Tornado Warnings and Tornado Fatalities: The Case of May 22, 2011 Tornado in Joplin, Missouri

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SUMMARY

A massive tornado that tore a 6-mile path across southwestern Missouri killed 162 people as it raged through the heart of Joplin on the evening of 22 May 2011. This EF5 tornado event stands as the deadliest single tornado to hit the United States since modern record-keeping began in 1950, surpassing the 8 June 1953 tornado that claimed 116 lives in Flint, MI. The record number of deaths caused by the single tornado in Joplin, MO, was far higher than the average number of yearly tornado deaths caused in the United States during the period 2000-2011. This study explores the reasons for the unexpectedly high number of fatalities caused by the 2011 Joplin, MO, tornado. This was accomplished by examining the nature and extent of warnings residents of Joplin, MO, received prior to the tornado touchdown and how they responded to these warnings. Questionnaire survey conducted among tornado survivors, and conversations with emergency personnel and others suggest that three reasons are associated with remarkably high number of tornado fatalities in Joplin, MO: sheer magnitude of the event, its path over a densely populated area, and physical characteristics of homes in Joplin. Several recommendations are forwarded implementation of which will reduce future tornado fatalities in Joplin, MO and elsewhere in the United States.

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INTRODUCTION

A massive tornado that tore a 6-mile path across southwestern Missouri killed at least 162 people as it raged through the heart of Joplin on the evening of May 22, 2011.[1] This EF5 tornado, which at its zenith was three-quarters of a mile wide, levelled much of the city's south side, and completely flattened some neighbourhoods, with leaves stripped from trees, giving the landscape an apocalyptic aura (Figure 1). The tornado traveled from the west side of the city to the southeast, thus this was a right-turning tornado, implying a bigger tornado. The damage zone stretched from about 26th Street and Schifferdecker Avenue to 20th Street and Prosperity Road (Figure 2). A half-mile wide when it hit Joplin, the twister grew to a width of three-quarters of a mile wide before dissipating to a width of half mile (Joplin Globe 2011a). The tornado struck Joplin at around 5:40 pm (2240 UTC) on May 22, 2011. Keith Stammer of the Jasper County Emergency Operations Center (JCEOC) claims that the first siren went off at 5:11 pm (2211 UTC).[2]

The tornado of May 22, 20111 destroyed nearly 7,000 Joplin homes and damaged hundreds more (Globe 2011b) (Figure 3). The damage covered 1,800 acres of area, over a quarter of the city, which is home to 50,000 residents. An unknown number of people were injured and a series of gas leaks caused overnight fires around the city. One of the community's hospitals, St. John's Regional Medical Center, was heavily damaged, which hampered initial response efforts (Figure 4). The twister packed winds of up to 200 mph (320 kph) and intensified remarkably quickly, morphing from a mere funnel cloud into a monstrous and powerful tornado with multiple vortexes in under 10 minutes (Mustain 2011; OCC 2011). The Joplin tornado caused an estimated $3 billion in insured losses, not counting all the damaged structures that were not insured.

The Joplin event stands as the deadliest single tornado to hit the United States since modern record-keeping began in 1950, surpassing the June 8 1953 tornado that claimed 116 lives in Flint, MI (Mustain 2011). In contrast to this horrific new record, 45 tornado fatalities were recorded in the United States during all of 2010, and just 21 stemmed from the 2009 calendar year. Average annual tornado deaths in the country were 55 for the period 2000-2010 period, but if the 544 deaths caused by the 2011 tornadoes are added, the figure increases to about 63.5 (Figure 5). The record number of deaths caused by the single tornado in Joplin, MO, was far higher than the average number of yearly tornado deaths caused in the United States during the both time periods (i.e., 2000-2010 and 2000-2011). This study explores the reasons for the unexpectedly high number of fatalities caused by the 2011 Joplin, MO tornado. This is accomplished by examining the nature and extent of warnings residents of Joplin, MO, received prior to the tornado touchdown and how they responded to these warnings.

We believe analyses of warning systems helps us to identify factors associated with the large number of tornado fatalities in Joplin, MO. To provide background for this study, an overview of risk factors associated with tornado fatalities is presented next. That is followed by a section which provides an account of data collection and data analysis. Results, discussion, and conclusion of this study are presented in the last three sections. Findings of this study will aid policy makers, and private and public emergency management agencies in improving existing warning system, including compliance with such warnings. This, in turn, helps in reducing fatalities and injuries as well as lessening damage and suffering from future tornadoes in Joplin, MO, and elsewhere in the United States.

