Stimers and Paul, J Geogr Nat Disast 2017, 7:2
DOI: 10.4172/2167-0587.1000202

Journal of
Geography & Natural Disasters

Review Article Open Access

Can Elevation be Associated with the 2011 Joplin, Missouri, Tornado Fatalities? An Empirical Study

Mitchel Stimers* and Bimal Kanti Paul

Department of Natural and Physical Sciences, Cloud County Community College, Junction City, Kansas, 66441, USA

Abstract

The 2011 Joplin, MO, USA, tornado set a record in terms of the number of lives lost-no other tornado in the United States had killed as many as 161 people since 1950. There are many stochastic parameters that can affect the speed, direction, and magnitude of a tornado and it is thought that elevation may play a role in tornado intensity. The Joplin tornado created a track whose elevation was approximately 50 m from beginning to end, providing the impetus to examine whether or not the elevation change over the damage path tornado is associated with fatalities that resulted from the event. Using data collected from various sources, and the application of GIS as well as non-parametric statistics, we reveal that the elevation and tornado fatalities are inversely related, however; the relationship is not statistically significant, the reasons for which are discussed.

Keywords: Joplin tornado; Tornado fatalities; Elevation; Damage zone; GIS

Introduction

The catastrophic tornado that struck the southcentral part of Joplin, MO, in the early evening hours of Sunday, May 22, 2011, killed 161 people. As a part of a larger late-May tornado outbreak sequence, it began in a rural area just east of Kansas-Missouri state line and caused minor damage. The tornado entered Joplin, Missouri, at its southwest corner near Schifferdecker Avenue, a north-south road that bordered the heavily populated areas of the city (Figure 1). At that point, the tornado was approximately a half-mile wide and grew to three-quarters of a mile wide between 26th and East 20th Street. It travelled a total of 22.1 miles (35.6 km) and lifted in a rural area east of the city [1].

Six miles of the total track crossed through the city of Joplin. Over no less than four of those six miles, the tornado was rated EF5, the first EF5 (F5 by the pre-2007 Fujita scale) tornado in Missouri since the Ruskin Heights tornado struck south of Kansas City in 1957[1]. It also marks the first EF5 tornado on record in southwest Missouri [2]. The tornado took 13 min to pass through the city, which was long enough to severely damage well-developed commercial and residential areas in Joplin that were home to 20,820 people, or about 41 percent of its total population.[2] The resulting damage to the built environment was the costliest on record for a tornado in the U.S., with insured losses of about $2 billion as of April 30, 2012 [3].

The Joplin 2011 tornado was a record-setter in terms of damage to the built environment, economic loss, the total damage area, the number of people affected, the number of non-residential structures damage and/or destroyed, and above all the number of people killed. In total, approximately 553 non-residential buildings were severely damaged, including hospitals, commercial structures, public and parochial schools, churches, fire stations, and both large and small commercial facilities. The storm also damaged 7,411 residential structures, ranging from single-family homes to large apartment buildings. The damage area covered 7.44 square miles, more than six times than the average tornado damage area in the United States [4].

[1]Since February 2007, the Enhanced Fujita (EF) scale replaced the traditional Fujita (F) scale. The EF scale has the same basic design as the original F scale, with six categories from 0 to 5 representing increasing degrees of damage [22].

[2]The estimated population of Joplin in 2010 was 50,175 [23].

Dating to 1950, when official tabulation began, no other tornado in the US had killed as many people as the Joplin event. Looking back a bit further, the 1925 Tri-State tornado stands out as the single deadliest event by a considerable margin (for a lengthy discussion on the meteorological synopsis of the 1925 event, see Maxwell et al.). Traversing over parts of Missouri, Illinois, and Indiana, the tornado took the lives of 695 people, However, the area of tornado deaths resulting from the Joplin is denser than the massive 1925 event, as the former storm covered less ground; while the Tri-State tornado killed over 3 times as many people, it covered 10 times the surface area.[3] The Joplin tornado's high death toll occurred despite an official tornado warning time of about 17 min, greater than the National Weather Service (NWS) national average warning time of approximately 14 min [5].

Because of the record number of deaths, several researchers [6,7] have analyzed the circumstances, causes, determinants, and other relevant aspects of tornado-related mortality caused by the event. Although a number of studies [8-14] suspect a relationship between elevation, genesis, wind speed and damage, no one has yet explored how the elevation affects deaths caused by tornadoes. To fill this research gap, this study focused on examining deaths caused by the 2011 Joplin tornado partitioned by elevation of the damage path. This tornado is selected primarily because of its record number of deaths. Although the 27 April 2011 Tuscaloosa, AL, tornado passed through a track whose elevation from beginning to end was higher than the

[3]The Tri-State Tornado is currently the U.S. record holder for longest tornado track, most deaths in a single tornado, and most injuries in a single tornado. It crossed the three states, tearing through thirteen counties of Missouri, Illinois, and Indiana. It crossed over and destroyed or significantly damaged nine towns and numerous smaller villages [24-26].

