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Research Article

Population Recovery in U.S. Communities Affected by Tornadoes, 2000-2010

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ABSTRACT

We investigated the demographic changes in American communities impacted by tornadoes from 2000 to 2010, exploring the factors influencing population recovery in tornado-affected communities, considering short-term (within one year) and long-term (2–10 years) outcomes. To identify significant contributors to population recovery, we analyzed seven predictor variables using logistic regression models, including tornado strength, community size, population trend and state status (Sunbelt or Snowbelt). The data encompassed 516 tornado-affected communities across the conterminous United States. Our findings revealed that about 55.81% of the communities experienced no significant population change immediately after the tornado event. However, 44.19% of the communities witnessed a population decline and only 10.66% fully recovered within 2–10 years. Results indicated community size and trends were pivotal in population recovery. Communities with negative population trends, especially those with fewer than 5,000 residents, faced significant challenges in regaining their pre-tornado population size within 1 year. The data did not show a significant difference in population recovery between communities in the Sunbelt and Snowbelt regions. The study highlights the importance of community-level factors in shaping population recovery dynamics following tornado events. Understanding these factors can aid community leaders and disaster managers formulate effective strategies to retain populations and encourage rapid recovery. Although certain limitations exist due to data availability, future researchers could explore additional factors, such as post-tornado policies and socioeconomic variables, to gain comprehensive insights into post-disaster population dynamics. Our research contributes valuable to social science disaster research, helping communities build resilience in the face of tornado hazards.

Keywords: Tornadoes; Snowbelt; Sunbelt; Communities; Demographic

INTRODUCTION

Disasters, such as tornadoes, produce various demographic changes in affected communities. For some communities, the post-disaster total population never reaches or takes some years to attain the pre-event level-primarily caused by some disaster survivors resettling nearby or distant unaffected communities. People move out of affected communities because of many factors: (a) limited access to employment opportunities, particularly in small communities; (b) lack of safety and security provision in the aftermath of the disaster; (c) non-availability of housing or increased housing costs; and (d) previous migration experience [1-4]. Movement also depends on the imposition of new land use regulations, building codes and construction practices and other programs such as new development restrictions by emergency managers and local government entities of disaster-affected communities [5-7].

Some disaster-affected communities show no effect on the total population size. In such communities, the population continues to grow consistently immediately following the event and in subsequent years. Thus, they experience net population gains or even an acceleration in total population growth [4,8,9]. This differential response to disaster-affected communities has yet to be studied much by either population or hazard researchers-we examined post-event changes in population size in American small and medium-sized towns and cities affected by tornadoes

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from 2000-2010 and their determinants to help fill this gap. Specifically, we tested two models to identify the factors: (a) one model for no population change occurred immediately after tornadoes struck them, and (b) a second model employed whether these communities recovered pre-tornado population within 2–10 years. This study makes crucial contributions to the social science disaster research literature by examining post-event population recovery in the context of tornado risk and vulnerability. Population dynamics, particularly population growth and migration, are among the most critical factors that have increased our exposure to disasters and their damage and loss of lives [10,11].

Theoretical framework

A community's post-disaster population size depends largely on the relocation decisions of surviving individuals and households. Among other considerations are post-tornado policies and programs for the housing recovery and improving safety measures by the affected community leaders influencing these decisions? Empirical evidence suggests that some survivors leave the affected community immediately after the event [12,13]. Concurrently, no individual moves to the community from neighboring and distant places, so the community would lose population in the year following the event.

In this paper, we endeavored to understand the recovery of the population of communities in the United States struck by a tornado through the lens of the fear of severe weather, termed lilasophobia, and other relevant theoretical frameworks in the hazards and disasters literature. Westefeld was the first person to coin the phrase "severe weather phobia" to describe those "persons with an intense, debilitating and unreasonable fear of severe weather" [14]. According to the Diagnostic and Statistical Manual of Mental Disorders, version 5 (DSM-5), diagnostic prevalence of lilasophobia is approximately 7%–9%, and about 1 in 50 people will develop the phobia [15,16]. Westefeld narrowly defined severe weather in terms of severe thunderstorms and tornadoes. Westefeld et al. also examined severe-weather phobia to explain characteristics, causes, and potential treatment methods associated with the phenomena, implying that people, in general, express a fear of losing their homes during inclement weather. As a result, they are perceived to be injured and can even die from a disaster outbreak [17].

Lilapsophobia exists in many residents in tornado- and hurricane-prone areas to some extent [18]. An intense and unhealthy fear of these two extreme events can affect people's daily life in the short- and long-term [19]. This fear can cause trauma, anxiety, distress, or disruption, as sufferers expect to face a significant risk of physical harm during a tornado event [20]. The fear can worsen over time and even include Post-Traumatic Stress Disorder (PTSD) after an event [21]. Lilapsophobia often leads to thanatophobia (the fear of death). In some cases, people leave the tornado-vulnerable community and relocate to a safer community where the perceived frequency of the event is less likely [18].

