

A Summary of Recent National-Scale Lightning Fatality Studies

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ABSTRACT

There is a major difference in population-weighted lightning fatality rates between the lower fatality rates in developed countries and the higher fatality rates in developing countries. The large decrease in annual rates of population-weighted lightning fatalities in the United States is described over the last century. A similar large reduction in lightning fatality rates has occurred during recent years in Australia, Canada, Japan, and western Europe, where there has also been a change from a mainly rural agricultural society to a primarily urban society. An important accompanying aspect of the lower casualty rates has been the widespread availability of lightning-safe large buildings and fully enclosed metal-topped vehicles, as well as much greater awareness of the lightning threat, better medical treatment, and availability of real-time lightning information. However, lightning exposure for many people in lesser-developed countries is similar to that of a century ago in developed countries. The number of people living in these areas may be increasing in number, so the number of people killed by lightning may be increasing globally due to these socioeconomic factors. It can be difficult to locate national lightning fatality data because of their mainly obscure publication sources. The present paper synthesizes lightning fatality data from 23 published national-scale studies during periods ending in 1979 and later, and maps these fatality rates per million by continent.

1. Introduction

The population-weighted lightning fatality rate in developed countries has experienced a major reduction during the last century to a contemporary low value. In contrast, there continue to be higher rates in the developing countries of the world. There are published national lightning fatality data for only 23 countries for periods ending in 1979 and later, for which reasonably recent statistics can be compared. Many of these results are in relatively obscure publications, although there has been some tendency in the last few years for journal publication. Because of the difficulty of locating these publications, a number of national lightning studies in recent years have quoted only a few or several of these papers. A major reason for the sporadic reference to past national lightning fatality totals is the lack of a resource combining national studies into one location. The purpose of this paper is to fill this information gap concerning published national-scale fatality studies in

the last quarter century that are dispersed across a spectrum of publications.

2. U.S. lightning fatalities and injuries

The number of lightning fatalities in the United States has decreased from a maximum of greater than 400 deaths per year early in the twentieth century to less than 30 deaths annually in recent years (Curran et al. 2000; Holle et al. 2005; Jensenius 2014; López and Holle 1998). (The yearly fatality total is updated annually for the last decade at <http://www.lightningsafety.noaa.gov/media.shtml>.) The lightning fatality rate decreases from as high as six fatalities per million people per year early in the twentieth century (Fig. 1) to 0.1 fatalities per million people per year in recent years (updated from López and Holle 1998). This trend has occurred simultaneously with a decrease from a 60% rural U.S. population in 1900 to the present rural population below 20%. While the number of people in the United States has increased by more than a factor of 4 during this period, the actual number of fatalities has greatly decreased. Also during these years, there has been a substantial increase in the quality of homes, workplaces, schools, and other public and private buildings with

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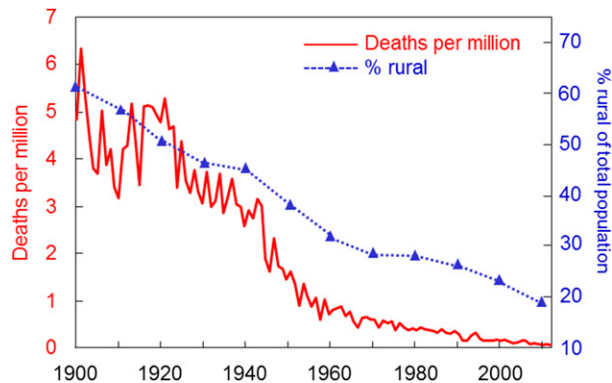


FIG. 1. (solid red line) U.S. lightning deaths per million people from 1900 to 2013. (dashed blue line) Percent rural population (updated from López and Holle 1998).

