Lightning fatalities in China, 2009–2018

Qiyuan Yin\textsuperscript{a,b,1}, Hengyi Liu\textsuperscript{a}, Xiangpeng Fan\textsuperscript{a}, Yijun Zhang\textsuperscript{c}, Yanxun Zhuang\textsuperscript{b}, Fei Wang\textsuperscript{a}, Hui Du\textsuperscript{b}, Xingxing Huang\textsuperscript{b}, Shaodong Chen\textsuperscript{d} and Lyuwen Chen\textsuperscript{d}

\textsuperscript{a}State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, Beijing 100081, China
\textsuperscript{b}Guangdong Meteorological Public Safety Technical Support Center, Guangzhou 510640, China
\textsuperscript{c}Institute of Atmospheric Sciences, FuDan University and Shanghai Institute of Pollution Control and Ecological Security, Shanghai 200438, China
\textsuperscript{d}Guangzhou Institute of Tropical and Marine Meteorology, Guangzhou 510080, China

Abstract

The statistical characteristics of 1789 deaths, 1552 injuries and 1904 disasters caused by lightning based on the 2009 to 2018 National Lightning Disaster Compilation of mainland China were analyzed. The results showed that males accounted for 53\% of casualties. Lightning disasters were more common in the east and south than in the west and north. The number of lightning disasters and casualties in the south accounted for 82.98\% and 82.94\% of the totals, respectively. May to August of each year is the intensive period of lightning disasters in China, and the number of deaths, injuries and disasters caused by lightning during these four months accounted for 84.80\%, 79.45\% and 82.77\% of the total numbers per year, respectively. From 2009 to 2018, the annual injury and death rates per million people in China were 0.13 and 0.12, respectively. After population weighting, the high death rate of lightning disaster shows a certain trend of transferring from the concentrated area to the sparsely populated area, after area weighting, the casualty density was higher in small provinces and lower in large provinces. The analysis of the environments in which lightning disaster casualties occurred found that environments closely related to agriculture, such as farmland (35\%) and paddy fields or ponds (4\%), accounted for nearly 40\% of the casualties; accordingly, rural farmers were the main victims, accounting for 80.96\% of the total casualties. Lightning protection and disaster reduction measures in rural agricultural areas should be the focus of future work.

Key words: China, Lightning, Lightning Casualty, Lightning Disaster, Lightning Fatality

1. Introduction

Lightning disasters pose a great threat to human society and have long been listed as "one of the ten most serious natural disasters" by the United Nations. Lightning is also an important component of meteorological disaster science (Wang, 1991).

Lightning-associated casualties are one of the most serious meteorology-related disasters. Holle, 2014, estimated that 6,000 to 24,000 people died annually from lightning and that the number of people injured by lightning was 10 times higher than the number of lightning-related deaths each year (Ab-Kadir \textit{et al.}, 2010). However, many countries lack accurate statistical recording systems for lightning disasters, thus limiting the accuracy of such data. In recent years, attention has been paid by various countries to lightning disasters. Holle \textit{et al.}'s study pointed out that in the past quarter century, there were 4,176 lightning-related deaths in 26 countries each year (Holle, 2016b). Based on the reports for 1023 fatalities associated with natural hazard processes in Switzerland during the period from 1946 to 2015, more than 16\% of the cases were caused by lightning, making it the second most frequent cause of loss of life among the natural hazards in Switzerland (Badoux \textit{et al.}, 2016).

In developed countries, the shift of populations from labor-intensive agricultural areas to cities, the reduction and mechanization of agricultural activities, and rapid economic development have resulted in the development of relatively safe lightning-proof buildings and completely enclosed metal vehicles; these advancements have greatly reduced the death toll caused by lightning in the last century (Cooper and Holle, 2010; Holle, 2016a). In the United States, the number of lightning deaths per million people has dropped from approximately 6 in the early 20th century to approximately 0.3 currently (Roeder, 2012; Holle \textit{et al.}, 2017).

The number of lightning deaths per million people in developed countries like the United States, has decreased by more than two orders of magnitude over the previous century. But among the major natural disasters, lightning causes more casualties than any other meteorological disaster except flood disaster.

In developing countries, there are still large populations of people engaged in labor-intensive agricultural work, living in houses without lightning protection measures, working in buildings without lightning protection measures, lacking an education and with an insufficient understanding of the hazards...
of lightning; therefore, the number of lightning deaths per million people is still very high (Holle, 2016a).

In China, lightning is the third most fatal meteorological disaster after floods and geological disasters, with casualties affecting thousands of people every year (Ma et al., 2008a).

According to the analysis of lightning disaster characteristics in China from 1997 to 2006 by Ma Ming et al., lightning disasters mostly occurred in eastern coastal areas and southern areas of China, with Guangdong Province being the most affected (Ma et al., 2008b).

