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Extreme Weather, Chemical Facilities, and Vulnerable Communities in the U.S. Gulf Coast: A Disastrous Combination

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Key Points:
- Natural hazards can trigger explosions, fires, and chemical releases at industrial facilities, endangering public health and safety
- Approximately 4,374,000 people live within 1.5 miles of 872 highly hazardous chemical facilities along the U.S. Gulf Coast
- Public health risks from colocated chemical facilities, people, and natural hazards are understudied, yet potentially large and growing

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Abstract Many chemical facilities are located in low-lying coastal areas and vulnerable to damage from hurricanes, flooding, and erosion, which are increasing with climate change. Extreme weather can trigger industrial disasters, including explosions, fires, and major chemical releases, as well as chronic chemical leakage into air, water, and soil. We identified 872 highly hazardous chemical facilities within 50 miles of the hurricane-prone U.S. Gulf Coast. Approximately 4,374,000 people, 1,717 schools, and 98 medical facilities were within 1.5 miles of these facilities. Public health risks from colocated extreme weather, chemical facilities, and vulnerable populations are potentially disastrous and growing under climate change.

Without adequate preventative measures, industrial disasters can be triggered by natural hazards, such as hurricanes, floods, lightning, and earthquakes (Krausmann et al., 2011; Salzano et al., 2013). A recent example occurred during Hurricane Harvey, when over three feet of flooding disabled the refrigeration system at the Arkema plant in Crosby, TX, causing organic peroxides to spontaneously combust. As a result, 21 people sought medical attention and 200 people within 1.5 miles of the facility evacuated and could not return home for a week (U.S. Chemical Safety and Hazard Investigation Board, 2018). Like the Arkema Crosby facility, which was located within the 100- and 500-year flood zones, many chemical facilities in the United States are located in low-lying coastal areas, leaving them vulnerable to damage triggered by hurricanes, flooding, and erosion, which are increasing as a result of climate change-related sea level rise (Cruz & Krausmann, 2013; Kopp et al., 2014; Wuebbles et al., 2014). Texas in particular is projected to lead the nation in climate change-related flood damage (U.S. Environmental Protection Agency, 2015) and has many chemical facilities surrounded by vulnerable communities (Tinney et al., 2016; U.S. Chemical Safety and Hazard Investigation Board, 2016).

Extreme weather, such as hurricanes and accompanied storm surge flooding, can have direct and indirect effects on public health, safety, and welfare. For example, Hurricane Maria led to nearly 3,000 fatalities in Puerto Rico, though initial government reports had estimated only 64 deaths (Santos-Burgoa et al., 2018). Downstream effects of extreme weather can include storm surge flooding, power outages, reduced capacity of healthcare facilities, and road closures limiting access to medical care. Natural hazards can also trigger industrial disasters from chemical explosions, fires, and releases, as exemplified by the Arkema explosions after Hurricane Harvey (Cozzani et al., 2010; Nascimento & Alencar, 2016; World Health Organization, 2018). These natural hazard-triggered technical disasters, often referred to as "natech" events, are the subject of a growing area of research. Natural hazards can trigger industrial disasters in various ways, including by washing out chemicals into floodwaters, damaging storage vessels and pipes containing chemicals, lightning strikes igniting flammable materials, and damage to power supply that can upset processes or affect temperature and pressure of stored chemicals. As natural hazards often also damage the capacity, effectiveness, and functioning of public services, the health consequences of natech events may be particularly difficult to manage during the event itself. A preventative approach that avoids vulnerability to natech events would be more effective, especially given potential increases in natural hazard events as the climate changes.

Explosions, fires, and chemical releases occur at industrial facilities frequently, subjecting the communities surrounding these facilities to public health and safety hazards including injury from debris, inhalation or dermal exposure to chemicals and smoke, and burns. We obtained access to the U.S. Chemical Safety Board's "incident screening database," which logs fires, explosions, and chemical releases at industrial facilities in the United States, via a Freedom of Information Act request in October 2018. From 2001 to 10 October 2018, the database captured 9,406 incidents, an average of ~1.5 incidents per day. Of these, 978 incidents (10%) occurred in Texas, and 1,890 (20%) occurred in the five Gulf Coast states (from most to least: Texas, Florida, Louisiana, Mississippi, and Alabama). Incidents involved chemicals, food, metal, petroleum (refineries), and other types of facilities (Gomez et al., 2008). Approximately 40% of industrial incidents in the database led to injury or fatality among workers and/or the public.

