

ASSESSING RISK OF SUPERFUND SITES TO NATURAL HAZARDS WITHIN TEXAS

by

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CHAPTER 1 - INTRODUCTION

Since the inception of the Environmental Protection Agency (EPA) the Superfund program created through the Comprehensive Environmental Response, compensation and Liability Act (CERCLA) of 1980, created for the protection of human and environmental health through the cleanup of hazardous sites around the nation has been an ongoing battle (EPA 2015, TCEQ 2022). These sites, in various phases of cleanup, can be exposed to the elements and severely impacted by any natural hazard that has the possibility of occurring in that area. As discussed later in these studies, the possibility of Superfund sites being affected and worse, spread by a natural event, is a high probability. With over 168 confirmed EPA and TCEQ Superfund sites listed within the state of Texas, located in various locations, the need to be able to identify which of these sites could be affected by natural hazards is evident. The interaction between Superfund sites and natural hazards usually leads to the exacerbation of the original site issues, dispersing the toxic chemicals contained within these sites (EPA 2015). Through the data collected and analyzed within this study, a means of assessing the risk of various Superfund sites' Risk to natural hazard events is provided.

1.1 Problem Statement

As climate change affects our global climate in various ways, natural hazards have changed with the climate, leading to increased events and the severity recorded during these events. In recent studies, such as Summers et al. (2021), various key Superfund sites in the United States were given a risk assessment of the probability of being affected by a natural hazard. Very few studies have looked at just an individual state, and, in that pool, none have

looked at just Superfund sites in Texas. This leaves decision-makers in the dark on which sites in Texas should be prioritized to avoid the spread of these toxic sites due to these natural hazards.

1.2 Research Study Question

By Analyzing the superfund sites within the state of Texas, Which natural hazards pose a higher risk of impacting superfund sites and of those sites effected by natural hazards which sites are most vulnerable to being impacted by these hazards?

1.3 Importance of Study

It is important to understand where the Superfund sites are, and which ones are more vulnerable than others to the effects of natural hazards. The EPA targets these sites for reasons of human and environmental health, and if they are allowed to be disturbed, there could be costly and dangerous effects from inaction (EPA 2015). Being able to identify which natural hazards pose a higher risk to Superfund sites will allow decision-makers to plan and enact preemptive management practices that could prevent further harm to humans and the environment.

Identifying key Superfund sites that pose a higher risk of being affected by natural hazards will allow for the prioritization of these sites, saving both money and the possibility of the spread of hazardous material after the collision of a natural hazard. This study will provide both an understanding and a form of analysis that has not yet been performed on Texas Superfund sites and their risk to natural hazards.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

Superfund sites are either costly reminders of our mismanagement or a need to move problems elsewhere at the cost of permanent damage to the land. These sites, though mostly stationary and unchanging, can in the blink of an eye, due to interactions with natural hazards, be moved and spread over unmeasurable distances. In this review, I will look at what happens to Superfund sites when these interactions take place and what actions can be taken to prevent the spread of Superfund sites due to natural hazards. I want to look at the studies that have been conducted on the effects of natural hazards on Superfund sites and what can be done to identify sites that are at a higher risk of being impacted by these natural hazards. In this review, I will look at research that has been conducted on as many natural hazards as have been analyzed and how the hazards have affected Superfund sites. Most research that has been found is about the effects of Superfund sites post-natural disaster in various scenarios across the United States. The studies looking at predictive modeling must use the same methods I will be using by combining various data sets to create a predictive model using risk to determine which sites are at a higher risk than others. Altogether, these articles are the collective research conducted by various groups, organizations, and researchers to show the various effects natural hazards have on Superfund sites and how we could predict these interactions between natural hazards and Superfund sites.

2.2 Identifying a Superfund Site

According to the Environmental Protection Agency (EPA, 2015), a superfund site is created "due to hazardous waste being dumped, left out in the open, or otherwise improperly managed," and can be created by anyone, including manufacturing facilities, processing plants,

landfills, and mining sites, making these areas dangerous for people, plants, and wildlife to inhabit (EPA, 2015). The issue that makes these sites important to recognize is that, if not identified, land could be used for purposes that could then place people and the environment in unsafe situations, as well as create a larger issue for whoever is trying to manage the land on which the superfund site is located. The reason superfund sites are an issue is that, roughly, 1 million people worldwide contract health effects due to the exposure to and proximity to former industrial and mining operations around the world (Cooper, 2021). Especially since North America is one of the top industrialized nations in the world, our history surrounding heavily industrialized production means that such sites will most likely be concentrated in areas around the United States.

2.3 History of Superfund Management

In the 1970s, the United States looked at creating regulatory functions to identify and control possible areas that could cause health and safety risks to the general public. These early laws were called "first generation" policies and sought to protect people's health (Sherman 2011). Nearly a decade later, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) were created to help clean up emergency and hazardous waste spills in the United States. Congress enacted the act on December 11, 1980, which is a relatively recent look at the history of the United States and all the innovation that has taken place (US EPA 2019). This act was necessary due to a major issue that had taken its toll on the environment: Love Canal. Love Canal was created in 1892 to connect parts of the Niagara River in New York State, but it was never finished (National Geographic Society 2011). Hooker Chemical bought the land and dumped about "22,000 tons of hazardous waste into the canal" (National Geographic Society 2011). This waste was not contained properly and eventually leaked out into the waterways and

the Niagara River. In the 1950s, Hooker Chemical sold the canal to a local school board, and a school was built on top of the drums filled with hazardous waste (National Geographic Society 2011). As the years went on, health issues started to arise in the community and among children due to the toxins being released, and eventually, this became national news (National Geographic Society 2011). This was the crucial step that led to lawmakers pushing the Superfund bill into law. This event and the actions of lawmakers provided the tools needed to effectively manage land that has been deemed a Superfund site in different and adaptive ways, allowing for proper remediation of the sites.