RISK FACTORS FOR TORNADO FATALITIES: AN OVERVIEW

Existing hazard literature (e.g., Brenner and Noji 1995; Daley et al. 2005; Schmidlin 1993; Schmidlin and King 1997; Schmidlin and Ono 1996; Sutter and Simmons 2010) suggests that the tornado's high death toll is an indicator of its magnitude, frequency, timing of occurrence as well as its path or track. Magnitude describes the strength or severity of tornadoes and is now expressed in terms of the Enhanced Fujita scale or EF scale.[3] In general, the greater the magnitude of a tornado, the greater the potential for fatalities, injuries, and damage to property (Paul 2011). Although in absolute terms, more people have died from EF0-EF4 tornadoes since EF5 tornados occur with less frequency.

SPC data suggests that during the period 2000-2011, only 299 of the 1151 tornado deaths were caused by EF5 tornadoes. This means 25.98% of all tornado deaths that occurred during the above period were caused by FE5 tornados (Table 1). However, in relative terms the most powerful EF5 tornadoes cause more deaths per event than tornadoes of lower magnitude. During the 2000-2011 period, EF5 tornados caused nearly 13 times more deaths per event compared to tornadoes of magnitudes EF4 and lower (Table 1). This clearly supports the contention that stronger tornadoes are more deadly than weak ones.

Frequency is another dimension of extreme events, including tornado, which is directly associated with fatalities caused by such events. Like magnitude, with higher frequency, comes a higher death toll from tornadoes and other natural disasters. Figure 5 illustrates the relationship between the number of killer tornadoes and the tornado-induced fatalities for the period 2000-2011, and suggests a positive association between these two variables. Calculation of Spearman's rank correlation coefficient (r_s=0.901) confirms the relationship to be statistically significant at the 0.1 level.

In addition to magnitude and frequency, several studies (e.g., Ashley 2007; Schmidlin and Ono 1996; Simmons and Sutter 2008; Sutter and Simmons 2010) also reported that timing of tornado is a contributory factor for fatalities caused by this event. Tornadoes are significantly more lethal at night than during the day primarily because people are likely to be home, they may not hear tornado sirens, or they are likely asleep. Simmons and Sutter (2008) found through a regression analysis that expected fatalities are 64% lower for tornadoes that occur during the day as opposed to ones that occur overnight. They came to this conclusion after controlling for other factors such as storm path characteristics, magnitude of the tornado, and the issuing of a tornado warning.

Studies (e.g., Balluz et al. 2000; Stimers 2011; Sutter and Simmons 2010) also suggest that location of a tornado path is an important determinant of deaths caused by this event. If the path passes over highly populated areas, deaths are likely to be higher than if it passes over less populated areas. In analyzing tornado events from 2000-2009, Stimers (2011) calculated that 981 or 7.75% of the 12,657 events occurred in the United States during the study period passed through communities. He also reported that this percentage is low for states located in the Great Plains region of the country. For example, Kansas experienced 1,121 tornadoes during the study period, but only 20 of these passed through communities; a percentage of only 1.78. A visual inspection of events occurring in Kansas revealed that a majority of the events from 2000-2009 struck in the less populated western half of the state, mostly in rural and open areas (Figure 6). Thus, the seemingly low percentage figure in Kansas and other states of the region are a function of the population and community placement within these states (stimmers 2011). In the US, both large and small population centers are located dispersedly. It is worth mentioning that the Joplin tornado touched down in a densely populated area.

Tornado deaths also depend on two non-structural factors, namely the nature of tornado warnings and compliance with such warnings (Daley et al. 2005). If advanced warnings are not issued in a timely manner, or warnings are not issued at all, the population at risk is unable to seek safety, which may contribute to higher instances of injury and death (Balluz et al. 2000; Simmons and Sutter 2008). Tornado warnings with sufficient lead-time and widespread compliance with such warnings can save many lives.[4] Because of improved warning systems the annual tornado death toll in the United States has consistently decreased over the last 50 years (Ashley 2007). Between 1925 and 2000, the annual fatality rate from tornadoes in the country went down from 1.8 per million residents to 0.11 per million (Sutter and Simmons 2010).

Studies (e.g., Paul et al., 2003; Sherman-Morris, 2005) dealing with tornado warnings suggest that people who receive warnings prior to tornado touch down often do not seek shelter for several reasons. Among many others, these reasons include: do not believe the warnings because they have proven wrong in the past; not realizing the danger; not having enough time to take shelter; no understanding warnings because of a language barrier (particularly applicable to immigrants); not believing that a tornado would be coming their way; or "God will protect us."

Myriad individual and household characteristics are also associated with tornado fatalities. These characteristics dictate who receive hazard warnings and who does not comply with such warnings (Paul and Dutt 2010). The poor and less educated are less likely to have full access to warning systems, thus inhibiting reception of warnings; consequently tornadoes pose a greater threat to their lives. They more likely own and/or live in old house, which may not have basement and/or safe room.[5] Wooden or old house, a house with walls not anchor to the foundation, and houses without a basement are other risk factors for high tornado mortality (Balluz et al. 2000).