***Corresponding author:** Stimers M, Department of Natural and Physical Sciences, Cloud County Community College Junction City, Kansas, 66441, USA, Tel: +1 800-729-5101; E-mail: mstimers@cloud.edu

Received May 22, 2017; **Accepted** May 31, 2017; **Published** June 01, 2017

Citation: Stimers M, Paul BK (2017) Can Elevation be Associated with the 2011 Joplin, Missouri, Tornado Fatalities? An Empirical Study. J Geogr Nat Disast 7: 202. doi: 10.4172/2167-0587.1000202

Copyright: © 2017 Stimers M, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

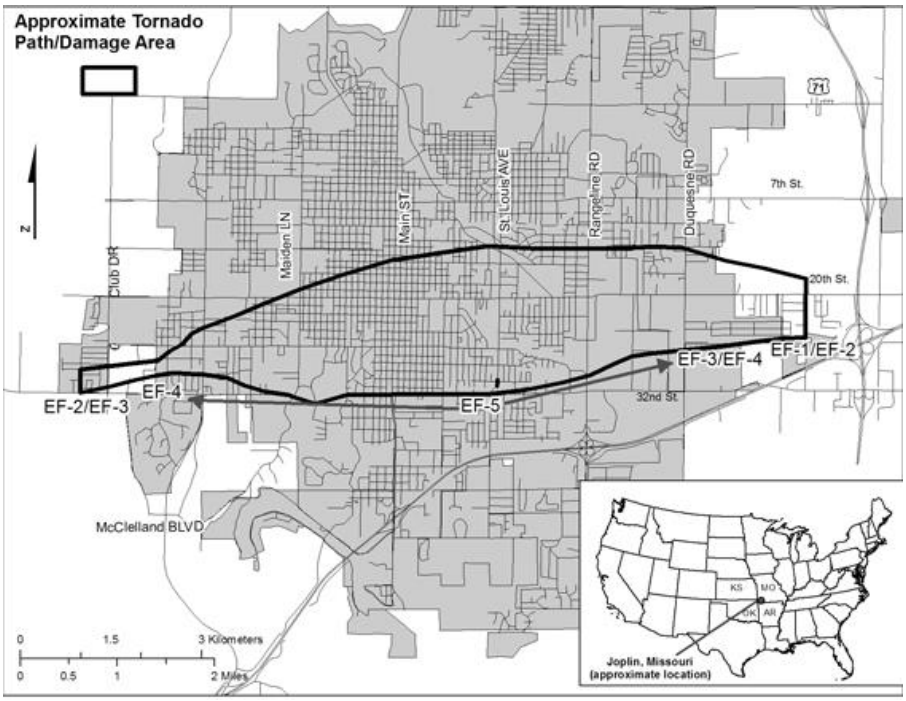

Figure 1: Damage path of 2011 Tornado in Joplin, MO.

corresponding elevation of Joplin, MO, the former tornado killed 64 people.[4] Additionally, the authors have previously published two papers [1,6] on the 2011 tornado fatalities in Joplin, MO; this provides useful insights in interpreting and analyzing the association between local elevation and extent of tornado-related deaths in Joplin.

The remainder of the paper is structured as follows: Section 2 provides a brief overview of the 2011 Joplin tornado. Section 3 describes the data collection procedure. Results are presented in Section 4, followed by a discussion and conclusion in Section 5.

2011 Joplin Tornado Fatalities: An Overview

As indicated, several studies analyzed different aspects of the Joplin tornado death toll.[5] Paul and Stimers explored the possible reasons for the large number of fatalities caused by the Joplin tornado and provided some perspective on the death toll. Based on primary data collected from the tornado survivors, and both formal and informal conversations with local residents and city officials, they concluded that five reasons were associated with the high number of tornado fatalities experienced in Joplin: (1) the sheer magnitude of the event; (2) its path through commercial and densely populated residential areas; (3) the relatively large size of damage area; (4) the physical characteristics of affected homes in Joplin, and; (5) the fact that some residents ignored tornado warnings.