Today, the Superfund program works specifically with the Environmental Protection Agency (EPA). The EPA has a mission to protect human health and the environment. They focus on ensuring that citizens have clean water, land, and air; reducing environmental risks based on the best available scientific information; administering, enforcing, and protecting human health and the environment by Federal laws; considering environmental stewardship in U.S. policies; providing all parts of society with access to accurate information in the managing of human health and environmental risks; cleaning up contaminated lands and toxic sites by responsible parties; and reviewing chemicals in the marketplace for safety concerns (US EPA 2019). All of these areas are important in maintaining the environment in the United States, especially in the industrial world. Having Superfund around, in particular, gives the EPA the funds to clean up hazardous and toxic spills that occur in the environment. CERCLA can be seen at a federal level as well.

2.4 Tornadoes

Tornadoes are a natural hazard often overlooked when considering the risks, they can impose on the spread of Superfund sites. Due to their unpredictable and uncontrolled creation and movement, it is hard to predict just where one might touch down. In this section, the observations of researchers where sure instances have occurred will be examined as the impacts these hazards can impose on Superfund sites.

Extreme weather events like severe storms that span tornadoes form and occur in a shorter period than other weather events (USGCRP 2018). Because of this type of hazard, it is very difficult to predict and see future trends. Climatologists have predicted that due to the rise in our global temperature, warmer weather has led to an increase in these severe weather phenomena since 1980 (USGCRP 2018). This means that as time progresses and our global temperature rises, the likelihood of these climatological events will only increase, leading to the further need to see extreme weather events like tornadoes as a threat to Superfund sites within areas of high risk. Though hard to fully quantify scientifically, climatologists and meteorologists have concluded that there has been a trend in increased events as well as a shift in the regions and areas these events can take place in (USGCRP 2018). Areas of a high probability that could be affected by tornadoes are along the Gulf of Mexico coastal shoreline, and in the scope of Texas, central Texas up to Tornado Alley are at a high risk of the occurrence of tornadoes (Summers et al. 2021). These regions provide the needed climatological and geographic features needed for the steady occurrence of tornadoes.

Areas that once contained industrial activities like those found in lead smelting plants located all over the United States are often labeled as Superfund sites once proper testing is

conducted by the EPA (Bienkowski 2014). In the example of Joplin, Missouri, a town known for its rich mines containing important metals, lead, and zinc, used heavily during the Industrial Revolution, the town quickly became a center for processing these materials (Caldwell 2022). It was due to these mining and processing factors that the town of Joplin quickly became a hotspot for lead and other heavy metals contained in the topsoil of these industrial sites (Bienkowski 2014). With these sites being labeled as Superfund sites by the EPA in the early 1900s, cleanup began to start trickling in near the end of the century. Then, on May 22nd, 2011, a large hurricane rated as an EF-5 tore through this former industrial town, causing extreme destruction throughout its wake (USDC 2016). As stated before, this town had several Superfund sites totaling over 150 million tons of EPA-labeled toxic waste created in the wake of these industrial sites; nearly 9 million tons of this waste were still present on the day of the severe tornado (Bienkowski 2014).

As a result of this severe tornado, nearly 40 percent of the town's yards after the event were tested and found to contain these heavy metals that were spread from centralized locations (Bienkowski 2014). With the major spread of these materials due to this natural hazard, the cleanup of these Superfund sites has been further exasperated, leading to increased risk to the people inhabiting the land around where this event took place.

With the increase of tornadoes due to increased severe weather events, it is very prevalent to consider the likelihood of these events affecting Superfund sites within designated higher-risk areas. As seen with the Joplin case, the price of allowing natural disasters such as tornadoes to collide with hazardous Superfund sites could have irreversible consequences that far outweigh the cost of the original cleanup cost of such sites.

2.5 Wildfires

Though there has been little academic research into the impacts of wildfires on Superfund sites, it is still a natural hazard that should be considered for its ability to impact certain Superfund sites in dry and fire-prone regions. In this section, I will go over what academic literature and research have been conducted and how wildfires can play a role in the spread of hazardous material from Superfund sites.

Given the likelihood of severe droughts and occurrences of widespread wildfires in this region (Summers et al. 2021), the higher chance of these hazards taking place in the state of Texas, few cases have been presented in the academic landscape. Continuing from the Summers reading, the evaluation of the risk of wildfires' role in the interaction with Superfund sites was conducted. In this study, the researcher concluded that through the interaction of Superfund sites with wildfires, the occurrence of the release of airborne toxins through this interaction (Summers et al. 2021) was observed. In most of these cases within this study, the sites at risk usually were structures containing hazardous materials, and the combustion of these sites would release these particulates into the air and further spread these materials.

The threat of wildfire interactions with Superfund sites has little documentation or research that has been conducted in this interaction, but this hazard still has to be considered and kept within the viewpoint of this study.

2.6 Hurricanes and Coastal Flooding

Hurricanes pose the largest threat to coastal and inland Superfund sites out of any natural hazard, accounting for 60% of the nation's total Superfund sites due to flooding caused by storm

surges (GAO 2019). Therefore, these two natural hazards need to be given the most attention due to the high likelihood of hurricanes and flooding.

Hurricanes and flooding combined have the most literature and research conducted; this section presents the most case studies and research that have been conducted by the scientific community. Similar to the case of the increased activity in tornadoes due to increased greenhouse gases, there is a higher probability of increased occurrences of the frequency and magnitude of hurricanes in the Atlantic Ocean (USGCRP 2018). Studies conducted have found that in most coastal regions, the Superfund sites identified in these areas lie both in the 100- and 500-year flood plains (Mandigo et al. 2016). As the storms increase in frequency and magnitude, the bounds of these FEMA floodplains may no longer be relevant in cases placing these Superfund sites in these areas at a heightened risk of spread due to these storm systems. In extreme cases like Hurricane Harvey, several Superfund sites that were outside the scope of these floodplain maps were, due to extreme circumstances, submerged under the flooding caused by the storm (Mandigo et al. 2016). The issue presented is that, though Hurricane Harvey was an extreme case, so are the storm systems that come the following year, breaking records created the previous storm season. In the case of Harvey, extremely hazardous materials like raw sewage, benzene, dioxins, trace metals, and petroleum by-products were released from hazardous sites during these floodings (Mandigo et al. 2016).