Additionally, the poor are more likely to live in manufactured or mobile homes.[6] Based on analysis of tornado data collected for the period 1996-2007, Sutter and Simmons (2010) reported that the probability of tornado fatalities in mobile homes is ten times or more than for permanent homes in the United States (also see Brooks and Doswell 2002; Brown et al. 2002; Daley et al. 2005; Simmons and Sutter 2006). Between 1985 and 2007, 43.2% (536 of 1240) of US tornado fatalities occurred in mobile homes, which comprised only 7.6% of US housing units in 2000 (Sutter and Simmons 2010).[7] Daley et al. (2005) reported that mobile homes in the path of a tornado are consistently associated with a particularly high risk of death or injury. In analyzing tornado-related deaths and injuries in Oklahoma due to the 3 May 1999 tornado, Brown et al. (2002) claimed that higher rate of death is associated with being inside a mobile home, an apartment complex, or outdoor than in permanent houses.

Sutter and Simons (2010) further reported that a larger proportion of fatalities occur in mobile homes in less powerful tornados - those rated EF1, EF2, or EF3 on the Enhanced Fujita Scale – than fatalities overall. More specifically, EF1 and EF2 tornadoes are potentially lethal for residents of mobile homes. They observed no significant death toll difference caused by EF4 and EF5 tornadoes between mobile and permanent home residents. In terms of timing of occurrence of tornadoes, Schmidlin et al. (2009) and Sutter and Simon (2010) claim that mobile home fatalities are especially likely to occur at night, particularly from midnight to 6 am.

Daley et al. (2005) and Gruntfest (1987) claim that elderly people in a tornado's path have a greater risk of deaths, as they have a tendency to dismiss warnings in a cognitive process framed by situational factors, such as compromised mobility and media access (Schmidlin and Ono 1996). People with past tornado experience are considered more responsive to future hazard warnings than those who have never been affected by a tornado. Thus, past experience is thought to be inversely associated with tornado-related deaths (Mileti and Sorensen 1990).

It is evident from the above that tornado deaths depend not only on the physical characteristics of this extreme event, but are also a function of the complex social, economic, and demographic factors of people exposed to such an event. Risk factors associated with tornado deaths can broadly be divided into two groups: structural (e.g., characteristics of housing and availability of public tornado shelters) and non-structural. The latter can be subdivided as (i) warning characteristics, including compliance with warnings, (ii) physical characteristics of tornado itself (e.g., frequency, magnitude, and timing of occurrence) and (iii) individual and household characteristics (e.g., age, education level, gender, income, and immigration status). There is considerable overlap among risk factors of different groups. For example, whether a person owns a permanent house depends on his/her economic conditions. Similarly, economic conditions also determine access to tornado warning systems.

METHODS

The major data set used in this report came from a population-based cross-sectional questionnaire survey conducted among residents of Joplin, MO, during the period 24 June to 30 July 2011. A pre-structured interview schedule was used to collect relevant information from the residents who were in the city on the evening of the tornado. This means, the respondents were selected for this study irrespective of their tornado experience. The schedule used contains three types of information: (1) questions related to knowledge about the tornado warnings and the compliance with the warning message, (2) questions regarding the property damage, injuries sustained, number of deaths in household, past tornado experience along with characteristics of the residential structure, and (3) relevant demographic and socio-economic questions to collect information on the respondents' gender, age, marital status, educational attainment, employment status, and annual household income.

We sought and subsequently received approval to the use interview schedule for this study from the Human Subject Review Committee of the Kansas State University (KSU). Written informed consent was formally obtained from each and every respondent who agreed to participate in the interview after being explained the nature and the objectives of the study. The data collected contained no identifiers. Residents participation in the study interview were voluntary and non coercive. Participant confidentiality was respected throughout the study. Face-to face interviews were conducted among 99 respondents by five trained personnel, including the principal investigators of this study, an anthropology instructor from Cloud County Community College, Junction City, KS, and two graduate students in the department of geography, Kansas State University. Interviews were conducted in various locations within Joplin, including malls, other shopping places, libraries, restaurants, pubs, residences, golf courses, gas stations, temporary shelters, and offices of emergency agencies. In addition, eight interviews were completed using a combination of telephone and the social media Internet website Facebook, giving a total of 107 responses.

The research team traveled to Joplin two times to administer the questionnaire surveys in person, as well as to observe the destruction and progress toward recovery and rebuilding of the community. Another important purpose of these visits to Joplin was to gather information on the survivors' personal experiences, their knowledge regarding tornado victims, and other pertinent information from community leaders, emergency officials, private constructors, and members of volunteer groups helping tornado survivors cope with impacts of this devastating tornado, and assisting in relief and debris removal. Published reports in electronic and print media about the Joplin tornado were also regularly monitored and provided valuable information and insight regarding this deadly tornado. The collected data are summarized and analyzed using relevant descriptive and bivariate statistics.