respect to lightning safety (Holle 2012). In addition, an increase has taken place since the early twentieth century in the availability of fully enclosed metal-topped vehicles that provide safety from lightning (Holle 2012). A large shift occurs in the types of lightning fatality incidents from agricultural and indoor settings (Fig. 2) to recreation and nonagricultural outdoor incidents a century later (Holle et al. 2005; Jensenius 2014). The outdoors category in this figure identifies all activities that are occurring outside except those in agriculture, recreation, and sports (Holle et al. 2005). Another possible factor in the trend to the reduced lightning fatality rate may be the multi-pronged U.S. lightning education and awareness campaign that has been sustained across the United States for more than a decade (Cooper and Holle 2012; Jensenius and Franklin 2014). In general there are 10 lightning-related injuries requiring medical treatment per lightning fatality (Cherington et al. 1999). With respect to fatalities, the U.S. distributions of state-by-state lightning fatalities and fatality rates are well known (Fig. 3). The lightning fatality maps do not duplicate the lightning flash density or population maps, but are more complex and based on such factors as recreational and occupational activity, the time of the day and season of the year when lightning occurs, and other factors (Holle 2012, 2014; Roeder et al. 2014).

3. Global lightning fatalities and injuries

Compared to the United States, there is a less complete understanding of global lightning fatalities. One estimate is several thousand (Gomes and Ab Kadir 2011), another is 6000 fatalities per year (Cardoso et al. 2011), and the third is 24 000 fatalities per year (Holle and López 2003). Underreporting of lightning fatalities, and especially injuries, is a major issue due to a number of factors, especially since most events involve one

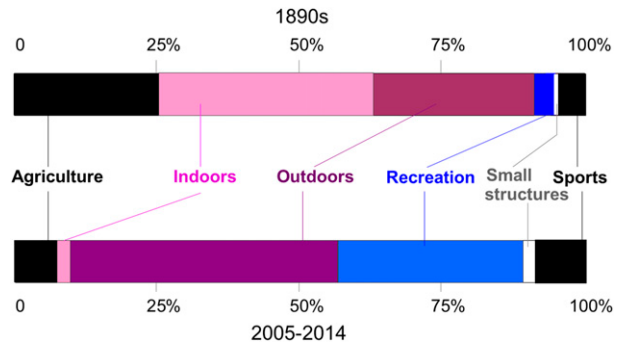


FIG. 2. Comparison of the percentage of types of U.S. lightning fatalities in the 1890s vs 2005 through 2014 (updated from Holle et al. 2005).

person at a time (López et al. 1993). As a result, there is no complete global information regarding lightning fatalities and injuries. Instead there is a limited number of published formal and informal papers in recent years summarizing lightning fatalities on a national scale. Many of these studies are not in the refereed literature because of the multidisciplinary nature of lightning and its impacts, and also because of researchers in other countries publishing in a variety of journals, conference proceedings, and other venues. In the absence of direct reports of lightning fatalities in many countries, another approach is to combine observed lightning frequency with U.S. population maps to identify where the highest number of lightning fatalities may occur (Roeder et al. 2014). Such an approach has yet to be tested outside the United States. In the absence of such an approach at this time, the following summary is a resource to all known national-scale summaries for multiple years ending in the last quarter century.

National fatality rates by decade since the 1800s have been published for a few of the more developed countries of the world (Holle 2008). The studies to be summarized here only include published national-scale projects to determine lightning fatalities ending during the last few decades. Regional, short-period (Ab Kadir et al. 2010) and Internet-based reports are not included. The most recent published results are applicable for periods ending in 1979 or later (Table 1, Fig. 4). The average period of record is 10 years. Many studies in this summary are not in journal articles but in less widely available conference proceedings, but they are nevertheless taken as being representative of the lightning fatalities in these countries. It can be difficult to obtain national statistics on lightning fatalities; sources may be death certificates, meteorological agencies, or other resources within natural hazards communities. No opinion is formed on the quality or quantity of possible underreporting or survey issues; results are summarized as