Curtis and Fagan analyzed 135 of the 161 Joplin tornado fatalities by type of location which they grouped into seven categories: typical residence, apartment or condominium, in commercial areas, in a care facility but not the hospital, in a public meeting place such as church, the body was found outside, and the body was found in a vehicle. They also analyzed fatalities in terms of the Tornado Injury Scale (TIS) and linked tornado-related deaths to damage rate maps constructed at two relatively fine (building and street) scales. Mortality patterns are also investigated with regard to social vulnerability and type of residential structures as well as building types, materials, age and height. Curtis and Fagan reported that the upper most stories of multilevel apartment complexes experienced the worst of the building's damage. They concluded that the number of elderly fatalities was significantly higher than other cohorts. This finding is consistent within neighborhoods and not just as a result of single-site losses, as has been found in other disasters.

Kuligowski et al. investigated the wind environment and technical conditions associated with the 2011 Joplin tornado fatalities and injuries. They determined the pattern, location, date, and cause of fatalities and injuries. Of the 161 deaths resulting from this tornado, 155 (96 percent) were caused by impact-related factors (e.g., multiple blunt force trauma to the body/being struck by debris during the storm). The remaining fatalities were caused by stress-induced heart attacks, pneumonia, or chronic obstructive pulmonary disease due to blunt-force trauma to the body. Of the 155 impact-related fatalities, 135 (87 percent) involved persons who are known to have been located inside structures during the tornado. The structures in which these people died included both residential (59 percent of the 135 victims) and non-residential (41 percent) buildings. Most of the people killed by the tornado (77 percent) died on the day that it occurred, May 22, 2011.

Virtually all of the buildings in which the 135 impact-related fatalities occurred experienced maximum estimated winds associated with tornadoes rated EF3 or higher [13]. The exceptions were the Meadows Healthcare facility, where two of the deaths occurred, and five single-family homes that were the sites of six of the fatalities. No fatalities occurred in demolished, detached homes in which people took refuge in basements. Additionally, Kuligowski et al. found no

[4]The tornado path elevation was about 50 m from beginning to end in Joplin, MO, and 120 m in Tuscaloosa, AL.

[5]For a review of tornado fatalities in the United States, see Paul and Stimers [6].

evidence that any of those killed were located underground during the tornado. A disproportionate number of people aged 60 years or older died as a result of this tornado. Approximately eight fatalities occurred per thousand people in Joplin aged 60 years and over compared with two fatalities per thousand people in Joplin below 60 years. This disproportionate result remains even after removing all hospital and nursing home deaths.

Kuligowaki et al. also explored the influence of environmental conditions, particularly wind speed, for the impact-related deaths that resulted from the May 22, 2011, Joplin tornado. They concluded that the majority of the tornado fatalities occurred in areas where the tornado produced the strongest wind speeds (e.g., EF3 or EF4 wind speed zones). The tornado produced winds that exceeded the design parameters used for many of the buildings within Joplin, and these winds posed risks for people regardless of whether they were indoors, in vehicles, or outdoors without any protection.

Paul and Stimers examined the deaths caused by the 2011 Joplin tornado by four horizontal damage zones (catastrophic, extensive, limited, and moderate) and location of death (permanent homes, business facilities, vehicles, and outside/open). They observed that the strength of tornadoes does not vary only linearly or horizontally, but also within or across the path; the authors claim that if the central zones experiences EF5 damage, then the immediate two outermost zones (labelled as moderate) would experience lower than EF5 damage.[6] Their hypothesis proved to be true; they found that the number of deaths, death rates per 1000 population, and deaths per square mile differ significantly by zone of destruction. The central zone (labelled as catastrophic) had the most deaths, with the number decreasing systematically in both directions from the center of the damage zone.

Instructed by the Federal Emergency Management Agency (FEMA), the map of the four damage zones was prepared by the U.S. Army Corps of Engineers (USACE). The staff of the latter organization collected damage data from the affected areas using GPS. With the help of GIS, the USACE combined pre- and post-disaster aerial photographs, parcel, property, and other relevant information from the city and county, and prepared the damage zone map. However, the results of Paul and Stimers' study further show that more people died in non-residential buildings in Joplin than is usual for a U.S. tornado event. They also analyzed Joplin tornado deaths by gender and age of victim per damage zone. Similar to previous studies, and found a relatively higher proportion of deaths among the elderly population. They did not find significant variations in tornado deaths by gender.

