Communities Disproportionately Affected by Carbon Monoxide Exposure After Winter Storm Uri

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Extreme cold in February 2021 precipitated prolonged power failure in Texas. In Houston, many patients presented for carbon monoxide exposure from neighborhoods with lower per capita income, higher rates of limited English proficiency, and greater median Social Vulnerability Indices than Greater Houston. Weather-related disasters disproportionately affect socially vulnerable communities. *(J Pediatr 2024;13:200114).*

In February 2021, Winter Storm Uri struck Texas and the surrounding Gulf states, leading to historically cold and sustained low temperatures, heightened energy demands, and massive power failure. Approximately 10 million people and 4.5 million homes and businesses were left without power for an average of 46 hours and as long as 120 hours.[1-3] Residential buildings in Texas are not routinely built to withstand such cold temperatures for prolonged periods of time. As a result, some households used unconventional, unsafe heat sources, inadvertently exposing inhabitants to carbon monoxide.

Although the entire city felt the effects of Uri, the ability to mitigate the consequences of the storm may have varied between families and communities. Studies from previous natural disasters, such as Hurricane Harvey, demonstrated that heavily affected communities were among the most vulnerable in the US with regards to their social, economic, housing, and infrastructure resilience.[4-6] Similar findings were described after Hurricanes Katrina and Rita.[7,8] Like hurricanes, winter storms may disproportionately burden susceptible communities.

We hypothesize that the effects of Winter Storm Uri disproportionately affected vulnerable communities in Greater Houston as defined by high Social Vulnerability Index (SVI) scores. We report SVI scores for census tracts from which patients who were evaluated for carbon monoxide exposure during Winter Storm Uri presented. We compare these and additional census tract characteristics with those of other census tracts in the Greater Houston Area. This study also describes the individual characteristics of patients who were evaluated for carbon monoxide exposure. On the basis of our review, this is the largest pediatric observational study of carbon monoxide exposures related to a single weather event.[9]

EMR	Electronic medical record
PED	Pediatric emergency department
SVI	Social Vulnerability Index

Methods

Setting and Study Participants

This study is a case series with a cross-sectional descriptive analysis that evaluated census tract–level SVI scores, as well as additional census tract and individual characteristics of patients presenting for evaluation for carbon monoxide exposure during Winter Storm Uri at a quaternary, urban children's hospital system in Houston, Texas. Any patient (child or adult) presenting at any of three affiliated pediatric emergency departments (PEDs) from February 13 to 17, 2021, with either primary presenting concern of carbon monoxide exposure and/or presenting symptoms attributed to carbon monoxide exposure was included. This study was approved by the institutional review board of Baylor College of Medicine.

Data Collection

We screened for potential cases by querying the electronic medical record (EMR) using diagnosis-code and laboratory-order queries for all PED arrivals during the study dates. All patients presenting during the storm dates with any of the *International Classification of Diseases*, *Tenth Revision*, codes listed in **Table I**, or with any of the laboratory orders listed at the bottom of **Table I** were reviewed to assure they met the aforementioned inclusion criteria. Data were extracted by study investigators, then verified by 2 study authors, who reached agreement on all included cases and excluded potential cases. Demographic data (**Table II**) and patient addresses were extracted from the EMR. As many individuals presented with other members of the same

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https://doi.org/10.1016/j.jpedcp.2024.200114

Table I. ICD-10 codes and laboratory values for case identification

Diagnosis	ICD-10 Code	Number of Cases with Code Assigned
Toxic effect of carbon monoxide, unintentional, initial encounter; OR Accidental poisoning by carbon monoxide, initial encounter OR Carbon monoxide poisoning, initial encounter *(with various qualifiers)*	T58.91XA; T58.91XS; T58.91XD	55
Carbon monoxide exposure OR Exposure to carbon monoxide	Z77.29	13
Accidental exposure to carbon monoxide	Z77.098	4
Accidental poisoning by utility gas and carbon monoxide	T59.891A	3
Exposure to other specified smoke, fire and flames, initial encounter	X08.8XXA	1
Smoke inhalation	T59.811A	1
Toxic effect of carbon monoxide from unspecified source, undetermined intent, initial encounter (*with various qualifiers)*	T58.94XA; T58.94XS; T58.94XD	1
Carbon monoxide poisoning from motor vehicle exhaust (*with various qualifiers)*	T58.01XA; T58.01XS; T58.01XD; T58.03XA; T58.03XS; T58.03XD; T58.02XA; T58.02XS; T58.02XD; T58.04XA; T58.04XS; T58.04XD	0
History of carbon monoxide poisoning	Z91.89	0
Toxic effect of carbon monoxide from utility gas	T58.11XA; T58.11XS; T58.11XD	0
Toxic effect of carbon monoxide from utility gas, undetermined intent	T58.14XA; T58.14XS; T58.14XD	0
Toxic effect of carbon monoxide from other source, undetermined intent, initial encounter	T58.8X4A; T58.8X4S; T58.8X4D	0
Toxic effect of carbon monoxide from other source, accidental (unintentional)	T58.8X1A; T58.8X1S; T58.8X1D	0
Toxic effect of carbon monoxide from incomplete combustion of other domestic fuels, accidental (unintentional), initial encounter	T58.2X1A; T58.2X1S; T58.2X1D	0