In the case of Hurricane Harvey, sixteen federal and nine state-designated Superfund sites were contained within Harris County, and due to severe flooding, many of these sites were affected by the storm. It was confirmed that seven of these sites were underwater for an extended period (Ratnapradipa et al. 2018). After the resurgence of the floodwaters, the EPA conducted

several site assessments and found that several sites, including the San Jacinto River Waste Pits, leaked several hazardous toxins, resulting in readings of 70,000 ng/kg, which is almost two thousand times higher than the safe level of 30 ng/kg of these harmful toxins (Ebbs 2017). These startling discoveries show how a centralized, contained Superfund site can be irreversibly spread across possible miles of area. Hurricane Harvey showed what extreme weather events can do to a localized area if factors line up, leading to severe wind and rain resulting in extreme flooding over a large area.

Hitting the East Coast, Hurricane Sandy affected several Superfund sites and led to hazardous materials being spread due to flooding. In October 2012, the storm hit the region, affecting one of the most contaminated sites in New York City, the Gowanus Canal (Russell 2014). As a result of Hurricane Sandy, this site was spread almost one block in all directions with its hazardous, cancer-causing material in and around the site. Due to the heavy industrial part of the New York area, several other Superfund sites were spread to be diluted due to the flooding created by the storm. In some cases, the EPA still has inconclusive results on just how much hazardous material was transported due to Sandy (Russell 2014).

The continued theme with hurricanes is that flooding usually follows, making it the greatest threat to Superfund sites. The last major example of a natural hazard drastically affecting Superfund sites was Hurricane Katrina, which made landfall in August 2005 and was one of the most disastrous hurricanes to date at that time. The Agriculture Street Landfill, located in New Orleans, was a city-operated waste dump that was in operation from the early 1900s to 1958, containing several hazardous materials such as lead, arsenic, and other carcinogenic hydrocarbons that were still located within the site's soil (Wiegand 2006). This site of significant

hazardous waste was directly hit by Hurricane Katrina's floodwaters, spreading these materials across adjoining sites. The major significance of this site is that it had previously been cleaned up in partnership with the EPA and the CERCLA, but due to the extreme nature of the hurricane, materials that were covered up were exposed and washed away, carrying hazardous sediment with them (Wiegand 2006). Though this is isolated to a few sites in some areas, the EPA reported that levels of heavy metals and toxins actually declined after Hurricane Katrina, but as stated by the EPA, this was mainly due to dilution and was still seen as an overall negative result (Wang and Kanter 2014).

2.7 Inland Flooding

Superfund sites affected by flooding can also occur in areas that just experience flooding and are not triggered by the result of flooding from a hurricane. Floods can cause erosion of landfills and lead to the release and transport of toxic material (Laner et al., 2009). In a study by Kiaghadi et al. (2020), researchers concluded that a large portion of the facilities in their study was built within the 100-year and 500-year floodplains and could be susceptible to extreme flooding events (Kiaghadi et al., 2020). The possibility of Superfund sites being affected by flooding events is becoming more and more likely in these FEMA floodplains. In areas of former industrial activities like Milltown, Montana, though remediation efforts were made by the EPA, locals claimed these remediation efforts were taking place too slowly, leaving areas vulnerable to natural hazards like flooding (Pagliara & Ruocco, 2018). In this case, one day during a high-level spring weather system, the river flowing through Milltown started exceeding the normal flow of the dam, causing the shoreline to creep up beyond normal shorelines into ponds created by the EPA that contained tons of hazardous tailings from local mines. During the encroachment of the floodwaters, sediment containing these toxic tailings was carried

downstream during this flood event, spreading this toxic material with an estimated of over 68,000 tons of this tailing being spilled every year (Pagliara & Ruocco, 2018). Due to the slow remediation of this site and the continued impact of seasonal flooding, this Superfund site continued to contaminate the town and downstream towns until the area's final cleanup and restoration in 2012 (Pagliara & Ruocco, 2018). Like in the previous example, Juracek & Drake (2019) found that, though remediation efforts were found in floodplain areas, the need for cleanup and prevention should be highly prioritized due to the enormous cost of cleaning up these sites after a natural hazard like a flooding event.

2.8 Ranking Natural Hazards

Earthquakes and hurricanes to floods and wildfires, natural hazards can cause significant damage to infrastructure, property, and human life. One way of assessing the severity of natural hazards is by ranking them based on their destruction and economic impact. Ranking the effects of natural hazards is difficult by nature due to the uneven distribution of natural hazards around the world. Even looking at the scale of the United States it can be difficult to fully narrow down which natural hazards could pose a risk to superfund sites within Texas. Using historical data collected by FEMA used for the national risk index, other factors are used to define the level of risk each hazard might pose. In the National Risk index published in 2021 natural hazards are ranked by several factors including “natural hazard risk (likelihoods and consequences), Social vulnerability, and Community Resilience” which give an overall viewpoint of how each hazard can impact Texas (Zuzak et al. 2021). Within this report natural hazards were analyzed by the frequency, magnitude and impact each natural hazard might produce from its occurrence. From this study they categorize each hazard by region and which natural hazard had the most potential in damage its areas to both infrastructure and people. From this report analyzing the Texas region

it looks like FEMA ranks hurricanes and coastal flooding as the top natural hazard due to its frequency and magnitude (Zuzak et al. 2021). Ranking natural hazards is a complex and challenging task. While some may argue that certain hazards are more dangerous than others, it is important to consider the unique characteristics of each hazard and the potential impact on the environment.

