Final Report: Texas Flood Social Vulnerability Index (TX F-SVI)

Texas Water Development Board Contract # 2301792689

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Background

Texas Water Development Board (TWDB) and other agencies in Texas utilize Social Vulnerability Indices (SVIs) for a variety of flood risk management purposes including, but not limited to, flood planning and allocation of flood mitigation funding. There are two widely available sources of SVIs: first, the Social Vulnerability Index (SoVI) from the Hazards and Vulnerability Institute at the University of South Carolina; second, the SVI created by the Agency for Toxic Substances and Disease Registry at the Centers for Disease Control (CDC). Both are primarily used at the census tract scale and are developed across the geographic domain of the United States. SoVI and SVI are agnostic to the type of hazard for which social vulnerability is being modeled. Although these existing SVIs have a wide range of applicable uses, they are customized neither for flood hazard, nor for Texas.

The purpose of this research effort is to develop a flood-specific SVI (TX F-SVI) for Texas that considers and utilizes parameters applicable and relevant to providing information on social vulnerability to flooding. Certain social conditions influence a household's ability to prepare for, mitigate against, respond to, and recover from flooding events. For example, some factors – people working at lower wage jobs, as well as those unable to work or underemployed, those who live in aging housing or with poor access to telecommunication infrastructure, and seniors and people with disabilities who face challenges evacuating – are underlying vulnerability factors that lead to differential outcomes when a flood event occurs. The TX F-SVI developed in this project specifically considers the characteristics of Texans in building a composite social vulnerability index for flooding. This research was financially supported by the Texas Water Development Board and conducted by an academic research team from the University of Texas at Austin and Princeton University.

The project's scope of work and research process is framed as follows:

- Stage 1 - Investigation and Determination
    - Task 1: Literature Review
    - Task 2: Stakeholder Interviews and Input from the Public and TWDB
- Stage 2 – Texas Flood Social Vulnerability Index Construction
    - Task 3: Base Case Model Development
    - Task 4: Sensitivity Analysis
    - Task 5: Index Development and Geospatial Analysis and Visualization (in GIS)
    - Task 6: Develop a Report Based on Tasks 1-5
- Task 7: Project Management and Reporting
- Task 8: Regional Flood Planning Group Support and limited TX F-SVI Update

Eight deliverables were associated with Tasks 1-5, including this report. The schedule of deliverables, link to deliverables, and other notable activities are in the table below. Access to the TX F-SVI data and GIS files are in Table 6 on page 32.

Table 1. List of project deliverables.

Deliverable	Date Submitted (final version)	Link to product
Memo #1: Systematic Literature Review	April 5, 2023	Memo #1 hyperlink
Memo #2: Qualitative Interview Method and Results	August 11, 2023	Memo #2 hyperlink
Mid-Project Report: Stage 1: Investigation and Determination	August 30, 2023	Stage 1 Report hyperlink
Public Comment Period	September 12 – October 13 2023	No deliverable
Memo #3: Summary and Response to Public Comments	November 6, 2023	Memo #3 hyperlink
TWDB Issues Notice to Proceed to Stage 2 Research	November 16, 2023	No deliverable
Memo #4: Model Development and Index Construction	February 9, 2024	Memo #4 hyperlink
Memo #5: Uncertainty and Sensitivity Analysis	April 29, 2024	Memo #5 hyperlink
Memo #6: Index enhancement and geospatial analysis and visualization	June 7, 2024	Memo #6 hyperlink
TX F-SVI Draft report and Index	June 7, 2024	
TX F-SVI Final Technical Report and Index	July 19, 2024	

This final technical report follows the sequential order of the tasks.

Stage 1: Investigation and Determination

During the investigation and determination stage (Stage 1), the research team found a wide array of indicators that are related to understanding and explaining social vulnerability with respect to flooding. The systematic literature review (Task 1) identified 33 research articles and government reports that explicitly mention drivers of social vulnerability, explicitly mention flooding, and are based in the United States or Canada. Four of these articles were based in Texas. Through the review, the research team identified 25 specific indicators that have been used to measure social vulnerability to flooding.

The stakeholder interviews (n=15), carried out under task 2 for the project, identified a similar set of indicators. The interviews were conducted with flood planning, mitigation, and recovery professionals that included community members, watershed protection specialists, academics, and members of TWDB regional flood planning groups. The sampling strategy was purposive so that the interview participants represented a spectrum of Texas locations and geographies, including Central Texas, North Texas, the Gulf Coast, and the Rio Grande Valley. Additionally, interviewees have experienced a wide variety of flooding types, including fluvial, coastal, flash floods, and stormwater.

Based on Stage 1, the research team identified similarities and differences between the systematic literature review and the interviews, providing a good rationale for base case index construction. A cross-walk exercise between the stage 1 findings and existing and publicly available social vulnerability indices suggests opportunities to design an index that is tailored specifically for Texas and for flooding.

1.1 Task 1: Systematic Literature Review

Our systematic literature review was conducted in accordance with the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines (Moher et al. 2009) illustrated in figure 1. Over 1,000 articles were identified and through an initial search [flood AND social vulnerability], 152 articles were selected through an additional eligibility criterion [United States AND between 2010 and current] and manually reviewed. We manually reviewed the articles generated from our search criteria and selected articles that were flood specific, discussed indicators associated with social vulnerability, and were geographically based in the United States or Canada. This review resulted in N=48 for full text review and systematic coding. Fifteen articles were subsequently excluded due to lack of sufficient information in the coding framework resulting in a total of 33 articles included in the systematic literature review having met the final inclusion criteria of 1) explicitly mentions drivers of social vulnerability, 2) explicitly mentions flooding, and 3) are based in the United States or Canada. A full list of articles from the review and the coding framework can be found in this online resource and is available as a list in Appendix A.

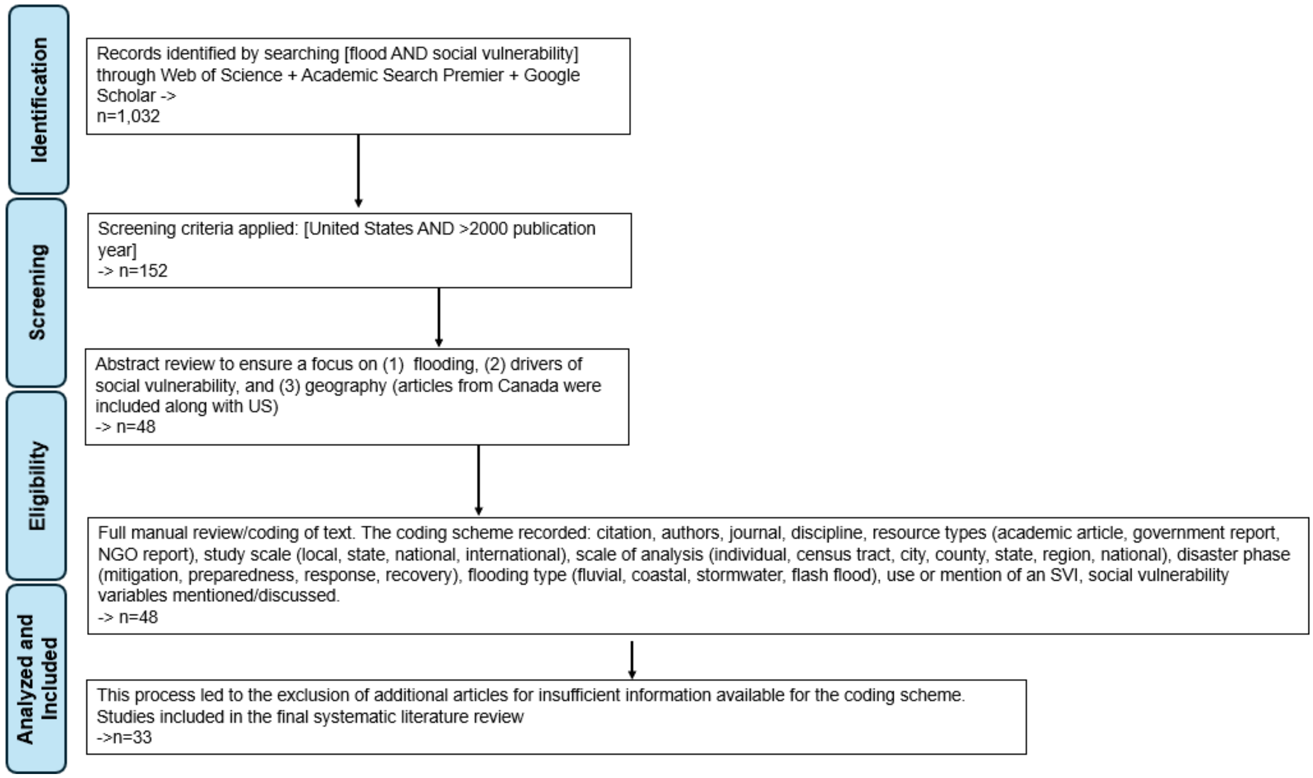

Figure 1. Identification and article exclusion process.

Twenty-five unique social vulnerability indicators emerged from the analysis. Of the 33 articles in the literature review, 22 included a social vulnerability index (SVI) in their analysis. Most (19) of the indices were constructed for the purposes of the study by the researchers. Only 3 of the articles directly used the CDC SVI. Of the indices that were constructed, the most cited articles for methodology were Cutter et al., 2003 (SoVI) and Flanagan et al., 2011 (SVI). All indices used data available from the Decennial US Census or the American Community Survey estimates (US Census Bureau 2022). The number of researchers opting to construct their own indices indicates that there is not a "one size fits all" approach to social vulnerability indices development and use. Other insights from the review include that researchers report challenges in combining physical and social data because they are collected at different units and scales (Wilhelmi and Morss 2013).

The research team identified four articles that were specific to Texas in the systematic literature review. Three of the articles utilized an SVI. Of the articles, the main findings were as follows:

1. "The results suggest that while age, disaster experience, and income are associated with preparedness, the relationship between preparedness remains complex. Furthermore, policymakers should consider initiatives that address the socioeconomic and other issues that shape preparedness for a disaster" (Donner and Lavariega-Montforti 2018).
2. Populations that remain in place during a natural disaster and those that evacuate may have different needs (Rickless et al. 2023).

3. Communities with socially vulnerable populations experience more casualties. More research is needed as the unit of analysis was limited to the county level (Zahran et al. 2008)
4. There is a "positive and significant relationship of social capital on adaptive behavior even when controlling for social vulnerability of a neighborhood. This suggests that policies and programs that strengthen the social connectedness within neighborhoods can increase adaptive behaviors thus improving community resilience to flood events" (Bixler et al. 2021).

The literature review suggests that policies that increase social capital and reduce social vulnerability may reduce flood fatalities and flood risk. However, understanding if and why some regions or types of flooding have a different set of underlying social vulnerability indicators was difficult to discern from the literature review. Interviews with a diverse group of experts on the ground were used to illuminate some of the idiosyncrasies for assessing flood-specific social vulnerability in Texas.

1.2 Task 2: Expert Interviews and Input from the Public and TWDB

Between April and July 2023, the research team conducted 15 interviews with flood planning, mitigation, and recovery experts, that included community members, watershed protection specialists, academics, and members of Regional Flood Planning Groups. The goal of the interview process was to gather qualitative information on factors that make communities and households in Texas more likely to experience adverse impacts during an event or a prolonged recovery time relative to others who experience the same flooding event.

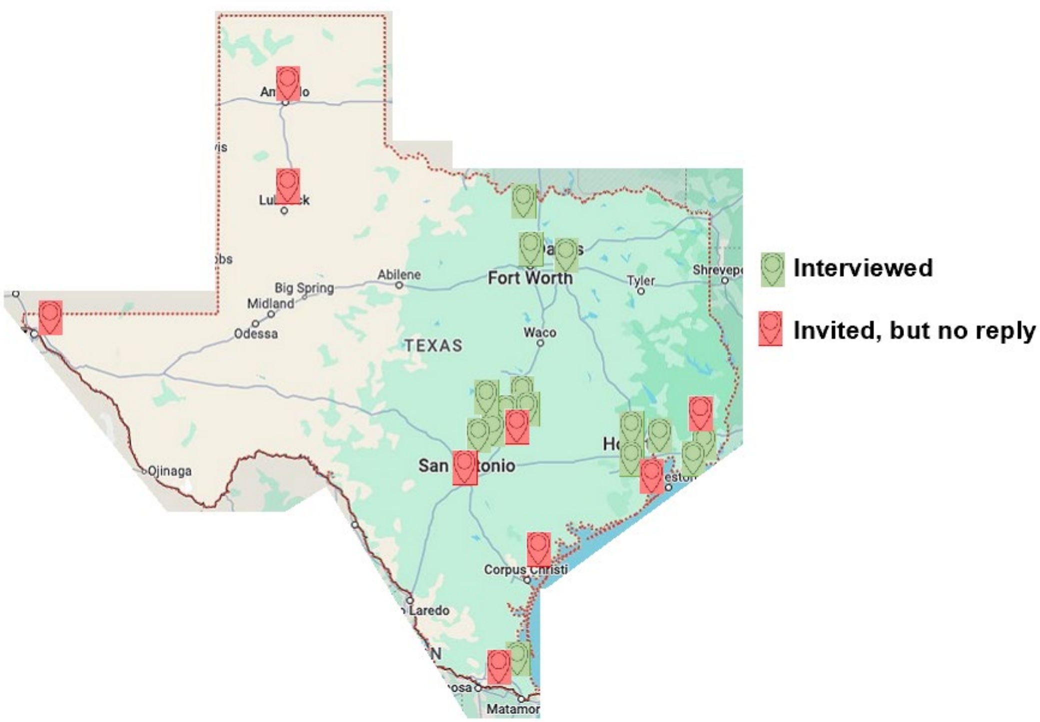

Figure 2. **Location of interview sample and interview participants**

The interviews for the TX F-SVI project gathered information from individuals who live in, work, or interact with communities that experience floods and could have insight into the unique factors that are more prevalent in their region. We generally refer to the people who participated in interviews as “stakeholders”.

Interviews were semi-structured, meaning that the research team followed a pre-determined guide but also allowed participants to discuss topics or issues of importance that may not have been explicitly a part of the interview protocol. The interview questions were designed to discern information related to specific indicators, if and how some indicators are weighted compared to others, and how those indicators aggregate (add together) or interact in ways that compound the effects. Participants were sent the interview guide and a list of literature-identified social vulnerability indicators prior to the interview. The interview guide is in Appendix B.

The interview sample population was identified through three methods: first, the research team generated a list of people and organizations that were known to have experience or expertise in working with populations typical of socio-economic and/or socio-demographic vulnerability. Second, TWDB Flood Planning sent a request to Regional Flood Planning Groups to nominate interview participants. Finally, at the end of interviews that were conducted, we asked the participants if they could recommend others with expertise in the area (snowball sampling). The interview participants represented a spectrum of Texas locations and geographies, including Central Texas, North Texas, the Gulf Coast, and the Rio Grande Valley. Additionally, the experts experienced a wide variety of flooding types, including fluvial, coastal, flash floods, and stormwater. An anonymized interviewee list can be found in Appendix C.