Some researchers have considered fear can be adaptive [22,23]. For example, adaptive fear of tornadoes can help households be prepared by constructing safe rooms within their houses and storm cellars outside the house or seeking shelter in basements when household members need to. Although these safety measures reduce the risk of loss of life, injury, and property damage, as well as increase tornado resilience for households and communities, these measures require the financial abilities of the households. For example, the construction of prefabricated safe rooms ranges in price from as low as $3,000–$9,500, depending on size and height [6]. Note that in some states of the United States, such as Oklahoma, there are better options than a basement due to high water table levels, which render basement construction challenging. In other areas or parts of other states (e.g., Joplin, Missouri, struck by a massive tornado in 2011), construction of basements is not possible due to the rocky soil.

Like lilapsophobia, the Terror Management Theory (TMT) indicates that potential fear or anxiety of death motives some households to leave the disaster-prone community [24-26]. Others reject their fear and traumatic experience by denying their vulnerability to threat, distorting its immediacy, and distracting themselves from it [26,27]. Generally, people who experienced a recent disaster assume that the event will not occur again in their communities for quite some time. Slovic et al. referred to this common misconception as the gambler's fallacy [28,29].

However, relevant leaders of disaster-affected communities can reduce the fear of weather-related hazards among their residents by introducing safety measures. This concept is known as the window of opportunity in the disaster literature [30-32]. The immediate aftermath of a tornado or any other disaster provides the opportunity for local government and disaster managers of affected communities for Disaster Risk Reduction (DRR) and improved redevelopment by enforcing and recommending new regulations to upgrade safety measures. These measures improve the quality of housing and therefore reduce potential loss of lives, injuries, and extent of destruction [33,34]. Depending on the cost of safety measures and available funds from outside, people of affected communities may be encouraged to stay in their residences. Some residents may wait for a disaster to build more substantial houses or repair their old houses [33].

People are most receptive to public policy changes immediately following an extreme event and pay closer attention to things that have just impacted their lives. Similarly, a recent disaster experience usually generates pledges of greater vigilance and safer behavior among survivors of tornadoes. Once the window closes, however, the opportunity may only come again after the next disaster [32]. Similarly, the interest of authorities who implement or recommend the safety measures declines over time. As recovery progresses, these measures are either forgotten or sidelined until another disaster strikes a community.

Local government entities and active support from state and federal governments provide financial support to tornado survivors to rebuild their destroyed or damaged houses according to newly imposed and recommended building and land use codes. For communities in developing countries, often this domestic support is supplemented by donor countries and foreign agencies, such as the World Bank, the Asian Development Bank (ADB), and United States Agency for International Development (USAID) [33]. Besides, other economic incentives, such as subsidies, low-interest loans for implementing new safety measures, or tax breaks by local government, reduce the out-migration of tornado survivors to surrounding communities. These incentive measures not only retain tornado survivors in an affected community but also benefit the community because it does not reduce the local tax base [13]. Suspecting that survivors of May 4, 2003, a tornado might move to other places, leaders of the five tornado-impacted cities (Liberty, Pleasant Valley, Gladstone and Northmoor in Missouri and Kansas City in Kansas within the Greater Kansas

City Metropolitan Area (GKCMA) quickly announced special incentives to encourage resident rebuilding in their communities [35].

Despite economic incentives, some residents of tornado-affected communities may either be leaving or thinking about moving to other towns or cities before the event [36]. A tornado event helps them to speed up the process. This is particularly true for some elderly residents, who generally view the post-tornado as providing an opportunity to move away from the affected communities after receiving insurance money [36]. If they live in isolated and rural communities in Snowbelt states [37], they generally prefer to move to communities in Sunbelt states [38]. A sizable portion of the older population did not return to Greenburg, Kansas, after an EF-5 tornado struck the Southwestern Kansas town of 1,400 people in 2007 [36]. Even by 2023, the city population had not reached the pre-tornado level.

For some people in their retirement years, the decision to rebuild houses after a tornado disaster is even more difficult. They must weigh the long-term financial costs and benefits and the availability of medical, assisted living and church facilities in the affected communities. As long-time residents of the affected communities, they also have strong emotional connections to the communities, which acts as a barrier to rebuilding in a new location [36,39]. However, a window of opportunity also leads to out-migration from tornado-affected communities. For example, after experiencing an F4 tornado in 2001, Hoisington city, Kansas, authorities enforced one land-use regulation, which restricted construction of damaged or destroyed homes on 50 feet-wide (15.24 m) lots in the tornado-affected northeastern part of the community. Many people who wished to rebuild homes in the affected area had to purchase adjacent lots to satisfy the requirement. As a result, the housing density in the area became less than 50% of pre-tornado density and is much lower than in the non-affected areas of the city [12]. Many people in the affected part of the city could not buy additional 50-foot lots to reconstruct their houses, consequently, many did not return to the city, and population decline followed. According to the U.S. 2020 population census, the city has failed to recover its pre-tornado population size after 20 years [40].

The frameworks and prior findings appear together to provide valuable concepts and powerful tools to understand the population recovery of communities affected by tornadoes. With the aid of these frameworks, we have selected the relevant determinants of whether a tornado-affected community recovers from pre-event population size. These determinants separate broadly into four classes: (a) physical characteristics of tornadoes, (b) post-tornado policies of affected communities, (c) community characteristics, (d) and individual or household attributes. The present research shows only one critical physical characteristic of tornadoes (strength or magnitude). This attribute triggers several threats and determines the extent of casualties among the population and the damage to structures in the affected community [5,12]. Other characteristics of tornadoes, such as duration, spatial extent, and width of the event path, are not considered because they vary little from one to another [41,42].

