008 (Pietrzak et al., 2012).

Certain social groups are more vulnerable to experiencing PTS after a disaster. Factors often grouped together under the rubric of social vulnerability are associated with PTSD, such as having a lower income (Lamond, Joseph, and Proverbs, 2015), being of older or middle age, belonging to a ethnic/racial minority, and having a lower level of education (Gruebner et al., 2015). Storm-related challenges have also been associated with PTSD, including more flooding at one's home (Lamond, Joseph, and Proverbs, 2015), having to relocate permanently (Lamond, Joseph, and Proverbs, 2015), having more hurricane-related stressors (such as displacement, absence of electricity, and a decline in income) (Gruebner et al., 2015), and greater hurricane-

related effects (such as property damage, financial hardship, familial separation, and/or a lost pet) (Schwartz et al., 2018).

There is limited evidence that disaster preparation might be associated with mental health benefits. While mitigation actions (that is, implementing door and window guards and moving valuable items to higher ground) were positively correlated with more severe health deterioration in bivariate analyses, mitigation actions were associated with a lower likelihood of mental health deterioration in the years following a major flood in a multivariable model (Lamond, Joseph, and Proverbs, 2015).

Event exposures and hurricanes and hurricane-induced flooding

Adverse event experiences, which include challenging and dangerous circumstances, regularly manifest among people affected by disasters. Little is known about how common these sorts of experiences were among residents after Harvey, but research on previous hurricanes suggests that the challenges may be widespread. For instance, Katrina evacuees in Houston shelters described having many adverse event experiences (Brodie et al., 2006). More than one-half said that they did not have a sufficient food or water supply during and following the event. Almost one-third stated that they had no access to their prescription medication. One-third reported being trapped in their homes prior to rescue and 40 per cent spent at least one day living on the street (Brodie et al., 2006). Three weeks after Harvey, researchers conducted a small-scale survey of 41 people at the George R. Brown Convention Center shelter (Schwartz et al., 2018). They discovered that most participants (88 per cent) experienced some type of adverse event (such as property damage, financial hardship, separation from family, and/or a lost pet) owing to Harvey. Home damage, displacement, contaminated water, and participation in a rescue were the most common experiences cited (Schwartz et al., 2018).

Households also suffer damage to their home after a hurricane due to water and wind. According to FEMA, more than 80,000 homes experienced at least 46 centimetres of flooding post Harvey (Jonkman et al., 2018). Meanwhile, Katrina led to an estimated USD 16 billion of damage to residential property in New Orleans and more than 80 per cent of the city's housing stock was damaged or destroyed (Pistrika and Jonkman, 2010).

Recovery from hurricanes and hurricane-induced flooding

While introducing challenges, experiencing stressors during and after a disaster can also be associated with post-traumatic growth and perceived benefits (McMillen and Fisher, 1998). For instance, becoming better prepared for future events and an increase in Good Samaritan acts were identified as 'silver linings' among adults after Hurricane Katrina (Stanko et al., 2015). Sometimes, greater trauma can lead to even more benefits. To illustrate, among a group of postpartum women, having experienced home damage during Katrina was associated with reporting that they had gained from the storm (that is, 81 per cent of women with home damage reported any

benefit versus 66 per cent without home damage). Gains included increased closeness to family or friends, the community pulling together, material benefits (such as a new house), and community enhancements (such as stronger levees) (Harville et al., 2010). It is also the case that perceiving benefits can weaken relationships between increased stressors and worsening mental health (Kaniasty and Norris, 1993; Clukey, 2010).

Contribution

There is very little research on the relation between Hurricane Harvey and the themes outlined above. Unlike the vast majority of other post-disaster analyses that entail convenience sampling (see, for example, Zhang et al., 2007; Schwartz et al., 2018; Taioli et al., 2018), the current study participants were initially randomly selected using a probability-based design for a survey about social vulnerability to flood hazards in summer 2012. Follow up with some of the same set of respondents within 90 days of Harvey enables a pre-/post-event study design, which is uncommon among research on disasters (Horney et al., 2018). In a review of 225 disaster mental health studies, the vast majority were cross-sectional, 'after-only' study designs (Norris, 2006). When respondents are surveyed only after a disaster, reported outcomes are usually more severe than when pre-disaster respondents are re-surveyed. This is because those assessed following a disaster are typically those more severely affected (for instance, they are staying at a shelter when a team comes to carry out research) than the average person for whom baseline data existed (perhaps they participated in a previous project unrelated to the disaster at hand) (Horney et al., 2018).

Owing to the challenging logistics of engaging in social science research on disasters (Taioli et al., 2018), the more commonly employed 'after-only' study designs habitually appraise people at shelters and community centres. These people have been most affected and may have the fewest resources with which to respond. For example, they are staying in a public shelter as opposed to paying for a hotel. While this provides an important snapshot of the experiences of those probably suffering the most, their experiences may not be representative of the general population. The nature of the current study sample enables the cataloguing of a wide range of experiences, which may more generally reflect Harvey's impact on Greater Houston households, instead of just those affected most who were in shelters.