Data and Methods

Information on casualties was obtained from several secondary sources. The Jasper County Emergency Management Office, the Jasper County Coroner's Office, and the Missouri Department of Public Safety provided lists of the Joplin tornado victims.[7] Obituaries published over several issues of the *Joplin Globe*, the local daily newspaper, provided additional details about victims' background and other pertinent information. In addition to publishing obituaries in different issues, the *Joplin Globe* [15] compiled and published a separate list of almost all tornado victims. Alvarez contributed a chapter in Turner and Hacker's book where he provided obituaries of 152 persons killed by the Joplin tornado. After comparing the information collected from these sources, a table was compiled with name, age, gender, date of death, and location of death of all Joplin tornado victims.[8]

Data obtained from the Jasper County Emergency Management office contained the street address of each fatality. These data were geocoded using the *Cartographica*® GIS package, in order to utilize the latitude and longitude of each point, as well as the elevation. A digital elevation model (DEM) file was downloaded from the National Map, and imported into *Cartographica*®, and a contour map was created from the raster image at five meter intervals. The resulting vector file was then used as a new layer in the GIS, and the point data of deaths was layered on top of that. Analysis was performed on the resulting two layers. Once the elevation contours were created, based on the tornado path boundary layer, the two shapefiles were joined; this allowed for the space between the contours to provide area data. Those data were exported into Microsoft Excel, and the area measurements were calculated as a percent of the entire area by contour level at five-meter intervals, and within contour level, by damage level.

Of the total 161 deaths, 154 (97 percent) are considered in this study. The remaining seven deaths attributed to the May 22, 2011, Joplin tornados have been omitted from the analysis. These seven omissions include six non-impact-related deaths plus the fatality attributed to the Golden Corral restaurant, which was omitted because the final location of injury (and death) for this individual remains uncertain. The six non-impact-related deaths were not included in this analysis, as all these deaths occurred after May 22. Some of the 154 deaths considered in this study were of people, who died days, weeks, or even months after the tornado hit Joplin from illness rather than solely from the injuries they sustained in the tornado. They were included because their death certificates specifically stated that they were injured by debris from the tornado.

Because the wind speed or wind strength increases with height from the surface to the upper troposphere for several reasons [16], the working hypothesis of this study is that the number of tornado deaths in Joplin was directly related to the elevation (change in elevation over the path). This relationship was examined using the Spearman's rank correlation co-efficient (SRCC). As will be evident, elevation is used as a categorized variable and for this reason SRCC is preferred over the Pearson Product Moment Correlation Coefficient (PPMCC).

Before analyzing the deaths by elevation, the number of deaths or injuries that led to death resulting from the May 22, 2011, Joplin tornado is presented. The structures in which 154 people died included both residential (60 percent of the 154 victims) and non-residential (28 percent) buildings (Table 1). Nineteen (12 percent) persons died outside. Compared to the other U.S. tornado fatalities in 2011, about 19 percent more fatalities occurred in Joplin in residential structures. In both cases, the percentage of death in permanent homes is much higher than the corresponding percentage reported for the period 1985-2012. As compared to the 1985-2012 periods, relatively more deaths occurred in Joplin in permanent homes, largely because of the absence of basement and inadequate structural conditions in housing units of the city. The absence of basements is not surprising considering 82 percent of houses in Joplin had no basements, due in part to rocky ground and a high water table. The city is located near the area that contained numerous lead and zinc mines that were operational from the late 1800s through the early 1950s. There are many houses in Joplin situated over old mine shafts, which has resulted in subsidence problems;

[6]Roueche and Prevatt also maintain that tornado forces rapidly attenuate with distance away from the center of the tornado, as EF-ratings can be reduced from EF4 to EF2 within 100 m. They further claim that catastrophic failures of buildings are most common at or near the center of the tornado's path (below the vortex).

[7]Joplin is a city of Jasper County, Missouri.

[8]For more detail about the data sources and methods, see Paul and Stimers.

obviously, this makes the construction of basements in Joplin difficult and impractical. Additionally, very few residents had in-home shelters. Most of the houses in Joplin are old and were constructed according to the standards of the time, which are far less rigorous than today's much stricter building codes. At the time of tornado, 64 percent of houses were over 30 years old [17]. Walls of many Joplin older houses were not anchored to the foundation and did not utilize hurricane roof straps. There were no community tornado shelters in Joplin.

Slightly over 12 percent of the tornado fatalities occurred outside of buildings: 12 in vehicles and seven outdoors (outside of any protective enclosure). Surprisingly, no one died in mobile homes during the 2011 Joplin event (Table 1). These homes accounted for slightly over 20 percent of tornado deaths in the United States in 2011. However, in Joplin, mobile homes accounted for only two percent of all housing units-a percentage much lower than the corresponding national percentage of eight percent [18]. Field surveys combined with a GIS analysis revealed that almost all of the mobile home units in Joplin were outside the tornado paths [19].