Pre- and post-tornado policies and programs, including financial incentives by the leaders of tornado-affected communities, are the second broad determinant, divided into two sub-types. The first sub-type includes community protection works (e.g., on-time issuing of a tornado watch, warning, and lead time), land use and building construction practices [5,11,43]. Community protection works to limit the impact of a hazard agent on the entire community and reduces weather-related fear among the residents. The second sub-type includes other supports and incentives the affected local government provided, as discussed above under the window of opportunities section.

The third broad category reflects community characteristics such as community size concerning population, population trend for the preceding census decades and whether it is the county seat or a suburb of a larger city. If the affected community is relatively large or characterized by a positive population trend, the community population will tend to recover quickly [5,13]. That is also true if the affected community is a county seat or a large city suburb. Community characteristics also include population composition (e.g., age, gender, percentage of African American, and percentage of manufactured homes) and economic conditions (e.g., poverty rate, median income and percentage of manufactured homes). Finally, the fourth broad group of determinants is the individual and the household's decision to stay or not stay in the tornado-affected community. Many factors influence that decision, including (a) a lack of employment opportunities, (b) the cost of rebuilding and (c) the intensity of the fear of tornadoes. Since the study unit was the community, these factors went unused here.

MATERIALS AND METHODS

Selection of the study period and the tornado-affected communities

The period considered in this study included 2000–2010. Using the terminal year helped follow the population change of tornado-affected communities for at least 10 years. Statista stated that 14,020 tornado events occurred in the United States during the study period. However, not all tornado events were selected [44]. The study excluded 8,887 (63.39%) of those events either rated as F/EF-0 on the Fujita/Enhanced Fujita scale or a category of unknown scale. However, most of these were a former category, which had minimal impacts on affected communities [42]. Note that F/EF-0 tornadoes are the most common in the United States. We eliminated tornado-affected communities with less than 500 and more than 100,000 people because their population growth potential is likely to be very small and large, respectively. Additionally, residents of smaller cities are often far more vulnerable to tornadoes than residents of larger cities. The latter cities are often better prepared than the former cities. Also, tornadoes can affect the entire area of a smaller city, while the effect can be only on a small part of a larger city [13,42] (Average area affected in the USA by a tornado is slightly over one square km [42,45]). Tornado-affected communities within the conterminous United States were selected, but we excluded those without relevant population information. Thus, 516 tornado-affected communities were chosen in this study as shown in Figure 1.

The National Weather Service's (NWS) Strom Prediction Center (SPC) annually publishes each detected tornado event in the United States in two forms. The SPC published killer tornado data by communities for the time 2000–2007 (A tornado event that kills at least one person is a killer tornado). The SPC also published tornado tracks data for the killer tornadoes since 2007 and non-killer tornadoes for the study period. The latter data for 2000–2009 emerged from Stimers [46,47]. The SPC provided tornado data for 2010. Following Stimers' [46] procedures, we extracted the necessary community data from tornado tracks using an initial base map from the National Atlas and shapefile data containing U.S. states, 3,116 counties and 25,148 communities. These map layers are called the states, county (or counties) and community (or communities) shapefiles. We imported those data into a Geographic Information System (GIS) program for analysis.

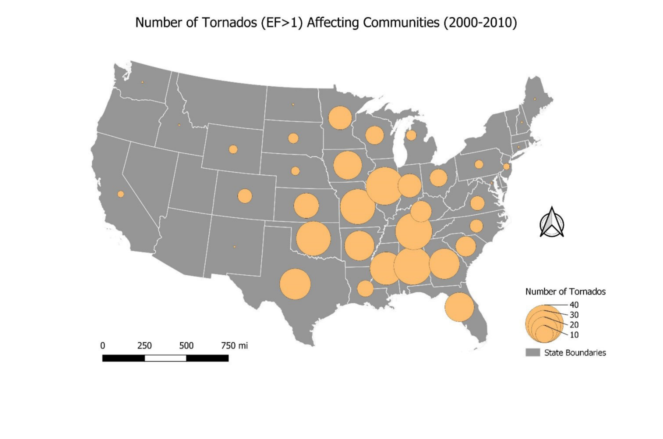

Figure 1: Number of tornadoes (EF>1) that affected U.S. Communities (2000–2010). **Note:** Number of tornados: (■): 10; (■): 20; (■): 30; (■): 40; (■): State boundaries.

Point data containing the beginning and ending latitude and longitude of all tornado events (herein named points) as well as polyline data for all tornado tracks (herein named as tracks) from 2000–2009 derived through the SPC's GIS data portal [48]. We imported the points and track shapefiles for all tornadoes during the study period into a GIS. This study considered only those tornadoes that passed through an American community (All tornado tracks in the U.S. do not intersect a community or pass-through population areas [42,46]. Note that a tornado track may not pass through a community or may pass through more than one community as shown in Figure 2 (Sometimes tornado does not strike even an entire small community. For example, an EF-5 struck Greenburg, KS on May 2007. It wiped out 95% of this small town. Before the tornado, it had nearly 1,500 population with an area of 1.79 square miles [49]). Generally, the tornado touches a part of a sizable community. If the size of the tornado-affected community is minimal, it may pass through the entire community. The above procedures were followed for communities affected by tornadoes in 2010 and killer tornadoes since 2008.

