Journal of Geographic Information System, 2023, 15, 563-579
https://www.scirp.org/journal/jgis
ISSN Online: 2151-1969
ISSN Print: 2151-1950

Tornado Impacts in the US from 1950-2015: A GIS-Based Analysis of Vulnerability and Evolving Risk Zones for Human Casualties

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How to cite this paper: Hwang, S.N. and Meier, K. (2023) Tornado Impacts in the US from 1950-2015: A GIS-Based Analysis of Vulnerability and Evolving Risk Zones for Human Casualties. *Journal of Geographic Information System*, **15**, 563-579.
https://doi.org/10.4236/jgis.2023.155028

Received: September 26, 2023
Accepted: October 23, 2023
Published: October 26, 2023

Abstract

The United States is one of the major countries in the world that faces a numerous number of tornadoes every year, directly and indirectly experiencing extensive property damage and human casualties as well as a variety of demographic, socioeconomic, and environmental impacts. This research provides a GIS-based examination of the ways past tornadoes that occurred in the US in the period 1950-2015 have played out in the context of bodily injuries and loss of human life. To this end, the research collected major secondary data (*i.e.*, georeferenced tornado point data) from the Storm Prediction Center (SPC) tornado database and conducted raster-based spatial analysis, utilizing techniques like point density analysis and map algebra to locate areas that have a high risk of tornadoes and to create maps that show relationships between the past tornado events and human casualties. One of the major research findings shown by the spatial analysis was that the geographic areas or regions impacted by tornadoes varied over time. In addition, the statistical results showed a trend that the tornado-prone regions extend from "Tornado Alley" to the states of Illinois, Mississippi, Tennessee, Alabama, and Florida, indicating that the communities in those states that are newly considered to be vulnerable to tornadoes should step up to develop their own tornado mitigation plan to help protect the public and its property from tornadoes. Such plans can play a crucial role in safeguarding the public and protecting property from tornadoes' potential impact. Additionally, urban planners and policymakers can use this information to make informed decisions about building codes and infrastructure development in tornado-prone areas, potentially reducing the impact of future tornado events on human lives and property.

Keywords

Tornadoes, Emergency Management, Spatial Analysis, Environmental

Hazard, Natural Hazard

1. Introduction

Tornadoes are recognized as one of the most severe natural hazards in the United States. Ashley [1] undertook a comprehensive spatial and temporal analysis of tornado fatalities, highlighting the severe toll they have taken over 125 years in the U.S. The country experiences over 900 tornadoes annually and from 1950 to 2015, there were a staggering 60,114 officially reported tornadoes, resulting in 5823 deaths and 193,856 injuries [2]. Tornadoes, particularly those with high wind speeds, can cause widespread property damage and lead to human casualties, directly affecting people and their belongings. The far-reaching effects of tornadoes also extend to various aspects, including demographics, socioeconomic conditions, and the environment. This heightened vulnerability raises concerns about how people experience tornado disasters.

Extensive research has been conducted to analyze past tornado events in the United States and their correlations with human fatalities and injuries. These studies have explored various factors contributing to tornado-related deaths, such as locational vulnerability, risk perception, social vulnerability, and the efficacy of prediction, detection, and warning technology [3] [4] [5] [6]. The findings from these past studies have indicated that several risk factors play a significant role in determining the loss of human life during tornado events in the country.

In further detail, there are several reasons why the impact of tornadoes has been on the rise. First, population growth and expansion into tornado-prone regions have had a substantial impact on tornado-related death rates [5]. What is noticeable is that urban areas in the United States have seen significant development in regions prone to natural hazards, including tornadoes. Strader *et al.* [7] emphasized how urban sprawl, especially in tornado-prone areas, leads to increased vulnerabilities due to the heightened concentration of residences. The phenomenon of urban sprawl and increasing population densities in such regions have heightened the risk of catastrophic tornado death events [8]. Agee and Taylor [5] also stressed the impact of population growth in tornado-prone regions on the increasing death rates. In line with this, Hall and Ashley [8] highlighted the threats posed by urban sprawl in regions like northeastern Illinois, where the risk of significant tornado impacts is magnified due to dense populations. This development pattern has unfortunately resulted in an increased concentration of people and property in areas that are at higher risk of tornado impacts [9] [10].

Second, along with locational vulnerability, prior research also suggests that fluctuations in tornado-related mortality rates are intricately linked to public perceptions of environmental hazards [6] [11]. The public's perceptions and judgments of tornado risks are central to both immediate and long-term protective actions [11]. Risk perceptions influence how people interpret tornado forecasts and warnings, thereby affecting decision-making processes that may either reduce or enhance the potential for tornado-related injuries [6]. Schumann *et al.* [12] noted that factors such as information-seeking habits and previous tornado experience greatly influence tornado risk perception and warning response. Direct experience with previous tornado events generally results in enhanced information seeking, risk perception, and protective action [13] [14] [15] [16]. In addition to previous tornado experience, local disaster culture has the potential to influence tornado awareness, preparedness, and mitigation [12]. Local disaster culture develops in response to a recurrent hazard and may result in either enhanced or diminished risk aversion [17].

Third, in addition to locational vulnerability and risk perception, there are numerous socio-economic and demographic factors that influence human casualties associated with tornado events [4]. The societal effects of tornadoes are vast, encompassing demographics, socioeconomic conditions, and environmental influences. Donner [4] specifically looked at how social, environmental, and political factors influenced tornado-caused deaths and injuries in the U.S. between 1998 and 2000. Using a political ecology perspective, the study suggested that the structure of society greatly impacts disaster outcomes. It especially noted the role of local politics and economics in determining how tornadoes affected communities. Meanwhile, research shows that shifting demographic patterns and increases in social vulnerability have a significant impact on overall tornado risk [3]. There are numerous socio-economic and demographic factors that affect a community's ability to respond to, cope with, recover from, and adapt to tornado-related hazards [18]. Factors such as income, education, race, gender, and housing type are major determinants of tornado-induced deaths. Existing studies indicate that counties with higher per capita income and per capita government spending on public safety have fewer tornado-related deaths than counties with greater income disparity [19]. Furthermore, these studies suggest that housing quality is a critical factor in explaining tornado-induced fatalities. Those with a lower socio-economic status are more likely to reside in mobile homes that do not provide adequate protection from tornado hazards [20]. The likelihood of a tornado-related fatality in a mobile home is believed to be ten times or more than that in a permanent home [21]. Additionally, research suggests that communities with higher education attainment experience decreased tornado-related fatality rates due to enhanced emergency decision-making processes [19] [22]. Along with socio-economic and demographic factors, existing literature suggests that prediction, detection, and warning technology significantly impact tornado-related fatality rates across the United States. As this technology improves, tornado-induced deaths and injuries are generally reduced [3]. One study found that improved tornado warning technology reduced tornado-related injuries by up to 40% [23].