Data was also collected from the JCEOC, and included a non-structured interview with its director Keith Stammer, as well as spatial data collected from the mapping division of the City of Joplin. Spatial data were analyzed within a Geographic Information System (GIS) to create the warning siren buffer as well as the damage path maps. Among the spatial data collected was a shapefile of point data that originated from the Federal Emergency Management Agency (FEMA). This file contained 8,440 points of damage within the tornado's path, rated by FEMA on a four-point scale as catastrophic, extensive, limited or moderate. Kriging was applied to the point data to interpolate the damage surface shown in Figure 2.

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RESULTS

Of the 107 respondents, 62 (57.94%) were male and the mean age of all respondents were 43.77 years. Slightly over 55% of the respondents were married at the time of survey, 28% were unmarried, and the remaining 17% were divorced, legally separated, or lost their spouse. The questionnaire survey reveals that 3.74% did not graduate from high school, 61.68% completed high school and the remaining 34.58% had an education above the high school level. Nearly 46% respondents indicated they were employed full-time at the time of survey and another 20% were employed on part-time basis. Only 7.48% were unemployed and the remaining respondents were students, disabled, retired, or home makers. In terms of yearly household income, nearly 34%

respondents reported an income under $20,000, while one-fourth of the total respondents earned more than $59,999 per year.

Of the 107 participants, 61 (57%) were at home when the tornado struck Joplin, MO, and the remaining 46 were outside home at different places, which are listed in descending order: churches (13), place of works (8), friend's and/or relatives' houses within Joplin (6), retail stores (5), on the roads (5), restaurants (4), gas stations (3), the movie theater (1), and Webb City (1), which is located immediately north and adjacent to Joplin. Because the tornado occurred on Sunday, a considerable proportion of participants were outside their homes either to attend church, or visit friends in their houses, or shop in stores. On the afternoon of the tornado, Joplin High School graduation was held at the Leggett & Platt Athletic Center on the Missouri Southern State University campus, which was not in the damage path, although the school itself was badly damaged (Figure 7).

The field survey reveals that none of the friends' houses where participants went prior to the touch down was in the direct path of the tornado. Similarly, several churches, work places, and stores where respondents of the affected areas had been at the time of tornado were outside the tornado path and thus these facilities sustained no damage. A considerable proportion of survey participants who was outside the tornado path at the time of the event experienced either partial or total damage to their homes and other property. Some of them survived only because they were outside the tornado-affected areas. One respondent told us that he was visiting his friend's house located outside the tornado path, on the day of tornado. He rented a house at 15th Street and Range Line Road, and lived there along with his landlord, who died when the house was demolished by the twister.

Nearly 49% of all respondents reported damage to their home and/or other possessions. This means slightly over half of the respondents were from outside the path of the devastating tornado. Two such respondents experienced total destruction of their Main Street real state properties which were in the direct path of the tornado. Only eight of 52 respondents who experienced damage lived in the zone most severely impacted by the tornado. In dollar terms, each one of them experienced loss in excess of US$100,000. It appears to us that most survivors of this zone are now living with friends, relatives, parents, fellow church members' homes not affected by the tornado, or other places within and beyond Joplin. Some residents have permanently moved to other locations. We were unable to contact many of these survivors for our study and they were not present near their damaged property at the time of person-to-person interviews. Most likely, some of these displaced people are in permanent exodus from Joplin.

Among 107 respondents, five were injured during the tornado. Including these respondents, a total of 18 person sustained injuries. They were from 13 households, meaning more than one person injured in five respondent households. The common type of injuries among survivors was soft-tissue injury, and most common causes of injuries were flying/falling debris, and collapsing walls, ceilings, roof materials (Figure 8). Among the juried, no one was outside the houses or buildings. The overwhelming majority of the injuries was minor and hospitalization was not required. Only three injured persons were under 18 years of age and none were over 64 years. Only one respondent reported a death of a 10-year old girl.

Tornado Warning Awareness and Compliance with the Warnings

In order to explore possible reasons for the very high death toll, this study aims at investigating knowledge of the respondents regarding tornado warnings and their response to such warnings. Did they receive the warnings? If so, was it in a timely manner? Did they take safe shelter? If not, why? We suspected that lack of tornado warnings and non-compliance with such warnings led to high tornado fatalities in Joplin, MO. The survey data reveals that 96 (90%) of the 107 respondents were aware of tornado warnings before it actually struck the community. Of the 11 respondents who were not aware of the tornado warning, the most common reason given was that they were inside their homes and not watching television or listening to radio. They also reported not hearing the warning sirens.