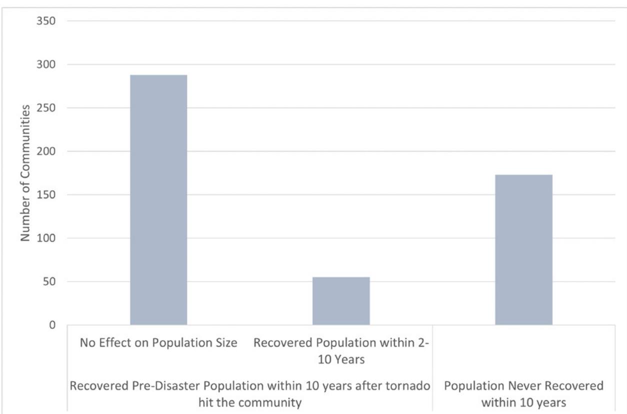

Figure 2: Community recovery and effect on population size.

Selection of determinants

Based on the theoretical framework and our experience with tornado studies in the U.S. for more than 2 decades, we selected seven factors for each model as independent variables as shown in Table 1. The two dependent variables of the study reflect population recovery to pre-tornado level, either within one 1 or 2 and up to 10 years after a tornado. The first independent variable is tornado strength (magnitude) or severity. It is a crucial physical dimension of the event, which generally influences the number of deaths and injuries-the distribution of tornadoes by F/EF-scale rating affects the threat to people and property [42,50] (From 1971 through 2007, tornado magnitude was measured on the Fujita scale or F-Scale. The Enhanced Fujita Scale (EFS) has replaced the FS since February 01, 2007. It was revised to reflect examinations of tornado damage surveys better, precisely to align wind speeds more closely with associated tornado damage. Both scales have six categories from 0–5 representing increasing degrees of damage [49]). While tornado deaths appear in the table as a second independent variable, injuries were excluded for one reason. Tornado events cause a wide variety of injuries, ranging from minor to life-threatening injuries. Those who sustained minor injuries comprise the majority, most of whom do not need medical attention. Most other serious injuries require hospitalization for months. Unfortunately, the SPC tornado data do not provide information about the severity of an injury.

The following determinant selected refers to the state attribute of whether the tornado-affected communities are in the Sunbelt or Snowbelt (Several maps classified the 48 conterminous United States into two groups: The snow-belt and the Sunbelt. These maps are not in complete agreement on the status of some states). We expect people to move from the Snow Belt to the Sun Belt for several reasons. The Sunbelt has been growing manufacturing activities for decades. Coupled with transportation improvements, abundant summer air conditioning and a favorable winter climate have attracted retirees and workers. However, the remaining determinants are community characteristics. Among these characteristics, we selected community size in terms of population size. This site was readily available from the U.S. Census. Where the annual population for concerned communities was unavailable, size was determined by interpolating past and subsequent U.S. Census or American Community Survey (ACS) data. The community population trend for at least 2 preceding decades appears as the fifth determinant in this study. The community population variable indicated whether the community was already growing or declining when struck by the tornado. A growing community may recover quickly post-tornado following its prior growth trajectory. Affected county seat or suburb status were included because these communities were relatively large, and thus they likely to recover post-tornado total population quickly. County seat or suburbs' special status and location close to metropolitan areas attract the press and politicians' attention [13]. Moreover, such communities have strong horizontal and vertical connections. As a result, Berke et al. [51] claimed that "well-developed ties to external resources and programs" and "viable horizontal network that will allow exerting power and influence in the recovery process" [52,53].

Analytical techniques

Whether tornado-struck communities had no (negative) effect on population size was used as a first response variable in this study, meaning that the affected communities returned or even increased to the pre-event population level within 1 year after the event struck. The second dependent variable considered whether the affected communities took 2–10 years to return to the pre-tornado population size. Although tornadoes can occur any time of year, they tend to strike during particular months. The time of year when the United States experiences the most tornadoes is termed the tornado season, and typically peaks from April–July [42,54]. The study data supported those peak months. Additionally, no tornado occurred on the first of January or the last day of December of the calendar year. Often yearly population of the tornado-affected communities was not available. In those cases, the yearly population of the study period was calculated based on the population growth or decline trend derived from the three most recent decennial censuses (2000, 2010 and 2020).

Since both dependent variables were categorical (yes and no), applying binary logistic regression was an appropriate statistical technique for this analysis. Two models were employed to identify which factors contributed to predicting the two dependent variables (whether communities recovered population within 1 year and whether communities reached pre-tornado population within 2–10 years). Within each separate model, the best-fit model emerged based on the Akaike Information Criteria (AIC) value and statistical significance of the predictor variables [55]. Each model provided a direct estimate of the Odds Ratio (OR) for all regressor variables. Before using the logistic regression technique, chi-square tested the crude effect of exposure variables on two dependent variables without controlling for other variables by cross-tabulation. R-Studio facilitated statistical analysis. Since all data were publicly accessible and the study unit did not focus on individuals and households, we did not seek approval from the Institutional Review Board (IRB) of any of the three author's universities.

Table 1: Selected determinants of population change in Tornado-Affected U.S. Communities.