2.9 Conclusion

This review identifies that natural hazards do pose a significant risk to the containment and cleanup of Superfund sites at risk of being impacted by various hazards. All the examples and ideas explored in this literature review support the idea that it is important to look at how Superfund sites are affected by natural hazards and what we can do to limit the effects of a post-natural hazard. Within most of these examples, it shows that there is a need to educate and implement ways of prioritizing and even speeding up the remediation efforts in areas at a higher risk than others. Most articles and studies prove that the interactions between natural hazards and Superfund sites are dangerous and costly in many ways and, overall, negatively affect the areas surrounding these sites. In a lot of these studies, the researchers' studies are only focused on one hazard at a time and are mostly only looking at the effects of easily obtaining sites. The few issues I have noticed in my research for articles is the lack of full consideration of hazards like wildfires and tornadoes and how they can affect Superfund sites. As my study area will be the state of Texas and with the high probability of wildfires in most parts of Texas, From this research an observation that more studies should be done on the effects of wildfires and how that hazard could affect and release toxins from Superfund sites in order to get a better understanding of its impacts. As for steps moving forward, I plan to analyze Superfund sites located within the state of Texas and the probability of those sites being affected by natural hazards. Through my

study, I hope to create some kind of way to prioritize Superfund remediation. By understanding how to identify what Superfund sites are at higher risk using predictive models, drawing a conclusion that a lot of the issues presented with most articles of post-site assessment can be prevented by stopping the spread of these sites before most natural hazards can reach these sites.

CHAPTER 3 - METHODOLOGY

3.1 Study Area

For this research study, the focus will be on data collection and assessment exclusively within the state of Texas. By limiting the scope to this specific region, a comprehensive analysis can be conducted on sites designated as superfund sites by both the Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ). As of 2022, there are approximately 168 such sites in Texas, which will serve as the primary subjects of investigation. Texas, being a vast state and situated along the Gulf of Mexico, is prone to various forms of natural hazards. The geographical location of Texas exposes it to a wide range of environmental challenges, including hurricanes, tornadoes, floods, droughts, and wildfires. These natural hazards can have significant impacts on the environment and public health, making them crucial factors to consider in this research study. By focusing on Texas, it is possible to delve into the specific challenges and risks faced by this state and develop targeted strategies for mitigating and managing these hazards effectively.

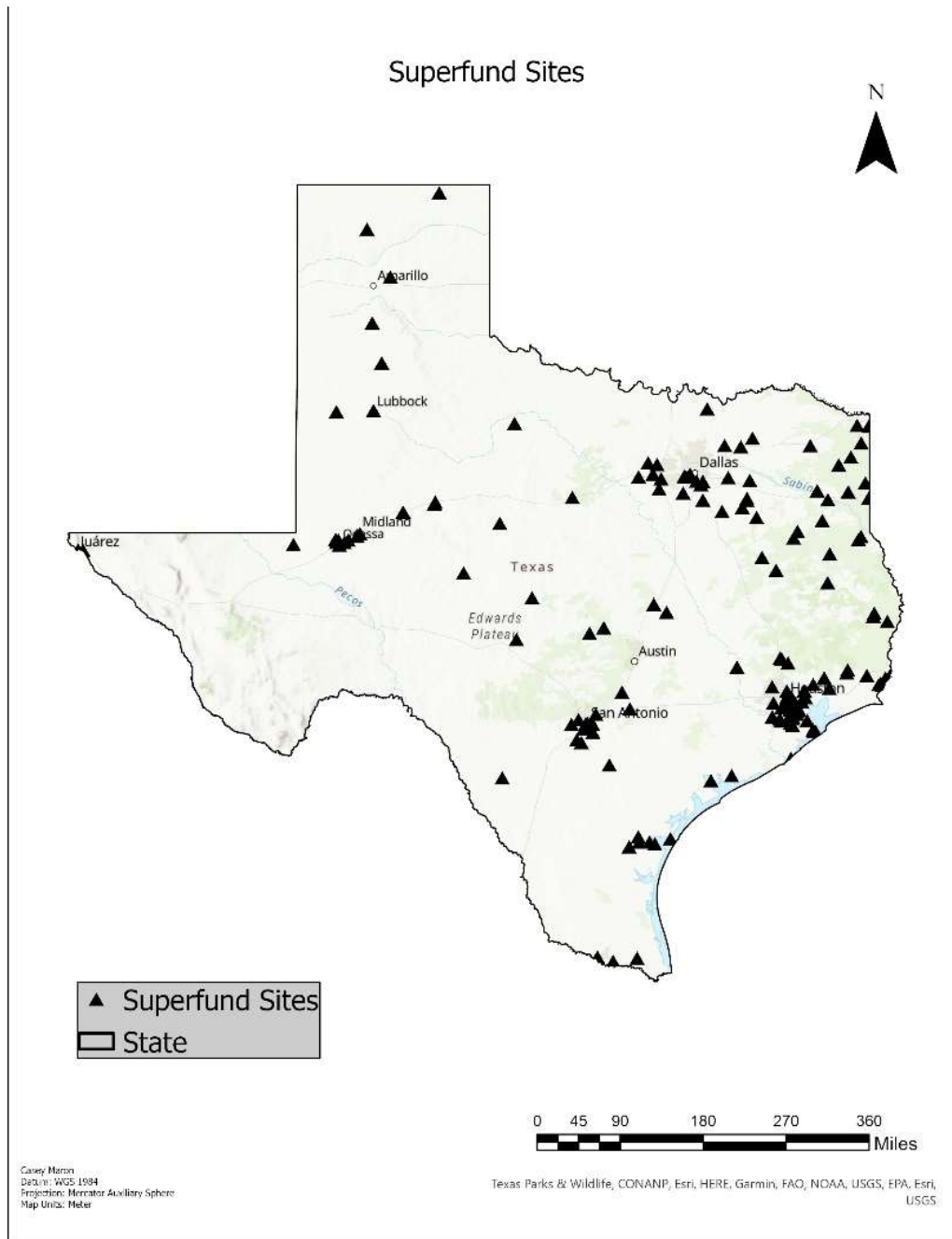


Figure 1 Location of each superfund site within the study area.

3.3 Data Sources

Within this study, the existing state was derived from publicly available databases that contained all the necessary data to complete the research. The locations of the superfund sites

within Texas were obtained from the Texas Commission on Environmental Quality (TCEQ) websites public data portal, which was last updated on March 31st, 2022 (TCEQ 2023). This comprehensive dataset includes information on all 168 registered superfund sites within the study area. To analyze the hazards associated with these sites, data was obtained from the Federal Emergency Management Agency (FEMA) National Risk Index. This index provided data on six natural hazards, namely hurricanes, wildfires, coastal flooding, inland flooding, tornadoes, and earthquakes. In the National Risk Index published in 2021, natural hazards are ranked based on several factors including the likelihoods and consequences of each hazard, social vulnerability, and community resilience (Zuzak et al., 2021). This comprehensive approach takes into account not only the physical impact of the hazards but also the social and economic aspects. Within the Nation Risk Index Report natural hazards are analyzed based on their frequency, magnitude, and impact and from that data a ranking for the hazards can be formed and shown in the list below. This list will make up the ranking list for the weighted analysis that will be used to perform the spatial analysis to determine which superfund sites are at risk of being impacted by natural hazards.