From the interviews, a total of 34 social vulnerability indicators were identified. The research team explicitly framed the conversation around Texas- and flood-specific social vulnerability indicators at the outset. However, about halfway through the interview, participants were prompted to distinguish the vulnerabilities they had mentioned thus far and indicate if they were unique to flooding, compared to other hazards such as extreme heat or winter storms (question 3b in Appendix A). This request prompted the respondent to be more explicit regarding drivers of social vulnerability specific to flooding. These indicators are indicated with an asterisk in Table 2. Because no Texas-wide social vulnerability indices currently exist, the information obtained from the interviews is an important way to account for Texas-specific context.

1.3 Comparing indicators identified in Task 1, Task 2, and Public Comment

A total of 38 social vulnerability indicators were identified through the systematic literature review, interviews, and public comment period. A list of these indicators can be found in Table 2. There were twelve individual indicators identified through the interviews that were not identified in the literature review (indicating some Texas- or flood- specific considerations, e.g., flood insurance, proximity to environmental toxics, veteran status, unhoused populations, etc.) and three indicators that were identified in the literature that were not identified in the interviews (e.g., occupation type).

Each indicator was assessed across three criteria in reference to the Texas F-SVI: relevance, credibility, and data availability/quality. Relevance considers the current and potential needs of stakeholders, including decision-makers and those affected by flooding. Credibility is usually defined as the rigor of scientific standards. Based on insights from extensive indicator work at the Competence Centre on Composite Indicators and Scoreboards (Joint Research Centre-European Commission 2008), we used the frequency of literature review occurrence as a measure of credibility and the frequency of interview occurrence as a measure of relevance. For both relevance and credibility, each indicator was categorized as low (L), medium (M), or high (H) based on the following frequency of occurrence criteria: L = less than 25%, M = 25% ≤ N < 60%, and H = greater than 60%. Data availability and quality were assessed on a scale of 0-2, where 0 = no known source of data, 1 = known source but poor quality, 2 = known source and good quality. In many cases, but not all, data are available from the U.S. Census Bureau such as the American Community Survey (U.S. Census Bureau 2022).

Table 2 Indicator list and assessment

		Task 1	**Task 2**		
Indicator	**Sub-indicators**	**Lit review count (n=33)**	**Interview count (n=15)**	**Public comments count (n=6)**	**Data availability and quality**
Indicators that were identified in 60% or more in both literature and interviews (H/H)					
Age	Under 10/over 65+	25 (76%)	7 (47%)	1	2
Minority	Specific minority groups aggregated into one indicator	25 (76%)	12* (80%)	1	2
Income	Income	23 (70%)	13* (87%)	1	2
Housing value	Median housing value	20 (61%)	13 (87%)	0	2
Indicators that were identified in 60% of one category and between 25% and 60% in another (H/M)					
Language	If English is a first language	12 (36%)	7 (47%)	1	2
Indicators that were identified between 25% and 60% in both literature and interviews (M/M)					
Renter	Owner/Renter binary indicator	16 (48%)	4* (27%)	-	2
Disabilities	Disability, mobility limitation	10 (30%)	4 (27%)	1	2
Transportation	Access to a car, access to reliable transportation	13 (39%)	4 (27%)	1	2
Indicators that were identified in 60% of one category and below 25% in another (H/L)					
Education	Specified diploma or degree	20 (61%)	2 (13%)	-	2

Poverty	Percentage of population in poverty, deep poverty	21 (64%)	1 (7%)	-	2
Indicators that were identified between 25% and 60% of one category and below 25% in another (M/L)					
Unemployment	Unemployment	11 (33%)	2 (13%)	-	2
Housing age	Discrete indicator	2 (6%)	6* (40%)	-	2
Single parent household	Single-parent household as a household structure	17 (52%)	3 (20%)	1	2
Gender	Female or male	16 (48%)	1 (7%)	-	2
Communication	Access to telephone, internet	2 (6%)	4* (27%)	-	2
Migration	Recently moved, recently migrated	2 (6%)	5* (33%)	-	2
Rural/Urban	Binary indicator	3 (9%)	4* (27%)	-	2
Flood Insurance	x/ flood insurance rates, percentage of residents with insurance	-	5* (33%)	2	2
Environmental Risk Factors	x/ Proximity of environmental risk factors	-	4* (27%)	1	2
Occupation	Type of occupation (extractive industries, service sector, transportation)	9 (27%)	-	-	2
Mobile homes	Mobile home as a housing type	10 (30%)	1 (7%)	-	1
Indicators that were below 25% in both literature review and interviews					
Access to Resources	Food/Water Access, supportive social network, proximity to essential facilities	-	3	3	1
Flooding History	x/ prior experience with flooding or disaster	-	1	2	1
Gentrification	x	-	3	-	1
Health	Health insurance, existing health condition, caregiving needs, chronic and severe problems	6	2	1	1
Housing density	Number of people in the home, multi-generational housing	8	-	-	2
Lack of Ability to Evacuate	x	-	1	-	1
Lack of Community Involvement	x	-	2	-	0
Mean gross rent	Percentage of income spent on rent or average rent cost for population	5	-	-	2

Mental health	Reported mental health condition	1	1	-	2
Nursing homes	If the individual is in a nursing facility	-	2	-	2
Pets	x	-	1	-	0
Recently moved	Reported that the individual recently moved	1	3	-	2
Social security benefits	Binary indicator	5	1	-	2
Student	x	-	1	-	2
Unhoused	x	-	1	-	1
Veteran Status	x	-	1	-	2
Trust and community cohesion	Cultural mix in the community; community confidence/trust	-	-	2	0
Immigration	Immigration status	-	-	1	1

*noted as flood specific in the interviews

Stage 2: Texas Flood Social Vulnerability Index Construction

The research team developed the Texas Flood-Specific Social Vulnerability Index (TX F-SVI) as a comparative metric that provides a snapshot of an area's relative social vulnerability to flooding, referred to as a "hazards of place" model (Cutter et al., 2003).

Uncertainty and sensitivity analysis measures how sensitive a model is to changes in parameters, i.e., how much does the output (TX F-SVI) change given a change in the input (which can be a different combination of indicators or method of computation). This first step is to establish a "base case" that makes decisions on (1) indicator selection, (2) indicator normalization/scaling, (3) weighting, (4) aggregation, (5) index structure, and (6) analysis scale (Tate 2012). Sensitivity analysis is an iterative and exploratory process. The base case represents the starting point for the iterative exploration of different index construction decisions.

After establishing a base case, we employed global sensitivity analysis (GSA) to examine how variation in model outputs can be apportioned to multiple sources of variation in the input modeling assumptions (Saisana and Tarantola 2016; Saltelli et al. 2008). Multiple iterations occurred from the base case to the construction of the final index to align with policy objectives and to increase the internal consistency and statistical robustness of the TX F-SVI.

2.1 Index construction decision steps and the Base Case Model

Analytical scale. The analytical scale refers to the geographic aggregation level of the indicators and index. Options typically include US County, census units such as census tract or census block groups, ZIP codes, or neighborhoods. We considered two spatial scales as appropriate for the analysis for the TX F-SVI: census tract and census block group. Census tracts are subdivisions of counties, and census block groups are statistical divisions of census tracts for which the Census collects statistical data. Texas has 5,265 census tracts and 15,811 block groups. The primary source of subcounty high resolution geographic data about the U.S. population comes from the American Community Survey (ACS), a Census Bureau program (Martin, Tosi Lacey, and U.S. Census Bureau 2024). Spatial science research has documented how scale impacts the outcome of index-based measures, an unsolved spatial analysis phenomenon known as the Modifiable Areal Unit Problem, or MAUP for short (Fotheringham and Wong 1991). Scale selection is a multifaceted decision based on factors such as project objectives, intended end-use, and data availability, variability, and quality (Tate 2013; Fekete, Damm, and Birkmann 2010).

When developing a composite indicator such as SVI, each spatial scale of analysis has its advantages and disadvantages. Research that compares multiple scales of SVI has found that *highly* socially vulnerable residents are better detected at finer spatial scales (Hinojos et al. 2023), such as the census block group. However, the census tract scale offers a better level of analysis for capturing overall dynamics of social vulnerability indicators by explaining a higher level of variance (Hinojos et al. 2023; Chu, Tan, and Mortsch 2021). A significant consideration for the TX F-SVI is effective sample size of ACS estimates and the associated margin of error (MOE). Each estimate published in the ACS is accompanied by a margin of error (MOE) that reports the uncertainty associated with the estimate. Due to the larger scale of aggregation, census tracts have larger sample sizes than census block groups, and the larger the sample the smaller the standard error and less uncertainty about the true characteristics in population (Folch, Spielman, and Graber 2023; Spielman, Folch, and Nagle 2014). The advantages of higher data quality (more reliable estimates with less uncertainty) and better data availability (some indicator estimates are not produced at the census block group) lead us to select census tract as the spatial scale for the base case. This analytical scale also facilitates comparisons with existing SVI including the Center for Disease Control and Prevention's (CDC's) SVI at the census tract level and the Federal Emergency Management Agency's (FEMA's) National Risk Index (NRI) for Natural Hazards (which integrates the South Carolina SoVI). Our base case utilized a census tract geography.

Index structure. As outlined in Tate (2012), there are three primary approaches to index structure.

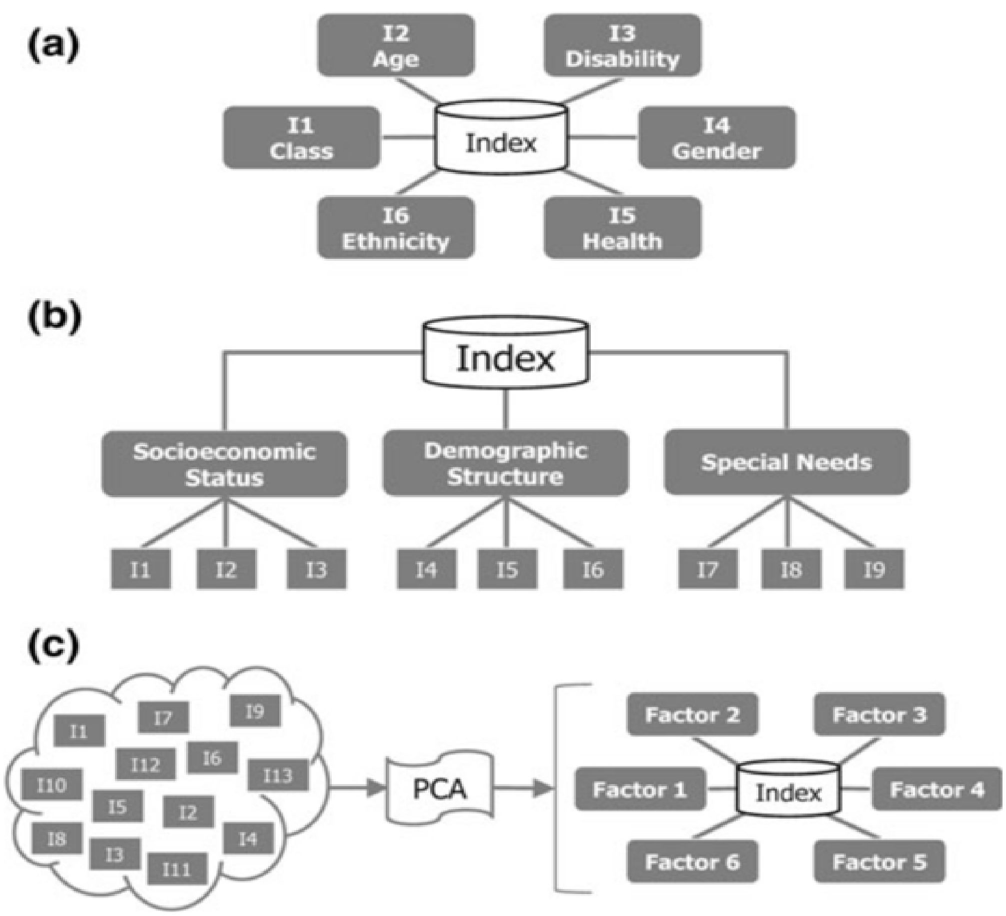

Figure 3. Deductive (a), hierarchical (b), and inductive (c) approaches to index construction (figure from Tate 2012)

The deductive approach takes each indicator and includes it in the index (Figure 3a). A hierarchical index design (Figure 3b) separates indicators into groups (sub-indices) that share the same underlying dimension of vulnerability. The sub-indices are aggregated to the index. Inductive approaches (Figure 3c), an approach popularized by the “Social Vulnerability Index (SoVI)” (Cutter, Boruff, and Shirley 2003) begin with a larger set of indicators that are reduced to a smaller set of uncorrelated latent factors using principal component analysis (Jolliffe and Cadima 2016) as indicated by PCA in Figure 3c.

Our base case model utilized a deductive approach, directly including each indicator in the index, as this approach is the most straight forward to understand. The sensitivity analysis will assess each of the three index structure approaches.

Indicator selection. The 19 indicators selected for the base case were above the “L/L” criteria established for relevance and credibility and were assessed to have available data (Table 2). Once an indicator is selected, the next step is operationalizing that indicator, i.e., defining the measurement of that indicator. This step includes selecting a specific data source and denomination strategy and transforming the data into a value utilized for index construction: operationalization, data source, and denomination. Since units of the same analytical scale will differ in size (for example, a census tract in Houston will have a different population size than a census tract in far west Texas) simply taking a count of an indicator may not suffice (e.g., the number of people with a college degree in the Houston census tract is likely to be higher than the number of people in the west Texas census tract, but as a fraction of the total population they may be similar). This operation is referred to as denomination. Appendix I includes a “fact sheet” for each indicator selected that includes the conceptual definition and justification, the data source, and denomination approach.

Indicator normalization and scaling. Normalization is the operation of bringing indicators onto comparable measurement scales so that they can be aggregated more fairly. Our base case utilized min-max scaling, as it preserves the original scale, making the interpretation of the index more intuitive and accessible. Min-max scaling transforms the indicators to a common scale, typically between 0 and 1, ensuring a consistent and comparable contribution of each indicator to the index. Additionally, min-max scaling was deemed suitable for the F-SVI base case for its simplicity and ease of implementation.

Indicator weighting. Indicator weighting refers to the relative degree of indicator importance in an index. Approaches to weighting include equal weighting, using expert opinion on the relative importance of one indicator vs another (creating a budget allocation for each indicator), or using the “factor loadings” that result from a principal component analysis. Our base case utilized equal weighting. Equal weighting was selected so that the sensitivity analysis could assess the influence of a “budget allocation” weighting approach assigned by the occurrence frequency from literature review and interviews (found in Table 1).

Indicator aggregation. Our base case model applied an additive aggregation method. This approach sums the scaled values of the indicators to create an index. It is straightforward, allowing for a simplified interpretation of the index, as higher values indicate higher social vulnerability. The sensitivity analysis compared additive and multiplicative methods, using arithmetic and geometric means, respectively.

A summary of the decisions made for the base case, and how these decisions compare to other established indices such as the CDC's SVI and Dr. Cutter's SoVI, are below in Table 3.