There is also limited extant research on the unintended consequences and broad-based advantages of home-site hazard mitigation and disaster preparedness. The pre- and post-event design utilised here uniquely facilitates an examination of how preparations made in the years before Harvey have translated into outcomes in the aftermath of disaster. Other studies have investigated unanticipated ramifications pertaining to other hurricane phenomena, including: how having flood insurance may undermine homeowners' financial incentive to protect against hurricane damage via structural mitigation actions (Burrus, Dumas, and Graham, 2011); and how New Orleans' levee system gave residents a false sense of security, leading to delayed evacuation during Katrina (Wetmore, 2007). But they have not appraised the multifaceted post-event consequences of home-site mitigation or disaster preparedness.

Materials and methods

The study area: Greater Houston

Greater Houston is a nine-county MSA in Texas, which is bordered in the southeast by the Gulf of Mexico. With a total population of 6,892,427 in 2017 (American Community Survey, 2017), it is the second largest MSA in the state after Dallas–Fort Worth and the fifth largest in the US as a whole. According to the U.S. Climate Data website, average annual precipitation in the city presently amounts to 45.28 inches per annum.[2] Greater Houston is vulnerable to tropical storms and hurricanes that crisscross the Gulf of Mexico. Tropical Storm Allison claimed the lives of 22 people, damaged thousands of homes, and caused widespread flooding in 2001. Subsequently, Houston has been significantly affected by Hurricanes Rita and Katrina in 2005, Ike in 2008, and Harvey in 2017.

Sampling

Structured survey data collected in 2012 from a probability-based sample of 600 Greater Houston area householders constitute the baseline of this project. The strategy was selected to accord with the requirements that the sample be constructed randomly using probability methods and be socially and spatially representative of residents in this MSA. A two-stage sampling approach was employed that involved stratifying and randomly selecting a subset of census tracts across geographic quadrants of the Houston area (Stage 1) and then completing telephone interviews with randomly selected residents in each selected census tract (Stage 2) (Maldonado et al., 2016). Comparable approaches have been implemented elsewhere (Vallée et al., 2007; Duran et al., 2013).

The sampling strategy used in 2012 necessitated the completion of telephone interviews with five randomly selected residents in each of 120 randomly selected census tracts (based on 2010 decennial census boundaries) in the Greater Houston area, for a total of 600 completed surveys. To select the census tracts where the sampling of household participants would take place, geographic quadrants in the Greater Houston area were delineated to contain equal numbers of tracts. Within each quadrant, census tracts were stratified into quintiles based on a measure constructed from two 2010 US Decennial Census–derived variables representing race/ethnicity and socioeconomic status. Within each quintile in each quadrant, six census tracts were randomly selected, for a total of 30 per quadrant. To obtain the household sampling frame, a marketing research firm was recruited, which supplied lists of all residential landline telephone numbers located within the selected census tracts. Those numbers were randomly dialled by partners at a survey research firm. They used a team of trained bilingual (English–Spanish) interviewers to finalise five 30-minute telephone surveys in each selected tract. Only landlines were targeted, because they are tied to a specific location, ensuring that the original participants lived in specific neighbourhoods of Greater Houston.

The response rate to the survey was 33 per cent. The 2010 US Decennial Census and the 2007–2011 American Community Survey estimates for Greater Houston provide useful comparison data to assess the sample's representativeness. The sample

was generally representative in terms of household income (the median was USD 45,000 and the mean was USD 64,065 in comparison to the Houston MSA median of USD 56,876) and the percentage of adult black (19.7 versus 16.7 per cent) and white (48.9 versus 43.5 per cent) residents. However, it underrepresents adult Hispanic residents (21.5 versus 31.6 per cent) (Collins et al., 2015).

This paper reports the results of a follow-up survey of these respondents conducted in December 2017. A rigorous multi-step procedure was administered to find them. Initially, their updated addresses were acquired from a marketing research firm that specialises in sampling. Those respondents no longer residing permanently in the study area as of 25 August 2017 and those who said that they did not want to be contacted for follow up were excluded from the analysis. Then, the marketing research firm used the current address information to update the telephone numbers of the remaining Greater Houston residents (N=484), including landline and cellular telephone numbers. The latter are important for this wave of data collection, since they allow for contact with people who relocated (temporarily or permanently) because of Hurricane Harvey. E-mail addresses for each respondent were also obtained, using responses to the survey in 2012 as well as the sampling company's databases.

Participants and procedures

The 484 respondents were contacted via e-mail (when available) and then via landline and cellular telephone by the survey research firm. Multimodal approaches such as these help to increase response rates (De Leeuw, 2005; Dillman, Smyth, and Christian, 2014) and are appropriate when trying to find respondents after a disaster.

Respondents could complete the survey online or via telephone and in English or Spanish. Specifically, 27 completed the English survey online, 42 completed the English survey over the telephone, two completed the Spanish survey over the telephone, and zero completed the Spanish survey online. Of the 484 households in the sample from 2012, 125 were reached and 71 consented to participate. According to the American Association for Public Opinion Research (AAPOR) calculator, the response rate to the 2017 survey is 0.15 (15 per cent) and the cooperation rate is 0.57 (57 per cent).

Low response rates are endemic in survey research in the contemporary era. The average rate of response in the US to telephone surveys is nine per cent (Keeter et al., 2017). However, the response rate is an unreliable indicator of bias and decisions to participate in telephone surveys are not strongly related to political, religious, or social attitudes (Keeter et al., 2017).