Location of injury/death	Number of victims (%)
Sores/Restaurant/Other facilities	*36 (23.4)*
AT&T store	1 (0.6)
Home depot	8 (5.2)
Walmart	3 (2.0)
Pizza hut	5 (3.2)
Elk lodge	4 (2.6)
Stained glass theater	3 (2.0)
St. John's Regional Medical Center	12 (7.8)
Places of worship	*7 (4.5)*
Full Gospel church	4 (2.6)
Harmony heights Baptist church	3 (2.0)
Outside	*19 (12.3)*
Vehicles	12 (7.8)
Outdoors	7 (4.5)
Residences	*92 (59.8)*
Greenbriar Nursing Home	19 (12.3)
Meadows healthcare facility	2 (1.3)
Apartments[a]	12 (7.8)
Detached home	59 (38.3)
Total	154 (100.0)

[a]These apartments are located in the same area near the intersection of 20th and Connecticut. These apartments include: Somerset Complex, Connecticut Pointe Apartments, and Hampshire Terrace.

Source: Kuligowski et al. [3].

Table 1: Number of Joplin tornado fatalities by location (of death or injury that led to death).

Results

The topography of Joplin, including the section of the city affected by the 2011 tornado, consists of many low hills and valleys. The elevation of the affected area ranges from 290 m to 345 m (Figures 2 and 3). The general trend of the elevation is to increase from west to east. Although western part of Joplin has lower elevation compared with the eastern counterpart, the western section is more undulating than the eastern section. Based on a Digital Elevation Model data (DEM), Karstens et al. [12] estimated the elevation along the Joplin tornado damage path (Figure 2) and they reported that from beginning to end of the tornado track, total relief difference was about 50 m. They also found increasing trend of elevation from west to east along the tornado path.

Table 2 presents the distribution of Joplin tornado deaths by elevation as well as information on the area for each elevation category. The elevation of the tornado path is divided into 10 categories or groups with an interval of five meters. The table clearly shows that the area under each elevation category differs, ranging between 0.01 square miles (or 0.07 percent of damaged area) and 2.61 square miles (or 53.14 percent of damaged area). Therefore, the absolute number of deaths in each elevation category needs to be standardized by the respective area, which is considered here as death density (i.e., number of death per square mile). The standardized death rates are calculated and presented in the last column of Table 2.

A comparison of elevation and death density suggests no consistent decrease with increase of elevation (also see Figure 4). With six deaths and 0.94 percent of all damaged area, the second elevation category (296-300 m) experiences the highest death density, followed by the fourth elevation category (306-310 m) with 58 deaths and 13.27 percent of damaged area. No deaths occurred in the lowest or first elevation category (≤295 m) and the seventh elevation category (321-325 m) considered in this study. When the SRCC (r_s) is calculated between elevation and death density, a negative value (r_s) is obtained, but the calculated value of-0.164 is not statistically significant (p=0.661). This does not support the idea that the elevation is positively associated with tornado fatalities.

As noted, the FEMA divided the tornado path horizontally into four damage zones: catastrophic, extensive, limited, and moderate [16]. The number of deaths systematically decreased horizontally with increasing distance on both sides of the central catastrophic zone. With highest wind speed, the magnitude of tornado damage is the highest in

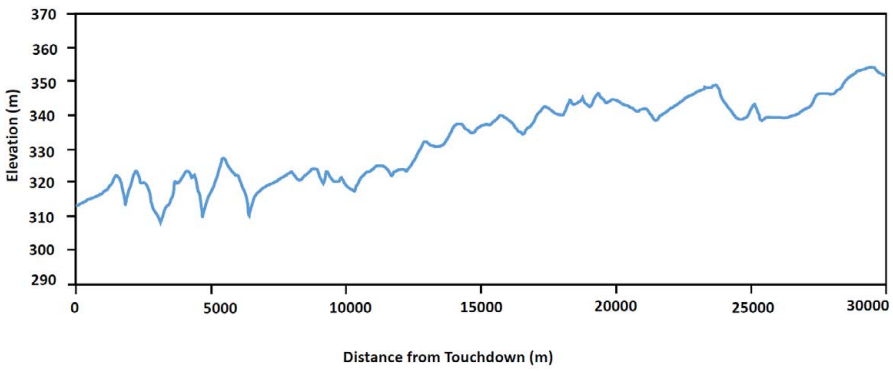

Figure 2: Elevation from touchdown in meters. Source: Drawn based on Karstens et al. [12].