Lastly, considering the broader implications of climate change, Greenough *et al.* [24] discussed the potential impacts of climate variability on extreme weather events, suggesting that anthropogenic influences might be exacerbating the frequency and intensity of such events. Though climate-induced extreme weather events have been a secondary area of interest in related research, existing studies suggest that anthropogenic climate change may influence the frequency, timing, intensity, duration, and regional occurrence of extreme weather events like tornadoes [24]. It appears that the impact of climate change on tornado-induced human mortality is not fully understood [25] but there is evidence of increasing tornado outbreak risk in the United States. However, it remains uncertain how much of this increased risk is attributed to a changing climate [26] [27]. While the link between climate change and tornado activity is tenuous, current research suggests that anthropogenic climate change may increase the likelihood of atmospheric conditions that contribute to tornado events [28]. Other research indicates that "tornado alley", a loosely defined area of the U.S. where there is a high potential for tornado development, may be shifting and expanding alongside changing climatic conditions [29]. It is predicted that the median annual impact of tornadoes will rise threefold in the coming decades due to increased climate variability and growth in the human-built environment [7]. The risk that changing tornado activity poses to human life must be adequately understood in order to effectively increase resilience among vulnerable populations.

Indeed, an extensive body of literature delves into these issues, guiding researchers in comprehending the present scope of the aforementioned relationships. Nonetheless, limited investigation has been conducted to elucidate the interplay between tornado frequency, intensity, human fatalities, and injuries through the utilization of geospatial technology. Thus, this GIS-based study is poised to offer a chance to capture a momentary portrayal of areas where specific demographic groups might face detrimental consequences due to such tornado risk. More specifically, this research is anticipated to enhance and advance the scientific understanding of how past tornadoes that occurred in the US between 1950 and 2015 have impacted bodily injuries and loss of human life. For this purpose, the research gathered significant secondary data, specifically georeferenced tornado point data, from the Storm Prediction Center (SPC) tornado database. To analyze the relationships between past tornado events and human casualties, GIS technology and geoprocessing tools were employed to create informative maps.

There has been an array of discussions regarding the location of the regions susceptible to tornadoes in the US [30]. Therefore, this research aims to identify specific locations at the state or regional level in the US with the highest frequency, as well as the ones most vulnerable to deaths and injuries due to the historical tornado events during the period 1950 and 2015. The study area is the entire United States. Although tornadoes have been identified in many places of the world, they are largely concentrated in the US, especially the Midwest, Southeast, and Southwest regions. In particular, the region that has the highest tornado frequency is called Tornado Alley which includes: Texas, Oklahoma, Kansas, South Dakota, Iowa, Illinois, Missouri, Nebraska, Colorado, North Dakota, and Minnesota. The next section discusses how this research has been conducted, followed by the research results and conclusions.

2. Data and Analytical Methods

As delineated in the introduction, this study embarks on a Geographic Information System (GIS)-based analysis to explore the repercussions of tornadoes occurring in the United States from 1950 to 2015, with a specific emphasis on ensuing bodily injuries and human fatalities. Notably, a limited number of previous studies have investigated these particular relationships. Thus, crafting and utilizing our unique methodology, illustrated in **Figure 1**, proves to be meaningful.

This research encompasses the entire United States as its study area, with the unit of analysis conducted at the state level as shown in **Figure 2**.

To achieve the research objectives identified through the literature review, secondary data were sourced from the Storm Prediction Center (SPC) tornado database, managed by the US National Weather Service (NWS). This database encompasses information about historical tornado events in the United States throughout the 1950-2015 timeframe. The data were assimilated into ArcMap, a leading Geographic Information System (GIS) software, to conduct exhaustive geospatial analyses employing methodologies such as point density analysis and map algebra.

This strategy not only identified areas with heightened tornado frequency and magnitude. In addition, the GIS-based analysis aimed to investigate how past tornado events have influenced human lives in the US, particularly in terms of fatalities and injuries. To do this, the tornado events were grouped into multiple

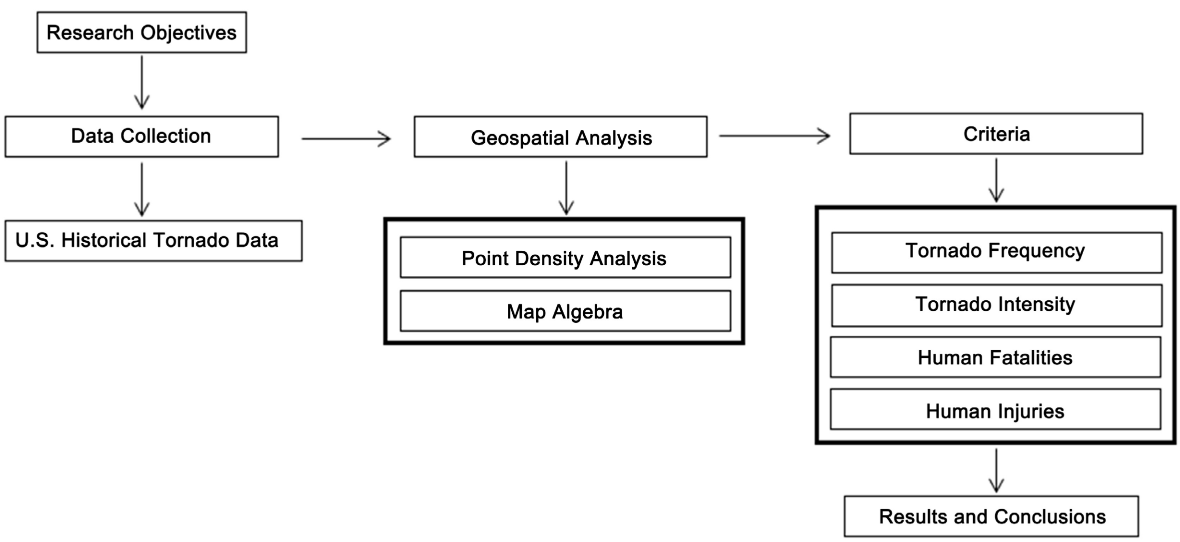


Figure 1. Research flow.