The survey was implemented between 29 November and 19 December 2017. For those completing the survey online, it took between 15 and 53 minutes (27 minutes on average), and over the telephone, between 15 and 65 minutes (35 minutes on average). The questionnaire is based on an instrument previously designed by the research team to analyse an inland flood event (Collins, Jimenez, and Grineski, 2013; Jimenez, Collins, and Grineski, 2013). The instrument was modified to focus on hurricane-induced experiences and impacts. Moreover, information on critical social

vulnerability variables was also updated using the survey, which may have changed in the intervening five years, such as annual household income, as well as information on home-site mitigation among households that had moved to new addresses in Greater Houston since completing the 2012 survey (n=11).

Variables

Table 1 below summarises the descriptive statistics for analysis variables:

Table 1. Descriptive statistics for analysis variables (n=71)

Dichotomous	1 (yes)	0 (no)	N	Year measured
Older age (74+)	15	53	68	2012
Non-white	26	45	71	2012
Flood insured	27	42	69	2017
Continuous	**Mean**	**Minimum–maximum**	**N**	**Year measured**
Pre-event preparedness	4.507	0–6	71	2012
Pre-event mitigation*	3.563	0–7	71	2012
Household income	5.180	1–10	65	2017
Average flood depth	0.157	0–0.982	70	2017
PTS sum	24.40	17–61	65	2017
Physical health sum	2.557	0–12	70	2017
Adverse event experiences sum	6.529	1–25	68	2017
Home damage extent	1.630	1–5	70	2017
Recovery extent	8.210	1–10	67	2017
Perceived benefits	2.567	0–8	67	2017

Notes: * updated to reflect accurate information for the 11 households that moved within Greater Houston after completing the 2012 survey.

Source: authors.

In what follows, the analysis variables are organised into six groupings:

- pre-event actions;
- social vulnerability;
- control variables;
- health effects outcomes;
- event exposure outcomes; and
- recovery outcomes.

Within each group, information is presented on the source of each variable (that is, 2012 or 2017 survey), the survey questions used, and how the variables were constructed and coded.

Pre-event actions

- **Pre-event preparedness:** the 2012 survey asked each respondent if they had taken six general disaster preparedness actions. Each was coded yes='1' or no='0'; Table 2 lists the individual items. The responses were summed to create the variable for analysis.
- **Pre-event mitigation:** the 2012 survey asked each respondent if their household was protected in terms of seven different home-site flood hazard mitigation actions, either because their household or a separate property owner/manager had taken the step or it had already been taken when they moved into the house. Each was coded as action done='1' or action not done='0'; Table 2 lists the seven items. The responses were summed to create the analysis variable. For the 11 households that had moved home since the first survey, updated information pertinent to their new home was utilised, collected in the 2017 survey.

Social vulnerability

- **Older age:** drawing on a question about year of birth asked in 2012, it was determined which respondents were 74 or older as of 2017: 74 years of age or older='1'; the youngest survey respondent was 29, so 29–73 years of age='0'.
- **Non-white race:** drawing on questions about race and ethnicity asked in 2012, respondents were coded as '1' if they were from any ethnic/racial minority background or as '0' if they were non-Hispanic white. Ethnic/racial groups are not analysed separately owing to small counts.
- **Household income:** information on each household's pre-tax annual income was acquired in the 2017 survey, using the income item from the US Decennial Census: what was your total household income for the year 2016 before taxes? Include your income and income from anyone else in your household from jobs, investments, public assistance, unemployment insurance, social security, disability and pension funds, and all other sources. The response categories are: (i) less than USD 10,000; (ii) from USD 10,000 to just under USD 20,000; (iii) from USD 20,000 to just under USD 30,000; (iv) from USD 30,000 to just under USD 40,000; (v) from USD 40,000 to just under USD 50,000; (vi) from USD 50,000 to just under USD 75,000; (vii) from USD 75,000 to just under USD 100,000; (viii) from USD 100,000 to just under USD 150,000; (ix) from USD 150,000 to just under USD 250,000; and (x) USD 250,000 or more. The variable was analysed without transformation in the multivariate model.

Control variables

- **Flood insurance:** the following two survey questions were posed to determine which households had purchased flood insurance: (i) was the home, specifically the building that you lived in at the time of Hurricane Harvey, covered by a National Flood Insurance Program policy?; and (ii) were the contents of the home you lived in at the time of Hurricane Harvey covered by a National Flood Insurance Program

policy? The response options for both questions were 'yes' or 'no'. Respondents were coded as '1' if they reported having home and/or contents insurance and as '0' if they reported neither type of flood insurance coverage.

- **Average flood depth:** the address-matching capabilities of TransCAD 7.0 software and Google Earth were used to geocode the locations of the survey respondents, with the street network based on their home addresses. Flood depths were estimated for each geocoded respondent using a FEMA raster grid layer (that is, Harvey inundation footprint) containing flood depth values (feet) as an attribute of each grid cell (pixel). The study's geographic information system (GIS)-based areal density estimation technique was composed of four steps: first, the map layer containing the respondents' home locations was overlaid on the three-by-three metre resolution raster grid with flood depth values; second, a circular buffer with a 100 metre radius was constructed around each home; third, the sum of flood depth values was calculated using all pixels located within each circular buffer; and fourth, this sum was divided by the area of the circle (square metres) to derive a mean flood depth density value within 100 metres of each survey respondent's home. This continuous variable is used in the analysis.