- | | |
|---------------------|--------------------|
| 1. Hurricanes | 2. Wildfires |
| 3. Coastal Flooding | 4. Inland Flooding |
| 5. Tornadoes | 6. Earthquakes |

By utilizing the risk index score data from the National Risk Index for the state of Texas, spatial analysis was conducted to generate the results of this study. The integration of these

various datasets allows for a comprehensive assessment of the risks posed by superfund sites in Texas and provides valuable insights for environmental planning and management.

3.4 Spatial Analysis

The approach of this study is to create a weighted analysis following the ranking of natural hazards from most destructive to least and to then spatial going those hazards to the superfund sites in order to find which sites are at higher risk of being impacted from the studies hazards. In order to create the findings discussed later in this article a few steps were needed to clean up and refine the data provided by the National Risk Index to be able to create the weighted spatial analysis. These Steps include:

- 1) Located data from within the Nation Risk Index and reduced it down just the six natural hazards within this study along with trimming dataset down to just Texas (FEMA 2023).
- 2) Located data for reach superfund site with important data along with study area outline (location and name) (TCEQ 2023).
- 3) Normalized the risk index score for each hazard to a scale of 0-100 converting any null values to zero.
- 4) Composed a spatial join on each natural hazard to the superfund sites on a scale of census tracks.
- 5) Using thing composite index tool, the join all risk indexes according to these studies weighted scale ranking hurricanes at 6 the highest and earthquakes 1 for the lowest weight.

- 6) Using the combined weighted index, the superfund sites were then spatially joined to create a graduated scale to using the index score to represent the total risk to superfund sites from all natural hazards in a weighted scale.
- 7) Using the previous steps, the risk of each individual hazard was created to see the impact it produced.

CHAPTER 4 – RESEARCH FINDINGS

4.1 Superfund Site Risk

Superfund sites, which are areas designated by the Environmental Protection Agency and Texas Commission on Environmental Quality as being heavily contaminated and requiring cleanup, face the risk of being impacted by natural hazards. The gravity of this risk can be visually represented in Figure 1, which presents a combined analysis of all Superfund sites. This analysis takes into account both the weighted analysis of these sites and the spatial interaction that occurs with natural hazards. The figure employs a Risk scale ranging from 0 to 100, with 0 indicating a low risk and 100 signifying a very high risk of a Superfund site being impacted by a natural hazard. To enhance the clarity of the figure, the ArcPro software used in its creation divided the risk of these sites into natural breaks in classification, which are explained in the legend accompanying the figure. This comprehensive analysis and visual representation of Superfund site risks provide valuable insights for decision-makers, environmentalists, and communities affected by these hazardous areas, aiding in prioritizing cleanup efforts and implementing necessary measures to mitigate potential dangers.

