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Assessing Self-Rated Physical Health Scores Following Repeat Exposure to Anthropogenic and Natural Hazards in Houston, TX

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Abstract

Background: Research connects health outcomes to hazard exposures but often neglects the nature of the exposure or repeated events.

Methods: We undertook a cross-sectional study (N = 1,094) from a representative sample in the Houston Metropolitan Statistical Area (HMSA). Respondents were recruited using Qualtrics panels, targeting individuals reflecting the population of the HMSA. Physical composite scores (PCS) were calculated using the SF-12v2.

Results: Among the hazards (hurricanes, flooding, tornadoes, chemical spills, industrial fires), only chemical spills showed a dose-response: physical health scores declined significantly with repeated exposures. This decline persisted after multiple linear regression. Covariates including sex, race, age, education, and chemical exposure affected PCS, but chemical spill exposure remained the most significant, negatively affecting PCS even after adjusting for other factors (coef =–2.24, 95% CI, –3.33 to –1.15).

Conclusion: Grasping the effects of hazards, especially repeated ones, can guide emergency management in mitigation, recovery, and preparedness efforts.

Previous research has demonstrated that experiencing a significant hazard event strongly influences resident health and correlates to higher rates of public health complaints.[1] Utilizing the 12-item Short-Form Health Survey version 2 (SF-12v2), a study of a representative sample of New York City residents found lower and deteriorating physical health statuses 2 years after the World Trade Center disaster, even after accounting for previous physical health statuses.[2] Similarly, Heo et al. (2008) found that a Korean community reported a significant deterioration in self-reported health following flooding events.[3] These findings further support this correlation by reporting adverse effects on physical health for adults following a flood event, although effects were limited to the first year.[4] In addition, utilizing pre-hurricane physical health controls, a study found that the number of hurricane stressors was strongly associated with the number of diagnosed medical conditions.[5]

Anthropogenic hazards, referring to any hazard that is caused or influenced by human activity, have likewise shown impacts on human health.[6] For instance, a comparative analysis between oil spills and typhoon disasters indicates that oil spill survivors have worse physical health outcomes than typhoon survivors.[7] Researchers also agree that flood characteristics and people's vulnerability were indicators of various short- and long-term health effects.[8] Health problems in children and adolescents after man-made disasters have shown increases in musculoskeletal problems, stress reactions, and symptoms of the extremities.[9]

This reality is underscored within environmental justice communities as a growing body of evidence points towards complications within these neighborhoods that experience chemical and nonchemical health stressors. The risk of experiencing negative health implications from these experiences also increases in cities that lack adequate sustainability policies and programs.[10–12] An individual's perceived risk to disaster events can also influence their risk perception and response to future disasters.[13] In the context of disaster-related research, perceived vulnerability is described as an individual's sense of their ability or inability to endure the impact of natural and anthropogenic hazards. Some researchers contend that experiencing a natural hazard event increases perceptions of risk and responsiveness to warning systems.[14,15] There is, however, conflicting research that has found that these experiences differ across individuals and disaster types, sometimes resulting in lower perceptions of risk or vulnerability after a disaster event.[16] For example, Halpern-Felsher et al. (2001) found that people who experience disasters perceive they are less vulnerable to harm from these events than those without these experiences.[17]

The geographic region of Houston, Texas, is prone to natural hazards and anthropogenic disasters. Since 2001, the city of Houston has encountered 9 tropical storms and 6 hurricanes.[18] Collectively, estimated impacts from these tropical storms and hurricanes have resulted in 207 direct fatalities, 114 indirect deaths, and over $155 billion in damages.[18–22] In addition to these more significant disasters, the Houston area had 74 thunderstorms during 2019, which exceeds Houston's 62.8 per year average for the previous 48 years. [23] Harris County has completed numerous flood reduction projects; to date, the region has received more flood insurance funds than any other community in the National Flood Insurance Program.[24] Although Houston is outside Tornado Alley, the area has also faced 2 F4 tornadoes.[25] One of these significant tornadoes occurred in 1992, which resulted in few fatalities but damaged about 2850 homes, causing at least $500 million in damages,[26] revealing the breadth of events witnessed within this area.