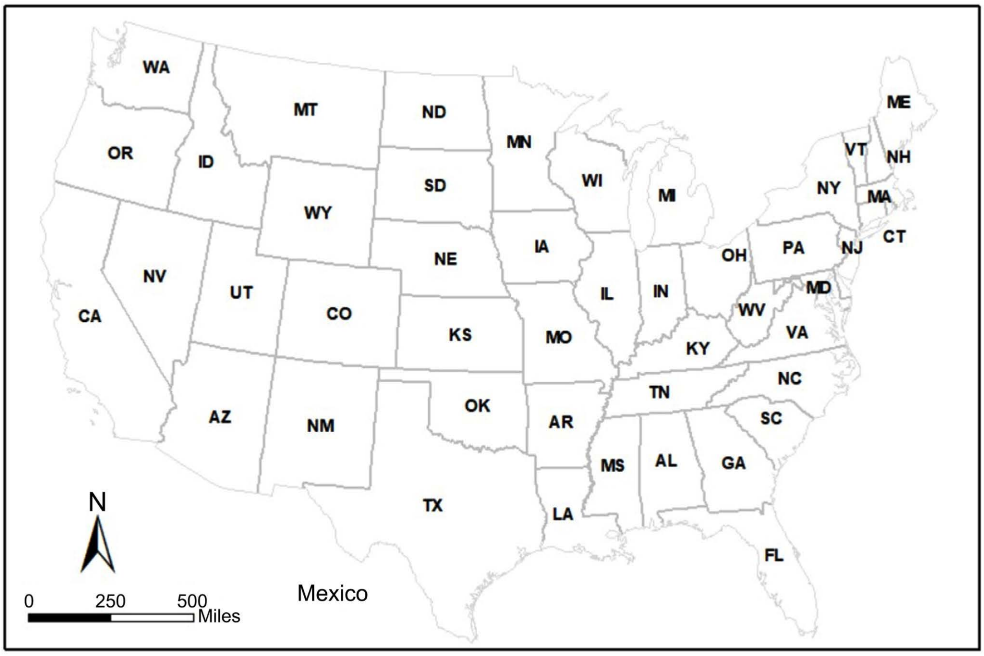


Figure 2. Map of the U.S.

time periods to show patterns and shifts in the number of casualties and injuries over the years as well as the impact of these natural disasters on each state.

To be more specific, the tornado layer was selected and separated into eight groups, based on different time periods by using attribute queries on ArcMap, each consisting of 10 years (e.g., ranging from the start of 1950 to the end of 1959), only except for the data that cover the entire time period (*i.e.*, 1950-2015) and the most recent data that range from 2010 to 2015, as shown in the next "Results" section. In particular, the data for the entire time period (1950-2015) showed a comprehensive overview of tornado occurrences in recent times.

The point density analysis was performed to create raster surfaces, based on four different criteria: tornado frequency, its intensity, human fatalities, and injuries. As shown in the results section providing a detailed account of the findings from the geospatial analysis, each of the raster-based maps contains tornado-related information within one of the four different categories over a certain time period: namely, insights into trends of tornado frequency and intensity over the years, spatial distribution of tornado events, and their effects on human populations in terms of fatalities and injuries. Then, the maps showing tornado intensity, and human fatalities and injuries were combined to create maps representing the locations with the highest vulnerability rates due to the historical tornadoes over each of the time periods.

3. Results

Tornado Frequency

The Point Density Analysis (PDA) was conducted on tornado data from 1950-2015 to produce tornado frequency map layers, as shown in **Figure 3**. These

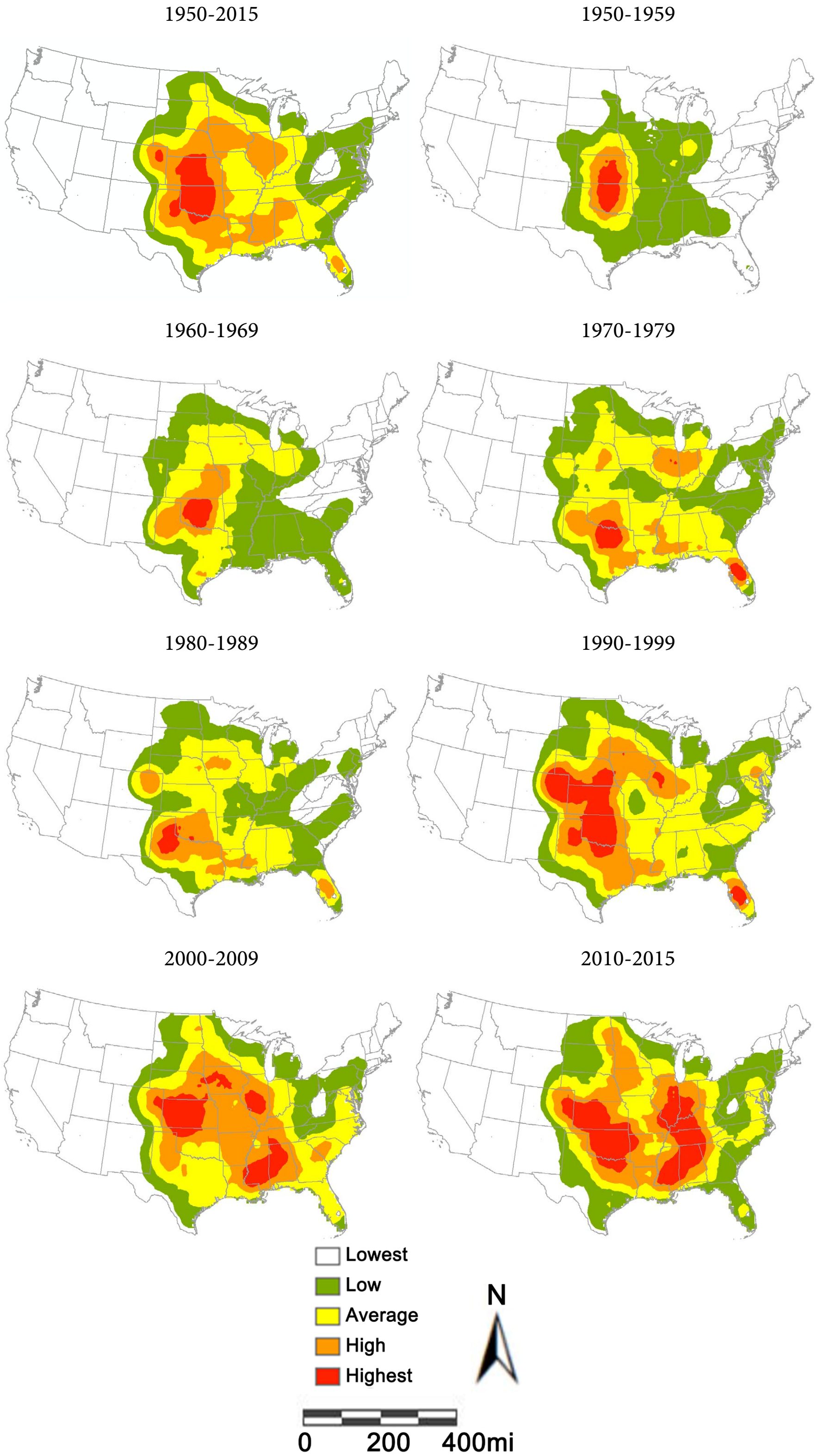


Figure 3. Tornado frequency in the United States.

layers depict regions prone to tornado activity. Each map displays tornado frequency variations over predominantly 10-year intervals. These variations are categorized into five levels, ranging from the lowest (0.00) to the highest (0.006). The patterns of tornado occurrences, as seen from the data, reveal that certain geographic regions have undergone significant changes in tornado activity over the years. When examining the 1950-1959 map layer, it becomes clear that the belt of the most intense tornado activity stretched from northern Texas, cutting through the heart of Oklahoma, and reaching up to the terrains of Kansas and Nebraska. This suggests a concentrated tornado corridor in this central region of the United States during that decade.