Variable	Source
Determinant	
State status (in terms of location of sun or snow belt)	Sunbelt: Jewell [38] Snowbelt: Balland and Rigby [37]
Community size (in terms of population size	Biggestuscities.com/city/name of the city-state name; U.S. Census Bureau's census (different census years); or ACS
Tornado strength (F/EF scale)	SPC
Tornado death (number)	SPC
Population trend (+ or -) at least for two preceding decades	Biggestuscities.com/city/name of the city-state name; U.S. Census Bureau's census (different census years); or ACS
County seat	City-data.com
Suburb status	City-data.com
Dependent variables	
No change in total population size	Biggestuscities.com/city/name of the city-state name; U.S. Census Bureau's census (different census years); or ACS
Recovered post-tornado population size within 2-10 years	Bigestuscities.com/city/name of the city-state name; U.S. Census Bureau's census (different census years); or ACS

RESULTS

In this investigation, the tornado selection criteria used allowed for examining tornado occurrences in the conterminous United States comprising 48 states. Among these, 37 states recorded tornadoes during the designated study period. While tornadoes can potentially affect all states within the country, the annual frequency of tornado occurrences varies significantly from one state to another. Traditionally recognized as a region where tornadoes are most frequent, tornado alley encompasses a loosely defined area in the central United States, stretching from northern Texas through Oklahoma, Kansas, Nebraska, Iowa, and South Dakota. Additionally, certain states such as Minnesota, Wisconsin, Illinois, Indiana, Missouri, Arkansas, North Dakota, Montana, and the Easternmost part of Colorado, New Mexico and Ohio have sporadically appeared in tornado alley maps [56]. However, researchers have indicated the primary tornado alley might be shifting eastward, away from the Great Plains, with tornadoes becoming more frequent in the southeastern states of the country, an area termed dixie alley as shown in Figure 1 [42,56-62]. The comprehensive tornado data compiled from the Storm Prediction Center (SPC) revealed that Alabama and Illinois experienced the highest number of tornadoes, followed by Tennessee, Missouri and Oklahoma.

In contrast, during the study period, there were no reported tornadoes in 11 states: Arizona, Delaware, Massachusetts, Montana, New York, Nevada, Oregon, Rhode Island, Utah, Vermont, and West Virginia. In those states, tornadoes are considered rare, with annual occurrences ranging from two to five and all falling below the F/EF-0 intensity level [42]. The study period featured an average of nearly 42 communities impacted by tornadoes yearly. The lowest number of communities (22) affected by tornadoes occurred in 2000, while the highest number (75) transpired in 2008. Additionally, data indicated that at least 29 communities experienced tornadoes twice during the study period: 18 of those communities encountered two separate tornado events in different years, seven experienced two tornadoes in the same year but on different days, and four encountered tornadoes on the same day but at different times. Twenty-five communities experienced multiple tornado events during the study period, either in different years or on non-consecutive days. The four communities that encountered tornadoes on the same day were considered a single event. Moreover, no community experienced more than two tornadoes during the study period. The study findings appear in two stages. Using cross-tabulation, we examined the raw impact of seven exposure variables on two dependent variables without controlling for other factors. As an empirical association between two variables does not necessarily imply a causal relationship, a multivariate approach was subsequently applied to estimate statistical functions that predict the behavior of the two dependent variables.

Contingency analysis

Among the 516 communities examined, approximately 55.81% (288 communities) experienced a complete recovery of their total population in the year immediately following the tornado strike as shown in Tables 2 and 3. This implies that their population sizes remained unaffected after the tornadoes struck them. Conversely, the remaining 44.19% (228 communities) witnessed a decline in their total population after being impacted by a tornado. Within this group, 55 communities managed to restore their population to pre-disaster levels within 2–10 years after the tornado event. These cases represented approximately 10.66% of the total sample. However, a considerable portion of 33.53% (173 communities) never recovered their pre-disaster population within 10 years after the tornadoes struck. The data illuminated the diverse patterns of population recovery observed in the aftermath of tornadoes across the studied communities, offering valuable insights into the complex dynamics of post-disaster demographics.

Table 2: Distribution of the selected 516 communities by independent variables.

Independent variable	Number of selected communities	Percentage
State status		
Snowbelt	293	56.78
Sunbelt	223	43.22
Community size		
>25,000 people	89	17.25
15,001–25,000 people	63	12.21
5,000–15,000 people	126	24.42
<5,000 people	238	46.12
Tornado strength		
F/EF-1	265	51.36
F/EF-2-3	225	43.6
F/EF-4-5	26	5.04
Tornado death		
Death	112	21.71
No death	404	78.29
Population trend		
Positive	229	44.38
Negative	287	55.62
County seat		
No	352	68.22
Yes	164	31.78
Suburb status		
No	463	89.73
Yes	53	10.27

Table 3: Contingency table analysis (N=516).