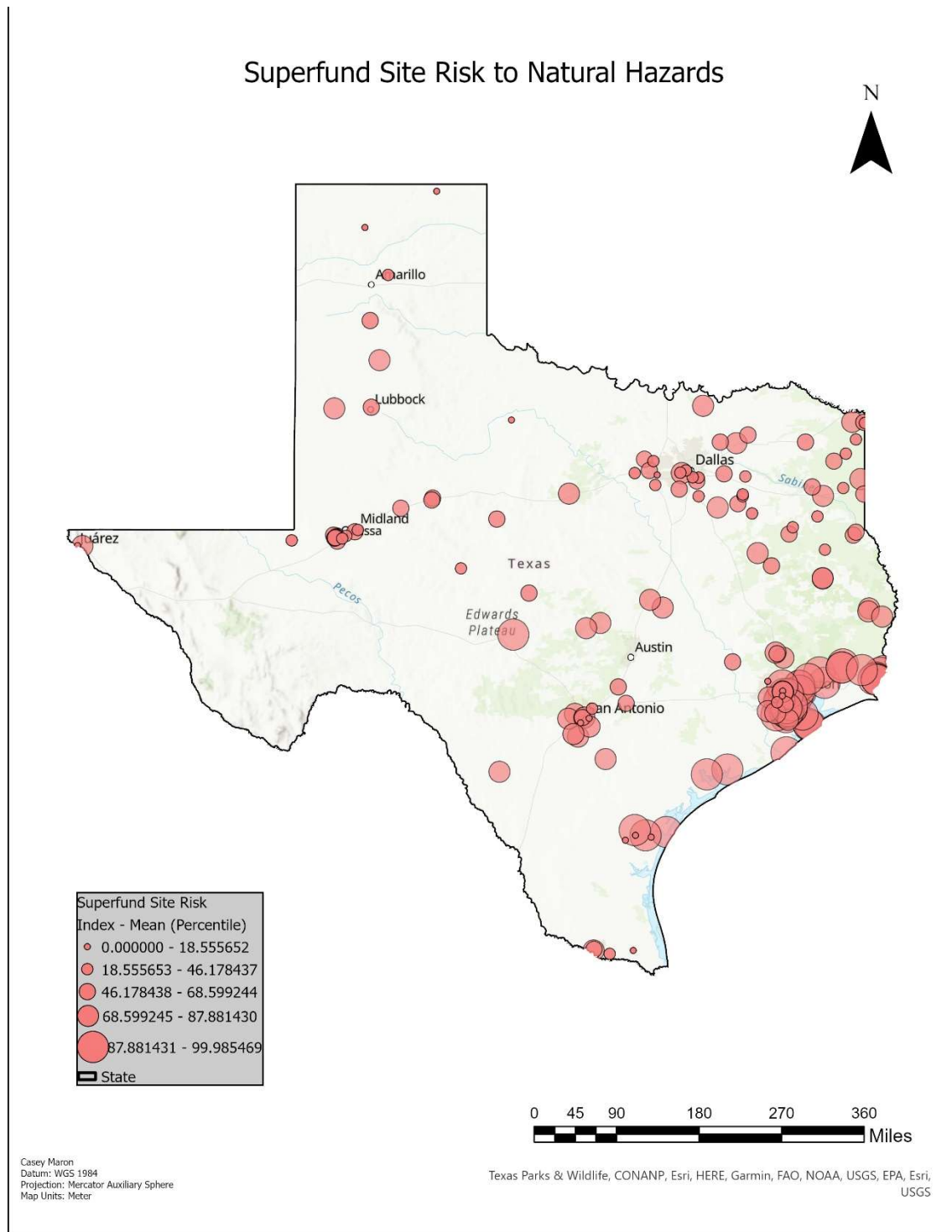
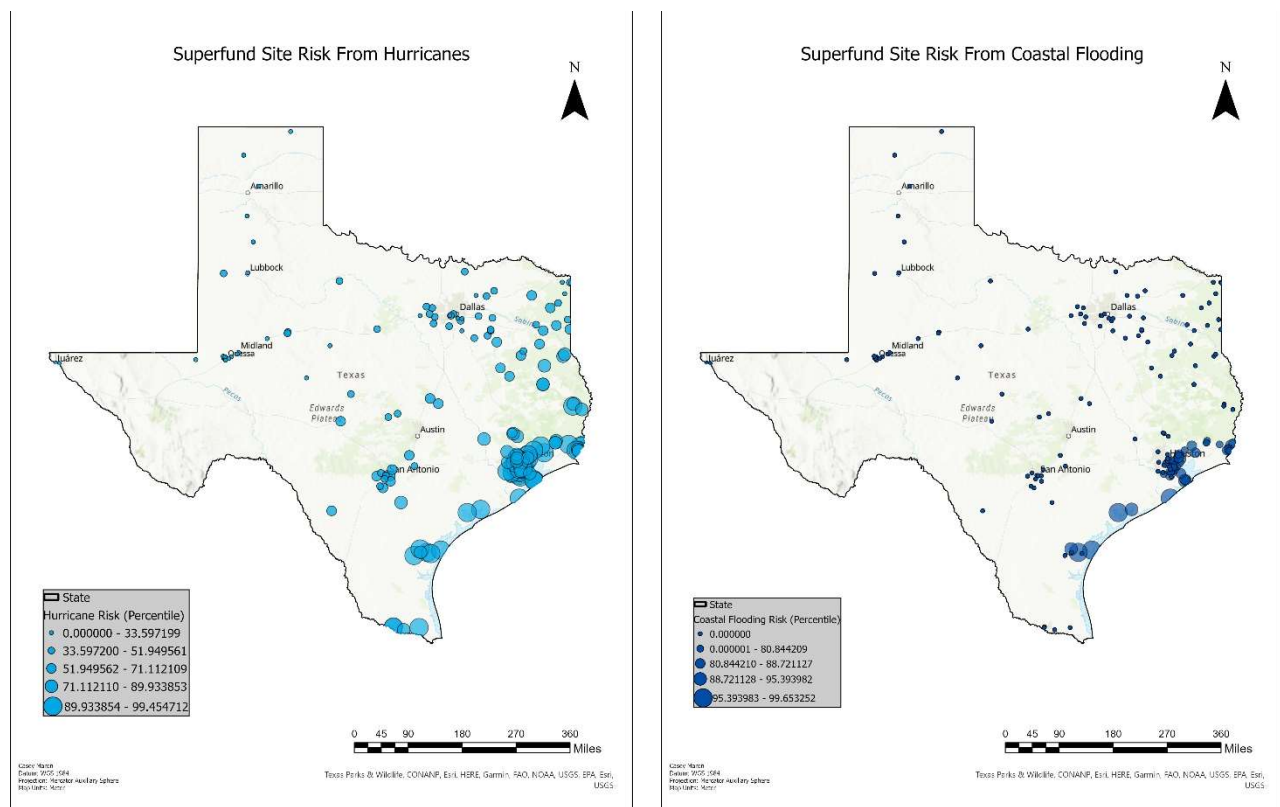


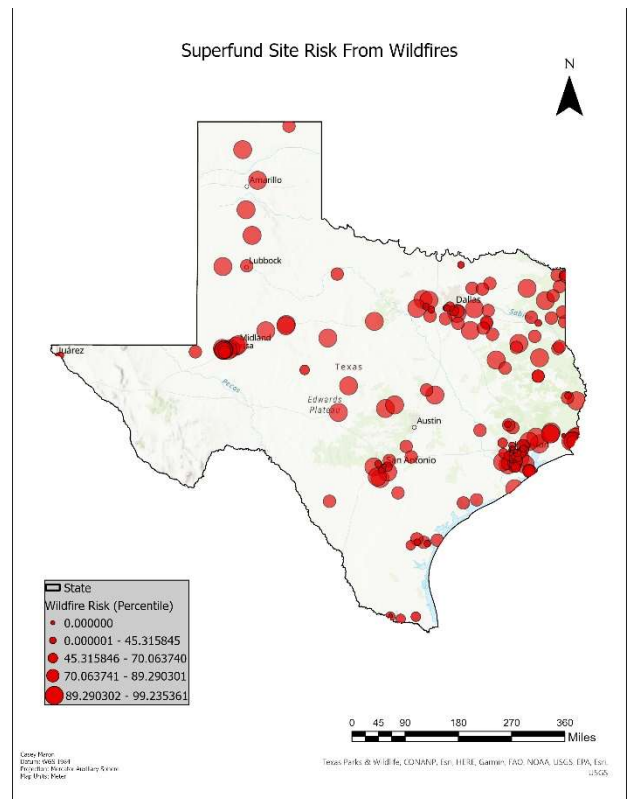
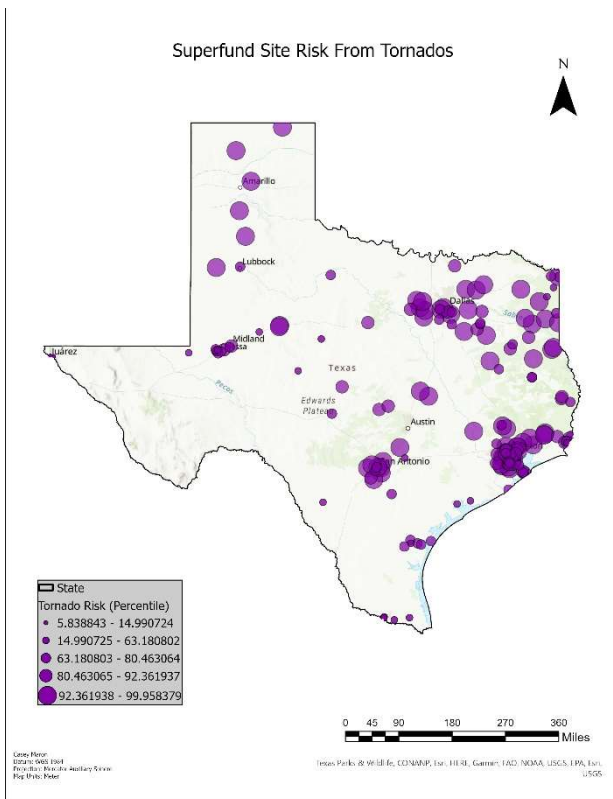
Figure 2 Shows the combined weighted analysis of all hazards. The larger circles indicate that a site is at a higher perceived risk.