Health effects outcomes

- **Physical health sum:** each respondent was asked if they had been affected by 12 different physical health problems 'during or soon after' Hurricane Harvey. Each was coded as yes='1' and no='0'; Table 3 lists the items. The items were tallied to create a composite measure of the number of problems affecting a respondent, as per Collins, Jimenez, and Grineski (2013).
- **PTS sum:** the standard civilian PTSD checklist (PCL-C), which contains 17 items (see Table 4 for a list), was used to sum PTS, and each item was scaled from '1' (not at all) to '5' (very much) (Weathers et al., 1994). Questions were asked about the time period since Hurricane Harvey. To create the composite indicator used in the multivariate statistics, the 17 items were summed to produce a PTS score; a similar approach is used by Gruebner et al. (2015). Higher values represent respondents with more symptoms happening more frequently (that is, more stress), as opposed to a threshold for a probable PTSD diagnosis. For the descriptive analysis, the items were recoded into a dichotomous format, which is what is reported for each item in Table 4.

Event exposures outcomes

- **Adverse event experiences sum:** the respondents were asked if they had experienced any of 25 different experiences (yes='1' or no='0') 'during or soon after' Hurricane Harvey. To create the variable, the respondents' responses to each experience were summed; Table 5 lists the individual items. A similar summed event experience variable was used by Schwartz et al. (2018). A list of 13 adverse experiences in a previous flood disaster study (Collins, Jimenez, and Grineski,

2013) was modified to make it specific to the Harvey case, including the addition of 'smelled unpleasant chemical odors'.
- **Home damage extent:** the respondents were asked: 'Was the home you were living in at the time of Hurricane Harvey "completely destroyed", "seriously damaged", "damaged to a limited degree", "damaged to a minor degree", or "not damaged at all"?'. The response options were coded on a scale ranging from '5' (completely destroyed) to '1' (not damaged at all) (Collins, Jimenez, and Grineski, 2013). This variable was used in a multivariate model without transformation.

Recovery outcomes

- **Recovery extent:** the respondents were asked: 'To what extent has your household recovered from the impacts of the disaster? Please select a number on a scale ranging from 1 to 10, with 1 meaning that your household "has recovered very little" and 10 meaning your household "has recovered completely"'. This variable was used in a multivariate model without transformation.
- **Perceived benefits sum:** the respondents were asked if they had benefitted in any of eight ways (yes='1' or no='0'; Table 6 lists the items) because of their experiences of Hurricane Harvey. They were summed to develop a composite measure, which was used without transformation. This measure was derived from the post-traumatic growth inventory (Cann et al., 2010).

These six groupings of variables are used in the univariate and multivariate statistical analyses, which are described next.

Analysis methods

Univariate descriptive statistics were utilised to answer the following six research questions:

- Before the event, how ready were households for a flood event like Harvey, based on their level of general disaster preparedness and home structure flood hazard mitigation?
- What were the most common physical health effects experienced by respondents after Hurricane Harvey?
- Did respondents experience PTS? What were the most common PTS symptoms experienced?
- Which were the most common adverse event experiences associated with Hurricane Harvey among this group of respondents?
- How extensive were the home damages experienced by the respondents and to what extent had they recovered 90 days later?
- Which were the most common perceived benefits to come out of Hurricane Harvey?

Generalised linear models (GzLMs) were used to answer a seventh question:

- How are pre-event preparedness and mitigation related to post-Harvey health effects, event exposures, and recovery?

Six outcomes are examined:

- a summative measure of physical health problems;
- a summative measure of PTS-related symptoms;
- adverse event experiences;
- the extent of home damage;
- the extent of recovery; and
- a summative measure of perceived benefits.

The focal independent variables are pre-event mitigation and pre-event general hazard preparedness, and older age, household income, non-white race, flood insurance, and flood depth are also included in the model.

In comparison to linear regression models, which assume normally distributed dependent variables, GzLMs support the analysis of non-normal distributions and multiple link functions (Nelder and Wedderburn, 1972; Garson, 2012). For the continuous dependent variables that include zero values, normal with identity link and normal with log link were tested. For the continuous dependent variables that contain only positive values, normal with identity and log links, gamma with identity and log links, and inverse Gaussian with identity and log links were tested. To select the best-fitting specification, the Akaike information criterion (AIC) was used. In terms of statistical power at the 0.80 level (that is, having a less than 20 per cent chance of making a Type II error), the sample size of 71 exceeds the 49 cases required to detect a large effect size (0.35) with seven independent variables in a multiple regression model at a p-value level of less than 0.05. However, the power was not there to detect a moderate effect (0.15), which would require a sample of 103 cases.

Results

Pre-event preparedness and mitigation

As Table 2 shows, approximately 70–80 per cent of households had taken each of the general preparedness measures with 66 per cent having a household member trained in cardiopulmonary resuscitation (CPR) and 87 per cent knowing how to turn off power to the home. Their structural mitigation actions varied to a greater degree, with only six per cent of households having an interior drainage system installed while 83 per cent had indoor heating, ventilation, and air conditioning (HVAC) components elevated to a safe height.