Independent variable	Dependent variable			
	Recovery of pre-tornado population within 1 year		Recovery of pre-tornado population within 2-10 years	
	Yes (%)	No (%)	Yes (%)	No (%)
State status				
Snowbelt (0)	177 (60.41)	116 (39.59)	205 (69.97)	88 (30.03)
Sunbelt (1)	111 (49.78)	112 (50.22)	138 (61.88)	85 (38.12)
Chi-square	5.383 (df=1; p=0.020)		3.358 (df=1; p=0.067)	
Community size				
>25,000 people (0)	74 (83.15)	15 (16.85)	79 (88.76)	10 (11.24)
15,001-25,000 people (1)	46 (73.02)	17 (26.98)	52 (82.54)	11 (17.46)
5,000-15,000 people (2)	81 (64.29)	45 (35.71)	96 (76.19)	30 (23.81)
<5,000 people (3)	87 (36.55)	151 (63.45)	116 (48.74)	122 (51.26)
Chi-square	73.981 (df=3; p<0.000)		66.062 (df=3; p<0.000)	
Tornado strength				
F/EF-1 (Weak) (0)	153 (57.74)	112 (42.26)	179 (67.55)	86 (33.45)
F/EF-2-3 (Strong) (1)	121 (53.78)	104 (46.22)	148 (65.78)	77 (34.22)
F/EF-4-5 (Violent) (2)	14 (53.85)	12 (46.15)	16 (61.54)	10 (38.46)
Chi-square	1.16 (df=2; p=0.281)		0.470 (df=2; p=0.791)	
Tornado death				
Death (0)	57 (50. 89)	55 (49.11)	74 (66.07)	38 (33.93)
No death (1)	231 (57.18)	173 (42.82)	274 (67.82)	130 (32.18)
Chi-square	1.16 (df=1; p=0.281)		1.254 (df=1; p=0.263)	
Population trend				
Positive (0)	213 (93.01)	16 (6.99)	227 (99.13)	2 (0.87)
Negative (1)	75 (26.13)	212 (73.87)	116 (40.42)	171 (59.58)
Chi-square	228.81 (df=1; p<0.000)		194.36 (df=1; p<0.000)	
County seat				
No (0)	188 (53.41)	164 (46.59)	225 (63.92)	127 (36.08)
Yes (1)	100 (60.98)	64 (39.02)	118 (71.95)	46 (28.05)
Chi-square	2.299 (df=1; p=0.129)		2.887 (df=1; p=0.089)	
Suburb status				
No (0)	240 (51.84)	223 (48.16)	292 (63.07)	171 (36.93)
Yes (1)	48 (90.57)	5 (9.43)	51 (96.23)	2 (3.77)
Chi-square	27.376 (df=1; p<0.000)		21.999 (df=1; p<0.000)	

Most of the communities 293 (56.78%) sit in the Snowbelt region, an expected finding considering 31 (64.58%) out of the 48 states in the conterminous United States are situated in this region. Regarding the first dependent variable, 288 (55.81%) of the tornado-affected communities replaced their pre-tornado population size within 1 year, indicating the tornado event had no significant impact on the population size of these communities during that period as shown in Table 3. Conversely, the remaining 228 communities' (44.19%) population did not recover within 1 year after being struck by a tornado. A relatively higher proportion of communities in the Snowbelt region achieved population recovery within 1 year compared to those in the Sunbelt region. The chi-square analysis for the first dependent variable and independent variable (Snowbelt vs. Sunbelt states) yielded statistical significance at p=0.05 (df=1) (df=disaster frequency), highlighting the variables association. However, the chi-square analysis for the second dependent variable and the same independent variable did not yield statistical significance, indicating the long-term population recovery of communities in the Sunbelt and Snowbelt states did not significantly differ.

The tornado-struck communities during the study period fell into four categories based on population size as shown in Tables 2 and 3. The largest community category comprised communities with more than 25,000 people at the time of the tornado strike, while the smallest category consisted of communities with less than 5,000 people. Among the smaller communities, approximately 63.45% did not return to their pre-tornado population size within 1 year. Both dependent variables showed a consistent trend of increasing percentages of communities failing to recover to pre-disaster population size with declining community size. The relationship between community size and the replacement of population within 1 year or not proved to be statistically significant, with a chi-square value of 73.98 and p<0.000 (df=3), which also holds true for the second dependent variable.

We excluded F/EF0 tornadoes and categorized the remaining tornadoes (F/EF1-5) into three groups based on their perceived strength: Weak (F/EF1), strong (F/EF2-3) and violent (F/EF4-5) tornadoes as shown in Tables 2 and 3. The data revealed that among the 516 communities struck by tornadoes during the study period, approximately 51.36% experienced weak tornadoes, while 43.60% encountered strong tornadoes. Only 5.04% of communities experienced a violent tornado. These figures aligned with the annual tornado strength patterns observed in the United States. Importantly, tornado strength exhibited statistical significance with both dependent variables, indicating a notable impact on population recovery.

In line with the overall U.S. pattern, most communities we examined experienced no fatalities from tornadoes. Among communities recording tornado-related deaths, most suffered only one death. Consequently, tornado deaths were categorized into two groups: (a) death and (b) no death as shown in Tables 2 and 3. For instance, Newburn, Tennessee, witnessed the highest number of deaths when an F3 tornado in 2006 claimed 16 lives. However, tornado-related deaths did not significantly affect the two dependent variables, as confirmed by the insignificant chi-square values as shown in Table 3. As expected, among the 516 communities selected for this study, approximately 44.38% showed positive population trends in at least two census years preceding the tornado strike, while the remaining 55.62% experienced negative trends as shown in Table 2. Most communities with a positive population trend (approximately 93.01%) observed no significant effect on population growth in the 1 year following the tornado event. Conversely, the communities with negative population trends were less likely to recover to pre-tornado population levels within 1 year, which also held true for the second dependent variable. The population trend emerged as the most influential factor among all independent variables considered in this study, with the largest chi-square values obtained for both dependent variables.