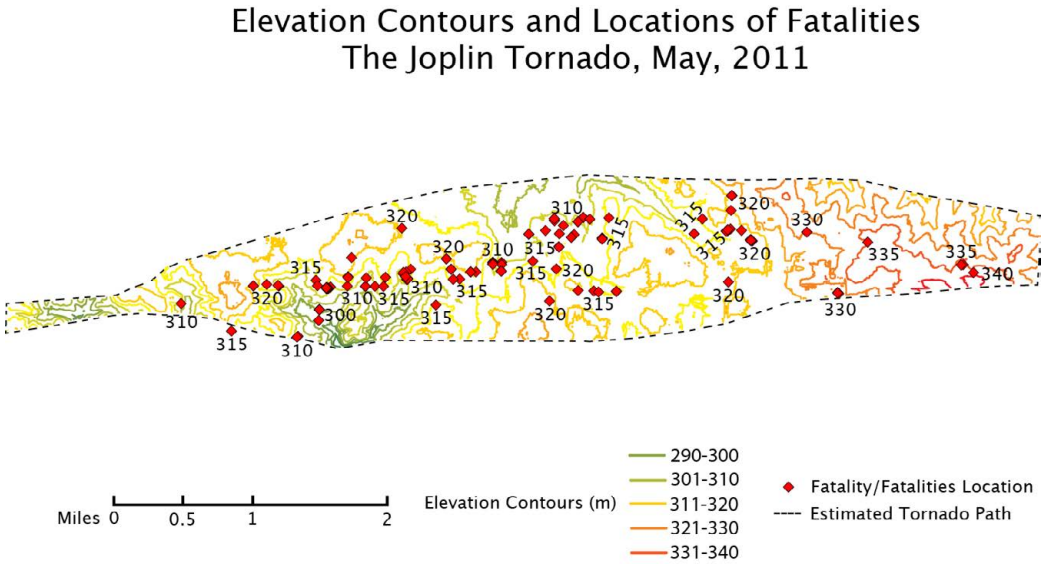

Figure 3: Elevation contours and location of Tornado deaths in Joplin, MO.

this zone, which contains the center of vortex. Wind speeds generally decrease horizontally with distance away from the central zone. Out of total of 154 deaths, 122 (79 percent) occurred in the catastrophic or central zone. Therefore, elevation of damage zones seems to play a crucial role in the extent of tornado fatalities in Joplin, MO. For this reason, an additional attempt is made here to examine the importance of damage zones on tornado mortality. Because most of the tornado deaths occurred in the central zone, the damage zone is dichotomized as catastrophic and non-catastrophic zones. Table 3 presents information on death density by elevation and two damaged zone.

Like elevation area, areas under catastrophic and non-catastrophic zones greatly vary among elevation categories. Of the total area (7.44 square miles) of the damage zone, 2.43 square miles (33 percent) are designated as belonging in the catastrophic zone (Table 3). Both death density patterns of catastrophic and non-catastrophic zones follow the pattern similar to the death density pattern calculated for each elevation category (Table 2 and Figure 4). But the death density remains above each elevation category for the catastrophic zone than the non-catastrophic zone. The calculation of Mann-Whitney U-test (U=14.5; p=0.01) proves that catastrophic zone has significantly higher tornado fatality rates in Joplin, MO, than the non-catastrophic zone.[9] This confirms that the damage zone is more strongly associated with tornado fatalities than the elevation difference.

Discussion and Conclusion

Contrary to the initial working hypothesis, no statistically significant direct relationship was found between elevation and the 2011 Joplin tornado deaths. This means, many other factors are associated with tornado fatalities in Joplin, MO. Apart from elevation and damage zone, Provic [20] maintains that underlying terrain conditions (e.g., land cover, surface roughness, and slope) correlate with storm intensities and hence extent of damage and deaths. Wurman and his colleagues [21] reported that surface roughness reduces near surface wind speed. In analyzing two contrasting subsections (rough versus smooth topography) of the 2011 Tuscaloosa tornado damage path, Karstens et al. concluded that underlying topography influenced magnitude of the near-surface wind field. As noted, the Joplin tornado passed over densely populated residential and commercial buildings; these buildings created surface roughness and thus reduced the impact of elevation on tornado fatalities.