The number of these types of industrial disasters that were triggered by natural hazards in the United States and globally is not well understood. One estimate indicates that 2–5% of incidents resulting in the release of hazardous substances were triggered by natural hazard events (World Health Organization, 2018). However, other studies suggest a higher frequency of natech events. A 2008 study estimated that 500–800 natech events occur throughout the United States each year (Steinberg et al., 2008). More recently, studies have estimated that up to 450 incidents annually involving on-shore hazardous liquid pipeline systems are triggered by natural hazards (Girgin & Krausmann, 2016), over 600 hazardous material releases from gas installations and offshore oil facilities and pipelines were triggered by Hurricanes Rita and Katrina (Cruz & Krausmann, 2009), and 16,600 hazardous material spills caused by natural hazards occurred from 1990–2008 in the United States (20% of which were due to hurricanes; Sengul et al., 2012). Floods were the second largest contributing cause of natechs in the EU in 2010, behind only lightning, and ahead of low temperature, rain, storm/wind, landslide, heat, and earthquake (Krausmann, 2010) These estimates vary but consistently indicate that natech events, including those triggered by floods, are relatively common. Without adequate mitigation measures, the frequency and impacts of these types of events may be exacerbated in the future as industrialization, urbanization, and hydrometeorological hazards associated with climate change increase simultaneously (Bernier et al., 2017; Piatyszek et al., 2017; World Health Organization, 2018).

Public health impacts from these natural hazard-triggered industrial disasters range from acute explosions, fires, and large chemical releases to longer-term, more chronic exposure to chemicals leaking slowly into the air, water, and soil. Facility damage may also cause extended shutdowns or closures, often leading to job losses and economic damages. Thus, the potential impacts of these types of events can be disastrous for individuals, families, and communities. Following Hurricane Harvey, the New York Times found that 1,400 chemical sites across the United States are in areas at highest risk of flooding (Tabuchi et al., 2018, February 6). However, there is limited public information available about where the facilities are, the chemicals stored there, the number of people and community buildings nearby, and the degree of changing risks from extreme weather.

To help understand the magnitude of the potential risk to public health and safety posed by highly hazardous chemical facilities in locations vulnerable to natural hazards, we calculated the number of people, schools, and hospitals near such facilities throughout the U.S. Gulf Coast. We used locations of facilities registered in the U.S. Environmental Protection Agency's (EPA) Toxic Release Inventory from the EPA's Facility Registration System Database and filtered for facilities within 50 miles of the coast to capture those potentially most exposed to flood hazards. We defined "highly hazardous chemical facilities" as those with EPA Risk Screening Environmental Indicator (RSEI) scores ≥ the median score of 415 (excluding facilities with a score of zero). RSEI scores reflect "risk-related impacts on chronic human health" and account for the magnitude and toxicity of stored chemicals and the population living nearby. We then calculated the number of people, schools, and hospitals within a 1.5-mile buffer around each facility (the size of the Arkema evacuation zone; Figure 1). We used census block group population from 2016 from the American Community Survey and locations of medical and educational facilities from the U.S. Geological Survey's National Structures Dataset (Manson et al., 2018; U.S. Geological Survey, 2018).

We identified 2,545 facilities located within 50 miles of the coast throughout Florida, Mississippi, Alabama, Louisiana, and Texas (Figure 2). Of these, 872 facilities had a RSEI score ≥ 415; for comparison, the Arkema Crosby plant had a score of 16. Approximately 14% (4,374,000 people) of the coastal population of these states, 1,717 educational facilities, and 98 medical facilities are located within 1.5 miles of these facilities. Half (50%) of the highly hazardous chemical facilities in this region were located in Texas, 23% in Florida, 19% in Louisiana, 5% in Alabama, and 3% in Mississippi (Table 1). The size of the nearby vulnerable populations in each of these states followed a similar pattern, with the largest number of