ICD-10, International Classification of Diseases, Tenth Revision.
Potential cases were identified using the following ICD-10 codes and/or any laboratory order or result for: "Venous blood gas with carboxyhemoglobin" OR "Venous blood gas with co-oximetry and/or carboxyhemoglobin."

household, and multiple patients presented from housing units located at the same address, only unique addresses/census tracts were used in the final analysis of census tract characteristics. We securely geocoded the home addresses of included patients using ArcGIS Pro and the Street Map Premium Address Locator.[10] Census tract number was ascribed to each unique address on the basis of its geolocation, which we then used to pull community-level SVI data (**Table III**) from the US Census Bureau's 2018 American Community Survey.[11] Finally, we pulled data from counties where cases reside (Harris County, Fort Bend County, Liberty County, and Montgomery County Appraisal Districts) to further characterize addresses as single-family vs multiunit housing (**Table II**).

The primary variable or characteristic of interest was the SVI of home census tracts for cases (**Table III**, **Figure**). The other characteristics of interest were the additional census tract characteristics (**Table III**) and EMR-abstracted individual characteristics of cases (**Table II**).

Social Vulnerability

The US Centers for Disease Control and Prevention's SVI uses US census data to determine the social vulnerability of every census tract in the US. It scores each tract from 0 to 1 on the basis of 15 social factors, including poverty, lack of vehicle access, crowded housing, etc. Lower scores (0-0.25) indicate low social vulnerability, whereas greater scores (0.75-1.0) indicate high social vulnerability. The SVI is a validated measure of communities' risk and resilience during a public health emergency or natural disaster and describes "the potential negative effects on communities caused by external stresses on human health."[12]

Analysis

We report frequencies and percentages for demographic variables. Medians and IQRs were calculated for skewed, continuous demographic data. Medians and IQRs also were calculated for case census tract characteristics and Greater Houston census tracts (excluding case census tracts) since data were skewed. These medians were compared using a Mann-Whitney *U* test. A value of $P < .05$ was considered significant. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS), version 28 (IBM Corp) and ArcGIS Pro, version 2.9.2.[10,13]

Results

Social Vulnerability Index

Seventy-eight patients met inclusion criteria. They presented from 34 unique households and 30 different census tracts. The census tracts from which cases presented had a median SVI score of 0.65 (IQR 0.38-0.91), which represents moderately high vulnerability. Fourteen tracts (45%) had an SVI score of 0.75 or greater, which is classified as "high vulnerability" (**Table III**, **Figure**).

Census Tract Characteristics

In addition to having significantly greater SVI scores than those of Greater Houston, there were multiple other census tract characteristics with statistically different medians compared with those of Greater Houston, including median

Table II. Individual characteristics of children and adults/caregivers presenting with concern for carbon monoxide exposure (n = 78)