Unlike natural disasters such as typhoons and floods, which receive substantial attention due to their large scope of influence and strong destructive power, lightning disasters have been underestimated in terms of casualties and their destructive power due to time and space limitations, although they also have serious impacts on life and property.

An improved understanding of lightning-related casualties and identification of primary strategies for lightning protection and disaster reduction will help decision makers formulate safety strategies to prevent lightning disasters and promote the revitalization and development of villages.

In this paper, the casualties caused by lightning in mainland China from 2009 to 2018 are statistically analyzed. Additionally, the casualty characteristics of lightning disasters in mainland China over the past ten years, including geographical distribution, time distribution, casualty environment distribution, urban and rural distribution and gender distribution characteristics, were evaluated.

2. Materials and methods

The national lightning disaster data evaluated in this study were obtained from the “2009–2018 National Lightning Disaster Compilation”, which was jointly compiled by the Lightning Physics and Protection Engineering Laboratory of the Chinese Academy of Meteorological Sciences and the Lightning Protection Management Office of the China Meteorological Administration. The data include time and space characteristics, damaged property values and the number of casualties due to lightning disasters in all provinces, cities and autonomous regions of the country.

In China, lightning protection technicians immediately rush to the scene of each lightning incident to investigate and verify each lightning disaster and record the details. The county meteorological bureau reports casualties and losses caused by lightning strikes to the municipal meteorological bureau every month, and the municipal meteorological bureau summarizes all the lightning disaster reports within its scope of responsibility and reports them to the provincial meteorological bureau. The 31 provincial meteorological bureaus report the relevant data to the National Meteorological Bureau, who summarizes the national meteorological reports for that month. At the end of each year, the local meteorological bureaus supplement the missing reports in the monthly report.

The description of the lightning disaster case includes the time, place, affected object, personnel or livestock casualties, and equipment or article damage in as much detail as possible. If they can be determined, the activity of the affected subject at the time of the lightning disaster, the impact and consequences caused by the lightning strike, etc. must also be recorded.

The advantage of this collection method is that the data are obtained by each county’s meteorological bureau at the most basic level, and reports are compiled by the municipal meteorological bureau in accordance with unified principles and standards, thus ensuring the accurate and comprehensive collection of lightning disaster data and accurate descriptions to the greatest extent.

Due to cultural, ethnic, religious or other reasons in some areas of China, some lightning disaster survivors or their families are unwilling to report the incident or seek assistance, resulting in a failure to record the corresponding lightning disaster information. Some disasters in which staff cannot confirm the cause of death are recorded as lightning-related, but in general, these events account for a very small proportion of the total.

The analysis of lightning disaster casualties in this paper is bound to deviate from the real situation of all lightning disaster casualties to some extent. The obtained characteristics of lightning disaster casualties over the past ten years represent incomplete statistical results.

3. Results and discussion

3.1 Geographical distribution of casualties

From 2009 to 2018, there were a total of 38,594 lightning-related disasters in mainland China, of which 1904 (4.93%) had casualties reports. The total numbers of deaths and injuries caused by lightning disasters were 1789 and 1552, respectively. The death toll is 1.15 times higher than the number of injuries. The death toll from lightning disasters in Malawi, Africa, is 2.8 times higher than the number of injuries, while in developed countries, such as the United States, the ratio of injury to death is 10:1 (Holle and Cooper, 2016b). Obviously, the lack of social and economic foundations in developing countries has led to the relative fragility of national security in lightning disasters.

The regional distribution of lightning casualties in China is obviously different. Fig. 1 shows the geographical distribution of casualties number per year (Fig. 1A), lightning disaster number per year (Fig. 1B) and fatalities number per year (Fig. 1C) according to a four-echelon natural breaks classification method. The number of lightning disasters in the eight provinces (Red) in the first echelon accounts for 54.46% of the total number of disasters, and the number of casualties accounts for 58.10% of the total number of casualties.

The distribution of lightning disasters is generally more in the southeast and less in the northwest. This is similar to the characteristics of lightning density distribution across the country obtained by Ma et al., 2008a. using satellite detector Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS) observations. It can be seen that the area with high lightning density corresponds to the high incidence area of lightning disaster, and the lightning casualties are closely related to local lightning activities. Lightning disasters in southern China accounted for 82.98% of the total number of disasters, and casualties accounted for 82.94% of the total number of casualties.
Fig. 1. Number of lightning fatalities and lightning disaster over China of 2009–2018 (A: casualties number, B: disaster number, C: fatalities number)
3.2 Distribution characteristics of lightning disasters weighted by population

From 2009 to 2018, the annual average number of deaths and injuries from lightning disasters in mainland China was 179 and 155, respectively, which was significantly lower than the averages of 387 and 359 in mainland China from 1997 to 2009 reported by Zhang et al., 2011; moreover, the disaster rate from lightning decreased by nearly 90% compared with the rate in 1997 to 2009 (Zhang et al., 2011). The completeness of data collection has declined slightly in recent years, which may affect the analysis results, but this is not the main reason for the obvious decrease in casualties.