Moreover, Houston's strong ties to the energy sector make the area highly susceptible to anthropogenic hazards. The Houston area has chemical spills or petrochemical fires roughly every 6 weeks that significantly impact the community, causing increased respiratory illness in affected areas.[27,28] Notable anthropogenic disasters for this geographic area include the Deepwater Horizon oil spill (DHOS) and the Intercontinental Terminals Company petrochemical fire (ITC). During the DHOS, a rig exploded, causing 5 million barrels of crude oil to release into the Gulf before capping the well.[29] The ITC petrochemical fire resulted in carcinogenic compounds seeping into neighborhoods along the Houston Ship Channel.[30,31] In addition, in 2019, 3 episodes of petrochemical fires led to pollutants, like benzene and isobutylene, entering the atmosphere. At a plant in Port Neches, the Texas Petroleum Chemical Group reported 2 explosions and a fire, which prompted an evacuation and released an estimated 1000 pounds of butadiene and 500 pounds of particulate matter into the atmosphere.[32]

This disaster-prone environment provides an opportunity to understand the population's perception of vulnerability and their physical health scores post-disaster. Although recent disaster-related research has emphasized mental health post-disaster, few studies have focused on an individual's physical health score related to disaster type and repeat exposures. This research seeks to close this gap in knowledge by utilizing the SF-12 health scales gathered from a representative survey completed in Houston, TX. Researching exposures by disaster type helps inform strategies to reduce the lasting impacts of these disasters and improve the public health response for this vulnerable population.

Methods

Site Location and Population

As of 2019, Houston made up 8% of Texas population, reaching 2.31 million residents. A quarter of the population is under 18 years of age, and 10.5% are over 65. White, Black, and Hispanic or Latino residents represent 57%, 23.5%, and 45% of the population demographic, respectively. American Indians consist of 0.8% and Asians represent 7.5%.[33] The unemployment rate is 3.9%, and the mean annual household income is $85 680. Harris County's 1778 square miles is considered part of a larger 9-county metropolitan area spanning over 9444 square miles with a population of 7 066 141. The city's economy is mainly industrial, focused on energy, manufacturing, aeronautics, and transportation. Houston is frequently referred to as the "Energy Capital of the World" due to its oil, gas, and wind production involvement. Houston is uniquely capable of providing information on the drives of this research due to its location and experiences with natural and anthropogenic hazards.

Survey Development

The survey included the 12-item Short-Form Health Survey version 2 (SF12v2), which is based on the medical outcome survey.[34] The SF12v2, a validated survey instrument, helps predict a population's general mental and physical health. The SF12v2 has been validated in several languages[35] for use within low socioeconomic status populations[36] and among immigrant populations[37]. This survey instrument was previously used in Houston, TX, specifically within the African American and Latinx neighborhoods that experience hazards.[38] The survey instrument generates composite scores for self-reported mental and physical health between 0 and 100, with a normalized composite score mean of 50 and a standard deviation of 10 at the national level; this allows for comparison between study populations and national scores.[39]

Data Collection

Respondents were recruited using Qualtrics panels that identify target respondents who were acquired from existing pools of research panel participants who have agreed to be contacted for research studies, using sampling limitations that mirror the current population make-up of the Houston Metropolitan Statistical Area (HMSA), including (1) residents must reside in a zip code located in the HMSA (which includes the following counties: Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller), (2) 15% to 25% of the sample must include populations with a household median income below $25 000, (3) no more than 60% of the responses for either gender (male/female), (4) 6% to 12% of the responses must be from elderly populations (age 65 or older), and 5) 5-15% people who speak English as a second language. In addition, only participants 18 years or older currently residing in a zip code located in the Houston Metropolitan Statistical Area (HMSA) at the time of the survey were targeted. The first question in the survey provides an information sheet and is used to determine if the respondent is willing to participate in the survey or if the respondent would like to opt out. Follow-up questions for participating respondents include age and zip code to ensure inclusion criteria are met. No compensation was provided for participants. The survey and accompanying consent materials were approved by the Texas A&M University Institutional Review Board (IRB2019-1550M).

Data Analysis

Statistics were calculated using STATA 16 (College Station, Texas) and Microsoft Excel (Redmond, Washington). Descriptive statistics were calculated for each variable, including demographics. Race was coded non-Hispanic white, non-white Hispanic, or African American. Bar graphs were used to visualize perceptions of vulnerabilities across hazard types, and boxplots were utilized to compare physical health scores across chemical hazard exposures. Multiple regression was used to assess the impact of experiencing chemical hazards on physical composite scores (PCS) and age, sex, income, education, and racial categories. Coefficients of the covariates, corresponding 95% confidence intervals (95% CI), and P values were reported. Mean PCS values were calculated across types of hazard exposures and the number of exposures experienced.