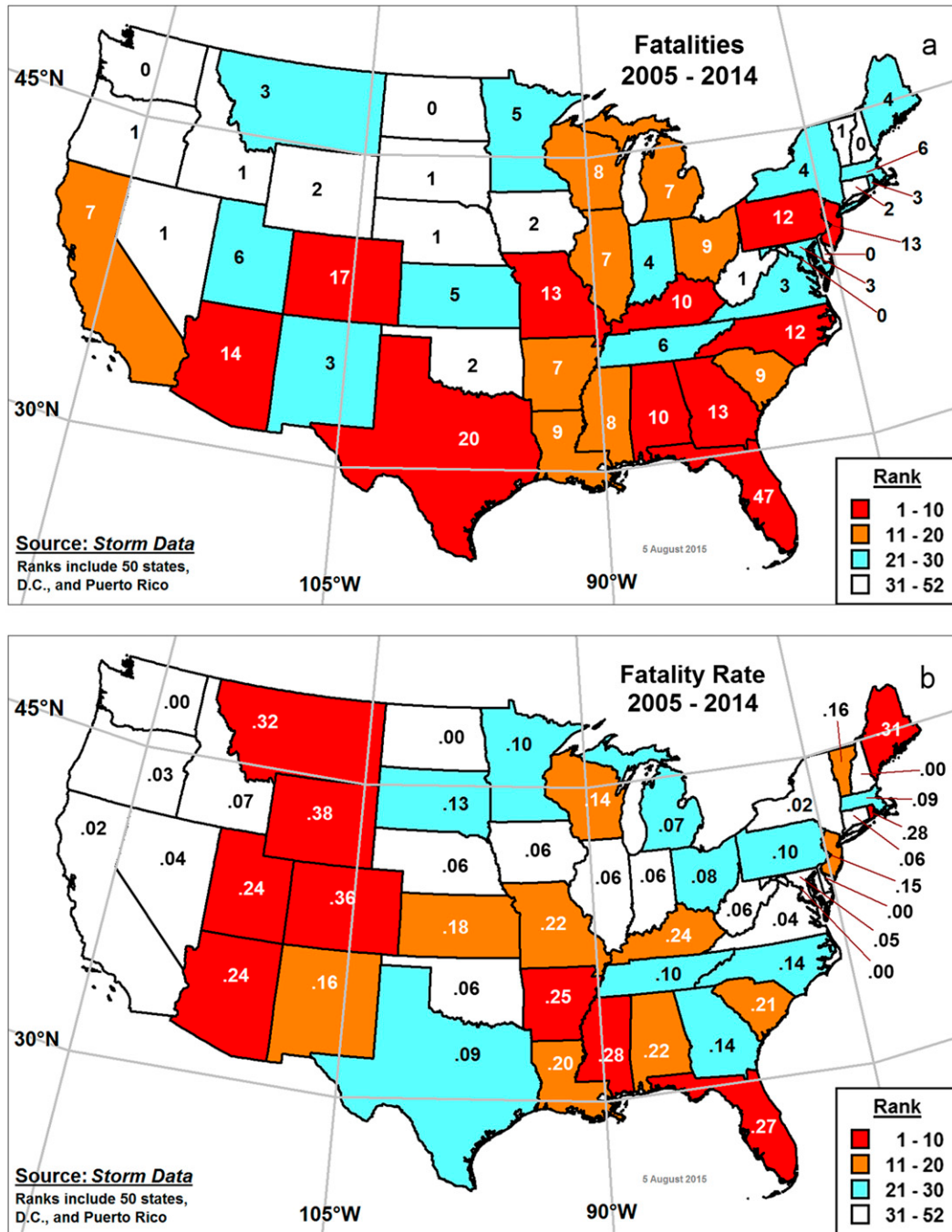


FIG. 3. (a) Ranks of lightning fatalities per state and (b) fatality rate per million people from 2005 to 2014 based on the U.S. National Weather Service publication *Storm Data*.

concluded in the publications with one exception. In the case of Turkey (Tilev-Tanriover et al. 2015), a database since 1930 showed few lightning fatalities until a greatly improved data collection method found many more lightning fatalities than earlier, so the last three years are referenced in Table 1 (and Fig. 5).

There are two exceptions to the requirement for the study to be published. One is Japan, where the data were obtained directly from Dr. Nobu Kitagawa, who published extensively on lightning casualties during a long period (Kitagawa et al. 2002). The other is the United States, where only the latest 10 years are

TABLE 1. Published annual lightning fatality rates per million people by country ending in 1979 or later.