Elevation (meter)	Number of death (%)	Area (sq. mile) (%)	Death density (number of death/sq. mile)
≤ 295	0 (0.0)	0.01 (0.07)	0.00
296-300	6 (3.9)	0.07 (0.94)	85.71
301-305	2 (1.3)	0.24 (3.17)	8.33
306-310	58 (37.7)	0.99 (13.27)	58.59
311-315	51 (33.1)	2.19 (29.44)	23.29
316-320	29 (18.8)	2.61 (35.14)	11.11
321-325	0 (0.0)	0.44 (5.96)	0.00
326-330	4 (2.6)	0.41 (5.52)	9.26
331-335	3 (1.9)	0.38 (5.15)	7.90
336-340	1 (0.7)	0.10 (1.34)	10.00
Total	154 (100.0)	7.44 (100.00)	20.70

Table 2: Tornado death by elevation categories.

It is worthwhile to mention that tornadoes usually spend most or all of their lifetime over sparsely populated areas. Using the tornado data collected from the Storm Prediction Center (SPC) and other relevant sources for the period 2000-2009, Stimers and Paul found that the percent of tornadoes that struck (U.S. Census-defnied) communities or places differed remarkably from state to state, ranging from a minimum of 1.73 percent to a maximum of 25 percent, with an average of 7.74 percent for the United States as a whole. This means, tornadoes in the United States do not pass through densely populated areas with high frequency. Additionally, only a small fraction of tornadoes (1-10 percent) are capable of causing the most intense damage.

Wurman and others maintain that the rotational velocity of tornadoes increases rapidly with decreasing altitude from 1000 m

[9]This non-parametric test is used because of three reasons: small sample size (n=10), the comparison was between two zones, and the death density was not in frequency form. The following formula was used to perform U test:

$$U = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum_{i=n_2+1}^{n_2} R_i$$ where U: Mann-Whitney U test; n1: Sample size one; n2: Sample size two; and Ri:Rank of the sample size.

Elevation (in meter)	Number of death		Area		Death density	
	Catastrophic zone	Non-catastrophic zone	Catastrophic zone	Non-catastrophic zone	Catastrophic zone	Non-catastrophic zone
≤ 295	0	0	0.003	0.007	0.00	0.00
296-300	4	2	0.012	0.058	333.33	34.48
301-305	1	1	0.042	0.198	23.81	5.50
306-310	46	12	0.446	0.544	103.14	22.06
311-315	40	11	0.781	1.409	51.22	7.81
316-320	24	5	0.650	1.960	36.92	2.55
321-325	0	0	0.105	0.335	0.00	0.00
326-330	3	1	0.161	0.249	18.63	4.02
331-335	3	0	0.187	0.193	16.04	0.00
336-340	1	0	0.046	0.054	21.74	0.00
Total	122	32	2.430	5.010	50.21	6.39

Table 3: Death density by elevation category and damage zone.

Figure 4: Death density by elevation category and damage zone.

Altitude above Ground Level (AGL) down to 100 m AGL. They further maintain that tornadic wind speeds at 10 m. AGL are less when a substantial fraction of the ground surface is covered by structures, increasing the effective surface roughness. Passe-Smith, on the other hand, claims that stronger tornadoes are less affected by local topography than are weak and moderate tornadoes. It is worth mentioning that the 2011 Joplin tornado was an EF5 tornado; probably for this reason elevation did not emerge as an important determinant of deaths.

Field visits reveal that irrespective of elevation, tree coverage around buildings was negatively associated with tornado fatalities in Joplin. Most of the deaths that occurred in non-residential buildings in Joplin were not surrounded by trees. Additionally, relatively more multiple deaths occurred in such buildings compared to residential buildings (Table 1). Even a number of deaths that occurred in residential buildings were not surrounded by trees. This is particularly true for the deaths that occurred in three apartment complexes (Table 1). Tree surroundings creates barrier for wind movement and thus reduces the wind speed-as noted, tornado damage and death are associated with tornadic wind speed.

Available studies and field visits clearly indicate that localized effects, either variation in building types, age of structures, or building placement, were important determinants of tornado-related deaths in Joplin. As indicated, 64 percent of the houses in Joplin at the time of tornado were over 30 years old and many of them suffered from added effects of aging and deferred maintenance. These conditions resulted in a large number of homes that were particularly vulnerable to extreme tornado wind forces. Additionally, the overwhelming majority of houses in Joplin were built following traditional construction practices or conforming to prescriptive building codes, which lack any specific structural engineering design to resist wind loads. Although the tornado fatalities are caused by interactions of many factors, this study provides insight regarding relationship between elevation of the tornado path and deaths caused by the tornado.