Results

At the completion of survey data collection, a higher proportion of women (n = 660) than men (n = 434) responded. Further, there were more non-Hispanic white individuals (n = 564) than African American respondents (n = 223), although this is keeping with census data reports (Table 1). The data indicate that ages 25 to 44 account for n = 463 of the response data, with an additional 12.63% (n = 123) of the sample size over the age of 65. Most of the respondents had completed a high school level education or higher. In addition, 39% (n = 223) of the respondents fell below an income level of $34 999, with slightly over 30% of individuals in the highest earning bracket of $85 000 or more.

Most respondents reported experiencing many hazardous events over the past 5 years: hurricanes and flooding (96.35%), tornadoes (79.82%), chemical spills (86.84%), and industrial fires (96.08%). When evaluating PCS across different types of hazard exposures (hurricanes, tornados, petrochemical fires, and chemical spills) as well as the number of exposures to these hazards over the last 5 years (0 to 5 or more), a reduction associated with exposures can be seen (Table 2). For instance, those reporting 0 direct exposures to hurricanes had a mean PCS value of 49.32, while those who experience 5 or more had a mean PCS value of 47.74. However, no hazard exposure type had a more dramatic drop in mean PCS scores than chemical spill exposures. From the range of the highest score of 50.46 (which closely correlates to state and national averages) to the lowest score of 38.33, results indicate over a full standard deviation drop with a reduction of 12.13 points. This was also viewed alongside individuals' perceptions of physical vulnerability (Figure 1), with hurricanes and chemical spills topping the list.

The SF-12 normalizes national mental and physical health data to 50, with a standard deviation of 10. Therefore, samples with values lower than 50 report physical health scores below the national average. Values less than 40 signify samples that are an entire standard deviation lower than the national average. Overall PCS values were close to national means (48.95 in our sample). However, a clear dose response is shown when looking at chemical spill exposures, with a reduction from national means to a greater than 10-point drop (Figure 2). While 0 to 2 exposures remain close to overall averages with greater variability, there is a marked reduction with 3 exposure events or more. This clear drop in physical health scores remains after multiple linear regression calculations (Table 3). The covariates sex, race, age, educational attainment, and chemical exposure were assessed for effects on PCS. Only age (coef =–1.25, 95% CI: –2.36 to –0.15) was negatively associated with PCS. Chemical spill exposures remained the most statistically significant with an inverse relationship with PCS even after adjusting for the other covariates (coef =–2.24, 95% CI: –3.33 to –1.15). This was the only such hazard exposure to reveal this trend.

Table 1. Distribution of study respondents

Characteristic	N (%)*
Gender	
Male	434 (39.67)
Female	660 (60.33)
Race / ethnicity	
Non-Hispanic White	564 (57.91)
Non-White Hispanic	182 (18.58)
African American	223 (22.90)
Refused	6 (0.62)
Age in years	
18 – 24	152 (15.61)
25 – 34	255 (23.10)
35 – 44	208 (21.36)
45 – 54	134 (13.76)
55 – 64	132 (13.55)
65+	123 (12.63)
Education	
Some high school	39 (4.00)
High school graduate	199 (20.43)
Some college	251 (25.77)
College degree	253 (25.98)
Some post-graduate college	42 (4.31)
Graduate degree	123 (12.63)
Trade/technical/vocational school	59 (6.06)
No answer	8 (0.82)
Income	
$15,000 – $19,999	54 (6.39)
$20,000 – $34,999	169 (20.00)
$35,000 – $49,999	121 (14.32)
$50,000 – $64,999	129 (15.27)
$65,000 – $69,999	28 (3.31)
$70,000 – $84,999	90 (10.65)
$85,000 +	254 (30.06)
Language preference	
English	868 (93.74)
Spanish	50 (5.40)
Other	8 (0.86)

*Values may not equal 100% due to rounding.