Table 2. Descriptive statistics for each pre-event preparedness and mitigation item

Preparedness measures	Percentage	N
Developed and practised an evacuation plan with all household members.	74.6	71
Learned about your community's emergency plans, warning signals, evacuation routes, and locations of emergency shelters and medical emergency centers nearest you.	76.1	71
Trained at least one household member in first aid and CPR.	66.2	71
Learned how to turn off your current home's electrical power at the main switch, and how to turn off the gas and water supplies at the valves.	87.3	71
Purchased a fire extinguisher and made sure that members of your household know where it is and how to use it.	76.1	71
Created and maintained an easy-to-carry emergency kit for use at home or during evacuation that is stocked with supplies such as a flashlight, first aid kit, and water.	70.4	71
Mitigation measures	**Percentage**	**N**
Had interior drainage system installed, including a sump pump with back-up power, to remove any water that might enter the home.	6.1	66
Home structure was originally built or later elevated above flood height.	52.3	65
Electric components of the home and home's water heater, furnace, and washer and dryer ALL installed above flood height.	70.0	70
Home indoor HVAC system components installed above flood height.	83.1	71
Outdoor service equipment—such as air conditioning and heat pump compressors, electric and gas meters, and fuel tanks—anchored above flood height.	61.4	70
Have floodwalls, berms, or levees built on site to protect the home.	34.3	67
Have hurricane shutters.	7.4	68
Have reinforced roof to protect against strong winds—for example, by installing hurricane straps or clips.	56.3	64

Source: authors.

Health effects

As Table 3 shows, experiencing allergies or hay fever was the most common physical health problem, affecting nearly one-half of the respondents. Nose irritation and headaches affected slightly fewer than one-third of the respondents. Eye irritation was present among one-quarter of the respondents.

Table 3. Descriptive statistics for the percentage of respondents' experiences of each post-event physical health effect

Health symptoms	Percentage	N
Allergies or hay fever	44.9	69
Nose irritation	28.6	70
Headaches	27.1	70
Eye irritation	25.7	70

Health symptoms	Percentage	N
Throat irritation or dry, hacking cough	22.9	70
Blurred vision	15.9	69
Dizziness	15.9	69
Diarrhea	14.3	70
Lung or airway irritations or inflammation	12.9	70
Nausea	11.4	70
Skin irritation	11.4	70
Fever	11.4	70
Asthma	10.0	70
Athlete's foot	7.1	70
Vomiting	5.7	70
Gastrointestinal infection	2.9	70
Any other infectious disease	1.5	68
West Nile Virus	1.4	69
Hepatitis A	0.0	68
Food poisoning	0.0	70

Source: authors.

One-third of respondents reported having none of the PTS symptoms; the remainder had experienced at least one of the 17 symptoms at least 'a little bit' of the time. In terms of the most common symptoms (see Table 4), having repeated disturbing memories, thoughts, or images of Harvey topped the list, with nearly one-third of the respondents reporting that this affected them 'moderately', 'quite a bit', or 'very much'. Feeling upset when reminded of Harvey, and being 'super-alert', watchful, or on guard impacted slightly fewer than one-quarter of the respondents 'moderately', 'quite a bit', or 'very much'. Thirteen per cent of the respondents had a score of more than 33 on the PTSD scale, suggesting that potentially they met a threshold for this mental health condition.

Table 4. Descriptive statistics for the percentage of respondents experiencing each PTS symptoms at least 'moderately'

Symptom	Percentage affected 'moderately', 'quite a bit, or 'very much	N
Having repeated, disturbing memories, thoughts, or images of Hurricane Harvey.	27.1	70
Feeling very upset when something reminded you of Hurricane Harvey.	24.3	70
Being 'super-alert' or watchful or on guard.	23.2	69
Having trouble falling or staying asleep.	17.1	70

Symptom	Percentage affected 'moderately', 'quite a bit, or 'very much	N
Avoiding thinking about or talking about Hurricane Harvey or avoiding having feelings related to it.	15.9	69
Feeling distant or cut off from other people.	14.5	69
Suddenly acting or feeling as if Hurricane Harvey was happening again—as if you were reliving it.	12.9	70
Having difficulty concentrating.	12.9	70
Feeling jumpy or easily startled.	12.9	70
Having physical reactions—that is, heart pounding, trouble breathing, sweating—when something reminded you of Hurricane Harvey.	10.0	70
Avoiding activities or situations because they reminded you of Hurricane Harvey.	10.0	70
Having a loss of interest in activities that you used to enjoy.	10.0	70
Feeling as if your future will somehow be cut short.	10.0	70
Feeling irritable or having angry outbursts.	10.0	70
Having repeated, disturbing dreams of Hurricane Harvey.	8.7	69
Having trouble remembering important parts of Hurricane Harvey.	8.6	70
Feeling emotionally numb or being unable to have loving feelings for those close to you.	7.2	69

Source: authors.