However, while the activity in some regions has fluctuated, Oklahoma stands out as a notable exception. Throughout the entire analysis period, this state has shown a remarkable consistency in its high tornado frequency. This could be attributed to a combination of geographical, meteorological, and atmospheric factors that make Oklahoma particularly susceptible to tornadoes. The consistent pattern observed in Oklahoma may warrant further study to understand the underlying causes and to develop targeted tornado preparedness and response strategies for the region.

Subsequent maps from the analysis suggest an evolving pattern of tornado activity. Initially, areas with higher tornado frequency were confined to states like northern Texas, Oklahoma, Kansas, and Nebraska. However, as time progressed, this high-frequency zone began to stretch and include states like Colorado, Illinois, Indiana, Kentucky, and Tennessee. Furthermore, the southern region of the U.S. began to show notable increases in tornado occurrences, with states such as Arkansas, Mississippi, Alabama, Georgia, and Florida becoming more prominent in the data.

This shift and expansion in tornado activity might indicate changing meteorological and atmospheric conditions over the decades. While the traditional Tornado Alley—comprising parts of Texas, Oklahoma, Kansas, and Nebraska—is well-known for its tornado-prone nature, it's crucial to recognize the increasing significance of other regions. States like Arkansas, Mississippi, Georgia, and Florida, which aren't typically part of the classic Tornado Alley definition, have demonstrated substantial tornado activity, warranting increased awareness and preparedness measures.

Tornado Intensity

The Point Density Analysis (PDA) used in this analysis provides a detailed representation of tornado intensity (**Figure 4**), utilizing metrics from the Fujita scale. The Fujita scale is a system developed to quantify the intensity of tornadoes based on the damage they cause. It starts from F0, indicating minimal damage, escalating up to F5, which denotes catastrophic and often total destruction. On the maps generated from the PDA, the severity of tornadoes was quantified numerically. The scale for this quantification is further subdivided into five distinct categories. These are benchmarked with values starting from the lowest level (0.00) and extending up to the highest level (0.005). This numeric representation provides a clearer, objective measure of tornado intensities across various regions, enabling us to discern patterns and evaluate risks.

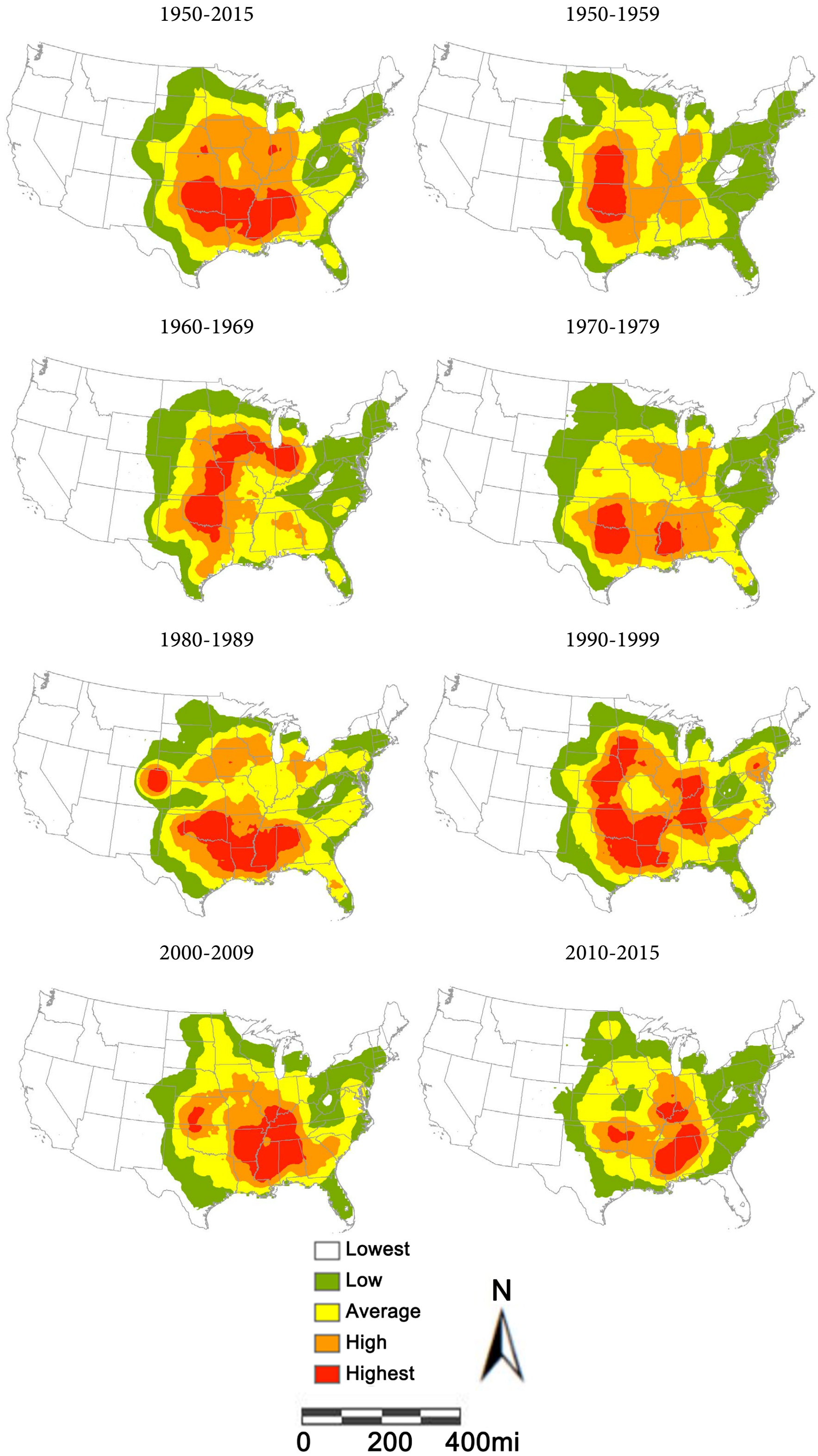


Figure 4. Tornado intensity in the United States.

The maps illustrating tornado frequency provide a visual testament to Oklahoma's consistent vulnerability to tornadoes. Throughout the duration analyzed, Oklahoma consistently emerged as the state most susceptible to tornadoes of high intensity. But it wasn't just Oklahoma that caught attention; several other states showcased heightened tornado activity as well. The layers of the map indicate an extension of high-intensity tornado zones to a broader swath of the U.S. States such as Kansas, northern Missouri, Iowa, northern Illinois, Kentucky, Tennessee, and Indiana are part of this zone. Furthermore, southern Nebraska, northern Texas, and southern states like Arkansas, Mississippi, Alabama, and Georgia too have experienced significant tornado activities over the time frame analyzed.