Continent Country	References	Period	Annual fatality rate per million
Africa			
Malawi	Mulder et al. (2012)	2007–10	84.0
South Africa	Blumenthal (2005)	1997–2000	6.3
Swaziland	Dlamini (2009)	2000–07	15.5
Uganda	Mary and Gomes (2012)	2007–11	0.9
Zimbabwe	Chitauo (1990); Van Olst (1990)	2004–13	14–21
Asia			
China	Zhang et al. (2011)	1997–2009	0.3
India	Iliyas et al. (2014)	1967–2012	2.0
Japan	N. Kitagawa (2007, personal communication)	1990–97	>0
Malaysia	Ab Kadir et al. (2012)	2008–11	0.8
Singapore	Pakiam et al. (1981)	1970–79	1.5
Australia			
Australia	Coates et al. (1993)	1980–89	0.1
Europe			
Austria	Kompacher et al. (2012)	2001–10	>0
France	Gourbière (1999)	1990–95	0.2
Greece	Peppas et al. (2012)	2000–10	0.1
Lithuania	Galvonaite (2004)	1994–2003	0.1
Poland	Loboda (2008)	2001–06	0.3
Turkey	Tilev-Tanriover et al. (2015)	2012–14	0.4
United Kingdom	Elsom and Webb (2014)	1988–2012	>0
North America			
Canada	Mills et al. (2010)	1990–2004	0.2
Mexico	Raga et al. (2014)	1979–2011	2.7
United States	www.lightningsafety.noaa.gov/media.shtml	2005–14	0.1
South America			
Brazil	Cardoso et al. (2014)	2000–09	0.8
Colombia	Navarrete-Aldana et al. (2014)	2000–09	1.8

included because of the greatly reduced rates in recent years (Fig. 1).

The color-coded maps of published national-scale lightning fatalities in Fig. 4 are the first known to have been compiled. The highest rates are in Africa and South America. The lowest rates are evident in the more developed countries of North America, western Europe, Japan, and Australia. The maps show the highest population-weighted annual rates of lightning fatalities occurring in countries with these features; many have been addressed in a series of studies summarized in Holle (2012):

- Fewer lightning-safe homes, workplaces, schools, and other facilities than in more developed countries.
- Fewer easily available fully enclosed metal-topped vehicles.
- High rate of labor-intensive manual agriculture.
- Lack of awareness or data about lightning threat, its avoidance, and its medical treatment.

The global population living in the conditions listed above may be increasing in absolute number, but such socioeconomic statistics are extremely difficult to obtain.

A recent indication of rapid population growth in Africa supports this concept (www.economist.com/news/middle-east-and-africa/21613349-end-century-almost-half-worlds-children-may-be-african-can-it). In developing countries, such as those of equatorial regions of Africa, not only is the population large, but there is high lightning frequency and often poor infrastructure. The trend toward a reduced percentage of the population in rural areas has not occurred in many areas of the world, compared with the socioeconomic trends for the United States in Figs. 1 and 2. For example, 97% of lightning fatalities in China occur in rural areas (Ma et al. 2008) and 86% occur in rural areas in Turkey (Tilev-Tanriover et al. 2015). As a result, the number of lightning fatalities and injuries globally may be increasing and will continue to increase until more people have ready access to safe structures and vehicles, and can spend less time in labor-intensive agriculture and other outdoor occupations (Gomes et al. 2012). The lightning fatality and injury rates per population are thought to be high in many of the countries with no published national fatality data in Table 1 and Fig. 4. For example, India had an average of 1755 lightning deaths