Discussion

This research sought to identify if repeat exposures to certain hazard events were correlated with a reduction in physical health scores. Our cross-sectional study showed that while most hazard events were not correlated, chemical exposures showed a strong significant inverse relationship between exposures and physical health scores. Other than repeat chemical exposures, age was the only variable to show significant reductions with PCS. This, however, is an expected outcome, as previous research has shown a reduction in PCS values as one ages.[40] The results also demonstrate that hurricanes were listed higher than chemical spills when individuals were asked to state their perceptions of physical vulnerability, despite not being associated with reductions in

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Table 2. Mean PCS value across type of hazard and number of exposures

Type of exposure	Number of exposures 0	1	2	3	4	5 or more
Hurricane	49.32	49.41	48.87	47.43	47.84	47.74
Tornado	46.37	48.67	47.36	44.26	43.02	43.28
Petrochemical fire	49.12	47.70	49.14	48.15	–	41.59
Chemical spill	50.46	46.72	48.85	43.25	38.33	40.25

PCS values. Several factors could explain these results. First, as previous research indicated, individuals perceive acute risks as more dangerous than those exposures that take months or years to realize implications.[41]

Second, many disaster planning efforts and risk communications are often targeted at natural hazards. If natural hazard triggered technological (NATECH) hazards, such as chemical or hazardous materials (hazmat) exposures, are discussed, they are briefly mentioned but not included in the mitigation action plans in detail.[42,43] To better protect themselves from NATECH or technological risks, residents should be informed of potential risks and what protective actions they can take during such events. When this information is not available, people are less likely to engage in protective behaviors.[42,44,45,46]

This tendency to refrain from protective behaviors when adequate information about risk is not supplied could explain why our results indicate that physical health is significantly lower than the national average only for chemical exposures. Many disaster risk communication efforts and initiatives are often targeted at protecting oneself from natural hazards, such as the flooding-targeted Turn Around, Don't Drown,[24] or the Ready Houston (multi-hazards, mostly natural hazards)[47] initiatives. These are federal programs that address natural hazard preparedness, which are tailored to and carried out at the city or county jurisdictional level. Hazard mitigation plans at different jurisdictional levels also contain different information, the majority of which are natural hazard risks. For example, the City of Houston (2018) Hazard Mitigation Plan Update explicitly discusses natural hazards and climate change. Chemical or hazardous material releases are only mentioned as possible secondary hazards resulting

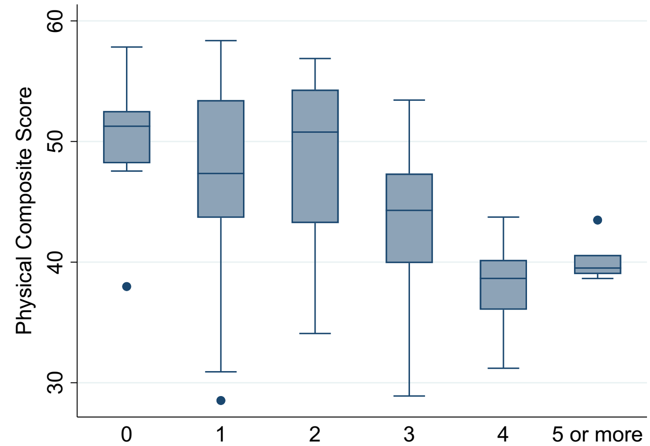

Figure 2. Physical Composite Score (PCS) by number of chemical spill exposures over the last 5 years.

Table 3. Multiple linear regression comparing the covariates sex, race, age, and exposure to chemical hazards on PCS value

Predictor	Coef	Std. Error	P-value	95% Confidence interval
Sex	–2.20	0.55	0.17	–5.34 to 0.94
Race	0.12	0.57	0.83	–1.02 to 1.26
Age	–1.25	0.55	0.03*	–2.36 to –0.15
Education	0.04	0.08	0.94	–0.83 to 0.90
Chemical exposure	–2.24	0.55	<0.001*	–3.33 TO –1.15

*Statistically significant P value <0.05.

from a climatological or geophysical disaster (e.g., flooding first responders may be exposed to hazmat releases while conducting rescue efforts).[48] In contrast, the Harris County Multi-Hazard Mitigation Action Plan discusses toxic release and hazmat incidents in greater detail but for a much larger area.[49] Even then, NATECH disasters are often omitted in regional and national hazard risk management plans.[42]

Finally, the examples above are also focused solely on NATECH disasters. These plans do not consider everyday