The Superfund risk of being impacted by natural hazards is a significant concern, as depicted in Figure 1. This map showcases the percentage of risk associated with natural hazards

affecting the 168 superfund sites in the study area. It becomes evident that superfund sites located in coastal regions face a higher risk due to natural hazards like hurricanes and coastal flooding. This is particularly alarming, as these sites are more susceptible to the adverse effects of such hazards. Figure 3 further highlights this issue by presenting a table illustrating the top 10 at-risk superfund sites, as determined by a weighted analysis. All of these sites fall within the 98th percentile of perceived risk when it comes to being impacted by natural hazards. Notably, there is another area of concern in the central and northeast section of the study area. Here, the risk stems from the potential contact between tornados, wildfires, and the superfund sites. This high-risk zone emphasizes the need for proactive measures to mitigate the potential damage and ensure the safety of these sites.

4.2.1 Superfund Site Risk by Each Hazard





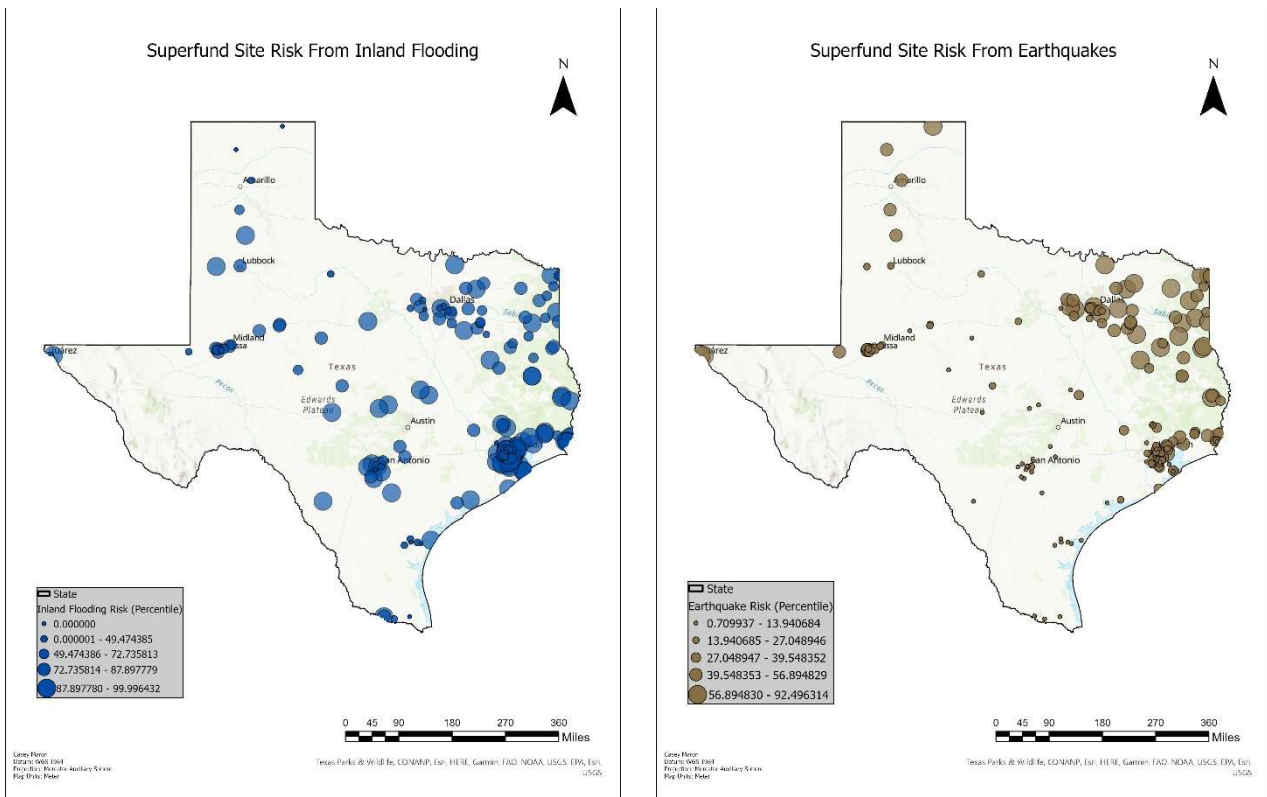


Figure 3 Superfund Site risk shown by each individual hazard. The larger circles indicate that a site is at a higher perceived risk.