Table 3 TX F-SVI Base Case decisions and comparison to established methods

Decision step	CDC-SVI	SoVI	TX F-SVI base case
Indicator selection	16	29	19
Normalization/scaling	Percentile rank	Z-score	Min-max scaling
Weighting	Principal Component Analysis	Principal Component Analysis	Equal weighting
Aggregation	Additive	Additive	Additive
Index structure	Hierarchical	Inductive	Deductive
Analysis scale	Census tract	County level	Census Tract

2.2 Results from Uncertainty and Sensitivity Analysis and Index Construction Revisions

After constructing the index using the base case decisions, we employed a global sensitivity analysis (GSA) to examine how variation in model outputs can be apportioned to multiple sources of variation in the input modeling assumption (Saltelli et al. 2008). In some cases, the base case decision is the most appropriate because the sensitivity analysis illustrates that decision minimizes uncertainty in the model. In other cases, the base case decision needs to be reconsidered because the analysis indicates that decision increases uncertainty. In total, we conducted two iterations of index construction. Iteration #1 and iteration #2 were assessed using GSA. The first index iteration was presented in Memo #5, which resulted in a process to gather feedback from the external review panel and the TWDB review team on how to revise the index for the next iteration.

In total, the GSA provides information on 10 index model parameters: normalization, weighting, aggregation, index structure, analysis scale, indicator selection (all listed as decisions steps in Table 2) plus three additional components of the indicator selection:

1) The indicator distributions and assessing the influence of highly skewed distribution of indicator observations. For example, the flood insurance indicator (D_FLIN) has a significant right-skew where most of the observations are in the lowest decile of the distribution and most of the extreme values are on the right (the higher values of the indicator). When this indicator distribution is normalized (e.g., min-max scaling of [0, 1]) a large majority of census tracts have a very low score, but some have a very high score. The observations at the extreme dominate the normalized scores, reducing the discriminatory power of the indicator.
2) The denomination of the indicators (described in section 2.1).
3) Treatment of the indicator. Data treatment is the process of altering indicators to improve their statistical properties, mainly for the purposes of aggregation. Data treatment involves changing the values of certain observations or transforming an entire distribution. There can be many reasons to employ data treatment, but in composite indicators the main reason is to adjust heavily skewed distributions.

For each parameter, one of three approaches to move towards the next index iteration was made (represented by different icons):

(1) Base case decision is the most appropriate as it minimizes uncertainty. 

(2) The sensitivity analysis results indicated limited influence in increasing uncertainty. A decision can be made to make the index construction parsimonious (simple and easy to explain). 

(3) Base case decisions need to be reconsidered as the GSA indicated this parameter was driving uncertainty. 

Table 4 outlines each of the 10 decision steps and how each parameter output was assessed and considered for index iteration #2. More information on parameter outputs are available in Memo #5.

Table 4. Results of uncertainty and sensitivity analysis and steps to next iteration

Decision step	Results of GSA for index iteration #1 (presented in memo #5)	Implications and revisions made for final draft index	
Analytical scale	Higher data quality and better data availability lead us to select census tract as the spatial scale.		No change made.
Index structure	Results of GSA indicate the hierarchical structure is least biased and most precise approach for the TX F-SVI.		Revise the hierarchical structure for "fit" based on indended index use and statistical coherence.

Indicator selection	GSA results assess four aspects of the indicators: (1) indicator distributions, (2) indicator denomination, (3) treatment effects, and (4) the relative influence to the overall index when a single indicator is removed (a process that cycles through each indicator).	(1) Make decision to include/exclude problematic indicators with highly skewed distributions. (2) Check the denomination to ensure decisions are statistically sound and correct. (3) Consider treatment solutions for highly skewed indicators (note: GSA results indicated no direct effect to uncertainty from treatment). (4) Assess indicators with minimal influence and cross-reference with highly skewed problematic indicators.
Indicator normalization	GSA results indicate limited direct influence of normalization.	Decide between min-max scaling and percentile normalization based on indended application of TX F-SVI.
Indicator weighting	The sensitivity analysis shows that weights have no direct effect but interact with the indicator distribution, normalization, and aggregation	Decide between equal weighting and indicator weighting for hierarchical structure parsimony.
Aggregation	The arithmetic mean and geometric mean resulted in large differences in rank change.	Decide between arithmetic mean and geometric mean for index construction parsimony.

2.3 Decisions made for the Final Draft TX F-SVI Index

Analytical scale. Census tracts are utilized as the analytical scale for the final draft index for reasons explained in section 2.1.

Index structure. Based on the results of the GSA plus the opportunities for comparability of the approach to the CDC-SVI index structure, a hierarchical index structure is utilized for the final draft index. Vulnerability indices that apply hierarchical designs have typically employed roughly ten to twenty indicators, separated into groups (sub-indices) that share the same underlying dimension of vulnerability (Tate 2012). Individual indicators are aggregated into sub-indices, and the subindices aggregated to the index (Figure 3b). How the indicators are grouped into sub-indices is important. The TX F-SVI hierarchical structure progressed through three conceptual framework iterations: first, the indicators selected (section 2.1) were mapped onto the CDC themes. Second, the research team in collaboration with the external review panel and the TWDB review team revised the names of the sub-indices and the groupings of variables within each sub-index (see Appendix D).

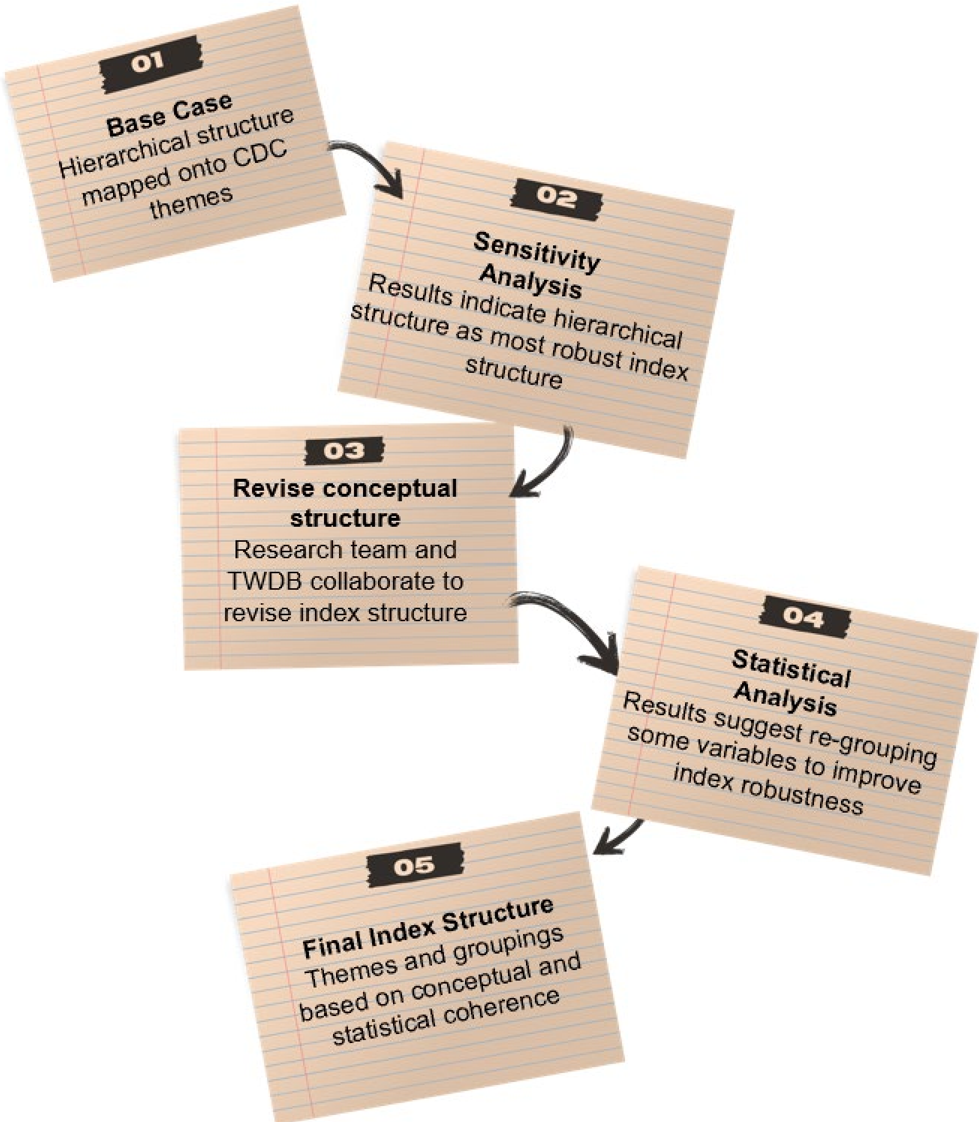

Figure 4. Five steps towards final index hierarchical structure.

The research team then modified the hierarchical structure to improve the correlation structure, internal consistency and overall robustness of the composite index by applying and interpreting results from the following statistical techniques: Cronbach's Alpha (Cronbach 1951), Guttman's Lambda (Guttman 1945) and principal component analysis (PCA) (Jolliffe and Cadima 2016). A final index structure was constructed based on conceptual and statistical coherence (Figure 5). Uncertainty analysis was conducted on the final draft index structure. The final TX F-SVI index structure is comprised of six dimensions: (1) socio-economic, (2) place and status, (3) socio-cultural, (4) rurality, (5) infrastructure, and (6) socio-demographic. Dimensions 1, 3, 4, 5, and 6 have a conceptual coherence to them. Dimension 2, Place and Status, is different in that it includes both environmental and social factors (e.g., exposure to environmental risk factors, renter status, and recent migration). The grouping of these indicators was informed by the statistical understanding of the data structure as this combination of variables provided the most internal consistency based on factor analysis and correlation structure.

Figure 5. Hierarchical structure of the TX F-SVI

Indicator selection. Decisions on indicators to include in the final set were based on statistical guidance from the sensitivity analysis, internal consistency analysis, indicator distributions, the statistical transformation functions available and data quality standards. Four indicators were removed: flood insurance, public transport, gender and education. Flood insurance and public transportation were both highly skewed and transformation functions did not maintain the indicator distribution properties (i.e., treatment of the data had a negligible effect in the sensitivity analysis). The data quality for flood insurance was also problematic, with a significant number of census tracts having a null value. Gender and education were removed based on statistical inconsistencies in the correlation structure. The data source for one indicator, migration, was updated to include migration from place to place within the United States plus international migration. Including both data sources is both conceptually coherent with the literature (new residents that migrated from state to state are less familiar with hazard risks in their new place) and resulted in a more uniform distribution. Two indicators were successfully transformed for uniform distributions and updated normalization: no vehicle and rural. Additionally, mobile homes were included, and was coherent with internal consistency and modeling. Indicator variables and data sources are found in Appendix E.

Table 5. Index construction decisions for the final index

Decision step	Steps suggested following Memo #5 and Checkpoint meetings	Decisions for final index
Analytical scale	No change made.	Census tracts. No change made.
Index structure	Revise the hierarchical structure for "fit" based on indended index use and statistical coherence.	Five steps to improve the conceptual and statistical coherence of the final index were used from the base case to the final hierarical structure (Figure 4). The final hiearchical structure has six dimensions and 18 indicators.
Indicator selection	(1) Include/exclude highly skewed distributed indicator. (2) Check the denomination. (3) Consider treatment solutions for highly skewed indicators. (4) Assess indicators with minimal influence and cross-reference with highly skewed problematic indicators.	Described in indicator selection in section 2.3, the following steps were taken for highly skewed indicators: • Removed: flood insurance, public transport, gender, education • Modified data source: migration • Revised via data treatment: no vehical and rural. • New indicator: mobile homes
Indicator normalization	GSA results indicate limited direct influence of normalization.	Percentile rank normalization is selected for final index normalization for ease of communication and interpretability: a given score is the percentage of scores in its that are less than that score.
Indicator weighting	The sensitivity analysis shows that weights have no direct effect but interact with the indicator distribution, normalization, and aggregation	Equal weighting is selected for the final index for ease of communication and interpretatbility and due to the GSA results (section 2.2).
Aggregation	The arithmetic mean and geometric mean resulted in large differences in rank change.	Arithmetic mean is selected.

Denomination. The results of the uncertainty and sensitivity analysis indicated a direct influence of denomination on uncertainty. For each indicator, we reassessed how the indicator was denominated to ensure that the approach was utilizing the best available scientific ratio and that the approach for each indicator was statistically correct. Denomination variables and calculation of indicators with denomination are found in Appendix F and Appendix G, respectively.

Normalization. The final index uses a percentile rank normalization approach, rather than a min-max scaling that was used in the base case. The decision to utilize this normalization approach for the final index was based on the application and use of the index for flood planning. The focus of percentile rank transformation is to improve discrimination and comparability across census tracts. It results in a balanced score across the entire geographic area by mitigating the impact of outliers and is easy to communicate. For example, if a census tract has a final TX F-SVI score of 0.75, that means 75% of all the other census tracts have a lower F-SVI score.

Weighting. The final index uses an equal weighting approach. The sensitivity analysis results indicated no direct influence of different weighting schemes on the uncertainty of the index output. Moreover, the use of nominal weights did not have their intended impact due to the complex interactions among indicators, which negated their influence. Thus, applying differentiated weights was not a valid approach, as the interactions among indicators undermine the effectiveness and rationale behind assigning different weights. Equal weighting was selected as the most appropriate method due to its simplicity, transparency, robustness, and internal consistency.

Aggregation. The final index uses the arithmetic means for aggregation. Arithmetic means aggregation is favorable for statistical reasons and thematic application of the index. Statistically, considering the percentile rank normalization, arithmetic mean is suitable for uniform distributions, whereas geometric mean aggregation depends on the multiplicative relationship between numbers and relative distances. Thematically, the computation is straightforward and interpretable, explaining the index scores and showing clear thematic drivers of socio-economic vulnerability for planning and decision-making.

2.4 Geospatial Analysis and Visualization

Once the final index is constructed, each census tract in Texas is assigned a percentile rank score. Spatial variability in TX F-SVI scores across the region provides a unique view into the distinct patterns of potential adverse flood hazard impacts based on social vulnerability. Mapping the geographic pattern of vulnerability demonstrates that place can be very influential in understanding and characterizing social vulnerability. Figure 6 maps the TX F-SVI across the entire range of the percentile rank distribution using a blue-yellow color scale. Figure 6 presents a continuous scale of the percentile rank distribution.