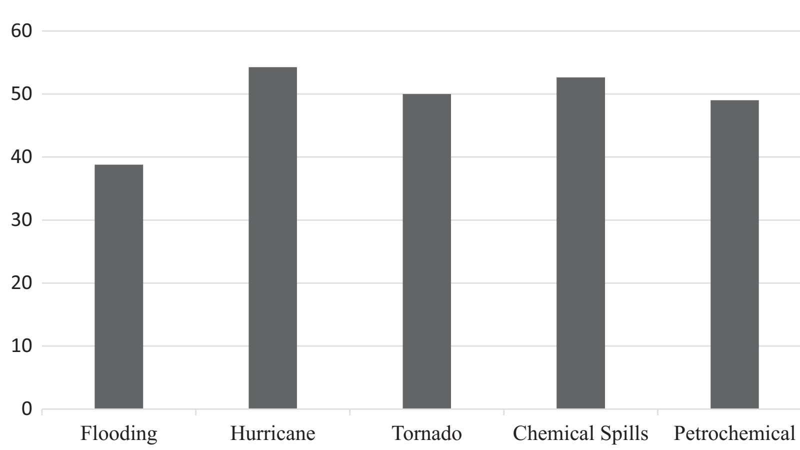

Figure 1. Self-reported perceptions of being "vulnerable" or "very vulnerable" to physical injury from different hazards (%).

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chemical or hazmat risks faced by some communities in Houston, particularly those who face environmental injustices from nearby industrial and oil and gas complexes nor have all major industrial pursuits prepared for these events.[50] As one of the most diverse cities in the world, generalized plans such as these may not be accessible or relevant to many communities in Houston, particularly those who face daily anthropogenic hazards.[51] Technological or NATECH accidents are more preventable than natural hazards, as they are operated and managed by people or industries.[52] Their risks are foreseeable and easier to prevent through environmental awareness, preparedness, and mitigation, unlike natural hazards. However, the "persisting gaps and deficiencies in corporate NATECH risk management systems and government oversight" [52] perpetuate the occurrence of NATECH accidents and disasters. If NATECH and technologic risks knowledge and preparedness specifically are not implemented or accessible at the local scale, residents will not have the risk information they need to better physically protect themselves from such exposures or even know that they have been exposed at all.[46,53] While their risk will never be zero, such risks are often considered acceptable due to the essential goods and services these operations provide. However, risk acceptance is built on trust that companies and the government manage risk at an acceptable level for the local population.

A collaborative effort involving urban planners, public health officials, and state environmental agencies like the Texas Commission on Environmental Quality (TCEQ) could significantly enhance urban resilience against chemical exposures. By integrating real-time monitoring and public alert systems that track air quality indices and toxic releases, similar to weather alerts, these groups could collectively improve community safety. Updates would be immediately available through mobile apps and public broadcasts. Additionally, this collaboration could support the development of community-driven data platforms, facilitated by local tech startups, where residents can actively report unusual smells or suspected chemical releases. Incorporating smart city technologies, such as IoT sensors in industrial areas, into this framework would not only promote proactive risk management but also engage communities directly in their safety protocols. This approach aims to enable quicker evacuations and more effective emergency responses, potentially mitigating the health impacts of hazardous exposures.

There are several important limitations to this study. Firstly, the survey required respondents to opt-in for participation before data collection. These self-selection criteria may have allowed data to be collected from participants already presenting with self-awareness of vulnerabilities and physical health issues. Secondly, the survey was performed electronically, preventing obtaining sample data from individuals with a lack of Internet access in parts of Houston, TX. For instance, in the super neighborhood of Fifth Ward, residents are 53% more likely to lack access to basic technology than in the greater Houston area,[54] and thirdly, the survey was only conducted in English and did not allow for collection of other common languages in the area, such as Spanish.

Understanding the impacts of hazards, especially multiple exposures, on individuals may assist emergency management professionals with focusing on planning mitigation and recovery strategies as part of the preparedness efforts. For instance, food insecurities have been noted as a concern post-hurricane.[55] This potential lack of healthy food options may be contributing to the reduced PCS values. The impacts of food insecurities may be mitigated by appropriate preparedness planning for logistical needs. In addition, understanding how repeated exposures to hazards impact people may be vital to understanding the growing concern for the mental health outcomes of first responders.[56]

There is a need to repeat this research to help establish consistent results between populations. By repeating this study with various demographics in different geographic areas, a more substantial baseline could be established on the impact of multiple hazard events, independent of the experiences unique to the HMSA population.

Data availability statement. Data will be made available for any reasonable request.

Author contribution. Conceptualization: Sansom, Thompson; methodology: Sansom, Thompson, Fawkes; writing: all authors; writing – review and editing: Sansom, Sansom, Glanzer, Losa; funding acquisition: Sansom, Thompson; supervision: Sansom, Sansom, Fawkes, Dixon.

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Competing interest. The authors declare no conflict of interest.

Ethical standard. Ethical guidance and approval were obtained from the Texas A&M University Institutional Review Board (IRB2019-1550M).

Consent to participate. All participants provided written consent to participate.

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