References

1. Paul BK, Stimers MJ (2012) Exploring probable reasons for record fatalities: The case of 2011 Joplin, Missouri, tornado. Natural Hazards 64: 1511-1526.
2. Alvarez J (2011) In memory of lives lost: Obituaries. In 5:41: Stories from the Joplin tornado. In: Turner R, Hacker J (eds.) 161-220. Kansas City: Kansas City Star Books. American Housing Survey.
3. Kuligowski ED, Lombardo FT, Phan LT, Levitan ML (2013) Technical investigation of the May 22, 2011, tornado in Joplin, Missouri. Washington, DC: National Institute of Standards and Technology (NIST).
4. Simmons KM, Sutter D (2011) Economic and societal impacts of tornadoes. Boston: American Meteorological Society.

5. NWS (National Weather Service) (2011) NWS Central Region service assessment Joplin, Missouri, Tornado-May 22, 2011. Silver Spring, MD.
6. Paul BK, Stimers MJ (2014) Spatial analyses of the 2011 Joplin tornado mortality: Deaths by interpolated damage zones and location of victims. Weather, Climate, and Society 6: 161-174.
7. Curtis A, Fagan WF (2013) Capturing damage assessment with a spatial video: An example of a building and street-scale analysis of tornado-related mortality in Joplin, Missouri, 2011. Annals of the Association of American Geographers 103: 1522-1538.
8. Alexander C, Wurman J (2005) The 30 May 1998 Spencer, South Dakota, Storm. Part 1: The structural evolution and environment of the tornado. Monthly Weather Review 133: 72-96.
9. Passe-Smith MS (2008) Effect of topography on weak and moderate tornadoes. Proceedings of the 2008 ESRI International Users Conference.
10. Doswell CA, III, Brooks HE, Dotzek N (2009) On the implementation of the enhanced Fujita Scale in the USA. Atmospheric Research 93: 554-563.
11. Lewellen DC (2012) Effects of topography on tornado dynamics: a simulation study. Presented at the 26th Conference on Severe Local Storms held in Nashville, 5-8 November.
12. Karstens CD, Gallus Jr.WA, Lee BD, Finley CA (2013) Analysis of tornado-induced tree fall using aerial photography from the Joplin, Missouri, and Tuscaloosa-Birmingham, Alabama tornadoes of 2011. Journal of Applied Meteorology and Climatology 52: 1049-1068.
13. Franklin TL, Roueche RD, Prevatt DO (2015) Comparison of two methods of near-surface wind speed estimation in the 22 May, 2011 Joplin, Missouri Tornado. Journal of Wind Engineering and Industrial Aerodynamics 138: 87-97.
14. Elsner JB, Elsner SC, Jagger TH (2015) The increasing efficiency of tornado days in the United States. Climate Dynamics 45: 651-659.
15. Joplin G (2011) 32 Minutes in May: The Joplin Tornado. Pediment Publishing. Canada.
16. Manwell JF, McGowan JG, Rogers AL (2010) Wind Energy Explained: Theory, Design and Application. Hoboken, NJ: Wiley.
17. Roueche DB (2003) Prevatt. Residential damage patterns following the 2011 Tuscaloosa, AL and Joplin, MO tornadoes. Journal of Disaster Research 8: 1061-1067.
18. US Census Bureau (2015) American Housing Survey (available online at https://www.census.gov/programs-surveys/ahs.html) (last accessed 19 May 2017).
19. USGS (US Geological Survey) (2011) Seamless data warehouse (available online at: last accessed 15 June 2015).
20. Prociv KA (2012) Terrain and land cover effects of the southern Appalachian mountains on the rotational low-level wind fields of super cell thunderstorms. M.A. thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.
21. Wurman J, Alexander C, Robinson P, Richardson Y (2007) Low-level winds in tornadoes and potential catastrophic tornado impacts in urban areas. Bulletin of the American Meteorological Society 88: 31-46.
22. Paul BK (2011) Environmental hazards and disasters: Contexts, perspectives and management. Chichester, UK: Wiley-Blackwell.
23. US Census Bureau (2010) Joplin, Missouri quick facts (available online at (last accessed 20 April 2015).
24. Maddox RA, Gilmore MS, Doswell CA, Johns RH, Crisp CA, et al. (2013) Meteorological Analysis of the Tri-State Tornado Event of March 1925. Electronic Journal of Severe Storms Meteorology 8: 1-27.
25. Stimers MJ, Paul BK (2016) Toward Development of the Tornado Impact-Community Vulnerability Index. Journal of Geography and Natural Disasters 6: 1-11.
26. Wurmann J, Gill S (2000) Finescale radar observations of the Dimmitt, Texas (2 June 1995), Tornado. Monthly Weather Review 128: 2133-2164.