Among the 516 selected communities, 164 (31.78%) were identified as county seats and 53 (10.27%) were categorized as suburbs of large cities as shown in Table 2. The county seat status of tornado-affected communities did not significantly impact their ability to return to pre-event population size within 1 year or 10 years following the tornado strike, as evidenced by the non-significant chi-square values for both dependent variables. However, the suburbs' status exhibited a discernible effect on population recovery to pre-disaster levels as shown in Table 3. Out of the seven independent variables analyzed, four showed statistically significant associations ($p<0.05$) with the recovery of pre-event population size within 1 year or 10 years after the tornado impact. These variables, ranked in descending order of association with the two dependent variables, are population trend, community size, and suburb and state status (Sunbelt vs. Snowbelt). All seven variables were incorporated into logistic regression models.

Logistic regression analysis

Two logistic regression models were employed to investigate the factors significantly influencing the recovery of pre-tornado population size in American communities impacted by tornadoes during the study period as shown in Table 4. The logistic regression output provides coefficient estimates, Odds Ratios (OR), and each variable's model fitness statistic AIC. Among the independent variables, two were statistically significant-negative population trend and communities with less than 5,000 people-one with a significance level of $p<0.001$ and the other with a significance level of $p<0.01$.

The logistic regression analysis revealed that the negative population trend is the most influential predictor in explaining the recovery of pre-tornado population size within one year in the affected communities, as it was statistically significant at $p<0.001$. The negative population trend exhibited the highest odds ratio of 29.21, indicating that tornado-affected communities experiencing a positive population trend were approximately 29 times more likely to return to their pre-tornado population size within 1 year than those with negative population growth. Similarly, reference communities (with more than 25,000 people) were 3.24 times more likely to recover their pre-tornado population size than the smallest communities with less than 5,000 people, and this difference was statistically significant at $p<0.01$. However, the other two categories of community size were insignificant predictors as shown in Table 4. While the odds ratios decreased with increased community size, the reference communities remained 1.5 times more likely to recover their population within 1 year than their immediate second-largest counterparts (with a population between 15,001 and 25,000; Tables 3 and 4).

In Model 1, among the three sizes of communities, only the smallest community size (i.e., less than 5,000; Table 4) demonstrated statistical significance. The community size category 2 (5,000–15,000 people) came close to reaching significance at $p<0.05$. The reference category for the smallest community size, in terms of the independent variable, was the community size with more than 25,000 people. The three non-reference categories of this variable displayed odds ratios greater than 1, suggesting that these community sizes have higher odds of recovery than the largest community size (greater than 25,000 people). Moreover, this implies that smaller tornado-affected communities require a longer time to recover to their pre-event population size than larger communities. The odds consistently increased with decreasing community size, with the smallest community size exhibiting the highest odds ratio of 3.24 as shown in Table 4. The remaining five independent variables were not statistically significant, although they displayed expected signs and odds ratios. Notably, one independent variable showed a negative sign, as anticipated. Communities that did not experience any tornado-related deaths during the study period recovered within one year compared to those communities that encountered the death of one or more individuals.

Table 4: Logistic regression results.

Explanatory variable	Model 1		Model 2	
Intercept	Model fitness statistics AIC			
	451		418.54	
	Estimate	OR	Estimate	OR
	-4.166**	0.016	-6.291**	0.002
State status				
Sunbelt (1)	0.1	1.105	-0.022	0.978
Community size				
15,001-25,000 people (1)	0.431	1.538	0.095	1.1
5,000-15,000 people (2)	0.854	2.348	0.444	1.559
<5,000 people (3)	1.176*	3.241	0.894	2.455
Tornado strength				
Strong, F/EF 2-3 (1)	0.419	1.521	0.191	1.211
Violent, F/EF 4-5 (2)	0.75	2.118	0.836	2.307

Tornado death				
No (1)	-0.471	0.624	-0.288	0.75
Population trend				
Negative (1)	3.375**	29.213	4.818**	123.727
County seat status				
No (1)	0.214	1.239	0.276	1.317
Suburb status				
No (1)	0.636	1.889	0.994	2.702

Note: *p<0.01; **p<0.001.

Model 2's dependent variable pertains to whether the tornado-affected communities returned to their pre-disaster population within 2–10 years as shown in Table 4. Similar to Model 1, the same independent variables were included in Model 2. Also consistent with Model 1, population trend and intercept were statistically significant at p<0.001. However, the remaining independent variables were not statistically significant. The interpretation of odds ratios remains consistent with the discussion on Model 1 as shown in Table 4. The data demonstrated a better fit in Model 2 than Model 1, as evidenced by the lower AIC value for Model 2 (418.54 versus 451.0).

DISCUSSION

We used two logistic regression models, each incorporating seven predictor variables, to examine the factors contributing significantly to the recovery of pre-tornado population size in American communities impacted by tornadoes during the study period as shown in Table 4. The chi-square test was initially applied, revealing that four independent variables (state status, community size, population trend, and suburb status) exhibited statistical significance in Model 1, focusing on population recovery within one year. Subsequently, through logistic regression, two variables, namely community size with fewer than 5,000 people and population trend (both community factors), emerged as significant predictors in this model.