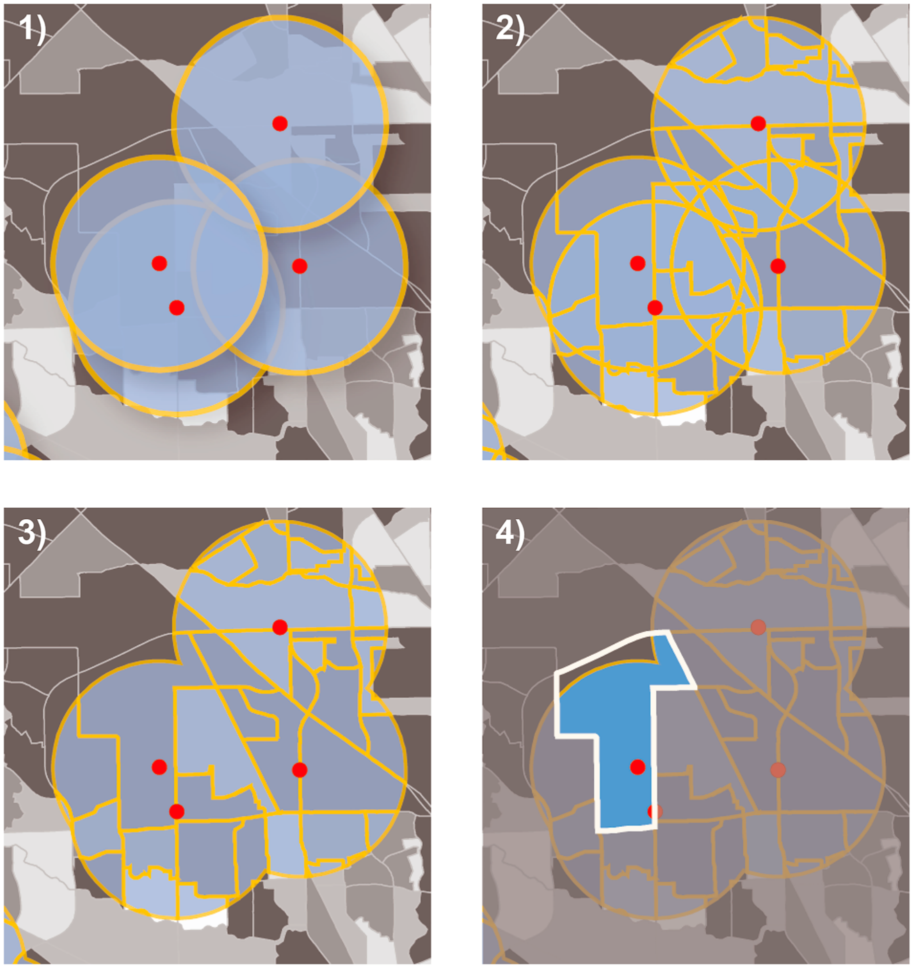

Figure 1. Illustration of the analytical steps taken in ArcGIS to determine population, educational facilities, and medical facilities within 1.5 miles of a highly hazardous chemical facility: (1) Draw 1.5-mile buffer; (2) divide buffers by census block boundaries; (3) dissolve buffers by GeoID to eliminate overlap; and (4) calculate percentage of each census track located within the buffer region. This percentage was then multiplied by the population of the census block, assuming the population was distributed evenly throughout the block group. We then performed a spatial join between the dissolved buffer layer and point locations of medical and education facilities. RSEI = Risk Screening Environmental Indicator.

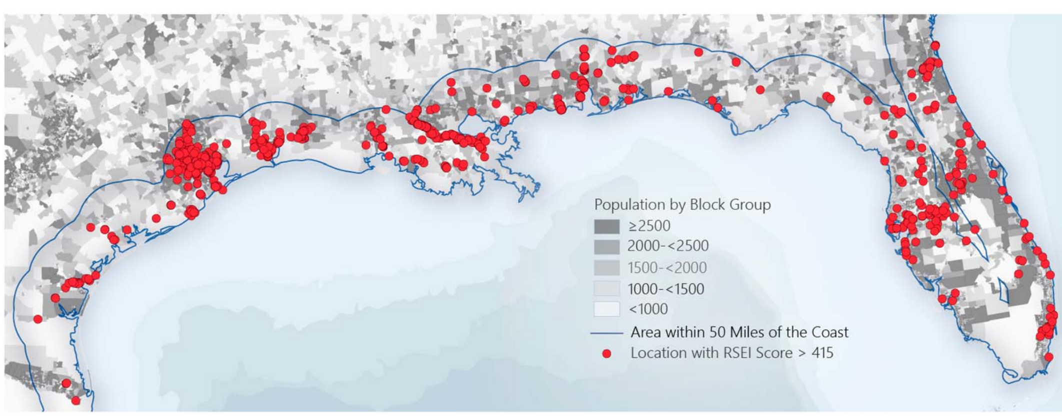

Figure 2. Locations of highly hazardous chemical facilities (Risk Screening Environmental Indicator score ≥ 415) within 50 miles of the U.S. Gulf Coast overlaid on census block group population size for 2016.