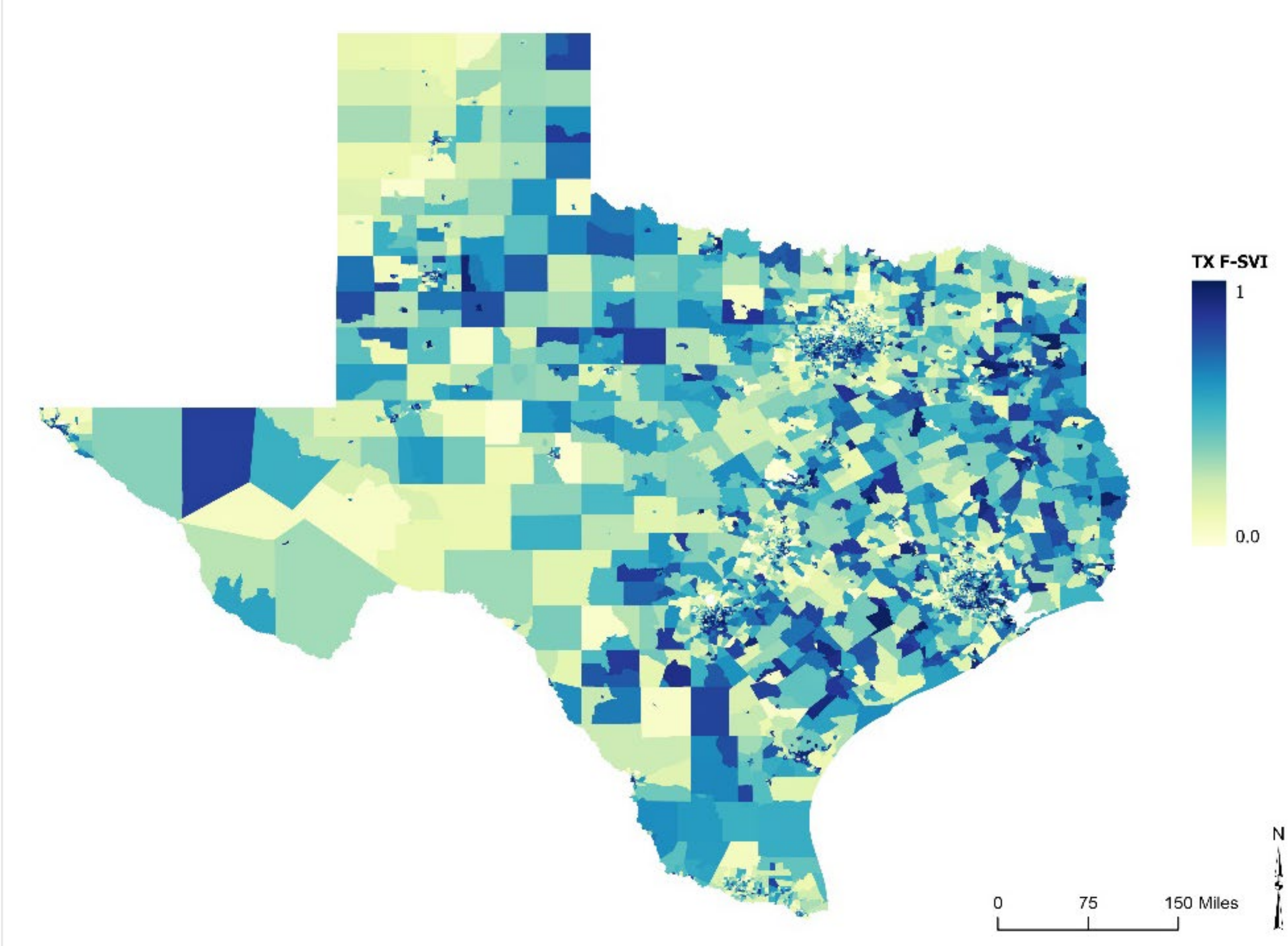

Figure 6. TX F-SVI by continuous percentile rank distribution.

Another approach for visualization and communicating a social vulnerability index is by assigning the distribution a class, such as low, medium, and high. Based on the TX F-SVI score, all census tracts were mapped into three classes (tertiles), categorizing the areas as low, medium, or high vulnerability (Figure 7). Census tracts with SVI scores in the top 33%, indicating the highest vulnerability, are highlighted in blue. Conversely, tracts with scores in the bottom 33%, representing the least vulnerability, are shaded in green. Because census tracts are apportioned based on population, census tracts that are grouped together in metropolitan areas are smaller in geographical area and are more difficult to discern from a statewide point of view. Figure 8 illustrates the low-medium-high TX F-SVI in the Dallas-Fort Worth Metropolitan area.

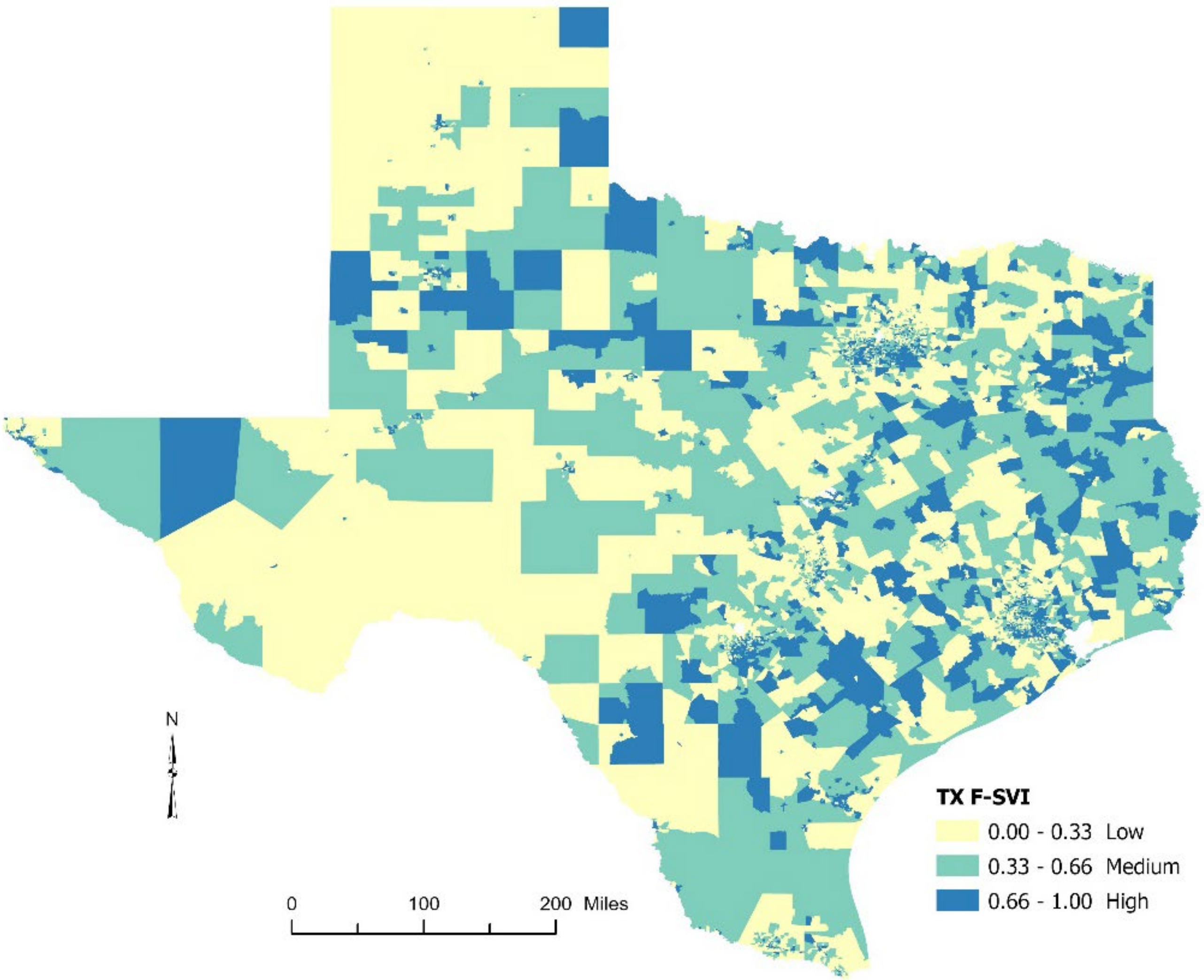

Figure 7. Texas F-SVI tract classes.

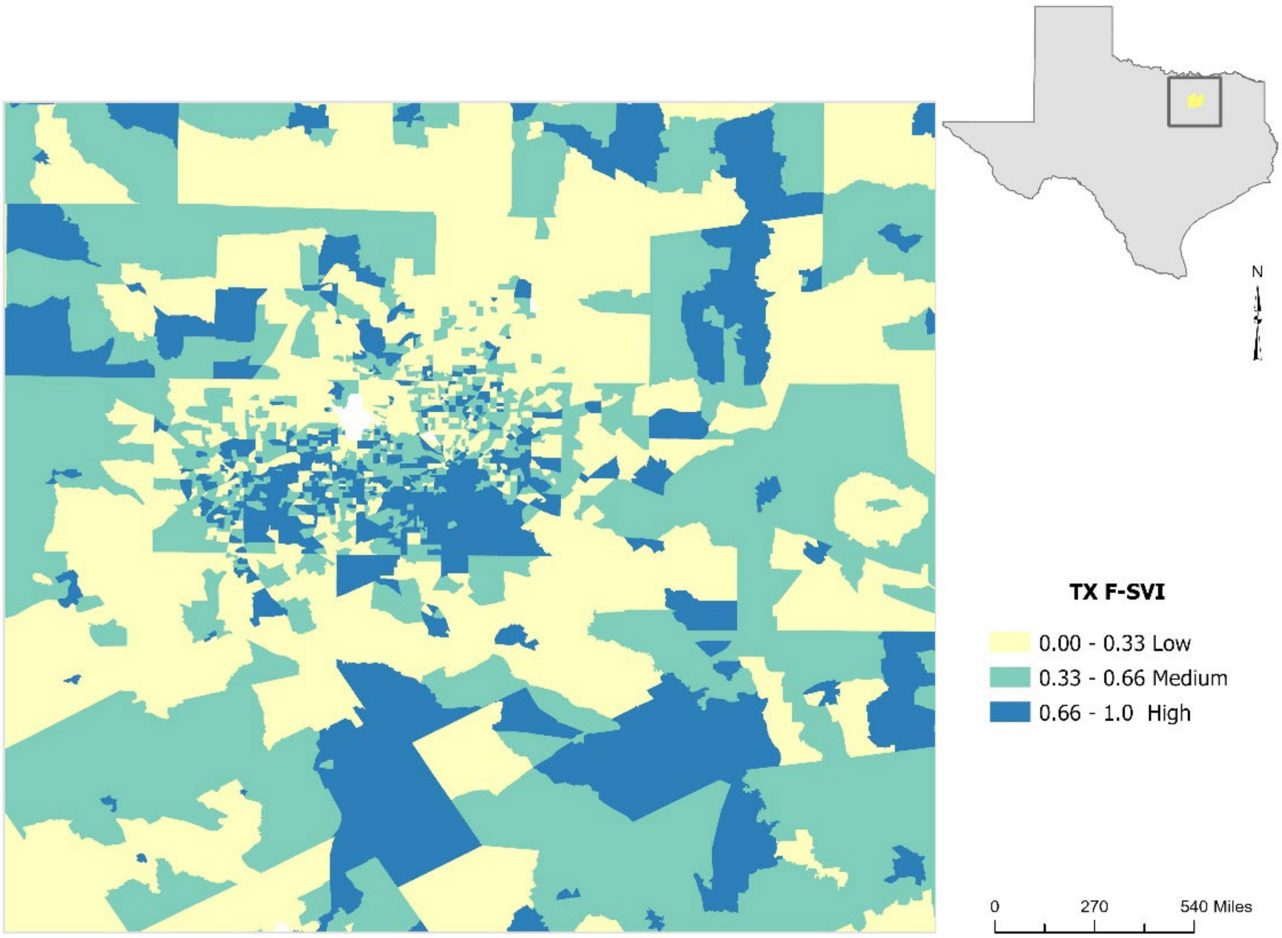

Figure 8. TX F-SVI Dallas-Fort Worth

Next, a hot spot analysis reveals clusters of census tracts in Texas that are more or less socially vulnerable to flooding (Figure 9). Hot spots and cold spots are identified using the Getis-Ord Gi* statistic (Grekousis 2020). Hot spots are areas that have a cluster of census tracts with high social vulnerability scores, and cold spots are areas that have a cluster of census tracts with low social vulnerability scores. Areas that are white show census tracts where there are no significant clusters of census tracts with high or low social vulnerability scores. Both hot spots and cold spots are present across the state of Texas, suggesting varied social vulnerability to flooding.

Specific areas like Austin show significant cold spots, indicating lower social vulnerability to flooding. On the other hand, San Antonio and eastern and southeastern parts of Texas exhibit numerous hot spots indicating high social vulnerability to flooding, particularly around Houston and the Beaumont area. These regions may face greater challenges in managing flood impacts on vulnerable populations. Predominantly non-significant areas with some cold spots are observed in rural areas, Western and southwestern Texas, suggesting lower overall social vulnerability to flooding.

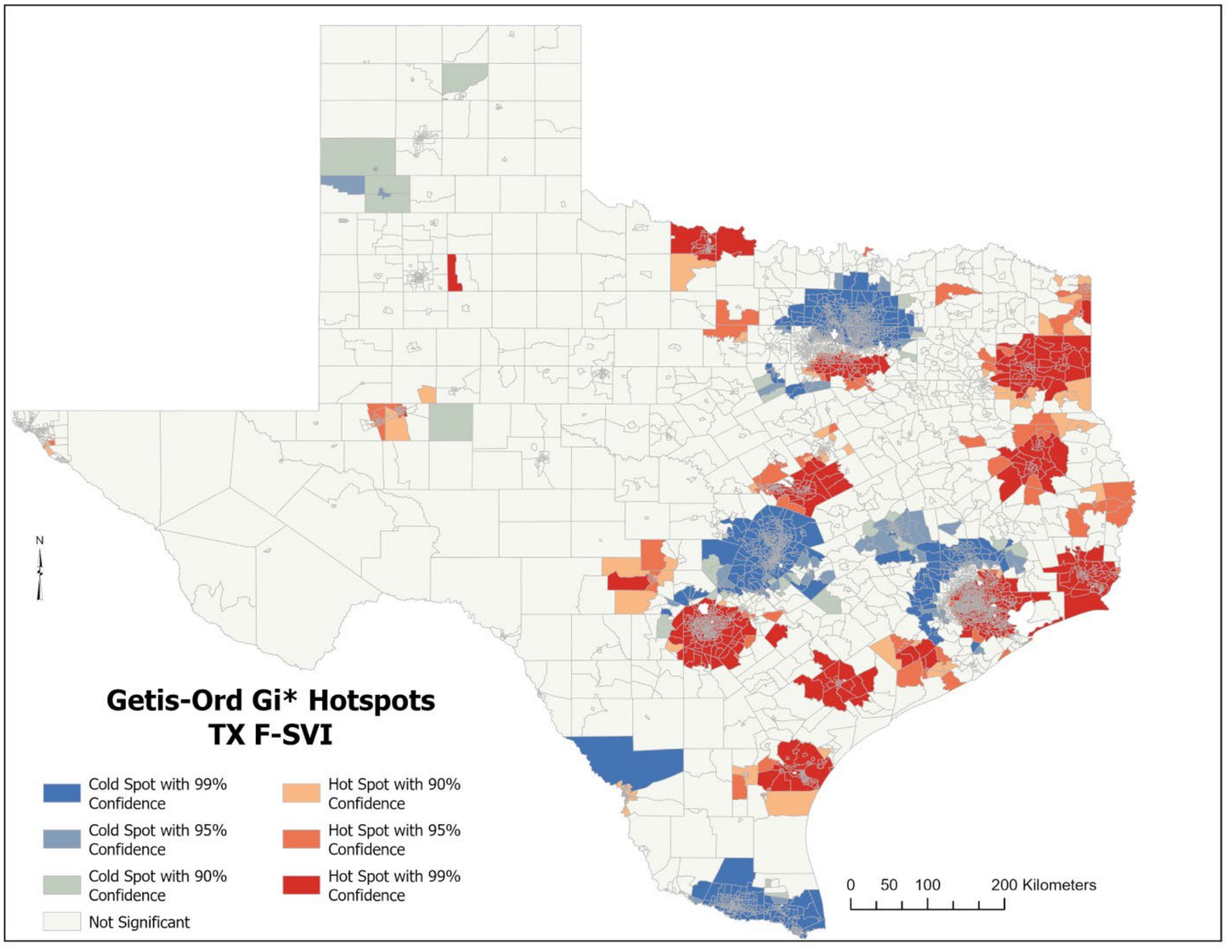

Figure 9: Hotspot analysis of TX F-SVI

Additional statistical analysis and visualization (Figure 10) comparing highest and lowest F-SVI census tracts can help us describe and characterize the drivers of flood social vulnerability in Texas.