4.2.2 Hurricanes and Coastal Flooding

When examining the data presented in Figs. 4, it becomes clear that hurricanes and coastal flooding play a substantial role in contributing to the perceived risk of natural hazards in coastal regions. This is primarily due to the higher probability of occurrence along the coastal line, as well as the historical paths that these storms tend to take, leading to areas near the northeast part of Texas showing higher levels of risk. The consistent impact of hurricanes and coastal flooding in these areas has heightened the awareness and concern for potential hazards among the local population. Conversely, in the northern parts of the study area where the likelihood of being impacted by these hazards is minimal, the model effectively demonstrates

lower levels of risk. This suggests that the model accurately reflects the varying degrees of risk across the region based on the specific hazards that pose a threat. By focusing on the data presented in Figs. 4, it becomes evident that hurricanes and coastal flooding are significant factors in assessing the perceived risk of natural hazards in coastal regions, while other areas with fewer occurrences of such hazards exhibit lower risk levels.

4.2.3 Tornadoes

Analyzing Figs. 4, it becomes evident that the map depicting the risk associated with tornadoes reveals a concerning reality: a majority of the sites within the study area are at risk of being impacted by tornadoes. These findings align with our knowledge of weather patterns and areas that have previously experienced tornadoes. It is worth noting that sites situated within the southern tip of Texas, as well as certain central locations, particularly in the more mountainous regions, appear to have a relatively lower risk. This observation suggests that these areas may be less susceptible to tornadoes compared to other parts of the study area. By examining this map, it becomes apparent that the hazards data for tornadoes significantly influences the overall risk, as it exerts its influence throughout the entire study area. Such information is crucial for understanding and mitigating the potential impact of tornadoes on the region.

4.2.4 Wildfires

Looking at figs. 4 on wildfire risk, it has been observed that wildfires pose a significant threat to non-urban superfund sites across the entire study area, similar to tornadoes in figs. 4. This finding highlights the importance of understanding and mitigating the risk of wildfires, especially in regions like Texas with a naturally drier climate. The study reveals that the risk of superfund sites being impacted by wildfires is generally consistent throughout the study area.

However, there is a slightly lower risk within the coastal region, presumably due to the assumed wetter conditions in that area. These findings underscore the need for proactive measures to prevent and manage wildfires in order to protect non-urban superfund sites and the surrounding environment from potential devastation.

4.2.5 Inland Flooding

Inland flooding, as observed in figures 4, displays a relatively sporadic risk compared to other hazards. The distribution of this risk is not evenly spread due to its association with riverine flooding, which tends to occur in specific areas prone to rising rivers. Analyzing the map, it becomes evident that the majority of superfund sites at risk are concentrated in the central to southeast part of the study area, with a few located in the panhandle. This uneven distribution can be attributed to the fact that the map data utilizes census tracks, which may encompass either rivers along their borders or multiple rivers within a concentrated track. These factors contribute to the portrayal of a higher risk in certain areas and highlight the sporadic nature of inland flooding.

4.2.6 Earthquakes

Earthquakes, though uncommon, can indeed occur in Texas, as indicated by the map in figure 4. This natural hazard primarily impacts superfund sites, with the majority located in the northeast region, and a few scattered in the northwest and panhandle areas. However, it is important to note that earthquakes pose a minimal risk to most superfund sites, and they carry the least weight in terms of their potential effects on the overall risk to these sites. While any risk should be taken seriously, the occurrence of earthquakes in Texas is relatively infrequent compared to other natural hazards. Therefore, the impact of earthquakes on superfund sites in the

state is generally minimal. It is crucial, however, to ensure that appropriate measures are in place to mitigate and manage the risk of earthquakes in these areas.

4.2.7 Superfunds Sites Most at Risk

1) FALCON REFINERY, INGLESIDE, TX	2) PATRICK BAYOU, Deer Park, TX	3) HU-MAR CHEMICAL S Palacios, Tx	4) SAN JACINTO RIVER WASTE PITS, Highland, Tx	5) FRENCH, Crosby, Tx
6) MOTCO, Texas City, TX	7) SPECTOR SALVAGE YARD, Orange, Tx	8) GULFCO MARINE MAINTENANCE, Brazoria, Tx	9) TRIANGLE CHEMICAL, Orange, Tx	10) MCNABB FLYING SERVICE, Brazoria, Tx

Figure 4 Shows the top 10 superfund sites that are at risk they are all 98 percent or greater on the index score scale.

Based on the analysis of the total weighted data in figure 5, it is evident that the top 10 most at-risk superfund sites in the study area are primarily concentrated along the Texas coastline surrounding the Houston metropolitan area. These sites have all received a percentile ranking greater than 98, indicating that they are at the highest level of risk. The significance of this list lies in the fact that not only does the coastal region contain the largest number of superfund sites, but it is also one of the most densely populated areas within the study area. Considering the higher vulnerability of this region to various natural hazards, it becomes imperative to prioritize cleanup efforts in and around the Houston metropolitan area. By

addressing the environmental risks associated with these superfund sites, the potential impact on the large population residing in this area can be significantly reduced. Therefore, focusing cleanup efforts on this coastal region is not only logical but also crucial for ensuring the well-being and safety of the communities affected.

CHAPTER 5 – CONCLUSION

The analysis of this study reveals that the risk of a superfund site located within the state of Texas spreading due to the impact of a natural hazard is highly likely in almost every part of the state. The study indicates that superfund sites in the northeast coastal region face the highest level of risk when it comes to being impacted by a natural hazard, thereby increasing the risk of these sites being spread as a result of such interactions. Several hazards, including hurricanes, coastal flooding, and tornadoes, contribute to a higher risk factor. However, regardless of the site's location, the study demonstrates that there is some form of risk associated with the spread of these sites even after remediation efforts. The findings of this study provide decision-makers with valuable insights, suggesting that sites in the coastal region should be given priority in remediation efforts to safeguard both the environment and the health of the people residing near these sites. As natural hazards continue to change due to global environmental impacts, our approach to cleaning up and preventing the spread of toxic superfund sites must also evolve. By analyzing this data, stakeholders and policymakers can better plan for or prevent the spread of superfund sites in the face of natural hazards. Furthermore, this information highlights the need for future research to examine the potential impact and cost if these sites were to be spread by a natural hazard. Overall, this study underscores the strong evidence that natural hazards pose a significant risk to superfund sites and emphasizes the importance of proactive measures to address this issue effectively.

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