Figure 9, which shows the location of sirens across Joplin and surrounding areas, clearly suggests that almost all residents of Joplin and adjacent areas within the hinterland of such facilities are covered at least by one siren, and in many locations, there is considerable overlap of several sirens. Although the figure indicates that an area near the eastern most section of the tornado path was not covered by siren network, the people of that area should have heared the siren as the wind was moving west-east direction. Such movement created elliptically shaped buffers rather than circular ones as shown in Figure 9. However, warning sirens are not designed to hear from inside a house, particularly when doors and windows are closed. A siren can serve its hinterland assuming little or no topographical or artificial interference (Current and O'Kelley 1992). But the topography of Joplin contains many low hills and valleys. Sirens using electricity do not work after power is out. Additionally, the tornado was wrapped in pounding rain and hail, which may have contributed to residents' lack of awareness of the siren's klaxon. Although the number of respondents who were not aware of the tornado threat is not considered very high, there is a need to continue to improve existing tornado warning system so that all people at risk can receive such warnings in a timely manner.

Among the respondents who received a warning, the largest proportion of them (72.92%) received it from the warning sirens followed by information from their local television stations (37.50%). This adds up to more than 100% because the respondents received warnings from multiple sources. Cellular and landline telephone warned only 19 respondents (19.791%) and 18 (18.75%) received warning through commercial radio. Other sources include: word-of-mouth, weather radio, and Internet/e-mail (Table 2). Nine respondents reported being warned by their neighbors who came to their homes, the announcement of a tornado warning coming over a retail store's intercom system, looking at the sky, or through local police. These sources are listed as "others" in Table 2. Information presented in the table clearly shows the importance of sirens as a source of tornado warnings. This is also revealed in the reports published in the Joplin Globe between 23 May 23 and 30 July 2011. Based on conversations with respondents and others in the study area, it appears that when a tornado is about to hit, people expect to hear a siren.

Of the 96 respondents who received warning, 20 (20.83%) did not comply with the warning, meaning they did not immediately take shelter. This is not an appropriate and recommended measure once a warning is received. Additionally, at least three respondents went outside to see the tornado and to visually verify the tornado threat before taking shelter. This action is also not recommended as it involves considerable risk. Both non-compliance with warnings and visual verification of tornado suggest the need for additional public education among the residents of Joplin about how to respond to warning. However, nine the 20 respondents ignored the warning and did not seek shelter because they did not believe the warnings. One respondent thought there might be hail and some wind damage but nothing else to worry about. Five respondents stated that tornado warnings were such a common occurrence in their area that they tended to be hesitant in their response to the warnings. One resident stated:

“We hear tornado sirens all the time, and nobody pays attention to them.” This clearly illustrates as example of a laissez-faire attitude towards tornado warnings.

According to JCEOC Director Stammer, Jasper County, where Joplin is located, is number one in the state of Missouri for tornados since 1950. But the vast majority of these are of low magnitude tornadoes, ranging from EF0 to EF2. These are mostly short track tornadoes and move very fast on the ground. Given the high frequency tornados and their low magnitude, it is not unusual that some people do not take severe weather warnings seriously. Five respondents reported that they did not realize there was an imminent threat, with one stating: “It would not pass through our town.” Only two respondents did not have enough time to take shelter. Another two did not understand warning instructions. One of them thought the second siren meant the tornado had passed. The remaining two were in their car, returning to their homes.

Because sufficient tornado warning lead time is critical for taking shelter and thus reducing injuries and deaths, we looked at the nature of the lead time Joplin residents had prior to the tornado touch down. Table 3 presents this information by respondents’ opinion whether the warnings provided them enough time to seek safety. While the lead time is divided into five categories, the opinion is dichotomized as “had enough time to seek safety” (‘yes”) and “not enough time to seek safety” (“no”). Information collected from the survey reveals that the reported warning lead time to be between 1 and 60 minutes. Table 3 shows that 86 (90%) of the 96 respondents had lead time five minutes or more; five minutes is considered adequate time to take cover. The table further illustrates that 10 of the 96 respondents received warnings less than five minutes before the tornado hit Joplin. In all, 15 respondents considered they did not have enough time to take shelter; 10 of them had lead time five minutes or more.

Table 3 clearly indicates that the overwhelming majority of the respondents agreed that the warnings had given them enough time to seek shelter. Respondents were also asked whether they feel that the National Weather Service (NWS) did an adequate job in warning and/or preparing for the approaching tornado. Slightly over 86% (13 out of 96) respondents answered this question affirmatively. This response is consistent with the other opinion-type questions asked regarding timeliness of tornado warnings. Both evidences clearly support that the early tornado warning systems worked nearly flawlessly on the evening of May 22, 2011 in Joplin, MO. Conversations with non-respondents and emergency personnel working in Joplin at the time of questionnaire surveys also reveal that tornado warnings were issued in a timely manner and reached almost all people in impacted communities. The reports published in the Joplin Globe, a daily newspaper of Joplin, also support this view.