Event exposures

More than three-quarters of the respondents worried about family members or close friends suffering during the disaster (see Table 5). The second most common experience was being present when major flooding or hurricane damage occurred. The next two were being worried about crime and going without electricity. One-quarter to one-fifth of respondents went without adequate transportation and 'smelled unpleasant chemical odors'. In terms of home damage, 43 per cent of the respondents experienced none during Harvey, and seven per cent suffered major damage, including one participant whose home was completely destroyed. The other 50 per cent witnessed minor or limited damage.

Table 5. Descriptive statistics for the percentage of respondents suffering each adverse event experience post Harvey

Adverse event experience	Percentage	N
Worried about family members or close friends suffering from the disaster.	78.3	69
Were present when major flooding or hurricane damage occurred.	65.7	70
Worried about crime.	41.4	70
Went without electricity for some time.	31.4	70

Adverse event experience	Percentage	N
Went without adequate transportation for some time.	27.1	70
Lacked money for living expenses for some time.	24.3	70
Smelled unpleasant chemical odors.	20.0	70
Were stranded in an unsafe place during the disaster, for example.	17.1	70
Went without access to health care or medical services for some time.	17.1	70
Thought at least once that you might be injured or killed during the disaster.	17.1	70
Had to split up and stay in a different location from some members of your household for any period of time.	15.9	69
Went without running hot water for some time.	15.7	70
Experienced crowded living conditions.	14.3	70
Went without clean piped water for some time.	14.3	70
Had to perform a dangerous activity.	12.9	70
Made physical or skin contact with chemicals or contaminants.	12.9	70
Went without a comfortable place to sleep for some time.	12.9	70
Lost irreplaceable items.	12.9	70
Went without adequate food for some time.	11.6	69
Went without a bathroom with a toilet for some time.	11.4	70
Fled from home because water started flooding the house.	10.0	70
Were rescued by someone else who took you to a safe place.	10.0	70
Were separated for any period of time from any of your children who were living in your home.	10.0	70
Experienced unsanitary living conditions.	10.0	70
Went without adequate drinking water for some time.	8.6	70
Went without adequate clothing for some time.	7.1	70
Saw someone drowning or in danger of drowning.	5.7	70
Had an injury or health problem as a result of cleaning or repairing damage to a home site.	5.7	70
Inhaled smoke from chemical fires.	4.3	70
Lost a pet or had to abandon one.	1.4	70
Were a victim of a crime.	1.4	70

Source: authors.

Recovery

At the time of the survey, 61 per cent of the respondents reported that their households had recovered completely from Harvey; 25 per cent of them rated their household at between '1' and '6' on a scale of '1' to '10', with '10' standing for 'completely recovered'. More than one-half of the respondents stated that Harvey brought their family members and their friends closer together and approximately 40 per cent became more optimistic and developed better relationships with their neighbours (see Table 6).

Table 6. Descriptive statistics for the percentage of respondents experiencing benefits post-Harvey

Benefits of Hurricane Harvey	Percentage	N
Become closer to family members.	54.3	70
Become closer to friends.	52.9	70
Become more optimistic.	40.6	69
Developed more supportive relationships with neighbours.	38.6	70
Gained a sense of strength and control in facing problems.	35.7	70
Become more involved in church or other community groups.	28.6	70
Increased your financial income.	5.7	70
Found a better job.	1.5	68

Source: authors.

Pre-event preparedness and mitigation as predictors of post-event health effects, event exposures, and recovery

Table 7 presents the results of the GzLMs. Greater pre-event mitigation was associated with significantly fewer physical health problems, PTS symptoms, adverse event experiences, and perceived benefits. In addition, it was associated with significantly greater short-term recovery after the hurricane. Greater pre-event preparedness was counterintuitively associated with more physical health symptoms.

In terms of the other covariates, people over 75 exhibited fewer PTS symptoms than people aged between 29 and 74 years of age. Non-white respondents had more PTS symptoms and reported more perceived benefits, as compared to white respondents. Higher income was associated with significantly fewer adverse event experiences, PTS symptoms, and physical health problems, and was positively associated with greater recovery. Having flood insurance was associated with more PTS symptoms. Higher flood depth was associated with more physical health problems, PTS symptoms, adverse event experiences, home structure damage, and less complete recovery.

Table 7. Generalised linear models predicting post-Harvey impacts

	Physical health sum[a]	PTS sum	Adverse event sum[a]	Home damage extent[b]	Recovery extent[c]	Benefits sum[a]
Independent variable						
Intercept	-0.154	3.548	2.269	0.259	6.459**	0.758
Mitigation sum	-0.162**	-0.052*	-0.137**	-0.029	0.362**	-0.097*
Preparedness sum	0.477**	-0.003	0.108	0.055	-0.158	0.021
Older age (74+)	0.432	-0.348*	-0.443	-0.143	0.978	-0.504
Non-white	0.352	0.220**	0.326	0.134	-0.418	0.604**
Income	-0.277**	-0.085**	-0.238**	-0.022	0.417**	0.011

	Physical health sum[a]	PTS sum	Adverse event sum[a]	Home damage extent[b]	Recovery extent[c]	Benefits sum[a]
Independent variable						
Flood insurance	-.0265	0.194*	0.073	-0.170	-0.007	0.203
Flood depth	2.210**	1.053**	2.735**	1.757**	-6.293**	0.668
Analysis N	59	54	57	59	58	58

Notes: ** p<0.05, * p<0.10.