Interestingly, these geographic patterns of tornado intensity are not unique to this study. When comparing the results derived from this Point Density Analysis (PDA) model that focuses on tornado intensity to previous PDA models based on tornado frequency, this research observes striking similarities. This congruence reinforces the reliability of the PDA methodology in capturing tornado patterns across the U.S. and underscores the need for heightened preparedness in these repeatedly identified high-risk zones. The consistency between the two models suggests that areas frequently hit by tornadoes are also the ones that tend to experience tornadoes of higher intensity.

Human Fatalities

The visuals generated through the Point Density Analysis (PDA) offer an insight into the human fatalities attributed to tornadoes (see **Figure 5**). This quantification scale is divided into five specific categories. These categories are defined by values ranging from a minimum of 0.00 to a maximum of 0.007. The layers of the map specifically highlight regions where the fatality rates due to these violent storms are the highest. It is evident from the data that those areas most at risk of loss of life from tornadoes have shifted and evolved over different periods.

One of the most poignant findings is the eastward and northeastward trajectory of high fatality rates. While tornadoes are often associated with the plains of the U.S., the data indicates that the threat moves eastward through Mississippi and Alabama, and also northeastward through states like Tennessee, Kentucky, Michigan, and Pennsylvania. These areas, which might not traditionally be associated with frequent tornado activity, have experienced events with a tragic toll on human lives.

It is also significant to underline that while some states have seen fluctuating rates, others like Oklahoma, Kansas, Arkansas, Mississippi, and Alabama have consistently emerged as hotspots for tornado-related fatalities. Throughout the duration of the study, these states remained particularly vulnerable, indicating a persistent risk for their populations.

Human Injuries

These map layers generated from the PDA provide insights into the regions most impacted by tornado-induced injuries (see **Figure 6**). The quantification scale for human injuries follows a similar structure as the one used for human fatalities, with both being divided into five specific categories. Predominantly, states lying to the east of the Rocky Mountains emerge as the areas with the highest injury rates. Moreover, it is particularly significant to highlight the overlap

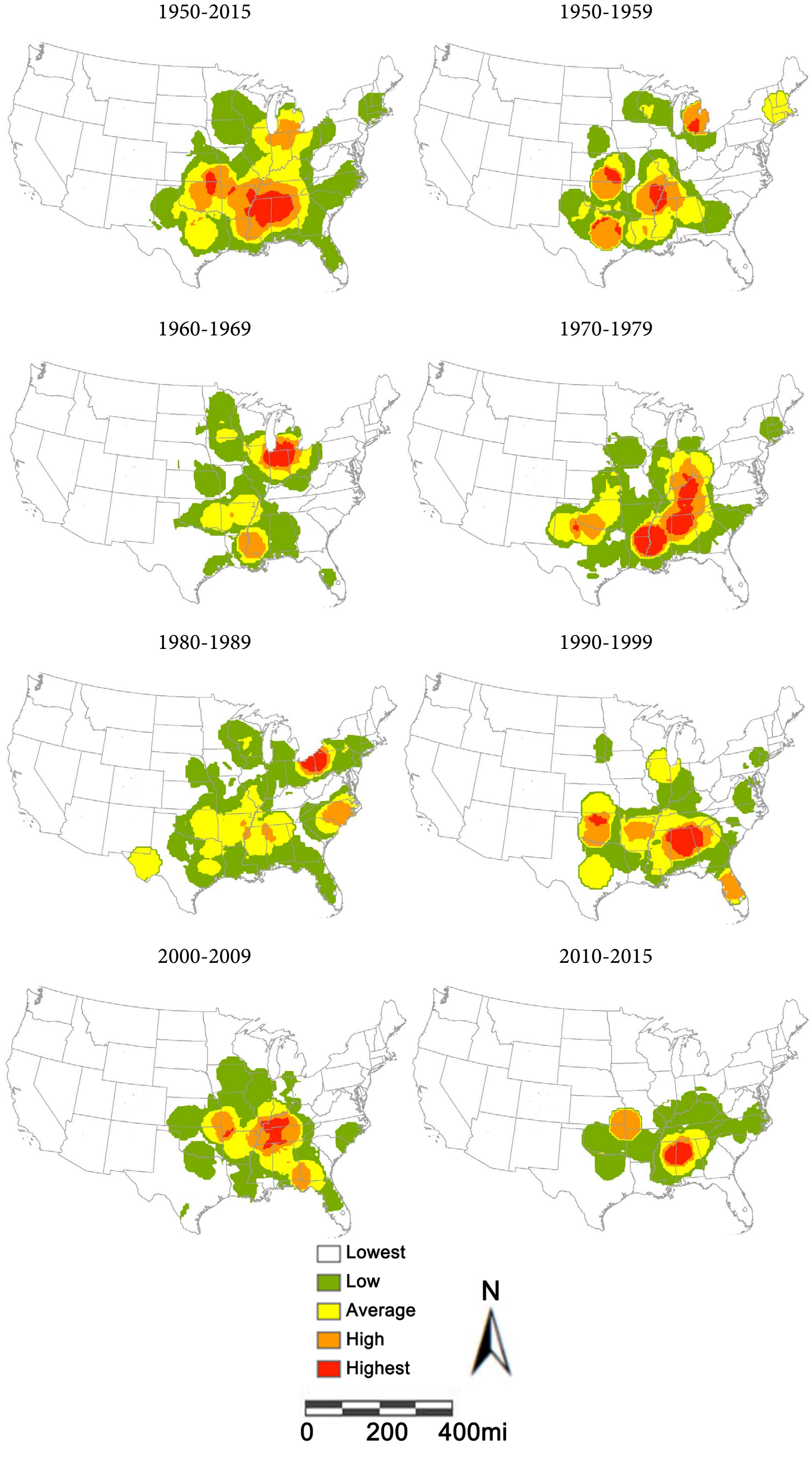


Figure 5. Human fatalities in the United States attributed to tornadoes.