As indicated, 76 respondents complied with the tornado warnings, meanings they sought shelter after receiving the warning. The places used as shelter is listed in Table 4. These places are divided into two groups: residential structures (e.g., mobile homes and permanent houses, including duplexes and apartment complexes) and non-residential structures (e.g., churches, restaurants, retail stores, and hospitals). The table suggests that the area of the house most widely used as shelter was interior room (i.e., a room inside the house without windows). Nineteen (25%) of the 76 respondents took shelter in the interior room. Six of these respondents used interior room of non-residential buildings, primarily in interior room of churches where they were attending Sunday services. The remaining 13 respondents used an interior room of their residential buildings. Thirteen (17.11%) respondents reported seeking shelter in basements. Four of them used church basements and one of them sought shelter in the neighbor’s basement.

Eleven respondents went to a closet, and bathtubs and bathrooms were also used for safety by 10 and seven respondents, respectively. Five respondents, all of them were in a gas station, restaurant, or retail store, used a commercial cooler as shelter. Four respondents went to nearby tornado shelters, two of them were living in mobile homes. Another four respondents were in a car, or moved to a car and drove perpendicular either to the right or left of the approaching tornado for safety. Two respondents went to safe room and one to home's crawling space (Table 4). The use of other forms of protection – such as standing behind a table, desk or bench - was not reported by any respondents. Some of them, however, mentioned that they cover themselves with a blanket or mattress.

DISCUSSION

Given the information provided above, this section aims to explore the reasons for the very high death toll caused by the 22 May 2011 Joplin, MO tornado. Contrary to our belief, Bill Davis, chief meteorologist with the National Weather Service in Springfield, MO, stated, "Every day since this event, I have thought about the sheer level of destruction and wondered why more people were not killed" (OCC 2011, 2). The same opinion was also expressed by many respondents and other residents of Joplin during our field surveys. Contrary to our view, they claim that given the strength of the tornado and conditions of housing, they expected many more deaths. We obviously differ with the above claim since there have been many US tornadoes with six-mile long path that did not kill 162 people. The deadliest tornado in the United States was on 18 March 1925. The "Tri-State Tornado" had a 291-mile path covering Missouri, Illinois, and Indiana, and killed 695 people (Grazulis 1993; Joplin Globe 2011c).

In comparing the two events, one finds that the Tri-State tornado killed 2.4 people per mile, while the Joplin tornado killed 27.2 people per mile. Using the tornado tracks in the Stimers (2011) study, it was found that of the 981 tornadoes that passed through a community from 2000-2009, 254 of them had path lengths greater than or equal to six miles, and of those only 46 resulted in at least one fatality. The largest death toll of those 46 killer tornadoes was the 6 November 2005 Evansville, IN, tornado that that killed 20; the Joplin toll was 8.15 times higher.

We found that the warning system in the study area was adequate. People heard warnings via many sources, such as commercial and weather radio, telephone calls, and television. The first tornado sirens went off at 5:11 pm (2211 UTC) and second sirens at 5:31 pm (2231 UTC). Moreover, weather radio started providing tornado warnings from 5:17 pm (2217 UTC). As many as 25 outdoor sirens are located within Joplin city boundary and these sirens should provide complete coverage to the residents of the city. According to our estimate, the residents had 29 minutes lead time because tornado touch down occurred at around 5:40 pm (2240 UTC). This lead time provided adequate opportunity to take cover. However, during our conversation with JCEOC Director Stammer, he stated that residents of Joplin did not pay much attention when they first heard sirens, but many took shelter after hearing the sirens for the second time.

Adequate warning is not effective if people at risk have no access to shelter (Balluz et al. 2000; NCDC 1989). The lack of a basement in a house or the inability to gain access to a nearby storm cellar is important factors for responding to tornado warnings. As indicated, only eight respondents had basement in their homes. The absence of basements in houses in Joplin is not surprising. According to the Jasper County Assessor's Office, nearly 78% of houses across the county lack basements, due in part to the area's rocky ground and high water table (Joplin Globe

2011b).[8] Joplin is a city of this county and it has an even lower percentage of basements compared to the county figure as a whole. Joplin is located near the borders of four states: Missouri, Kansas, Oklahoma, and Arkansas; this four-state area was undermined with lead and zinc mines from the late 19800s and early 1900s, all the way through the early 1950s. There are many places that have old mine shafts underneath them, resulting in subsidence problems in the area; this makes the construction of basements very difficult.