Table 1
For Each State Along the U.S. Gulf Coast, the Number of Highly Hazardous Chemical Facilities Within 50 Miles of the Coast and the Number of People and Percent of Coastal Populations in 2016 (Rounded to Hundreds), Number of Educational Facilities, and Number of Medical Facilities Within 1.5-Mile Buffer Region Surrounding Those Coastal Highly Hazardous Chemical Facilities

Category	Subcategory	Texas	Florida	Louisiana	Alabama	Mississippi	All five states
Highly hazardous chemical facilities	No. facilities within 50 miles of coast	949	1,045	388	106	57	2,545
	No. coastal facilities with RSEI ≥415	432	200	166	45	29	872
	Percent of state coastal facilities with RSEI ≥415	46%	19%	43%	42%	51%	34%
Population	Population within 50 miles of coast	8,468,000	19,492,000	3,187,200	693,700	511,900	32,352,400
	Coastal population within 1.5 mile buffer region	2,181,000	1,626,000	417,000	84,600	64,500	4,373,800
	Percent of state coastal population that is within 1.5 mile buffer region	26%	8%	13%	12%	13%	14%
	Population density within 1.5 mile buffer region of individual highly hazardous chemical facilities in people per mi^2 [mean (min-max)]	1,483 (3–9,656)	1,619 (6–6,865)	539 (5–4,495)	444 (16–2,361)	528 (15–1,551)	1,250 (3–9,656)
Educational facilities	No. within 50 miles of coast	2,839	5,804	1,382	287	224	10,536
	No. within 1.5 mile buffer region	731	672	217	57	40	1,717
	Percent of state coastal facilities that are within 1.5 mile buffer region	26%	12%	16%	20%	18%	17%
Medical facilities	No. within 50 miles of coast	160	285	119	17	15	596
	No. within 1.5 mile buffer region	43	27	21	3	4	98
	Percent of state coastal facilities that are within 1.5 mile buffer region	27%	9%	18%	18%	27%	16%

Note. RSEI = Risk Screening Environmental Indicator.

nearby people, educational facilities, and medical facilities in Texas, followed by Florida and Louisiana. This preliminary analysis indicates that there is a sizable population that would be vulnerable should fires, explosions, or chemical releases occur at nearby facilities. These communities include schools and hospitals, indicating that the surrounding population also include particularly susceptible subgroups. Further, using worst-case scenario predictions from the National Oceanic and Atmospheric Administration's Storm Surge Maximum of the Maximum data set (National Oceanic and Atmospheric Administration National Hurricane Center, 2019), massive flood events could occur following category five hurricanes, with 63 of these facilities potentially experiencing >20 feet of flooding. Given rising storm surge levels with climate change, this is a public health risk that is likely to grow in the future.

Awareness of natural hazard-triggered industrial events has been growing over the last decade (Cruz et al., 2006; Nascimento & Alencar, 2016; Steinberg et al., 2008), particularly in Europe (Nascimento & Alencar, 2016). In the United States, the industry is already aware of these risks to their operations and has pursued a $12 billion, 60-mile sea wall along the Gulf coast to protect refineries from sea level rise (Weissert, 2018, August 22). However, natech events in the United States remain poorly understood among the public and infrequently studied compared with other environmental health issues, such as air pollution and water quality. They are also not adequately regulated at the federal, state, or local level. The Chemical Safety Board's investigation of the Arkema incident found that the Occupational Safety and Health Administration and EPA consider flooding and extreme weather hazards to be part of a normal Process Hazard Analysis under Occupational Safety and Health Administration's Process Safety Management standard and EPA's Risk Management Program but that neither agency explicitly requires such extreme events to be addressed (U.S. Chemical Safety and Hazard Investigation Board, 2018), a regulatory gap that puts public health and safety at risk.

We focused this article on acute disasters, such as fires, explosions, and major chemical releases, that could endanger public health and safety. Slower, more chronic leakage of chemicals into floodwaters, air, and soil is also a relatively unexplored, and perhaps more pervasive, public health risk. Colocation of extreme weather, chemical facilities, and vulnerable communities is a potentially disastrous combination that is likely to worsen with climate change. When the next hurricane hits, will we be prepared?

Data Availability

All data used in this analysis are publicly available from the referenced sources.

Conflict of Interest

The authors declare no actual or perceived conflicts of interests.

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