[a] Used normal with log link, which fits better than normal with identity link, according to the AIC.

[b] Used inverse Gaussian with log link, which fits better than inverse Gaussian with identity link, gamma with log or identify link, and normal with log or identity link, according to the AIC.

[c] Used normal with identity link, which fits better than normal with log link, according to the AIC.

Source: authors.

Discussion

Descriptive analysis shows that the impacts of Hurricane Harvey were substantial among this sample of residents, 40 per cent of whom did not report any home-site damage. Almost one-half reported suffering from allergies after the event and two-thirds had some level of PTS. More than 75 per cent worried about family members or close friends suffering during the disaster. In terms of post-traumatic growth, one-half said that they become closer to family and friends.

The most important finding to emerge from these analyses are the diffuse benefits of home structure flood hazard mitigation for participating householders, extending well beyond the expected financial savings owing to lesser home damage. Greater pre-event mitigation was found to be associated with significantly fewer physical health problems, PTS symptoms, and adverse event experiences in the aftermath. These results suggest the following hypothesis: protecting the home keeps occupants safer as a storm approaches, both during and afterwards, and therefore seems to reduce some adverse subsequent impacts, such as poorer health and more challenging experiences. These are different endpoints than the more commonly studied financial savings because of diminished repair costs (Burrus, Dumas, and Graham, 2011) or home value rises (Simmons, Kruse, and Smith, 2002) that can stem from mitigation activities, but they are critically important for human safety and well-being in the wake of a disaster.

Home-site mitigation theoretically could prevent some of the adverse event experiences assessed here, as hypothetically, the householder would be safer in their home during and after an event if they had mitigated against some risks in advance. The results suggest that this could be the case, but this explanation should be tested directly by research in the future. Engagement in mitigation activities implies that a householder may be less likely to experience unsanitary living conditions and lose access to hot water (as the heater would have been elevated). Seemingly, the householder would be less likely to report feelings such as he/she might be injured or killed, having had

to perform dangerous activity, or being injured cleaning up, since the home site was safer to begin with and those risks would have been reduced substantially.

Being safer to begin with because of home-site hazard mitigation could also translate into fewer physical health problems and less PTS. While the study did not examine a path model, it may be that mitigation leads to fewer adverse event experiences and thus fewer negative health outcomes. Correlations indicate that having more adverse event experiences was significantly related to worse physical health (Pearson's r: 0.66 ($p<0.001$)) and more PTS symptoms (Pearson's r: 0.73 ($p<0.001$)). Apart from increased safety, engaging in mitigation could also translate into greater feelings of control during and after a storm, which are associated with better mental health outcomes and less PTS. Across a range of different traumas, including disasters, self-efficacy has an enabling and protective effect on people's abilities to recover from them (Benight and Bandura, 2004).

Furthermore, mitigation was associated with significantly greater short-term recovery post event, which is typically an intended consequence of implementing mitigation measures. This finding aligns with a body of research showing that home-site mitigation protects against financial losses (Kreibich et al., 2005; Poussin et al., 2012; de Moel, Van Vliet, and Aerts, 2014). In this case, mitigation was more closely related to rapid recovery after Harvey than to reduced home damage, although mitigation was also associated with reduced home damage, albeit not significantly ($p=0.38$).

Two additional findings seem more counterintuitive than those presented above. First, greater pre-event home structure mitigation was found to be associated with significantly fewer perceived benefits post event. Interestingly, these two variables are not significantly correlated (that is, r:-0.011, $p=0.932$), but this relationship emerged in a multivariate context controlling for flood depth. Among householders with similar levels of flooding, it would be interesting to know if those who had undertaken more mitigation had more negative attitudes about benefits owing to increased frustration stemming from the fact that costly and time-consuming actions may have not entirely protected their home from damage. Future research should test this hypothesis. In a sensitivity analysis (not shown), the significant negative relationship between mitigation and benefits persisted even when adverse event experiences or PTS were included as covariates, suggesting that greater impacts of Harvey did not influence the finding.

Second, greater disaster preparedness was counterintuitively associated with more physical health symptoms. This finding possibly emerged because householders who felt prepared may have been more complacent, which could have led them to experience greater dangers and more physical health problems. Feeling complacent has been shown to be associated with being flood insured and has resulted in reduced damage mitigation actions (Lamond, Proverbs, and Hammond, 2009). That aside, pre-event general disaster preparedness was not significantly associated with any of the other impacts. Complacency among householders who engaged in some preparedness activities may also relate to another finding, which is that having flood insurance was counterintuitively associated with more PTS symptoms.

Apart from the findings related to mitigation, other results from the multivariate models are notable. Having greater flood depth and lower income were significantly related to more adverse event experiences, physical health problems, and PTS, and less complete recovery 60–90 days after the storm. Having a low income introduces challenges when coping with a disaster, and socioeconomic variables have been strong predictors of post-flood impacts in many studies (see, for example, Lamond, Proverbs, and Hammond, 2009). In this case, lower incomes were not significantly related to greater home damage, but more damage was related to greater flood depth.