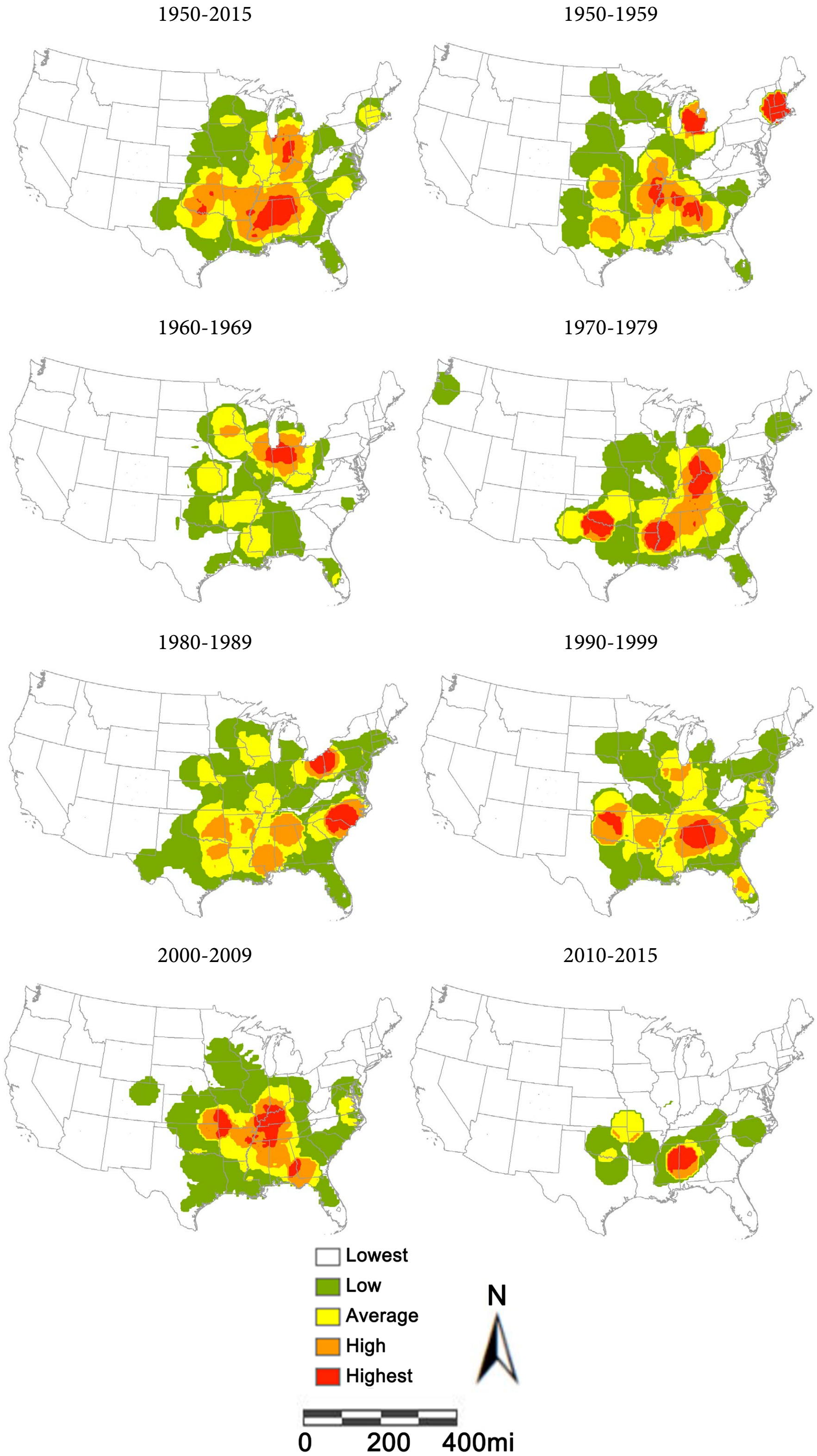


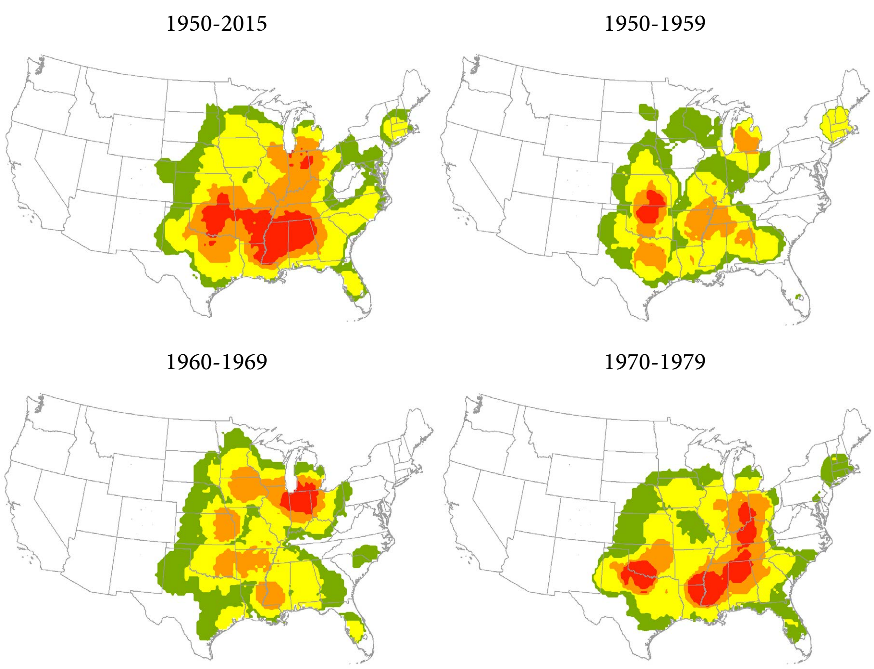
Figure 6. Human injuries in the United States Attributed to tornadoes.

between areas with high injury rates and those with high fatality rates. The regions that frequently experience higher injury numbers are essentially the same areas that record increased fatality rates. This congruence emphasizes the overall vulnerability of these regions to severe tornado impacts. As elaborated in the "Human Fatalities" section, the geographical patterns of regions most affected by tornadoes are not static. The PDA results paint a dynamic picture where the regions bearing the highest human injuries due to tornadoes have shifted over different periods. This variability indicates that while some areas consistently remain at risk, others become more susceptible based on evolving climatic, geographical, or infrastructural factors.

Vulnerability to Tornadoes

The creation of the raster-based map layers was a detailed process that meticulously merged data on tornado intensity with that of human fatalities and injuries. The end goal was to generate comprehensive maps pinpointing regions most vulnerable to historical tornadoes across various time frames, as shown in **Figure 7**. To achieve this, a methodical process was undertaken. First, the cell values of the individual raster layers, namely tornado intensity, human fatalities, and injuries, underwent a reclassification process. This ensured that each layer's output could be standardized into five distinct classes, ranked from 1 (lowest) to 5 (highest). The highest value of 5 was allocated to zones registering the densest data, whether in terms of tornado intensity or human impact (fatalities and injuries). After reclassification, the Raster Calculator tool was used so that the different layers were systematically overlaid to create maps that offered a holistic representation of regions most susceptible to tornado threats.