Characteristics	Children* n = 59	Adults/caregivers n = 19	All patients n = 78
Age, y	6 (3-11)	38 (28-43)	9.5 (4-16.5)
Sex			
Female	28 (47)	12 (63)	40 (51)
Male	31 (53)	7 (37)	38 (49)
Race			
Asian American/Pacific Islander	5 (8.5)	5 (26)	10 (13)
Black or African American	15 (25)	3 (16)	18 (23)
White	37 (63)	10 (53)	47 (60)
Unknown or not specified	2 (3.4)	1 (5.3)	3 (4)
Ethnicity			
Hispanic/Latino	34 (58)	9 (47)	43 (55)
Non-Hispanic/Latino	25 (42)	10 (53)	35 (45)
Preferred language			
Arabic	1 (1.7)	3 (16)	4 (5)
English	26 (44)	6 (32)	32 (41)
Spanish	30 (51)	9 (47)	39 (50)
Swahili	1 (1.7)	1 (5.3)	2 (2.6)
Vietnamese	1 (1.7)	0 (0.0)	1 (1.3)
Insurance status			
CHIP/Medicaid	36 (61)	2 (11)	38 (49)
Private insurance	7 (12)	4 (21)	11 (14)
Self-pay or no insurance listed	16 (27)	13 (68)	29 (37)
Household and housing			
Presented with other members of patient's household	47 (80)	16 (84)	63 (81)
Resides at a multiunit address (apartment building, trailer park, etc)†			56 (72)
Presented in a cluster with other residents of same multiunit address‡			21 (27)
Mechanism of exposure			
Car heater, sitting inside car	1 (1.7)	0 (0.0)	1 (1.3)
Charcoal grill brought indoors	35 (59.3)	13 (68.4)	48 (61.5)
Gas fireplace/stove	4 (6.8)	0 (0.0)	4 (5.1)
Gas grill brought indoors	5 (8.5)	1 (5.3)	6 (7.7)
Gas grill outdoors	2 (3.4)	2 (10.5)	4 (5.1)
Generator running indoors	4 (6.8)	2 (10.5)	6 (7.7)
Generator running outdoors	2 (3.4)	1 (5.3)	3 (3.8)

CHIP, Children's Health Insurance Program.
Data are No. (%) or median (IQR).
*Children are <18 years old.
†Of 30 unique addresses, 17 are characterized as multiunit by county appraisal district data, with number of units ranging from 120 to 921 units.
‡There were 4 addresses from which clusters of families/households presented.

per capita income, median percent of people who identify with minoritized racial and ethnic groups, and the median percent of people who speak English "less than well" (**Table III**).

Individual Characteristics

Of the 78 cases, most individuals (81%) presented with other members of the same household, resulting in a greater volume of adult patients than are typically cared for in our PED sites. The median age of children (n = 59) was 6 years (IQR 3-11), and the median age of adults (n = 19) was 38 years (IQR 28-43). Most cases identified with minoritized racial and ethnic groups: 55% of all cases identified as Hispanic/Latino, 23% identified as Black or African American, and 13% identified as Asian American/Pacific Islander. More than one-half (59%) of cases preferred a language other than English. Only 14% of cases had private insurance, whereas 49% had public insurance, and 37% were self-pay/uninsured. (**Table II**). For reference, during the entire calendar year of 2021 our PED sites saw 50% patients identifying as Hispanic/Latino, 20% identifying as Black/African American, and 5% identifying as Asian American/Pacific Islander, with 24% of patients speaking a language other than English. The payor mix was 25% private insurance, 61% public insurance, and 12% self-pay or uninsured.

On the basis of data obtained from each county appraisal district, 17 of 30 (57%) of addresses contain multifamily housing units, and 56 of 78 cases (72%) reside at these multiunit addresses. There were 21 individuals (27% of cases) who presented as part of 4 clusters of households that had shared exposures at their multiunit addresses (**Table II**). The most common reason for exposure was caused by a charcoal grill being brought inside a home (61.5%) (**Table II**). Cases had 1 of 7 possible ICD-10 codes for carbon monoxide exposure or toxicity, and the majority were diagnosed with toxicity (**Table I**). Of the 78 cases, all but 2 (both adult caregivers who were checked in for evaluation) were symptomatic. Two patients (2.6%) were admitted to the hospital, and 1 patient was transferred to another facility.

Table III. Census-tract characteristics for individuals presenting with concern for carbon monoxide exposure (n = 30 unique census tracts identified by patient addresses)

Characteristics	Census tracts in cohort Median (IQR) n = 30 census tracts†	Census tracts in greater Houston Median (IQR) n ≈ 1000 census tracts‡	*P* value*
Social Vulnerability Index scores§	0.65 (0.38-0.91)	0.51 (0.22-0.76)	**.03**
% Persons living below the federal poverty level	19% (8%-36%)	13% (6.8%-23%)	.09
Per-capita income	$21,011 ($14,191.75-$30,337.50)	$27,486 ($18,720.50-$40,441.50)	**.01**
% Unemployed	6.1% (4.4%-7.2%)	5.5% (3.7%-8.1%)	.88
% Persons uninsured	26% (15%-37%)	18% (9.8%-27%)	**.004**
% Persons age >25 y with no high school diploma	21% (12%-40%)	15% (6.5%-29%)	**.04**
% Persons age <17 y	30% (27%-33%)	26% (22%-30%)	**<.001**
% Persons identifying with minoritized racial and ethnic groups¶	89% (56%-96%)	65% (41%-90%)	**.01**
% Persons age >5 y who speak English "less than well" (limited English proficiency)	11% (4.9%-28%)	6.4% (2.6%-16%)	**.003**
% Single-parent household with children <18 y	14% (6.9%-23%)	9.9% (5.9%-15%)	**.01**
% Occupied housing units with more people than rooms	0.8% (0.1%-1.2%)	0.6% (0.2%-1.7%)	.37