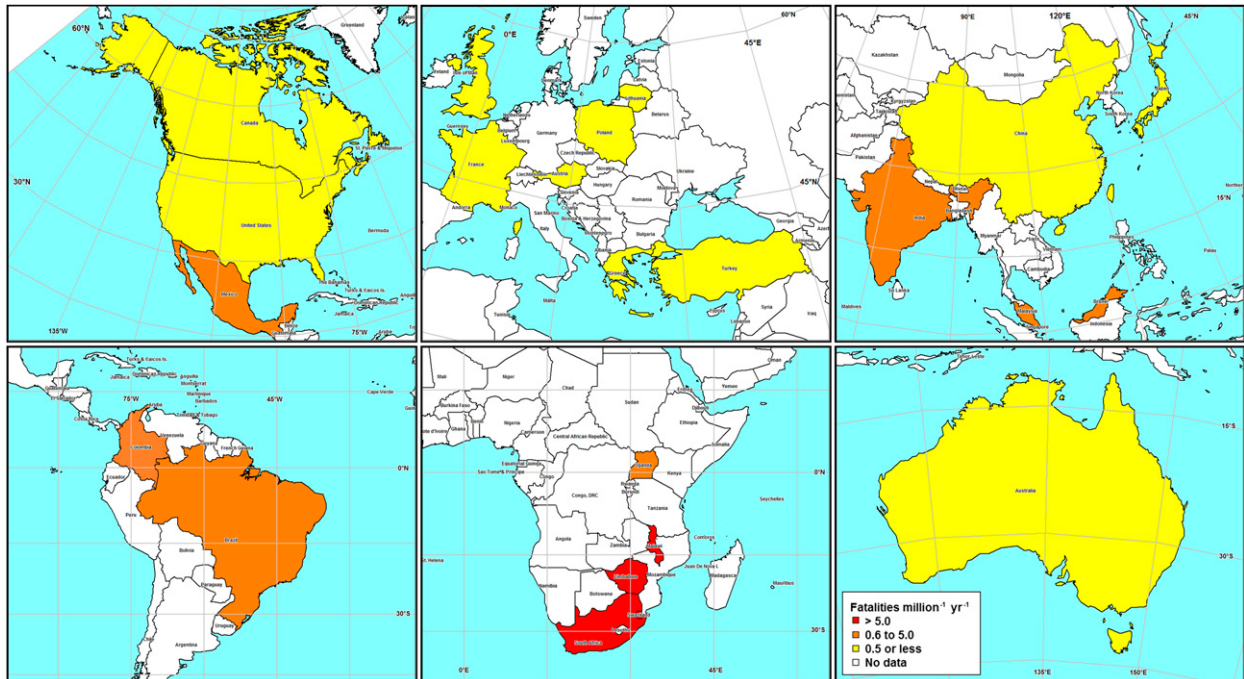


FIG. 4. Lightning fatality rate per million people per year by continent. Red shading indicates rate > 5.0 fatalities per million per year, orange is $0.6\text{--}5.0$, and yellow is 0.5 or less. White indicates no national summaries have been published for datasets ending in 1979 or later.

per year from 1967 to 2012 (Illiyas et al. 2014), which corresponds to 78 975 fatalities during this period.

4. Discussion

Maps of the climatology of cloud-to-ground lightning flash density have been prepared over the continental United States for many years using data from the National Lightning Detection Network (NLDN) on annual, monthly, and diurnal time scales (Holle et al. 2011; Holle 2014). Studies of lightning variability in time and space have also been made with national detection networks in numerous countries, mainly in more developed regions of the world. On a global scale, the network providing data to the Global Lightning Dataset GLD360 has been in operation since 2011 (Poelman et al. 2013; Pohjola and Mäkelä 2013; Said and Nag 2012). GLD360 data across the globe are available in real time (Fig. 5). Since 80% of GLD360 events are cloud-to-ground strokes, the actual lightning threat to people is now much better known around the globe than has been the case. Land areas have more than two-thirds of the world's cloud-to-ground lightning, based on a preliminary analysis, but lightning is not uniformly distributed, and this knowledge can be useful in improving understanding of the lightning threat.

A first step in combining lightning data with population noted the concentration of U.S. lightning fatalities in

urban areas (Ashley and Gilson 2009). This approach was extended in a subsequent study of lightning fatality risk mentioned earlier (Roeder et al. 2014). Such an approach could be considered in other countries without lightning fatality statistics by combining global lightning and demographic data to estimate fatality numbers.

Education and awareness are needed to take full advantage of global lightning data to reduce human casualties due to lightning. To be effective, there needs to be an end-to-end process initiated with an acceptance that lightning is a threat, and there are solutions to reduce lightning's human impacts. For example, there is a 1 in 1250 probability that a person in the United States will be killed or injured by lightning, or be 1 of 10 people such as a close relative or a friend who are estimated to be impacted by lightning to a person over an 80-yr life span (Cooper and Marshburn 2005). This probability is based on current U.S. lightning fatality and injury totals and the current population. In many developing countries, the probability is likely higher.