The final outputs are not only academically intriguing but carry significant practical implications. One of the most salient findings is that the areas with the highest vulnerability rates during 1950-2015 weren't restricted solely to the renowned Tornado Alley states like northern Texas, Oklahoma, and Kansas. While



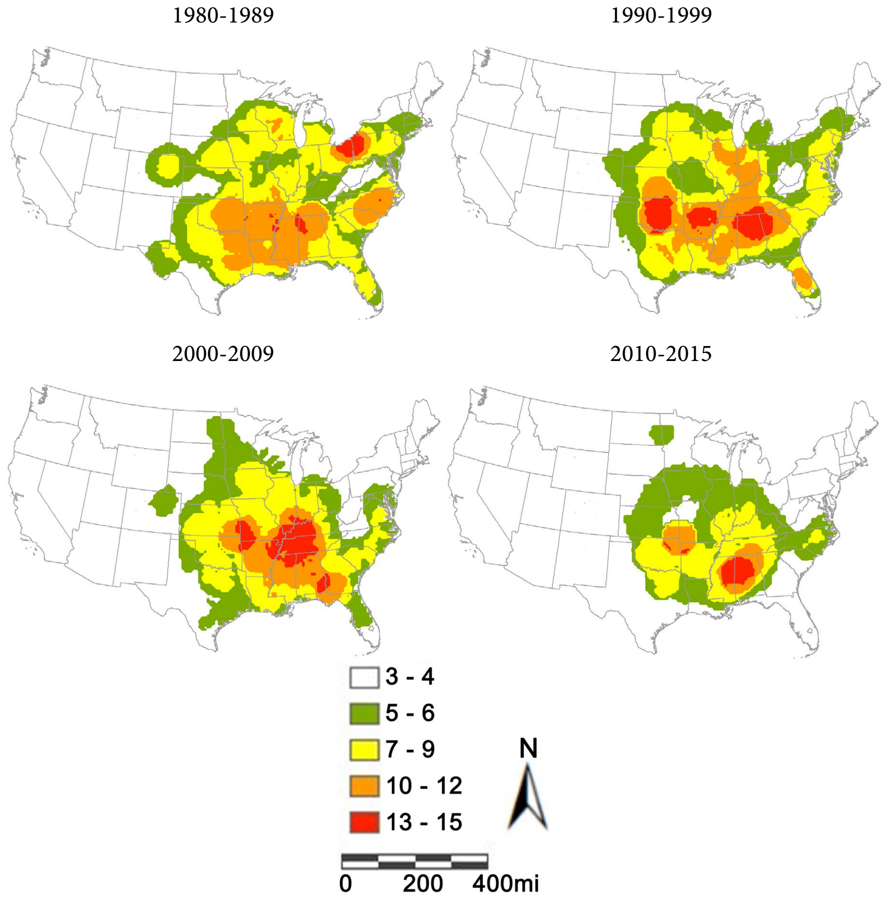


Figure 7. Tornado vulnerability across the United States.

these states indeed showed combined numbers ranging from 13 to 15, suggesting their pronounced vulnerability, the analysis revealed other states outside the Tornado Alley zone as high-risk areas too. South Dakota, Iowa, Illinois, Missouri, Nebraska, Colorado, North Dakota, and Minnesota all emerged as zones of heightened vulnerability. This broader geographical scope highlights the dynamic character of tornado threats and underscores the necessity of readiness beyond the conventional Tornado Alley.

4. Conclusion

This research on historical tornado events from 1950 to 2015 in the United States has provided insights into the patterns and impacts of tornadoes on human lives across various states. Significantly, the vulnerability to tornadoes is no t limited to the traditionally acknowledged Tornado Alley; it also encompasses such states as Arkansas, Mississippi, Georgia, and Florida. This wider geographical scope demands an adjustment in both preparedness and policymaking strategies. A significant correlation exists between areas experiencing high-intensity tornadoes and those with high tornado frequency calls for additional research and strategic planning. In addition, regions with high human fatalities from tornadoes tend to have higher injury rates. Understanding these patterns is vital for implementing specific emergency responses and promoting public awareness campaigns. The vulnerability maps, which merge data on tornado intensity and human casualties, highlight regions most at risk from tornado threats. This challenges the conventional emphasis on Tornado Alley and underscores the need for increased emergency preparedness and awareness throughout the United States. These findings enhance our comprehension of tornado vulnerabilities over a broader geographic scope and emphasize the ever-changing nature of these threats. This underscores the need for continuous adaptation in all phases of emergency management, including emergency preparedness, disaster response, recovery, and hazard mitigation.

5. Further Discussion and Implications

The relationship between areas of high tornado intensity and those of frequent occurrences necessitates an investigation into possible climatic or geographical factors. Delving into reasons why states, such as Oklahoma, are prone to high-intensity tornadoes, could unlock insights valuable for emergency preparedness and mitigation strategies. Furthermore, the association between elevated human fatalities and injuries in specific regions should inform emergency preparedness, infrastructure strengthening, and community outreach efforts, particularly in areas consistently identified as high-risk. The maps revealing a broader geographical range of tornado vulnerabilities necessitate enhancing preparedness and response strategies in states newly flagged as susceptible to tornadoes. Sharing best practices and collaborating between the traditionally known Tornado Alley states and newly pinpointed high-risk areas, like South Dakota, Illinois, and Minnesota, could boost these regions' ability to adapt. There's a need to ensure that first responders in these states have the requisite training and resources to handle tornado emergencies effectively. Future studies should aim to extend this research by incorporating newer data, identifying evolving trends, and delving into the interplay between urbanization, climate change, and tornado occurrences. It's essential to formulate adaptive measures that reduce human vulnerability and bolster resilience in tornado-prone areas throughout the United States. The use of GIS in understanding tornado patterns and risks can lead to informed decision-making. The dynamic interplay between urban development, climate change, and tornado activity emphasizes the importance of ongoing research to bolster resilience and readiness in tornado-prone US regions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ashley, W.S. (2007) Spatial and Temporal Analysis of Tornado Fatalities in the United States: 1880-2005. *Weather and Forecasting*, **22**, 1214-1228.

https://doi.org/10.1175/2007WAF2007004.1

[2] SPC (2017) Severe Weather Database Files (1950-2015). Storm Prediction Center, Norman. http://www.spc.noaa.gov/wcm

[3] Boruff, B.J., Easoz, J.A., Jones, S.D., Landry, H.R., Mitchem, J.D. and Cutter, S.L. (2003) Tornado Hazards in the United States. *Climate Research*, **24**, 103-117. https://doi.org/10.3354/cr024103

[4] Donner, W.R. (2007) The Political Ecology of Disaster: An Analysis of Factors Influencing US Tornado Fatalities and Injuries, 1998-2000. *Demography*, **44**, 669-685. https://doi.org/10.1353/dem.2007.0024

[5] Agee, E. and Taylor, L. (2019) Historical Analysis of US Tornado Fatalities (1808-2017): Population, Science, and Technology. *Weather*, *Climate*, *and Society*, **11**, 355-368. https://doi.org/10.1175/WCAS-D-18-0078.1