Two significant predictors of greater PTS have not been highlighted in this discussion as yet. First, people 74 and over exhibited fewer PTS symptoms than people aged between 30 and 73 years, suggesting that older age is associated with greater resilience. In previous studies on disaster mental health, older age is inconsistently associated with resilience to PTS, and middle-aged people are often most affected, potentially because of having to support others (Goldmann and Galea, 2014). After Hurricane Katrina, middle-aged adults (40–59 years) were 4.2 times more likely to have PTSD than older adults (60 plus) (Kessler et al., 2008).

Second, non-white respondents had more PTS symptoms than white respondents, which is expected given the results of a meta-analysis (Norris et al., 2002) and studies conducted subsequently. Following Katrina, for example, black residents disproportionately suffered from PTS symptomology relative to whites (Mills, Edmondson, and Park, 2007; Davis et al., 2012). Counterintuitively, non-white respondents also reported more perceived benefits owing to Harvey as compared to white respondents. In other words, they experienced greater post-traumatic growth. It could be that higher levels of PTS symptoms experienced among respondents of colour produced greater post-traumatic growth. The linkage between PTS and post-traumatic growth is increasingly being investigated. For instance, one year after the magnitude 8.0 Wenchuan earthquake in China, researchers found a positive correlation between PTSD and post-traumatic growth among a sample of 2,300 people who had experienced the event on 12 May 2008 (Jin, Xu, and Liu, 2014).

Limitations

Despite using the best marketing research tools available, it was not possible to reach the majority (74 per cent) of the 2012 survey respondents who qualified for this study (that is, who had consented to a follow-up assessment and who still lived in Greater Houston according to marketing data). Of those contacted, 57 per cent participated in this study, decreasing the final sample size to only 71 respondents.

There are strategies for conducting longitudinal studies that future research can employ, such as comprehensive initial data collection, flexible scheduling, monitoring subject loss (Woolard et al., 2004), and systematically tracking respondents using between-wave change of address cards (Fumagalli, Laurie, and Lynn, 2013). While the pre- and post-event design is a strength, baseline preparedness and mitigation were assessed five years before Harvey. Since the mitigation variables are specific to the home, the variables for households that had moved since the 2012 survey

were updated. For those still living in the same house, they could have taken flood/hurricane hazard mitigation actions in the time between the two surveys. Since the study did not evaluate just flood-affected households, controlling for flood characteristics at the home was important. And the study appraised only flood depth, owing to data availability, even though flow velocity is also an important determinant of damage (Pistrika and Jonkman, 2010).

Conclusion

This paper makes significant methodological and empirical contributions to the hazards/disasters literature with respect to the pre-and post-event research design, its focus on Hurricane Harvey, and in terms of discovering the wide-ranging benefits of home structure modifications. The findings suggesting that pre-event home structure mitigation had broad-based household-level advantages in Greater Houston in the wake of Harvey indicate the need for more pre/post comparisons to see if they are replicable elsewhere. Pre/post comparisons can also provide important insights that potentially enhance disaster planning and preparedness.

The results of this study yield preliminary evidence that the public should be made aware of the many benefits of taking home structure mitigation actions beyond just home protection. If confirmed in other studies of flood disasters, these could be included in public service announcements and government reports, such as *Mitigation Ideas* (FEMA, 2013). It seems important that non-governmental and governmental actors at all levels (such as municipal, state, and federal) continue to promote the value of home structure mitigation for households at risk of flooding, especially as the matter pertains to post-event recovery and human health.

Related to the social vulnerability findings, the results suggest the targeting of assistance towards particular groups. Non-white, low-income, and middle-aged adults are particularly vulnerable to PTS, indicating the need for low-cost and accessible mental health services post disaster. Suggested approaches to preventing psychiatric symptoms such as PTS include promoting social support among high-risk populations and implementing intervention strategies that reduce fear (Neria and Shultz, 2012). Cognitive behavioural therapy is one intervention strategy shown to speed up recovery and to lessen the likelihood of experiencing chronic PTS post disaster (Foa et al., 2005). Low-income people may also need assistance during flood disasters in the future to prevent the physical health challenges noted here. This could take the form of help with cleaning up, since promptly removing mould and remediating unsafe conditions can reduce illness and injury. Following Katrina, concentrations of mould were lower in structures that saw the prompt removal of water-damaged items, such as drywall and furniture (Chew et al., 2006). Physical health problems, including allergies and other breathing issues, were significantly higher among residents living in homes that were still being renovated after a flood event in Cedar Rapids, Iowa, US, in June 2008 (Hoppe et al., 2012), indicating the need to conduct clean-up activities quickly after a flood.

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Correspondence

Sara E. Grineski, Professor, Department of Sociology, University of Utah, 390 1530 E #301, Salt Lake City, UT 84112, US. E-mail: Sara.grineski@soc.utah.edu

Endnotes

[1] Sara E. Grineski is a Professor in the Department of Sociology at the University of Utah, United States; Aaron B. Flores is a Doctoral Student in the Department of Geography at the University of Utah, United States; Timothy W. Collins is a Professor in the Department of Geography at the University of Utah, United States; and Jayajit Chakraborty is a Professor of Geography in the Department of Sociology and Anthropology at the University of Texas at El Paso, United States.

[2] See https://www.usclimatedata.com/climate/houston/texas/united-states/ustx0617 (last accessed on 12 September 2019).

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