For example, we observe that on average higher TX F-SVI percentile rank census tracts tend to also score more highly on socio-cultural and socio-demographic dimensions and are more similar of rurality and socio-economic dimensions.

The TX flood-specific social vulnerability metric can be used to identify specific areas and neighborhoods that have the highest risk percentile rank and we can assess the different indicators underlying the social vulnerability in specific places. In the vignettes below, we provide examples of four locations that have the highest social vulnerability scores and break down individual indicators (Appendix H).

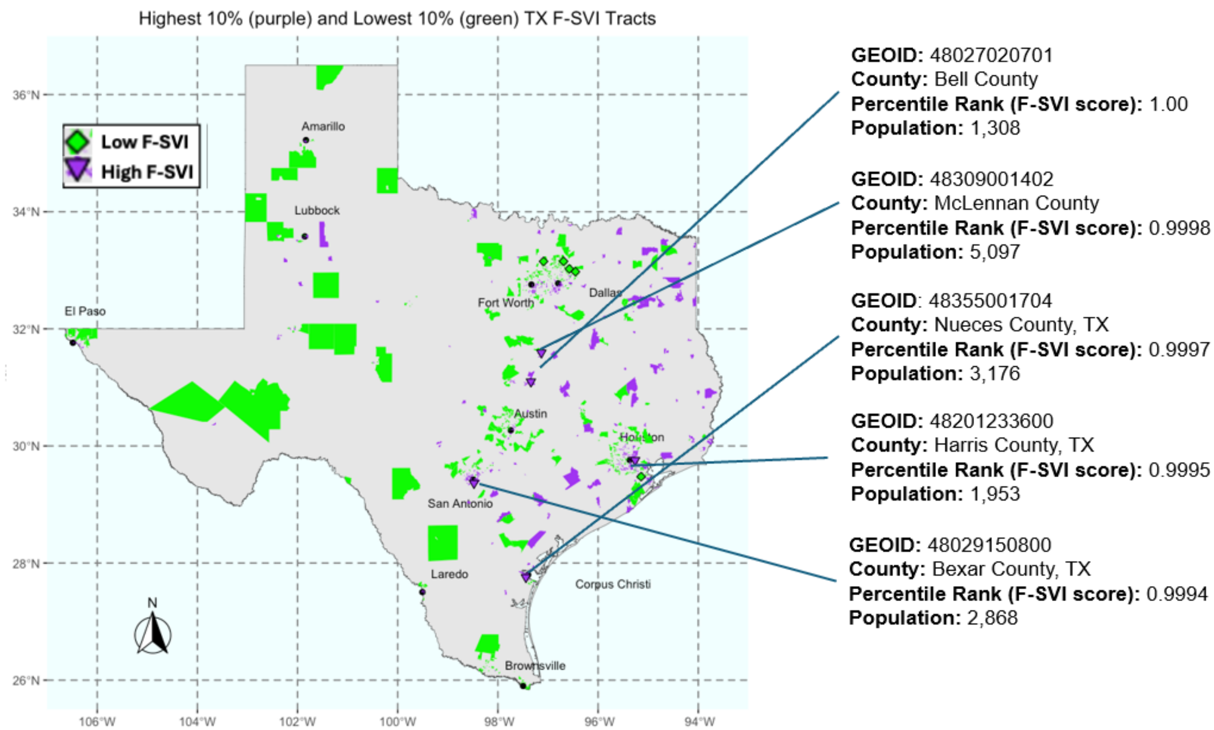

Figure 10: Highest and lowest F-SVI deciles plus five lowest tracts

Vignette #1

Census Tract: 48027020701

This census tract is located in central Texas along the I-35 corridor between Austin and Waco and was the highest scoring location on the social vulnerability index, with a score of 1.0 (on a scale from 0 to 1). This census tract covers an area of five square miles and has a population of 4,556. This census tract scored highest in the place and status definition, indicating that these residents experience disproportionately higher levels of exposure to environmental risk factors, and have more renters and migrants. Renters face a wider range of housing problems than homeowners, and migrants may be at risk because they are less familiar with hazard risks in a new location. This location also reported higher vulnerability for demographic and infrastructure indicators, and has a higher proportion of residents with disabilities, as well as individuals without a vehicle. This census tract also has a high score on poverty metrics and is one of the lowest scoring census tracts for income (meaning a lower median household income for residents of this census tract). Areas facing poverty without financial resources are less able to prepare for and recover from extreme events such as floods. This information is useful, because efforts to address flooding in this area should consider communication strategies that provide information to new residents about flooding risk, and make sure to prioritize transportation access and assistance for individuals without transportation or who have disabilities.

Vignette #2

Census Tract 48309001402

This census tract, located in McLennan County, had the second highest score on the social vulnerability index (0.9999). This census tract covers an area of one square mile and has a population of 1,438. The dimensions on which this area ranked most highly were socio-cultural and rurality. A high social vulnerability score on the socio-cultural dimension indicates a higher proportion of individuals do not speak English, and a higher percentage of the population identify as Hispanic or Latino, Black or African American, American Indian and Alaska Native, Asian, or Native Hawaiian and other Pacific Islander. This area also includes more residents who live in a rural location as well as in mobile homes. This census district also scored highly for having more single-parent households, renters, and less transportation access as well. Knowing the most prominent risk factors in this area can allow for targeted solutions, for example, providing accessible and reliable transportation options as well as communicating flood and emergency events in the languages spoken in the area. Like Vignette 1, this census tract also faces challenges with financial resources as well, scoring highly on poverty metrics and in the lowest percentiles for household income.

Vignette #3

Census Tract 48355001704

This census tract is located along the coast and with a score of 0.9997, this census tract ranks third on social vulnerability. Covering one square mile, this census tract has a population of 2,733. Socio-demographic and Infrastructure dimensions are particularly high scoring for this area, followed by socio-economic and socio-cultural factors. This census tract is identified as having higher vulnerability scores for single-parent households and households with elderly or young children. Single-parent households are socially vulnerable because they may lack the financial resources to respond to and recover from events like floods, and young children and seniors are more vulnerable to negative health risks associated with environmental hazards. This census tract also includes a higher vulnerability index score for residents living in older homes and lacking access to a vehicle. Older homes can be less structurally sound, and not having access to a vehicle can make responding to evacuation events more difficult. A higher proportion of residents also identify as Hispanic or Latino, Black or African American, American Indian and Alaska Native, Asian, or Native Hawaiian and other Pacific Islander. Addressing flood risk in this census tract may require solutions that prioritize connecting residents to transportation resources, as well as ensuring there is an adequate support system for single-parent households.

Vignette #4

Census Tract 48201233600

This census tract is in the Houston Metro area and ranks fourth with a social vulnerability index of 0.9996. This census tract has a population of 2,424 residents covering two square miles. This area has higher scores for socio-demographic, infrastructure, and socio-cultural dimensions, followed by place and status. The higher socio-demographic score is primarily driven by a higher proportion of individuals with disabilities, and the infrastructure vulnerability metric score can be attributed to older housing stock as well as a greater proportion of residents without vehicle access. This census tract is also home to a larger proportion of individuals who identify as Hispanic or Latino, Black or African American, American Indian and Alaska Native, Asian, or Native Hawaiian and other Pacific Islander, and this is one of the highest scoring census tracts for exposure to environmental risk factors. Lastly, this census tract has some of the highest scores for the poverty and unemployment metric as well. This area faces numerous compounding challenges. increasing residents' vulnerability to flooding events. For example, older housing stock may be less resilient to flood events, residents without employment and with low income may not have the financial resources to prepare for, evacuate from, or rebuild after an extreme flooding event. Environmental risk factors, potentially worsened by flooding, could further deteriorate public health.

2.5 Geospatial Data and Index Construction Code

Table 6. Links to deliverables

Deliverable	Link to product
Geospatial database (.xlsx with GEOID)	hyperlink
GIS (.gdb) files	hyperlink
Index construction (Jupiter notebook)	hyperlink
COINr package for index construction	https://bluefoxr.github.io/COINr/

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Appendix A: List of 33 articles for systematic review

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Appendix B: Interview guide

TWDB Flood-SVI Interview Protocol
6/09/2023

Interviewee: ____

Interviewed by: ____

Date: ____

Background
Interviews will be conducted in-person, over zoom and by phone. These interviews will be semi-structured. The interviewer will seek the interviews to be conversational in nature, therefore there is the potential for conversation and additional follow-up questions to arise organically.

Interview Guide for Stakeholder Representatives
Main Purpose: To understand how stakeholders perceive what makes individuals and households vulnerable to flooding in Texas.

Introduction:
Thank you for agreeing to participate in this interview. The interview is part of a study conducted by the University of Texas at Austin and Princeton University and sponsored by the Texas Water Development Board. Our aim of this study is to better understand the underlying factors that make people or communities more susceptible to the impacts of flooding in Texas.

When we invited you to participate, we sent along a glossary of terms. Do you have that glossary accessible? Do you have any questions about some of the terms we may ask about today?

Your responses to the interview questions will help us understand how and why people are vulnerable to flooding. This will inform the creation of a social vulnerability index that is specific to flooding in Texas.

The information you provide will remain confidential and will be securely stored. If applicable, I will seek your explicit permission to use quotes from your interview.
This interview will take 40-60 minutes. During that time, I will ask you approximately 10 questions and some follow up or clarifying questions.

Feel free at any time to skip questions that you do not feel comfortable answering. You can also stop the interview at any point.

Do I have your permission to record this interview?

Do you have any questions before we begin?

Thank you.
[hit record button]

Interview Questions:

1. Can you tell us a little about your organization and describe your current role?
    a. How does your organization help people mitigate flooding, prepare for flood events, and/or recover after flooding occurs? What services do you provide?

2. Flooding in Texas can occur from rivers overflowing, flash flooding, coastal flooding, and/or urban flooding from stormwater. Can you describe what kind of flooding is typical where you work?
   Alternative statewide Q2: Flooding in Texas can occur from rivers overflowing, flash flooding, coastal flooding, and/or urban flooding from stormwater. What kind of flooding typically consumes the most of your organizations time and resources?
    a. Recall a significant flood event that has happened in your region. Are there characteristics common to the people impacted most? {indicator selection}
    b. How unique is this [kind of flooding] and its subsequent impacts to people [with these characteristics] to your area compared to other regions in Texas? Do you think [this kind of flooding] impacts people [with these characteristics]

3. Who is the typical beneficiary of your work? Can you describe the individuals/communities that you primarily work with?
    a. What characteristics make people or households in your community have better or worse outcomes when it floods? [indicator selection]
    b. How much do you think these characteristics are similar or different to negative outcomes that could happen from other hazards such an extended heat wave or deep freeze? [flood specificity]

c. Which of these characteristics are most significant in how people are vulnerable to flooding, in your experience? Why? [Relative Weight/Influence]
d. To what extent are the vulnerabilities linked to these characteristics long-standing and pre-existing vs. something that emerges because of the event? [chronic vs emergent]

4. Reflecting on the characteristics that you listed – such as [list factors they've identified]
   a. How do they work to increase or decrease vulnerability? Do they work in combination? Do they work independently? [interaction/compound/aggregation]
   b. Are there other combinations of characteristics that make people more susceptible? [interaction/compound]

5. Flooding impacts different people in different places in different ways. What is unique about the people most impacted by flooding in the communities where your organization works?

   Statewide question: Flooding impacts different people in different places in different ways. What is unique about the populations of people in Texas that are impacted the worst?

Closing Questions

6. Is there anything regarding flooding and flood vulnerability that you would like to share that we have not had a chance to discuss yet?
   a. Is there other information we should know about communities being impacted in your region or for your organization?

7. Do you have any recommendations on who else I should reach out to regarding this topic?
   a. Can you share their contact information?
   b. Can you recommend other organizations or types of entities that you think are critical stakeholders in flood governance in your area?

Closing Remarks:

Thank you for participating in this interview about vulnerability to the impacts of flooding. Please feel free to follow-up directly with me or the study's PI, Dr. Patrick Bixler, if you have any questions or additional information on the study.

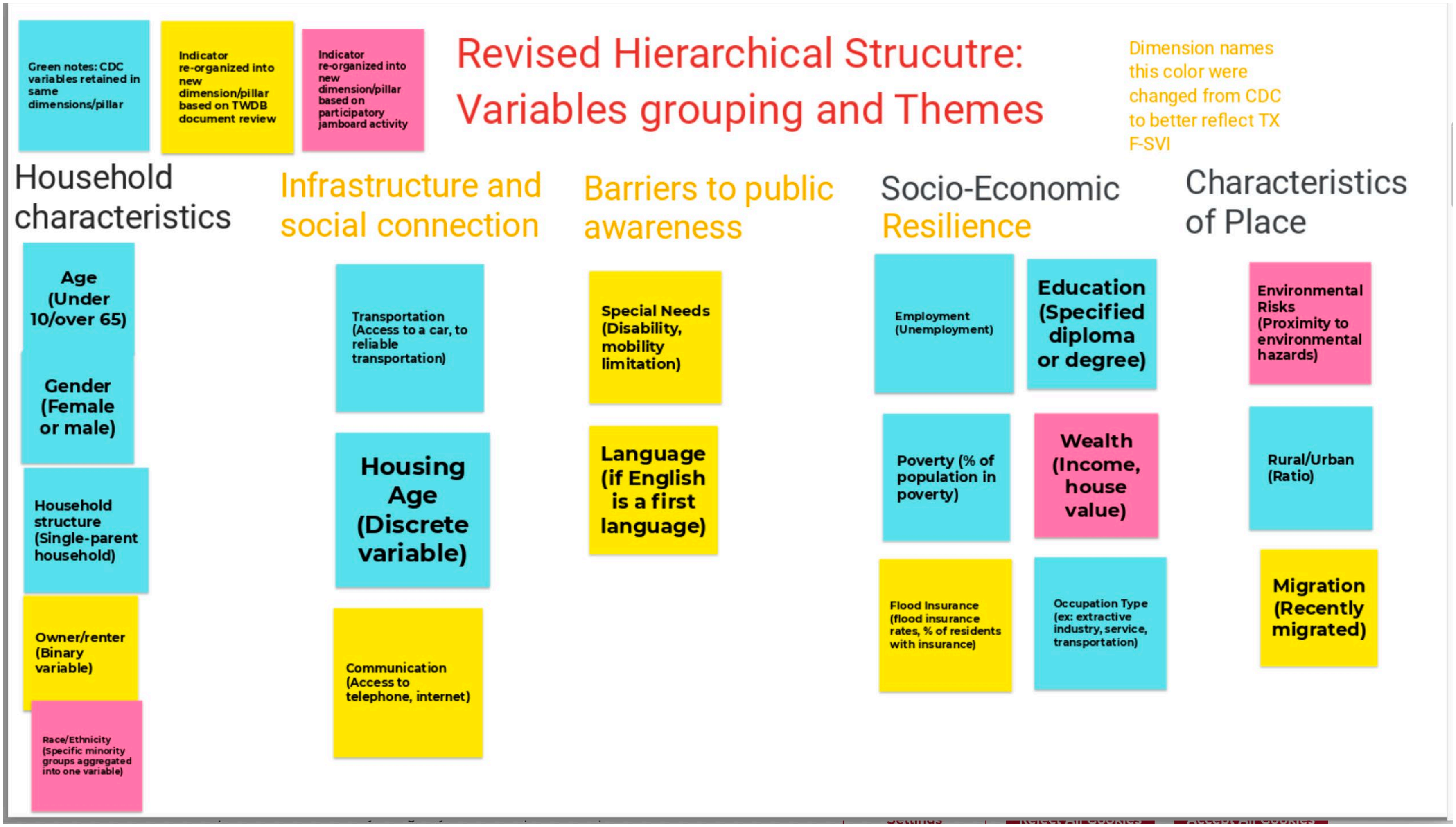
Thank you very much for your perspective and your time.