[6] Broomell, S.B., Wong-Parodi, G., Morss, R.E. and Demuth, J.L. (2020) Do We Know Our Own Tornado Season? A Psychological Investigation of Perceived Tornado Likelihood in the Southeast United States. *Weather*, *Climate*, *and Society*, **12**, 771-788. https://doi.org/10.1175/WCAS-D-20-0030.1

[7] Strader, S.M., Ashley, W.S., Pingel, T.J. and Krmenec, A.J. (2017) Projected 21st Century Changes in Tornado Exposure, Risk, and Disaster Potential. *Climatic Change*, **141**, 301-313. https://doi.org/10.1007/s10584-017-1905-4

[8] Hall, S.G. and Ashley, W.S. (2008) Effects of Urban Sprawl on the Vulnerability to a Significant Tornado Impact in Northeastern Illinois. *Natural Hazards Review*, **9**, 209-219. https://doi.org/10.1061/(ASCE)1527-6988(2008)9:4(209)

[9] Mileti, D.S. (1999) Disasters by Design: A Reassessment of Natural Hazards in the United States. Joseph Henry Press, Washington DC.

[10] Sorensen, J.H. and White, G.F. (1980) The Adoption of Tornado Protection Measures in Oklahoma. *Environment and Behavior*, **12**, 277-296.

[11] Dewitt, B., Fischhoff, B., Davis, A. and Broomell, S.B. (2015) Environmental Risk Perception from Visual Cues: The Psychophysics of Tornado Risk Perception. *Environmental Research Letters*, **10**, Article ID: 124009. https://doi.org/10.1088/1748-9326/10/12/124009

[12] Schumann III, R.L., Ash, K.D. and Bowser, G.C. (2018) Tornado Warning Perception and Response: Integrating the Roles of Visual Design, Demographics, and Hazard Experience. *Risk Analysis*, **38**, 311-332. https://doi.org/10.1111/risa.12837

[13] Comstock, R.D. and Mallonee, S. (2005) Comparing Reactions to Two Severe Tornadoes in One Oklahoma Community. *Disasters*, **29**, 277-287. https://doi.org/10.1111/j.0361-3666.2005.00291.x

[14] Ho, M.C., Shaw, D., Lin, S. and Chiu, Y.C. (2008) How Do Disaster Characteristics Influence Risk Perception? *Risk Analysis*: *An International Journal*, **28**, 635-643. https://doi.org/10.1111/j.1539-6924.2008.01040.x

[15] Lindell, M.K., Huang, S.K., Wei, H.L. and Samuelson, C.D. (2016) Perceptions and Expected Immediate Reactions to Tornado Warning Polygons. *Natural Hazards*, **80**, 683-707. https://doi.org/10.1007/s11069-015-1990-5

[16] Silver, A. and Andrey, J. (2014) The Influence of Previous Disaster Experience and Sociodemographics on Protective Behaviors during Two Successive Tornado Events. *Weather*, *Climate*, *and Society*, **6**, 91-103. https://doi.org/10.1175/WCAS-D-13-00026.1

[17] Wenger, D.E. and Weller, J.M. (1973) Disaster Subcultures: The Cultural Residues of Community Disasters. University of Delaware Disaster Research Center, Preliminary

Paper #9, 1-20.
https://udspace.udel.edu/server/api/core/bitstreams/8d48faff-ca32-45e0-8971-8d2f3ce12ca9/content

[18] Cutter, S.L., Boruff, B.J. and Shirley, W.L. (2003) Social Vulnerability to Environmental Hazards. *Social Science Quarterly*, **84**, 242-261.
https://doi.org/10.1111/1540-6237.8402002

[19] Lim, J., Loveridge, S., Shupp, R. and Skidmore, M. (2017) Double Danger in the Double Wide: Dimensions of Poverty, Housing Quality and Tornado Impacts. *Regional Science and Urban Economics*, **65**, 1-15.
https://doi.org/10.1016/j.regsciurbeco.2017.04.003

[20] Fothergill, A. and Peek, L.A. (2004) Poverty and Disasters in the United States: A Review of Recent Sociological Findings. *Natural Hazards*, **32**, 89-110.
https://doi.org/10.1023/B:NHAZ.0000026792.76181.d9

[21] Sutter, D. and Simmons, K.M. (2010) Tornado Fatalities and Mobile Homes in the United States. *Natural Hazards*, **53**, 125-137.
https://doi.org/10.1007/s11069-009-9416-x

[22] Muttarak, R. and Lutz, W. (2014) Is Education a Key to Reducing Vulnerability to Natural Disasters and Hence Unavoidable Climate Change? *Ecology and Society*, **19**, 42. https://doi.org/10.5751/ES-06476-190142

[23] Simmons, K.M. and Sutter, D. (2008) Tornado Warnings, Lead Times, and Tornado Casualties: An Empirical Investigation. *Weather and Forecasting*, **23**, 246-258.
https://doi.org/10.1175/2007WAF2006027.1

[24] Greenough, G., McGeehin, M., Bernard, S.M., Trtanj, J., Riad, J. and Engelberg, D. (2001) The Potential Impacts of Climate Variability and Change on Health Impacts of Extreme Weather Events in the United States. *Environmental Health Perspectives*, **109**, 191-198. https://doi.org/10.1289/ehp.109-1240666

[25] Fricker, T., Elsner, J.B. and Jagger, T.H. (2017) Population and Energy Elasticity of Tornado Casualties. *Geophysical Research Letters*, **44**, 3941-3949.
https://doi.org/10.1002/2017GL073093

[26] Tippett, M.K., Allen, J.T., Gensini, V.A. and Brooks, H.E. (2015) Climate and Hazardous Convective Weather. *Current Climate Change Reports*, **1**, 60-73.
https://doi.org/10.1007/s40641-015-0006-6

[27] Elsner, J.B., Elsner, S.C. and Jagger, T.H. (2015) The Increasing Efficiency of Tornado Days in the United States. *Climate Dynamics*, **45**, 651-659.
https://doi.org/10.1007/s00382-014-2277-3

[28] Diffenbaugh, N.S., Scherer, M. and Trapp, R.J. (2013) Robust Increases in Severe Thunderstorm Environments in Response to Greenhouse Forcing. *Proceedings of the National Academy of Sciences*, **110**, 16361-16366.
https://doi.org/10.1073/pnas.1307758110

[29] Inskip, S. (2021) Effects of Anthropogenic Climate Change on the Occurrence of Supercellular Tornadoes in the USA. *Reinvention: an International Journal of Undergraduate Research*, **14**. https://doi.org/10.31273/reinvention.v14i2.716

[30] Coleman, T.A. and Dixon, P.G. (2014) An Objective Analysis of Tornado Risk in the United States. *Weather and Forecasting*, **29**, 366-376.
https://doi.org/10.1175/WAF-D-13-00057.1