**P* values <.05 were considered statistically significant and are bolded for reference.
†Individuals presented from 34 households located at 30 unique street addresses.
‡The US Census masks census-tract level estimates of certain characteristics if the overall numbers are too low. As such, there are some census tracts that are left out of median calculations for certain characteristics.
§SVI score: 0 = least vulnerable and 1 = most vulnerable.
¶Minoritized: racial and ethnic groups except White, non-Hispanic.

Discussion

The consequences of any natural disaster not only reflect the severity of the event, but also a community's ability to prepare for and cope with that disaster. This was exemplified by the carbon monoxide exposure faced by many families across Greater Houston during Winter Storm Uri's extreme and prolonged cold. Patients presenting with carbon monoxide exposure were more likely to come from socially vulnerable neighborhoods as classified by SVI. Individuals were more likely to use a language other than English and have public insurance or be self-pay/uninsured. This study supports the hypothesis that socially vulnerable patients and communities were disproportionately affected by this

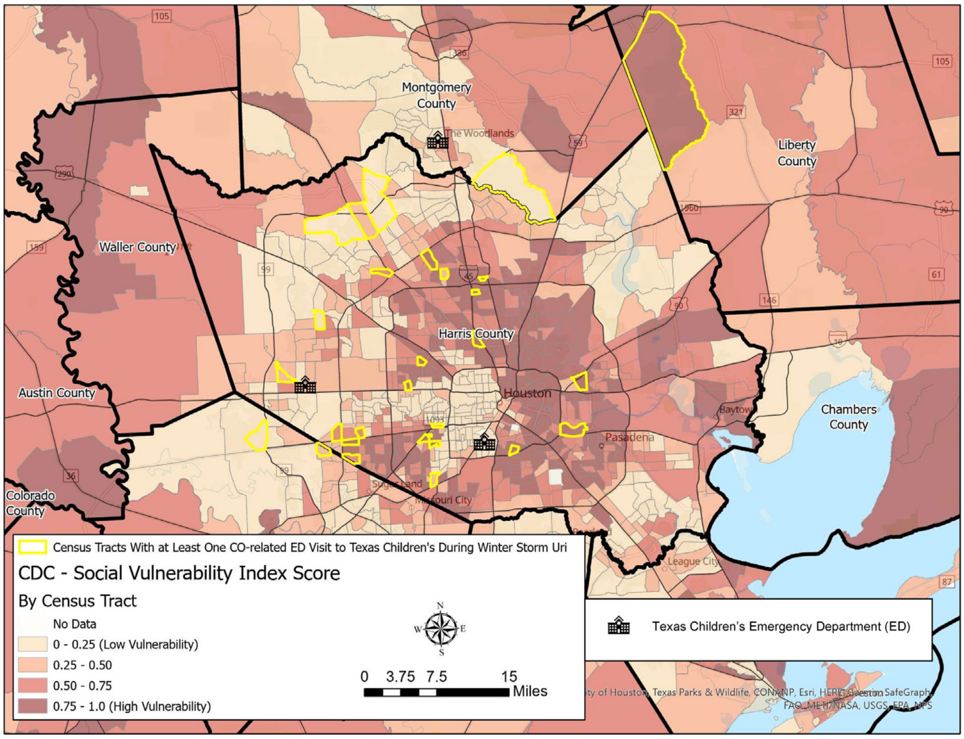

Figure. CDC - Social Vulnerability Index Score.

extreme weather event and less prepared to safely mitigate its impact. Our cohort of patients treated for carbon monoxide exposure had a higher median SVI than greater Houston, indicating increased vulnerability. Neighborhoods with a greater SVI likely have more difficulty mitigating the effects of a storm, as residents may have fewer resources and physical ability to adequately prepare for, address, or escape from a disaster such as a winter storm. For example, residents may be unable to evacuate in a private vehicle or prepare their homes in advance, and they are more likely to live in older homes that they do not own.[14-16] Those that lose power and cannot escape to warmer environments may turn to more readily available but potentially unsafe methods to stay warm, such as charcoal or gas grills, generators, propane heaters, or car engines in poorly ventilated areas, and thereby expose themselves to carbon monoxide.[17-19]