Appendix C: Anonymized Interviewee List

Table C-1. Anonymized list of interviewees by title, organization, and region.

Title	Organization	Region
Executive leadership	TGCRVOAD, SHUR	Houston
Executive leadership	West Street Recovery	Houston
Executive leadership	SETx Flood Control District	Region 5
Staff lead	Go Austin Vamos Austin	Austin
Executive leadership at Upper Brushy Creek WCID	Upper Brushy Creek WCID	Region 8
Science staff	Bayou City Waterkeeper	Houston
Executive leadership	Tarrant Regional Water District	Fort Worth
Professor	Texas State University	Central Texas
Community Engagement staff	Austin Department of Homeland Security and Emergency Management	Austin
Executive leadership	Museum of South Texas	RGV
Executive leadership	Dallas Water Utilities	Dallas
Executive leadership	Environmental Defense Fund	Statewide
Lecturer	Texas State University	San Marcos
Executive leadership	Port Arthur Community Action Network	Gulf Coast
Professor	UNT	North Texas

Appendix D: Jamboard Activity



Appendix E: Indicator codes and data sources

- Missing values are set to “NaN” and excluded from index construction.
- Datasets
    - All census data
        - ACS 5 year 2022
    - Rural Urban
        - DECENNIALDHC2020.H2-Data
- Missing values in the input datasets are not computed.

Table E-1. Descriptive information about each F-SVI variable.

Variable	Sub-variables	Variable Set	Code
Age	Under 10/over 65+	Over 65	S0101_C01_030E
		Under 5	S0101_C01_002E
		5 to 9	S0101_C01_003E
Minority	Specific minority groups aggregated into one variable	Hispanic or Latino	DP05_0073E
		Black or African American	DP05_0080E
		American Indian and Alaska Native	DP05_0081E
		Asian	DP05_0082E
		Native Hawaiian and Other Pacific	DP05_0083E
Income	Income	Occupied housing units!!Estimate!!HOUSEHOLD INCOME IN THE PAST 12 MONTHS (IN 2022 INFLATION-ADJUSTED DOLLARS)!!Median household income (dollars)	S2503_C01_013E
Housing value	House value	House value Median	B25077_001E
Language	If English is a first language	Speak only English	C16001_002E
Housing age	Age of building	Median year structure built	B25035_001E
Renters	House ownership	Total:!! Renter occupied	B25003_003E
Disabilities	Disability, mobility limitation	Total Civilian Noninstitutionalized Population!!With a disability	DP02_0072E
No vehicle	Access to a car	Occupied housing units!!No vehicles available	DP04_0058E
Telecommunication	Access to telephone, internet	Broadband	B28003_003E
		Dial-up	B28003_004E
		Phone Owner	B25043_003E
		Phone Renter	B25043_012E
Environmental risk factors	x/ Proximity of environmental hazards	Particulate Matter 2.5	PM25
		Ozone	OZONE
		Diesel particulate matter	DSLPM
		Air toxics cancer risk	CANCER
		Air toxics respiratory HI	RESP
		Toxic Releases to Air	RSEI_AIR

		Traffic proximity	PTRAF
		Housing units built before 1960	PRE1960
		Lead Paint	PRE1960PCT
		Superfund proximity	PNPL
		RMP facility proximity	PRMP
		Hazardous waste proximity	PTSDF
		Underground storage tanks	UST
		Wastewater discharge	PWDIS
Migration	Recently migrated	Moved; from abroad!!Population 1 year and over	S0701_C05_001E
		Moved; within same county!!Population 1 year and over	S0701_C02_001E
		Moved; from different county, same state!!Population 1 year and over	S0701_C03_001E
		Moved; from different state!!Population 1 year and over	S0701_C04_001E
Sector employment	Type of occupation (extractive industries, service sector, transportation)	Food service	S2401_C01_023E
		Building service	S2401_C01_024E
		Transportation occupation	S2401_C01_035E
		Mining, quarrying, and oil and gas extraction	S2403_C01_004E
Rural urban	Spatial Typology	Number of rural housing units	H2_003N
Poverty	Percentage of population in poverty, deep poverty	ALL INDIVIDUALS WITH INCOME BELOW THE FOLLOWING POVERTY RATIOS!!150 percent of poverty level	S1701_C01_040E
Unemployment	Unemployment	Population 16 years and over!!In labor force!!Civilian labor force!!Unemployed	DP03_0005E
Single parent	Female head of house, single-parent household	Female single households	B11012_010E
		Male single households	B11012_015E
Mobile Homes	!Total housing units!!Mobile home	!Total housing units!!Mobile home	DP04_0014E

Appendix F: Denominator variables

Table F-1. Descriptive information for denominator variables.

Variable	Name	Variable Set	Code
Total Population	TOTPOP	Estimate!!Total!!Total population	S0601_C01_001E
Total Housing Units	TOALHU	Estimate!!HOUSING OCCUPANCY!!Total housing units	DP04_0001E
Total Households	TOTHH	Estimate!!HOUSEHOLDS BY TYPE!!Total households	DP02_0001E
Population above 25	POP25	AGE!!25 to 29 years	S0101_C01_007E
		AGE!!30 to 34 years	S0101_C01_008E
		AGE!!35 to 39 years	S0101_C01_009E
		AGE!!40 to 44 years	S0101_C01_010E
		AGE!!45 to 49 years	S0101_C01_011E
		AGE!!50 to 54 years	S0101_C01_012E
		AGE!!55 to 59 years	S0101_C01_013E
		AGE!!60 to 64 years	S0101_C01_014E
		AGE!!65 to 69 years	S0101_C01_015E
		AGE!!70 to 74 years	S0101_C01_016E
		AGE!!75 to 79 years	S0101_C01_017E
		AGE!!80 to 84 years	S0101_C01_018E
		AGE!!85 years and over	S0101_C01_019E
Employable Population	TOTEMP	Estimate!!Total:	B23022_001E

Appendix G: Denomination and calculation of indicators

Table G-1. Description of calculations for F-SVI variables.

Variable	Unit	Transformation	Direction Correction
Age	# of people	(AGE / Total Population)* 100	no
Minority	# of people	(MRTY / Total Population)* 100	no
Income	Median $	No	Yes
Housing value	$ Dollar	No	Yes
Language	# of people	(LANG / Total Population)* 100	Yes
Housing age	# years	No	No
Renter	# housing units	(HOOW / Total Housing Units)* 100	
Disability	# of people	(DISB / Total Population)* 100	No
No vehicle	# housing units	(NOVE / Total Housing Units) * 100	No
Telecommunication	# housing unit	(COMC / 2 * Total Housing Units) * 100	Yes
Environmental risk factors	PM25	No	No
	OZONE	No	No
	DSLPM	No	No
	CANCER	No	No
	RESP	No	No
	RSEI_AIR	No	No
	PTRAF	No	No
	PRE1960	No	No
	PRE1960PCT	No	No
	PNPL	No	No
	PRMP	No	No
	PTSDF	No	No
	UST	No	No
	PWDIS	No	No
Migration	# people	(MIGR / Workforce) * 100	No
Sectoral employment	# people	(OCTY / Total Population) * 100	No
Urban rural	# housing units	(URRU / Total Urban Rural) * 100	No
Poverty	# people	(POVE / Total Population) * 100	No
Unemployment	Percentage	(UNEMP/ Workforce) * 100	No
Single parent	# households	(SINP / Total Households) * 100	No
Mobile homes	#housing units	(MOHO/ Total Housing Units) * 100	No

Appendix H: Highest and lowest deciles with dimension and indicator scores

Table H-1. Census tracts with five highest and lowest total F-SVI score deciles, presented by Dimension.

GEOID	TX F-SVI	SVI Class	Socio-Economic	Place & Status	Socio-Cultural	Rurality	Infra-structure	Socio-Demo graphic
48027020701	1.0000	High	0.7339	0.9701	0.9708	0.5276	0.8755	0.9403
48309001402	0.9999	High	0.5744	0.8586	0.9891	0.6935	0.8889	0.9504
48355001704	0.9997	High	0.8581	0.7043	0.8292	0.6153	0.9447	0.9924
48201233600	0.9996	High	0.7860	0.8616	0.9308	0.4565	0.9375	0.9472
48029150800	0.9994	High	0.6211	0.9273	0.9197	0.5877	0.8650	0.9908
48167720507	0.0009	Low	0.1404	0.0327	0.2237	0.2013	0.2951	0.1222
48397040203	0.0007	Low	0.2485	0.1811	0.2490	0.2013	0.1001	0.0222
48121021417	0.0006	Low	0.2160	0.0832	0.0019	0.2013	0.2485	0.1712
48085031332	0.0004	Low	0.1398	0.3727	0.0174	0.2013	0.0435	0.1054
48085030541	0.0003	Low	0.1651	0.1319	0.1934	0.2013	0.0817	0.0655

Table H-2. Census tracts with five highest and lowest deciles for Socio-Economic dimension.

			Dimension Percentile Rank	Socio-Economic Indicator Scores				
GEOID	TX F-SVI	SVI Class	Socio-Economic	Income	Poverty	Unemploy-ment	Housing Value	Sector Employ-ment
48027020701	1.0000	High	0.7339	0.0054	0.9635	0.7123	0.3141	0.7805
48309001402	0.9999	High	0.5744	0.0050	0.9933	0.6720	0.1946	0.7103
48355001704	0.9997	High	0.8581	0.1358	0.8824	0.8853	0.1417	0.9162
48201233600	0.9996	High	0.7860	0.0589	0.9851	0.9723	0.0862	0.7456
48029150800	0.9994	High	0.6211	0.0072	0.9949	0.5824	0.7694	0.2777
48167720507	0.0009	Low	0.1404	0.8609	0.0925	0.1857	0.7857	0.0652
48397040203	0.0007	Low	0.2485	0.9507	0.0023	0.1953	0.9630	0.0737
48121021417	0.0006	Low	0.2160	0.9161	0.1716	0.0205	0.8336	0.1975
48085031332	0.0004	Low	0.1398	0.8345	0.2793	0.0205	0.7203	0.1347
48085030541	0.0003	Low	0.1651	0.9594	0.0619	0.0205	0.8967	0.0989

Table H-3. Census tracts with five highest and lowest deciles for Place and Status dimension.

			Dimension Percentile Rank	Place and Status Indicator Scores		
GEOID	TX F-SVI	SVI Class	Place & Status	Environmental Risk Factors	Renters	Migration
48027020701	1.0000	High	0.9701	0.7570	0.9546	0.9809
48309001402	0.9999	High	0.8586	0.5576	0.9173	0.7946
48355001704	0.9997	High	0.7043	0.4617	0.7665	0.6627
48201233600	0.9996	High	0.8616	0.9932	0.5704	0.7140
48029150800	0.9994	High	0.9273	0.6872	0.9379	0.8711
48167720507	0.0009	Low	0.0327	0.3183	0.0179	0.1014
48397040203	0.0007	Low	0.1811	0.2557	0.0284	0.5756
48121021417	0.0006	Low	0.0832	0.3089	0.0594	0.2500
48085031332	0.0004	Low	0.3727	0.5074	0.1181	0.5990
48085030541	0.0003	Low	0.1319	0.4218	0.2720	0.0536

Table H-4. Census tracts with five highest and lowest deciles for Socio-Cultural dimension

			Dimension Percentile Rank	Socio-cultural Indicator Scores	
GEOID	TX F-SVI	SVI Class	Socio-Cultural	Language	Minority
48027020701	1.0000	High	0.9708	0.7585	0.5973
48309001402	0.9999	High	0.9891	0.8222	0.7459
48355001704	0.9997	High	0.8292	0.2256	0.8866
48201233600	0.9996	High	0.9308	0.3193	0.9127
48029150800	0.9994	High	0.9197	0.3574	0.8511
48167720507	0.0009	Low	0.2237	0.6764	0.2215
48397040203	0.0007	Low	0.2490	0.7605	0.1462
48121021417	0.0006	Low	0.0019	0.4742	0.1162
48085031332	0.0004	Low	0.0174	0.2503	0.4723
48085030541	0.0003	Low	0.1934	0.5228	0.3624

Table H-5. Census tracts with five highest and lowest deciles for Rurality dimension

			Dimension Percentile Rank	Rurality Indicator Scores	
GEOID	TX F-SVI	SVI Class	Rurality	Rural-Urban	Mobile Home
48027020701	1.0000	High	0.5276	0.3194	0.5821
48309001402	0.9999	High	0.6935	0.6874	0.5849
48355001704	0.9997	High	0.6153	0.3194	0.7020
48201233600	0.9996	High	0.4565	0.3194	0.5078

48029150800	0.9994	High	0.5877	0.3194	0.6540
48167720507	0.0009	Low	0.2013	0.3194	0.2202
48397040203	0.0007	Low	0.2013	0.3194	0.2202
48121021417	0.0006	Low	0.2013	0.3194	0.2202
48085031332	0.0004	Low	0.2013	0.3194	0.2202
48085030541	0.0003	Low	0.2013	0.3194	0.2202

Table H-6. Census tracts with five highest and lowest deciles for Infrastructure dimension

			Dimension Percentile Rank	Infrastructure Indicator Scores		
GEOID	**TX F-SVI**	**SVI Class**	**Infrastructure**	**Housing Age**	**Telecommunication**	**No Vehicle**
48027020701	1.0000	High	0.8755	0.8273	0.1677	0.9990
48309001402	0.9999	High	0.8889	0.6062	0.4252	0.9867
48355001704	0.9997	High	0.9447	0.8884	0.3192	0.9349
48201233600	0.9996	High	0.9375	0.9758	0.2822	0.8636
48029150800	0.9994	High	0.8650	0.5867	0.3927	0.9953
48167720507	0.0009	Low	0.2951	0.0974	0.8904	0.2551
48397040203	0.0007	Low	0.1001	0.0066	0.8576	0.0684
48121021417	0.0006	Low	0.2485	0.1409	0.9691	0.0684
48085031332	0.0004	Low	0.0435	0.1193	0.5708	0.0684
48085030541	0.0003	Low	0.0817	0.0258	0.6534	0.2037

Table H-7. Census tracts with five highest and lowest deciles for Socio-Demographic dimension

			Dimension Percentile Rank	Socio-demographic Indicator Scores		
GEOID	**TX F-SVI**	**SVI Class**	**Socio-Demographic**	**Age**	**Disabilities**	**Single Parent**
48027020701	1.0000	High	0.9403	0.7516	0.9981	0.6086
48309001402	0.9999	High	0.9504	0.6754	0.7300	0.9985
48355001704	0.9997	High	0.9924	0.9437	0.8173	0.9697
48201233600	0.9996	High	0.9472	0.7574	0.8930	0.7379
48029150800	0.9994	High	0.9908	0.9313	0.7626	0.9993
48167720507	0.0009	Low	0.1222	0.4943	0.1877	0.1120
48397040203	0.0007	Low	0.0222	0.1900	0.0832	0.0323
48121021417	0.0006	Low	0.1712	0.5914	0.0480	0.2851
48085031332	0.0004	Low	0.1054	0.1522	0.0755	0.5116
48085030541	0.0003	Low	0.0655	0.2570	0.0670	0.2624

Appendix I: Variable Fact Sheets

Appended PDF file that will not include page numbers.