Once the lightning threat is accepted, the availability of real-time and climatological lightning information leads to action in response to the presence of lightning. Initial activities have been taken with regard to education and awareness of the lightning impacts on people in several Asian countries through the Centre of Excellence on Lightning Protection (Cooper and Ab Kadir 2010; Gomes et al. 2006, 2012; Jayaratne and Gomes

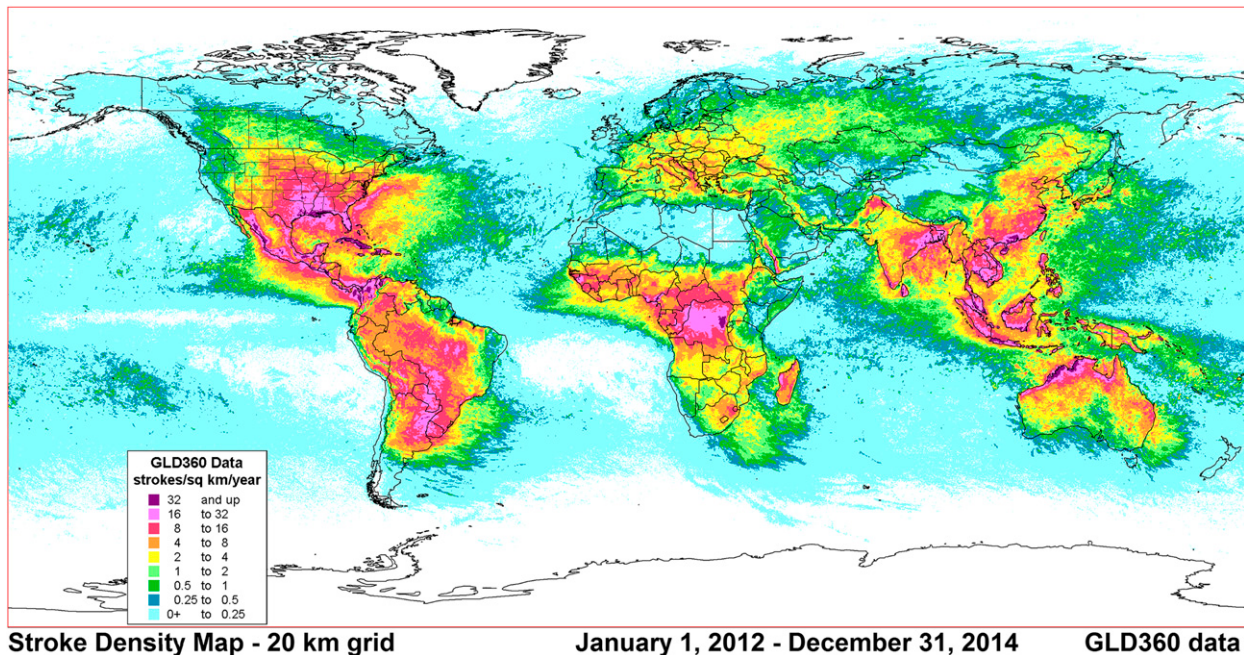


FIG. 5. Lightning stroke density per square kilometer per year from GLD360 for the globe from January 2011 to December 2014. A total of 2 358 685 762 strokes is plotted during these three years. Scale at lower left; grid size is 20 by 20 km.

2012) (<http://www.eng.upm.edu.my/celp/>) and the African Centres for Lightning and Electromagnetics (www.ACLENet.org).

5. Conclusions

The impacts of lightning are shown to differ greatly between developed and lesser-developed countries. Maps and a table of lightning fatalities per million people by country show these differences. In the United States, the population-weighted rate of lightning fatalities has reduced by more than an order of magnitude from a maximum approximately one century ago. In many lesser-developed countries, the population-weighted rate of lightning fatalities may be steady or slowly decreasing due to urbanization and the wider availability of lightning-safe buildings and fully enclosed metal-topped vehicles. However, the absolute number of lightning-vulnerable people involved in labor-intensive agriculture who live and work in unsafe dwellings and other buildings may be increasing, so the actual number of lightning casualties may be continuing to grow due to these socioeconomic factors.

More immediate solutions in lesser-developed countries appear to be providing protection to dwellings and public buildings such as schools, as well as providing safe places for agricultural workers during daytime thunderstorms. Data from lightning detection networks help identify the areas of most risk. Through a combination

of sound science, education, and uniform global lightning data availability, notable advances can be made in reducing the impacts of lightning on people.

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