Census-level data found that patients were significantly more likely to present from neighborhoods with lower per-capita income, greater percentages of uninsured individuals, greater percentages of minoritized racial and ethnic groups, and greater rates of limited English proficiency. This is consistent with other studies that have described an increased effect of natural disasters on socially vulnerable communities.[6,16,20] Other studies also have shown that individuals from minoritized groups are more likely to experience the negative effects of a disaster.[7-9,16,21] Environmental injustice and disproportionate hazard exposure have been described as generating racial and ethnic disparities in chronic illnesses of childhood,[22] and this observational study suggests that disparities in acute illness may also result from hazard exposure.

The patients included in this study represented a greater percentage of Hispanic/Latino, Black/African American, and Asian American/Pacific Islander than typically seen in our PEDs. In addition, we saw high percentages of patients who prefer a language other than English and had public insurance or no insurance. Most patients also live at multiunit addresses, and many had shared exposures at these locations.

This extreme storm and subsequent carbon monoxide exposures should be seen as a sentinel event highlighting the need to protect *all* communities during future extreme weather events. Across Texas, communities with greater percentages of minoritized racial and ethnic groups were significantly more likely to suffer blackouts than predominantly White neighborhoods.[23] Public officials should prioritize neighborhoods with higher SVI scores for energy infrastructure improvements to lessen the effect of future extreme weather events.

If power outages are anticipated or cannot be prevented, the findings of this study also suggest targets for carbon monoxide exposure mitigation efforts: census tracts with high SVI scores, families who speak languages other than English, and multiunit addresses. For example, public officials might consider distributing generators paired with carbon monoxide detectors to multiunit housing structures in high SVI neighborhoods. Existing literature suggests that carbon monoxide detectors should be paired with generators at the time of purchase, longer cords should be included to allow safer placement, low carbon monoxide emission generators should be regulated, and automatic shut-off systems should be required.[24] Carbon monoxide detectors may also be distributed through primary care centers that serve large non–English-speaking populations or distributed to multiunit addresses regardless of neighborhood SVI. Officials might also increase public safety communication about safe heating measures, how to find and access safe shelter, and how to identify and respond to carbon monoxide exposures if they do occur, particularly in languages other than English.

This study was limited in that it is a cross-sectional study without a patient-level comparison group. This design was necessary, since we were describing a specific population experiencing a sentinel event, but it limits the conclusions we can draw from our observations. In addition, while the study pediatric hospital system is by far the largest in the Greater Houston Area, there may have also been some selection bias for patients who live in closer proximity to the study hospital sites and preferentially chose the study hospital for location or other reason. We were also limited in that we relied on diagnosis codes and laboratory order codes for case identification. Carbon monoxide toxicity can be difficult to detect, therefore there may have been patients who were not recognized as having experienced carbon monoxide exposure. These patients may not have had laboratory testing completed nor diagnosis codes assigned for carbon monoxide exposure for their emergency department encounter, and therefore may have been left out of the cohort we evaluated.

Conclusions

Natural disasters and extreme weather events disproportionately affect socially vulnerable communities, as exemplified by carbon monoxide exposure after Winter Storm Uri. We must prepare for future disasters through infrastructure enhancement and targeted interventions for communities with higher SVI scores, multiunit housing, and lower average income. This study suggests that interventions should be employed with careful attention to a community's linguistic and cultural diversity. Disasters are not felt equally across all communities, but by prioritizing high-SVI census tracts and communities with the characteristics highlighted in this article, we may lessen the negative and disparate effects of future natural disasters. ■

CRediT Authorship Contribution Statement

Elyse N. Portillo: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Casandra Quiñones:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zachary C. Foughty:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Ryan Ramphul:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Asha T. Morrow:** Writing – review & editing, Resources, Methodology, Investigation. **Kathryn Fisher:** Writing – review & editing, Writing – original draft, Investigation, Data curation. **Stephen A. Harding:** Writing – review & editing, Supervision, Investigation. **Elizabeth A. Camp:** Writing – review & editing, Formal analysis. **Shubhada Hooli:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Eric A. Russell:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors received no funding specific to this work. The authors have no conflicts of interest to declare.

Submitted for publication Dec 29, 2023; last revision received Apr 17, 2024; accepted Apr 19, 2024.

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