Dimension 1: Socio-economic

Indicator: Income

Included in TX F-SVI ☑

Dimension: Socio-Economic

Data Source: ACS 5-year 2022

Denomination: Median USD

Spatial Resolution: Census Tract

Definition

Household income is an indicator of a household's net worth, and is an important determining factor of economic well-being. Individuals who have lower household incomes are less able to prepare for, respond to, and rebuild from extreme events such as floods.

Inclusion Justification

Low-income neighborhoods experience disproportionate exposure to environmental hazards, including flooding. Income was a recurrent theme in the literature (70%) and referenced in 87% of interviews as well as mentioned in public comments.

Household income is included in validated indices such as the Social Vulnerability Index (SoVI), CDC-Social Vulnerability Index (CDC-SVI) and the National Risk Index (NRI), as well as equity-focused environmental tools such as EJSCREEN and CEJST.

Literature Review

- [x] 60% or more
- [ ] 25% - 60%
- [ ] Below 25%

Interviews

- [x] 60% or more
- [ ] 25% - 60%
- [ ] Below 25%

References and Literature

- Bixler et al., 2021
- Chakraborty et a., 2014
- Chakraborty et al., 2021
- Cutter et al., 2013
- Darlington et al., 2022
- Donner & Laveriega-Montforti, 2018
- Harlan et al., 2018
- Jourdain, 2019
- Khajehei et al., 2020
- Lieberman-Cribbin et al., 2021
- Lim & Skidmore, 2019
- Lotfata & Ambinakudige, 2016
- Mazumder, Landry, & Alsharif, 2022
- NASEM, 2019
- Oulahen et al., 2015
- Rickless et al., 2023
- Sanders et al., 2023
- Shao et al., 2020
- Tate et al., 2021
- Tellman et al., 2020
- Wang & Sebastian, 2021
- Waweru, 2022

Indicator: Poverty

Dimension 1: Socio-economic

Included in TX F-SVI ☑

Dimension: Socio-Economic

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Poverty is defined as lacking the resources that are sufficient to meet basic needs. Basic needs include food, clothing, shelter, utilities, and telecommunication access. The poverty threshold varies by household size, state, area of residence, and whether someone is a renter or homeowner, and the official poverty threshold for the United States is an annual income of $31,200 for a household with two adults and two children.

Inclusion Justification

Extreme weather events and environmental hazards, including flooding, have a disproportionate negative impact on individuals who are lower-income. Poverty was referenced in 64% of the literature, though only emerged in one interview (7%)

Poverty is incorporated into validated indices such as the Social Vulnerability Index (SoVI), CDC-Social Vulnerability Index (CDC-SVI), and the National Risk Index (NRI), as well as environmental hazard exposure tools such as EJSCREEN and CEJST.

Literature Review

- [x] 60% or more
- [ ] 25% - 60%
- [ ] Below 25%

Interviews

- [ ] 60% or more
- [ ] 25% - 60%
- [x] Below 25%

References and Literature

- Bixler et al., 2021
- Chakraborty et al., 2014
- Chakraborty et al., 2021
- Cutter et al., 2013
- Harlan et al., 2019
- Jourdain, 2019
- Khajehei et al., 2020
- Lotfata & Ambinakudige, 2019
- Mazumder et al., 2022
- Oulahen et al., 215
- Qiang, 2019
- Reckien, 2018
- Rickless et al., 2023
- Sanders et al., 2023
- Shao et al., 2020
- Tate et al., 2016
- Tellman et al., 2020
- Van Zandt et al., 2012
- Waweru, 2022
- Wilhelmi & Morss, 2013
- Zahran et al., 2008

Dimension 1: Socio-economic

Indicator: Unemployment

Included in TX F-SVI ☑

Dimension: Socio-Economic

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Unemployment is defined as an individual who is able and available to work but does not have a job. Unemployment includes individuals who are note currently working and seeking a job. Individuals considered able to work are those 16 or older. Unemployment is calculated by dividing the number of unemployed individuals by the total workforce.

Inclusion Justification

Unemployment is a component of socioeconomic status, and individuals who have lower socioeconomic status experience disproportionate exposure to environmental hazards. Employment was identified in 33% of the literature as a significant indicator of social vulnerability.

While only being discussed in 13% of the interviews, employment is a component of validated indices such as the Social Vulnerability Index (SoVI), CDC-Social Vulnerability Index (CDC-SVI), and the National Risk Index (NRI), as well as screening indicators for environmental exposure tools such as EJSCREEN and CEJST.

Literature Review

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Interviews

- ☐ 60% or more
- ☐ 25% - 60%
- ☑ Below 25%

References and Literature

- Bixler et al., 2021
- Khajehei et al., 2020
- Lotfata & Ambinakudige, 2019
- Oulahen et al., 2015
- Rickless et al., 2023
- Sanders et al., 2023
- Tate et al., 2016
- Tellman et al., 2020
- U.S. Census Bureau, 2015
- Van Zandt et al., 2012
- Waweru, 2022

Indicator: Housing value

Dimension 1: Socio-economic

Included in TX F-SVI ☑

Dimension: Socio-Economic

Data Source: ACS 5-year 2022

Denomination: Median USD

Spatial Resolution: Census Tract

Definition

Housing value contributes to a household's net worth, and can be an indicator of economic well-being. Higher housing values can be an indicator of socio-economic status and having financial resources to respond to hazards.

Inclusion Justification

Low-income neighborhoods experience disproportionate exposure to environmental hazards, including flooding, and homes with lower values may be less structurally sound as well as an indicator of lower socio-economic status. Wealth, including income and housing value, was a recurrent theme in the literature (70%) and referenced in 87% of interviews as well as mentioned in public comments.

Wealth-based metrics are also included in validated indices such as the Social Vulnerability Index (SoVI), CDC-Social Vulnerability Index (CDC-SVI) and the National Risk Index (NRI).

Literature Review

- [x] 60% or more
- [ ] 25% - 60%
- [ ] Below 25%

Interviews

- [x] 60% or more
- [ ] 25% - 60%
- [ ] Below 25%

References and Literature

- Bixler et al., 2021
- Chakraborty et a., 2014
- Chakraborty et al., 2021
- Cutter et al., 2013
- Darlington et al., 2022
- Donner & Laveriega-Montforti, 2018
- Harlan et al., 2018
- Jourdain, 2019
- Khajehei et al., 2020
- Lieberman-Cribbin et al., 2021
- Lim & Skidmore, 2019
- Lotfata & Ambinakudige, 2016
- Mazumder, Landry, & Alsharif, 2022
- NASEM, 2019
- Oulahen et al., 2015
- Rickless et al., 2023
- Sanders et al., 2023
- Shao et al., 2020
- Tate et al., 2021
- Tellman et al., 2020
- Wang & Sebastian, 2021
- Waweru, 2022

Indicator: Employment type

Dimension 1: Socio-economic

Included in TX F-SVI ☑

Dimension: Socio-Economic

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Occupation type is defined by the industry in which a person is employed. Measures of social vulnerability consider those employed in extractive industries (mining, quarrying, and oil and natural gas extraction), the service sector (food or building service), or transportation.

Inclusion Justification

Occupation can be an indicator of socioeconomic status and individuals who are categorized as lower socioeconomic status experience disproportionate exposure to environmental hazards.

While the type of occupation was not identified in the interviews, it was discussed in 27% of the literature.

Literature Review

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Interviews

- ☐ 60% or more
- ☐ 25% - 60%
- ☑ Below 25%

References and Literature

- Chakraborty et al., 2014
- Khajehei et al., 2020
- MacDonald et al., 2009
- Shao et al., 2020
- Tellman et al.,2020
- Wanyun et al., 2020

Dimension 2: Place & Status

Indicator: Env Risk Factors

Included in TX F-SVI ✓

Dimension: Place and Status

Data Source: EPA EJ Screen

Denomination: Proximity

Spatial Resolution: Census Tract

Definition

Environmental risk factors refer to the external physical, chemical, biological and work-related factors that affect a person's health. They are key drivers of non-communicable diseases (NCDs) such as cardiovascular diseases, cancers, diabetes and chronic lung diseases. The connection between environmental risk factors and health outcomes is well established.

Inclusion Justification

Environmental risk factors were primarily referenced during interviews (27%) and was mentioned in public comments underscoring its importance within the context of flooding in Texas.

The environmental risk factors indicator uses a combination of multiple risk factors such as: particulate matter 2.5, ozone, diesel particulate matter, air toxics cancer risk, air toxics respiratory risk, toxic releases to air, traffic proximity, lead exposure (via housing units built before 1960). Environmental justice also incorporates proximity to RMP facilities, superfund sites, hazardous waste, underground storage tanks, and wastewater discharge.

Literature Review

- [ ] 60% or more
- [ ] 25% - 60%
- [x] Below 25%

Interviews

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

References and Literature

- Cutter, 1995
- Konisky, Reenock, & Conley, 2021
- Maantay, Chakraborty, & Bender, 2010
- Mohai, Pellow, & Roberts, 2009
- Mohai & Saha, 2015

Indicator: Renter

Dimension 2: Place & Status

Included in TX F-SVI ☑

Dimension: Place and Status

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Whether a household owns or rents a unit, referred to as housing tenure, captures the intersection of both social (household) and physical (housing unit) aspects of vulnerability. The Texas Department of Housing and Community Affairs distinguishes between renters (households that occupy a housing unit they do not own rented for cash or occupied without cash or rent payments) and owners.

Inclusion Justification

Renters have a wider range of housing problems than owners, and these difficulties have a greater impact, even outside of flooding hazards. Being a renter versus a homeowner was emphasized in the literature review (48%) and noted as flood specific in the interviews (27%).

Additionally, its inclusion in other social vulnerability indices such as the Social Vulnerability Index (SoVI) support its importance in understanding social vulnerability.

Literature Review

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

Interviews

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

References and Literature

- Cutter et al., 2013
- Harlan et al., 2019
- Hung, Wang, & Yarnal, 2016
- Khajehei et al., 2020
- Mazumder, Landry, & Alsharif, 2022
- NASEM, 2019
- Oulahen eta l., 2015
- Pricope, Halls, & Rosul, 2019
- Sanders et al., 2023
- Shao et al., 2020
- Tate et al., 2016
- Tate et al., 2021
- Tellman et al., 2020
- Van Zandt et al., 2012
- Wang & Sebastian, 2021
- Zachos et al., 2016

Indicator: Migration

Dimension 2: Place & Status

Included in TX F-SVI ☑

Dimension: Place and Status

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Migration is defined as those in the population who have recently moved into Texas, and includes both domestic migrants who move across or within U.S. state boundaries as well as and international migrants who move from abroad.

Inclusion Justification

New residents who migrate from another county, state, or country are less familiar with the hazard risks in the location to which they move.

Migration was only found in 6% of the literature, but it was referenced in 33% of the interviews and described as flood specific. The demographic and socio-economic dynamics of Texas necessitate considering migration patterns as a factor influencing social vulnerability to flooding in the region.

Literature Review

- ☐ 60% or more
- ☐ 25% - 60%
- ☑ Below 25%

Interviews

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

References and Literature

- Cutter et al., 2013
- Darlington, Yiannakoulias, & Elshorbagy, 2022

Indicator: Language

Dimension 3: Socio-cultural

Definition

Language refers to the system of shared symbols including speech, writing, numerals, and non-verbal gestures and expressions. Language is connected to literacy, the ability to listen, speak, read and write. There are over 160 languages spoken in Texas.

☑ **Included in TX F-SVI**

Dimension: Socio-Cultural

Data Source: ACS 5-year 2022

Denomination: Percentage of population

Spatial Resolution: Census Tract

Literature Review

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Interviews

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Inclusion Justification

Language can be a barrier during all phases of flooding hazard, from adequate preparation to emergency response. Warning messages are often issued in the dominant language with an expectation that people will take recommended action immediately. In Texas specifically, 35% of residents speak a language other than English at home.

Language appeared in 36% of the literature and was referenced in 47% of interviews, indicating its considerable relevance based on direct stakeholders' input. Language was also mentioned in public comments, underscoring its importance as an indicator for assessing vulnerability in Texas. Beyond direct language barriers, research indicates that linguistic culture influences how people receive and interpret messages.

References and Literature

- Bixler et al., 2021
- Carter-Pokras et al., 2007
- Jourdain, 2019
- Lotfata & Ambinakudige, 2019
- Oulahen et al., 2015
- Qiang, 2019
- Rickless et al., 2023
- Sanders et al., 2023
- Tate et al., 2016
- Tate et al., 2021
- Tellman et al., 2020
- U.S. Census Bureau, 2021
- Van Zandt et al., 2012
- Wilhelmi & Morss, 2013

Indicator: Minority

Dimension 3: Socio-cultural

Definition

Race and ethnicity is defined by an individual's self-identification with one or more social groups based on a social definition of race in the U.S. Race and ethnicity as a vulnerability indicator aggregates those who identify as Hispanic or Latino, Black or African American, American Indian and Alaska Native, Asian, or Native Hawaiian and other Pacific Islander into one variable,

☑ **Included in TX F-SVI**

Dimension: Socio-Cultural

Data Source: ACS 5-year 2022

Denomination: Percentage of population

Spatial Resolution: Census Tract

Literature Review

- ☑ 60% or more
- ☐ 25% - 60%
- ☐ Below 25%

Interviews

- ☑ 60% or more
- ☐ 25% - 60%
- ☐ Below 25%

Inclusion Justification

Research indicates that culture influences how people may receive and interpret warning messages, influencing how they may prepare or respond to flooding. Race and Ethnicity is included in the model because it was identified as an important indicator in 80% of the interviews and 76%% of the articles selected for the literature review.

Race/Ethnicity is also included in validated and established indices such as the Social Vulnerability Index (SoVI), CDC-Social Vulnerability Index, and the National Risk Index, as well as incorporated into environmental equity metrics in government tools such as EJSCREEN and CEJST.

References and Literature

- Bixler et al., 2021
- Chakraborty et al., 2014
- Chakraborty et al., 2021
- Cutter et al., 2013
- Darlington et al., 2022
- Donner & Lavariega-Montforti, 2018
- Harlan et al., 2019
- Hung, Wang, & Yarnal, 2016
- Jourdain, 2019
- Khajehei et al., 2020
- Lotfata & Ambinakudige, 2019
- Maldonado, Collins, & Grineski, 2016
- Mazumder, Landry, & Alsharif, 2022
- NASEM, 2019
- Oulahen et al., 2015
- Pricope, Halls, & Rosul, 2019
- Reckien, 2018
- Shao et al., 2020
- Tate et al., 2016
- Tate et al., 2021
- Tellman et al., 2020
- Van Zandt et al., 2012
- Waweru, 2022
- Zachos et al., 2016
- Zahran et al., 2008

Indicator: Rural and Urban

Included in TX F-SVI ☑

Dimension: Rurality

Data Source: Decennial

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Rural is defined as a county that is nonadjacent to a metropolitan area with a population of less than 20,000, or a county with a population less than 2,500 and adjacent to a metropolitan area.