In Model 2, which pertained to population recovery within 2–10 years, three independent variables (community size, negative population trend, and suburb status) showed significance in the bivariate analysis. However, only the population trend remained significant in the multivariate situation. It is noteworthy that aside from tornado events, many rural communities across the United States have experienced persistent population loss, especially in remote small communities [63]. More people have left nonmetropolitan (rural) counties than relocating to them, resulting in natural population decrease due to higher death rates than birth rates [64,65].

In Model 2, the smallest community size did not demonstrate statistical significance. Eighty-seven of the smallest communities recovered at least the base population within 1 year after the tornado struck them (Model 1). In contrast, in Model 2, 116 smallest communities achieved pre-tornado population size within 2–10 years as shown in Table 3. The additional recovery of 29 communities in Model 2 might link to the implementation of incentives provided by community leaders to discourage population loss after the tornado event. We did not collect information regarding post-tornado policies adopted by these and other tornado-affected communities during the study period. However, empirical studies have suggested that such policies and supports play crucial roles in facilitating the rapid recovery of tornado-affected communities and the subsequent increase in their population [6,12,49]. The enforcement of costly safety measures during repair and rebuilding processes and restrictive zoning ordinances delays recovery efforts and acts as barriers to regaining pre-tornado population size [10,66]. Conversely, tax incentives encouraging residents to rebuild houses in tornado-affected communities foster reconstruction and population retention [6,35]. We not only considered one physical characteristic of tornadoes, i.e., magnitude, which in both bivariate and multivariate analyses did not show statistical significance as shown in Tables 3 and 4. The result was not surprising, as strong and violent tornadoes rarely strike communities, with the United States experiencing approximately one EF-5 and ten EF-4 tornadoes yearly [42]. Furthermore, only about 20% of tornadoes result in fatalities, and most fatal tornadoes claim just one life.

The same applies to the state status, whether Sunbelt or Snowbelt, which was not significantly associated with population recovery. The desire of many elderly individuals from the Snowbelt to relocate to the Sunbelt, particularly states like Arizona and Florida, to avoid cold weather and snow has been well-documented [42]. However, it appears that either enough elderly individuals from tornado-affected communities in Snowbelt states did not migrate to the Sunbelt, or elderly individuals from the Sunbelt did not move to the former affected communities, mainly since the Sunbelt experienced stronger and more violent tornadoes than Snowbelt states during the study period. Notably, since 2000, killer and high-magnitude tornadoes have shifted from Snowbelt states to Sunbelt states, particularly in the southeast, where there are higher population densities, lower-income populations, and more obscured views of twisters due to increased tree coverage [67].

The county seat status of tornado-affected communities did not emerge as a significant predictor in both bivariate and multivariate analyses as shown in Tables 3 and 4. One plausible reason for this lack of significance is the wide distribution of tornado-affected places across all community sizes. The data indicated that out of the 316 selected communities, 164 were designated county seats, encompassing all four community size categories considered in this study. The smallest community size category accounted for nearly 31% of these county seats, while the largest size category represented 26%. Additionally, over a dozen county seats were suburbs of metropolitan areas. Particular communities experienced tornadoes multiple times during the study period. For instance, Leesburg, Virginia, was struck twice in 2003 (July and November). Benton, AR, and Owensboro, KY, were struck by tornadoes three times each during the study period. However, we excluded this variable from the analysis due to the relatively small number of such communities. Similarly, the mean or median annual income, another community-level variable, was excluded primarily due to a lack of relevant data for the study years.

CONCLUSION

We focused on seven factors while excluding other potential factors primarily due to data unavailability for each tornado-affected community and during the study period. For instance, the implementation of incentive programs by tornado-affected communities and the provision of timely tornado warnings are crucial factors influencing population retention or loss in these communities. Future research could adopt a smaller sample size and conduct interviews with authorities from the affected communities to gain insight into their post-tornado policies and strategies to overcome these limitations. Additionally, socioeconomic, race/ethnicity, employment, and poverty factors could be considered in future investigations, although unavailable for each study year in small and medium-sized communities.

However, the study revealed that four factors demonstrated significance in the bivariate analysis (state status, community size, population trend, and suburb status), and two factors (population trend and community size) remained significant in the multivariate situation in Model 1. Similarly, three variables (community size, population trend, and suburb status) showed significance in the bivariate analysis, with only population trend remaining significant in the multivariate situation in Model 2. Multivariate analyses emphasized the significance of the population trend as an essential determinant in both models for population recovery within one year or 2–10 years after tornado events. Consequently, community leaders and disaster managers should exercise caution, especially in smaller communities (<5,000 people) experiencing negative population trends before and immediately after a tornado event. Community leaders must exert all efforts to retain the population and discourage relocation to other communities following the disaster.

DATA AVAILABILITY

Data used in the research is publicly available (a) U.S. Census Bureau data and (b) National Weather Service data, aligned with the dates listed in the manuscript, or (c) regarding the Stimers (2011) dataset, used with permission from Mitchel Stimers, and freely available at https://krex.k-state.edu/handle/2097/8531.

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