Several studies (e.g., Balluz et al. 2000; Grazulis 1993) recommend the use of an interior room in the house as an alternative for people without basements. Depending on the conditions of a house, such a room often fails to provide adequate protection. Most of the houses in Joplin are old; 53% of all respondents reported living in homes constructed more than 30 years ago (Table 5).[9] They were constructed under the standards of the time, which compared to today's more rigorous building codes, were less adequate. Many of these houses were not even bolted down to their foundation and some of them did not even have foundation. Field survey reveals that the houses of 82% of the respondents were made of wood. Overwhelming the majority of the respondents had no idea about foundation anchorage and hurricane roof straps. Fortunately, after the tornado, the Joplin City Council has been encouraging residents to use hurricane straps to strengthen new construction (Joplin Globe 2011b).[10]

We suspect that lack of a basement and structural conditions of the house were contributing factors for relatively high death toll caused by the 2011 Joplin tornado. According to the SPC data, 66 (44.60%) of the 148 victims whose whereabouts were known when they died were in their residences, which include houses, apartment complexes and nursing homes (SPC 2011). Another 65 (43.92%) died were in their mobile homes. According to the Joplin, MO, Community Profile, of the 21,362 housing units, 350 (1.64%) were mobile home units in 2009

(Joplin, Missouri (MO) Profile 2011). This implies, odds of death for residents of mobile homes were much higher than the residents of permanent homes. This finding contradicts the contention of Sutter and Simmons (2010) that death tolls caused by EF5 tornadoes do not strikingly differs between residents of mobile and permanent homes, but supports Brooks and Doswell III's (2002) finding who analyzed the deaths toll caused by F5 tornado that hit Oklahoma City on 3 May 1999. Brooks and Doswell III concluded that the risk to mobile home residents was at least 20 times as great as risk to permanent home residents in the Oklahoma City tornado.

The SPC data does not disaggregate number of deaths by residential and non-residential structures. We found at least 20 victims died in non-residential structures. Of these, seven died in Home Depot store and seven in St. John's Regional Medical Center. It is surprising that too many people died in Joplin, MO, at homes even though 75% of the respondents reported having previously experienced a tornado. Most of these respondents experienced past tornadoes during the last ten years and an overwhelming majority of them were residents of four-state area.

In our conversations with emergency officials, respondents, and other residents of Joplin, MO, we asked them for probable reasons for the high death tolls caused by the May 22, 2011 tornado; three reasons were identified. First of all, the tornado was an FE5 throughout its 6-mile long path. A second reason given was that the tornado passed through densely populated areas. The final reason is associated with the physical characteristics of the majority of homes in Joplin, MO. As noted, many houses were very old and contain no basement, leaving few options for inhabitants of those structures to seek safety.

CONCLUSION

This study has analyzed the tornado warnings and compliance with such warnings in order to explore reasons for high death toll caused by the May 22, 2011 Joplin, MO tornado. We maintain that three reasons are associated with remarkably high number of tornado fatalities in Joplin, MO: sheer magnitude of the event, its path over a densely populated area, and physical characteristics of homes in Joplin, MO. This study reported that 11% of all respondents did not receive tornado warnings. Furthermore, nearly 21% of respondents did not comply with warnings after receiving them. This indicates a need on the part of emergency-management officials to improve existing systems of disseminating warning information in such a way that all at-risk populations are able to receive the intended warning. We recommend that all households who live in tornado-prone areas such as Joplin should purchase and utilize a weather radio.

Additionally, we recommend increased public education about how the residents can protect themselves after hearing a tornado warning. Currently, JCEOC organizes about a dozen weather presentations every year; it seems this number needs to be increased. To provide more access to tornado warnings, the JCEOC has recently distributed nearly 900 weather radio among residents of the county. This is a step in right direction, which should be promoted further. Advantages of weather radios include the feature of broadcasting county-specific warnings, and the ability to operate on battery power in the event of the loss of electricity service.

Given the physiography of the region, most notably the hard near-surface stratum of the Joplin area, we suggest several alternatives to basements, which residents should seriously consider before construction of new homes; one such alternative is safe room. Although building an in-house safe room costs no less than $6,000-$8,000, the public authority should provide financial incentives for constructing them. In the 1990s, FEMA provided grants in the range of

$3,000-$5,000 to residents of several cities of Kansas and Oklahoma to add a concrete safe room onto the existing house (Pattan 2003).

As alternatives to both basements and safe rooms, crawling spaces can be used as tornado shelter if the arrangements are made to have direct access to such spaces from the house. It is encouraging that we have seen during our field surveys a surge in safe room construction by Joplin residents affected by the May 22, 2011 tornado. Another alternative would be provision of multiple walls in the interior of a house. Given the geologic conditions which restrict building of basements, the Joplin city authorities can also seriously consider construction of community shelters that can withstand tornadoes. After a destructive tornado that struck Seneca, MO (located just 20 miles southeast of Joplin) in 2008, the city built such a community center. We believe our recommendations will be effective in reducing tornado-related deaths and injuries in Joplin and elsewhere in the United States.