Inclusion Justification

Texas has the largest rural population in the country, with approximately 4.8 million of its 30 million residents living outside of an urban area (U.S. Census Bureau, 2020), and 96% of the land in Texas is considered rural. While urbanization can contribute to increased flooding, rural communities can face challenges such as linguistic isolation, less economic opportunities, and lack of early warning systems.

Rural versus urban settings was mentioned in 27% of the interviews, and appeared in 9% of the literature reviewed. However, the variable is included because of its relevance to Texas.

Literature Review

- [ ] 60% or more
- [ ] 25% - 60%
- [x] Below 25%

Interviews

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

References and Literature

- Carruthers and Vias 2005
- Cutter et al., 2013
- Lim & Skidmore, 2019
- Tellman et al., 2020
- Texas Rural Health & Economic Development Advisory Council, 2018
- U.S. Census Bureau, 2020

Indicator: Mobile Home

Included in TX F-SVI ✓

Dimension: Rurality

Data Source: Decennial

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Housing type is defined by the housing unit in which a person lives, referring to a house, apartment, group of rooms, or a single room intended for occupancy as living quarters. Housing type as a social vulnerability indicator is defined by whether a household lives in a mobile, multi-family, or single family home.

Mobile homes are defined as a movable dwelling 8 feet or more wide and 40 feet or more long that are built following the U.S. Department of Housing and Urban Development building codes.

Inclusion Justification

Past work has found that mobile homes were disproportionately located inside the floodplain of central Texas, and residents in mobile homes can face additional vulnerabilities such as poverty or lower quality infrastructure. Housing type was mentioned in 30% of the literature reviewed, though it was only mentioned in one interview (7%).

Literature Review

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

Interviews

- [ ] 60% or more
- [ ] 25% - 60%
- [x] Below 25%

References and Literature

- Chakraborty et al., 2021
- Darlington, Yiannakoulias, & Elshorbagy, 2022
- Jourdain, 2019
- Lee & Jung, 2014
- Lieberman-Cribbin et al., 2021
- Lim & Skidmore, 2019
- Lotfata & Ambinakudige, 2016
- Qualahen et al., 2015
- Rickless et al., 2023
- Rumbach, Sullivan, & Makerewicz, 2020
- TDHGA, n.d.
- Van Zandt et al., 2012
- Waweru, 2022

Indicator: Housing age

Included in TX F-SVI ☑

Dimension: Infrastructure

Data Source: ACS 5-year 2022

Denomination: Number of years

Spatial Resolution: Census Tract

Definition

Housing age is defined as the number of years since the housing unit was built.

Inclusion Justification

Housing age can be an indicator of the home's condition and potential for aging infrastructure, and older housing units built before1970 not meet current construction standards because of changes in building codes.

Housing age was mentioned in only 6% of the literature reviewed, however, it came up in 40% of the interviews, highlighting its relevance for the Texas and flood-specific context.

Literature Review

- ☐ 60% or more
- ☐ 25% - 60%
- ☑ Below 25%

Interviews

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

References and Literature

- Hebb & Mortsch, 2007
- Oulahen et al., 2015
- Van Zandt et al., 2012

Indicator: Access to phone/internet

Included in TX F-SVI ☑

Dimension: Infrastructure

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Communication is defined as having access to a telephone or internet. Internet access includes broadband or dial-up, and telephone access includes availability of phone service either through ownership or renting.

Inclusion Justification

The 2020 U.S. Census estimates that 16.9% of Texas households lack internet access, and of those with internet, 14.7% only have access via their mobile phone. Households that lack internet access are more likely to be located in flood-prone areas. Communication was mentioned in 27% of the interviews but only 6% of the literature, and it was highlighted in a subset of public comments. This suggests that although it may not have been extensively discussed in academic sources, it does have relevance for flooding in Texas.

Literature Review

- ☐ 60% or more
- ☐ 25% - 60%
- ☑ Below 25%

Interviews

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

References and Literature

- U.S. Census Bureau
- Van Zandt et al., 2012
- Waweru, 2022

Indicator: No Vehicle

Included in TX F-SVI ☑

Dimension: Infrastructure

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Transportation is defined broadly as having access to a vehicle or some other reliable form of transportation such as public transportation. However, the social vulnerability indicator context defines transportation as a household that has reliable access to a vehicle.

Inclusion Justification

Lack of transportation can hinder mobility and increase social vulnerability. Transportation was identified in nearly 40% of the literature and referenced in 27% of the interviews. The inclusion of transportation as a topic in public comments underscored its significance related to flooding.

Transportation access is also included in both the Social Vulnerability Index (SoVI) as well as the National Risk Index (NRI).

Literature Review

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Interviews

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

References and Literature

- Bixler et al., 2021
- Colten, 2006
- Jourdain, 2019
- Khajehei et al., 2020
- Lotfata & Ambinakudige, 2019
- NASEM, 2019
- Oulahen et al., 215
- Reckien, 2018
- Rickless et al., 2023
- Tate et al., 2016
- Tate et al., 2021
- Tellman et al., 2020
- Van Zandt et al., 2012
- Waweru, 2022

Indicator: Age

Definition

Vulnerable age groups include young children under the age of 10 or seniors over the age of 65. Three variables from the American Community Survey five-year estimates contribute to this indicator: over 65, under 5, and aged 5 to 9.

- [x] **Included in TX F-SVI**

Dimension: Socio-Demographic

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Literature Review

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

Interviews

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

Inclusion Justification

Young children and seniors may not be physically able to, or otherwise complicate, evacuation during a flood situation. Age is included in the model because it was identified in 76% of the articles selected for the literature review, and mentioned in nearly half (47%) of the interviews conducted by the team.

Age is also included in validated and well-established indices such as the Social Vulnerability Index (SoVI), CDC-Social Vulnerability Index (CDC-SVI), and the National Risk Index (NRI), as well as incorporated into environmental exposure screening tools such as EJSCREEN and CEJST.

References and Literature

- Ashley & Walker 2008
- Benevolenza & DeRigne, 2018
- Bixler et al., 2021
- Cutter et al., 2013
- Darlington et al., 2022
- Donner & Lavariega-Montforti, 2018
- Harlan et al., 2019
- Hung, Wang, & Yarnal, 2016
- Jourdain, 2019
- Khajehei et al., 2020
- Lieberman-Cribbin et al., 2021
- Lim & Skidmore, 2019
- Lotfata & Ambinakudige, 2019
- Mazumder, Landry, & Alsharif, 2022
- NASEM, 2019
- Oulahen et al., 2015
- Pricope, Halls, & Rosul, 2019
- Qiang, 2019
- Reckien, 2018
- Rickless et al., 2023
- Shao et al., 2020
- Tate et al., 2016
- Tate et al., 2021
- Tellman et al., 2020
- Van Zandt et al., 2012
- Wilhelmi & Morss, 2013

Indicator: Disabilities

Included in TX F-SVI ☑

Dimension: Socio-Demographic

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Definition

Disabilities is defined as whether an individual reports a disability in one of the following categories: hearing difficulty (deaf or serious difficulty hearing), vision difficulty (blind or having serious difficulty seeing even while wearing glasses), cognitive difficulty (having difficulty remembering, concentrating, or making decisions), ambulatory difficulty (serious difficulty walking or climbing stairs), self-care difficulty (having difficulty bathing or dressing), or independent living difficulty (difficulty doing errands alone). It also includes those with limited mobility.

Inclusion Justification

A case study of Houston identified that flooding was greater in neighborhoods with a higher proportion of disabled individuals.

Disabilities is included as an indicator because nearly 30% of both the interviews and the literature identified it as an important metric. The National Risk Index also incorporates special needs.

Literature Review

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Interviews

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

References and Literature

- Cutter et al., 2013
- Jourdain, 2019
- Khajehei et al., 2020
- Lotfata & Ambinakudige, 2019
- NASEM, 2019
- Pricope, Halls, & Rosul, 2019
- Rickless et al., 2023
- Tate et al., 2016
- Waweru, 2022
- Wilhelmi & Morss, 2013

Indicator: Single parent household

Included in TX F-SVI ☑

Dimension: Socio-Demographic

Data Source: ACS 5-year 2022

Denomination: Percentage of population

Spatial Resolution: Census Tract

Definition

A family household consists of two or more individuals, including those related by birth, marriage, or adoption. Household structure is defined as a single-parent household (either male or female) with no spouse or partner that have children under the age of 18.

Inclusion Justification

Single-parent households may have limited financial resources which can have a negative effect on their resilience to and recovery from flood events, particularly for female households. Household structure was featured prominently in the literature (52%) and was referenced in 20% of the interviews.

Household structure is also included in both the National Risk Index as well as the CDC-Social Vulnerability Index underscoring its significance in assessing social vulnerability, particularly in the context of Texas.

Literature Review

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Interviews

- ☐ 60% or more
- ☐ 25% - 60%
- ☑ Below 25%

References and Literature

- Bixler et al., 2021
- Hung, Wang, & Yarnal, 2016
- Jourdain, 2019
- Khajehei et al., 2020
- Lotfata & Ambinakudige, 2019
- Mazumder et al., 2022
- Oulahen et al., 2015
- Pricope, Halls, & Rosul, 2019
- Qiang, 2019
- Reckien, 2018
- Rickless et al., 2023
- Sanders et al., 2023
- Shao et al., 2020
- Tate et al., 2016
- Tate et al., 2021
- Tellman et al., 2020
- Van Zandt et al., 2012

Indicator: Flood Insurance

NOT INCLUDED IN FINAL F-SVI

Definition

Flood insurance is a type of property insurance that provides coverage for damage caused by flooding, and can include coverage for damage to buildings and personal property. Flood insurance variables can be defined by whether or not a housing unit has flood insurance in addition to the cost for coverage.

- [ ] **Included in TX F-SVI**

Dimension: Socio-Economic

Data Source: ACS 5-year 2022

Denomination: Percent of total population

Spatial Resolution: Census Tract

Literature Review

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

Interviews

- [ ] 60% or more
- [ ] 25% - 60%
- [x] Below 25%

Non-Inclusion Justification

While flood insurance was referenced in 33% of the interviews and reflected in the public comments, it was not selected as an indicator because the data was highly skewed, and a significant number of census tracts had a null value, making it a problematic variable for the model.

References and Literature

- Flood insurance was not identified in the literature review.

Indicator: Education

NOT INCLUDED IN FINAL F-SVI

Definition

Educational attainment is defined as the highest level of education an individual has completed, such as a high school diploma, GED, associates degree, vocational degree, bachelor's degree, or advanced degree (which includes postgraduate degrees such as a master's degree or a doctorate).

- [ ] Included in TX F-SVI

Dimension: Socio-Demographic

Data Source: ACS 5-year 2022

Denomination: Percentage of population

Spatial Resolution: Census Tract

Literature Review

- [ ] 60% or more
- [x] 25% - 60%
- [ ] Below 25%

Interviews

- [ ] 60% or more
- [ ] 25% - 60%
- [x] Below 25%

Non-Inclusion Justification

While education was identified in 61% percent of the literature and was referenced in two interviews (13%) it is not included as an indicator because of statistical inconsistencies in the correlation structure.

References and Literature

- Bixler et al., 2021
- Darlington, Yiannakoulias, & Elshorbagy, 2022
- Donner & Lavariega-Montforti, 2018
- Harlan et al., 2019
- Jourdain, 2019
- Liebermann-Cribbin et al., 2021
- Lim & Skidmore, 2019
- Lotfata & Ambinakudige, 2019
- Mazumder, Landry, & Alsharif, 2022
- NASEM, 2019
- Oulahen et al., 2015
- Qiang, 2019
- Rickless et al., 2023
- Sanders et al., 2023
- Shao et al., 2020
- Tate et al., 2016
- Tate et al., 2021
- Tellman et al., 2020
- Van Zandt et al., 2012
- Waweru, 2022

Indicator: Gender

NOT INCLUDED IN FINAL F-SVI

Definition

Gender and sex are two separate concepts. Sex considers the biological attributes of men and women, while gender is a social construction based on culture and societal context. Gender may not correspond to sex, and refers to the socially constructed norms, behaviors, and roles. The data collected via the U.S. Census uses biological sex and identifies individuals as biologically female or male.

☒ **Included in TX F-SVI**

Dimension: Socio-Demographic

Data Source: ACS 5-year 2022

Denomination: Percentage of population

Spatial Resolution: Census Tract

Literature Review

- ☐ 60% or more
- ☑ 25% - 60%
- ☐ Below 25%

Interviews

- ☐ 60% or more
- ☐ 25% - 60%
- ☑ Below 25%

Non-Inclusion Justification

While gender was identified in 48% percent of the literature and was referenced in one interview (7%) it is not included as an indicator because of statistical inconsistencies in the correlation structure.

References and Literature

- Ashley & Walker 2008
- Bixler et al., 2021
- Cutter et al., 2013
- Donner & Lavariega-Montforti, 2018
- Harlan et al., 2019
- Hung, Wang, & Yarnal, 2016
- Khajehei et al., 2020
- Lieberman-Cribbin et al., 2021
- NASEM, 2019
- Oulahen et al., 2015
- Pricope, Halls, & Rosul, 2019
- Qiang, 2019
- Reckien, 2018
- Shao et al., 2020
- Tate et al., 2021
- Tellman et al., 2020

References & Reviewed Literature

- **Ashley, S. T., & Ashley, W. S. (2008). Flood fatalities in the United States. Journal of applied meteorology and climatology, 47(3), 805-818.
- Benevolenza, M. A., & DeRigne, L. (2019). The impact of climate change and natural disasters on vulnerable populations: A systematic review of literature. Journal of Human Behavior in the Social Environment, 29(2), 266-281.
- **Bixler, R. P., Paul, S., Jones, J., Preisser, M., & Passalacqua, P. (2021). Unpacking adaptive capacity to flooding in urban environments: Social capital, social vulnerability, and risk perception. Frontiers in Water, 3, 728730.
- Carter-Pokras, O. D., Offutt-Powell, T. N., Kaufman, J. S., Giles, W. H., & Mays, V. M. (2012). Epidemiology, policy, and racial/ethnic minority health disparities. Annals of epidemiology, 22(6), 446-455.
- Carruthers, J. I., & Vias, A. C. (2005). Urban, suburban, and exurban sprawl in the Rocky Mountain West: Evidence from regional adjustment models. Journal of regional science, 45(1), 21-48.
- **Chakraborty, J., Collins, T. W., Montgomery, M. C., & Grineski, S. E. (2014). Social and spatial inequities in exposure to flood risk in Miami, Florida. Natural Hazards Review, 15(3), 04014006.
- **Chakraborty, L., Thistlethwaite, J., Scott, D., Henstra, D., Minano, A., & Rus, H. (2021). Assessing social vulnerability and identifying spatial hotspots of flood risk to inform socially just flood management policy. Risk Analysis, n/a(n/a). Accessed December 1, 2022. https://doi.org/10.1111/risa.13978
- Colten, C. E. (2006). Vulnerability and place: Flat land and uneven risk in New Orleans. American Anthropologist, 108(4), 731-734. https://doi.org/10.1525/aa.2006.108.4.731
- Cutter, S. L. (1995). Race, class and environmental justice. Progress in human geography, 19(1), 111-122.
- **Cutter, S. L., Emrich, C. T., Morath, D. P., & Dunning, C. M. (2013). Integrating social vulnerability into federal flood risk management planning. Journal of Flood Risk Management, 6(4), 332–344. https://doi.org/10.1111/jfr3.12018
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