NOTES

1. The Storm Prediction Center (SPC) of the National Oceanic and Atmospheric Administration (NOAA) reported 159 deaths caused by this event (SPC 2011).

2. Personal communication, 29 July 2011.

3. From 1971-2007, tornado magnitude was measured on the Fujita scale or F scale. This was introduced by Theodore Fujita in 1971 and it raged from F0 through F5. Since February 1, 2007, Enhanced Fujita scale or EF scale has replaced the F scale. The EF scale has the same basic design as the F scale, with six categories from 0 to 5 representing increasing degree of damage (Paul 2011).

4. Lead time refers to the amount of time between warning issuance and tornado event.

5. Safe rooms are made of thick concrete walls and ceilings reinforced with steel bars. A safe room can be installed in a basement, in the center of the ground level of homes without a basement, or under a garage. The garage floor can serve as the ceiling. One can also dig out a space beneath a reinforced entryway, using its concrete slab as protection from above (Murphy and Sherry 2003).

6. Manufactured homes refer to factory as opposed to site built homes, and the older term mobile homes refer to homes capable of being moved. In tornado research these two terms are used interchangeably (Sutter and Simmons 2010).

7. According to the Storm Prediction Center (SPC) data, a total of 115 people died from tornados in the United States during 2000-2011. Of these deaths 432 (37.40%) occurred among mobile home residents and 398 (34.46%) occurred among residents of permanent homes (SPC 2011).

8. Basements are also not common in Oklahoma because of hard clay soil (Murphy and Sherry 2003). However, a basement is no guarantee of protection from tornados for several reasons. Many basements, for example, are not fully underground, which makes them vulnerable to a degree. Additionally, most basements have a wood floor overhead that could collapse when subjected to tornado-force winds.

9. In 2009, median house value ($93,108) of Joplin was 34% below Missouri sate average ($139,700) (Joplin, Missouri (MO) Profile 2011). This clearly reflects the state of housing in Joplin compared to the state.

10. This device is designed to hold roof, walls and foundation together, and provides greater security against high winds

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Table 1. Tornado fatalities in the United States by magnitude, 2000-2011

Magnitude	Number of Fatalities	Number of Killer Tornadoes	Number of Fatalities/Killer Event
EF-5	299	8	37.38
Others	852	294	2.90
Total	1151	302	3.81

Source: SPC (2011)

Table 2. Sources of tornado warnings received by survey participants n=96)

Source	Number	Percentage
Siren	70	72.92
Television	36	37.50
Cell/telephone	19	19.79
Commercial radio	18	18.75
Word-of-mouth	11	11.46
Weather radio	6	6.25
Internet/e-mail	4	4.17
Others	9	9.38

Table 3. Tornado lead time (in minutes) by respondents' opinions regarding adequacy of the time to seek safety (N=96)

Lead Time	Provided Enough Time		
	Yes (%)	No (%)	Total (%)
<5	5 (50.00)	5 (50.00)	10 (100.00)
5-9	20 (87.00)	3 (13.00)	23 (100.00)
10-14	11 (73.33)	4 (26.67)	15 (100.00)
!5 and more	45 (93.75)	3 (6.55)	48 (100.00)
Total	81 (84.38)	15 (15.62)	96 (100.00)

Table 4. Areas used for tornado shelter by residential and non-residential structures (76)

Area	Residential Structure	Non-residential Structure	Total
	Number (%)	Number (%)	Number (%)
Interior room	13 (17.11)	6 (7.89)	19 (25.00)
Basement	9 (11.85)	4 (5.26)	13 (17.11)
Closet	11 (14.47)	-	11 (14.47)
Bathtub	10 (13.16)	-	10 (13.16)
Bathroom	6 (7.89)	1 (1.32)	7 (9.21)
Cooler	-	5 (6.58)	5 (6.58)
Tornado Shelter	4 (5.26)	-	4 (5.26)
Car[1]	-	4 (5.26)	4 (5.26)
Safe room	2 (2.63)	-	2 (2.63)
Crawling Space	1 (1.32)	-	1 (1.32)
Total	56 (73.68)	20 (26.32)	76 (100.00)

[1]Includes under non-resident structure

Table 5. Reported construction year of residential structures by period and type (N=107)

Type	2010-2000	1999-1980	1979-1960	Before 1960	Total
	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)
Single detached	14 (17.50)	17 (21.25)	31 (38.75)	18 (22.50)	80 (100.00)
Apartment	5 (27.78)	9 (50.00)	2 (11.11)	2 (11.11)	18 (100.00)
Mobile home	1 (25.00)	-	3 (75.00)	-	4 (100.00)
Townhouse	1 (20.00)	3 (60.00)	-	1 (20.00)	5 (100.00)
Total	21 (19.63)	29 (27.10)	36 (33.64)	21 (19.63)	107 (100.00)