In the past ten years, the total number of lightning casualties in 13 provinces across the country has exceeded 100. Yunnan is ranked first (371), with nearly 47 times more casualties than Tianjin, which is ranked last (8). Yunnan, where lightning is frequent and economic activities involve mainly labor-intensive agriculture, contributes the most to the total number of lightning disaster casualties in China, while Tianjin, which is relatively small in area and relatively economically developed, has increase investment in lightning protection measures and personnel lightning safety training and education, resulting in few casualties.

Considering population weighting, compared with the results of 1997–2009, the death rate and injury rate of lightning disasters per million people in mainland China in 2009–2018 decreased from 0.31 and 0.28 to 0.13 and 0.12 (Zhang et al., 2011). Fig. 2 shows the ratio of casualties (Fig. 2A), disaster reports (Fig. 2B) and fatalities (Fig. 2C) in each province to the total number in the whole country after considering population weighting.

The death rate from lightning disasters in Tibet (2.07) is the highest, at nearly 3.8 times higher than that in Qinghai (0.55), followed by Jiangxi (0.53), Yunnan (0.35), Hainan (0.32) and Fujian (0.24). The provinces with the lowest death rates from lightning disasters are Tianjin (0.01), Gansu (0.03), Henan (0.03), Shandong (0.04), Shaanxi (0.04) and Shanxi (0.04). This result is similar to those in other countries and regions (Curran et al., 2000; Navarrete-Aldana et al., 2014; Holle et al., 2019). This is in line with the trend of transferring from the south-east area with concentrated population (Fig. 1A) to the west area with less population (Fig. 2A). Comparing Figs. 2 with Figs. 1, it is found that the top two (Tibet and Qinghai) in the lightning disaster rate are the most prominent. Its ranking in the number of lightning casualties has rapidly changed from the second and third echelon (9th and 16th) to the first echelon.

The death toll in Tibet is 6.2 per million people per year, and its total population is only 3 million. Qinghai’s population is also small. The two provinces do not have the largest numbers of deaths from lightning disasters, but the small populations lead to the highest death rates. Exposure to thunderstorms and long hours of outdoor work are the main causes of casualties in these two areas.

In contrast, in Asia, India’s death toll from lightning disasters from 1967 to 2012 was 1755, resulting in an average rate of 2.0 per million people per year (Illiyas et al., 2014), while Bangladesh’s death toll from lightning disasters in the past six years was 251, resulting in an average of 1.6 per million people per year (Dewan et al., 2017). In Africa, the death rates in Swaziland (Dlamini, 2008) and Malawi (Mulder et al., 2012) reached 15.5 and 84 per million people per year in 2000–2007 and 2007–2010, respectively. In the past ten years, the death rate per million people per year in Europe has been approximately 0–0.4 (Kompacher et al., 2012; Peppas et al., 2012; Elsom and Webb, 2014; TILEV-TANRIOVER et al., 2015). The death rate of 0.1 per million people in the United States in recent years (Holle, 2016c). In a sense, it shows that the quality of housing, workplaces, schools and other buildings in mainland China, especially lightning protection measures, has been greatly improved, and is gradually aligning with the level of developed countries.

3.3 Distribution characteristics of lightning disasters weighted by area

Figs. 3 shows the casualty density, lightning disaster report density and death density in each province considering weighted areas.

In general, the casualty density was higher in small provinces and lower in large provinces (Cooper et al., 2019). Shanghai, where lightning disasters and casualties are both in the fourth echelon (26th) in figs.1, has become the first echelon (1st) in both disaster density and casualty density.

The lightning casualty density in Xinjiang, the country’s largest area, is obviously the smallest, and Jiangxi, Zhejiang, Hainan, and Guangdong are still included in the top five. It is also in line with the trend of moving from larger provinces (western regions) (Figs. 1) to smaller provinces (southeast regions) (Figs. 3).

3.4 Monthly variations

Fig. 4 shows the monthly distribution of lightning casualties in China from 2009 to 2018. Lightning disasters mainly occurred from May to August. The numbers of deaths, injuries and disasters caused by lightning in these four months accounted for 84.80%, 79.45% and 82.77% of the annual total, respectively. The number of lightning disasters and casualties peaked in July, accounting for 24.37% and 25.43% of the annual total, respectively. The number of lightning injuries peaked in June, accounting for 27.00% of the annual total.

Lightning casualties in Bangladesh from April to June accounted for 69% of all annual lightning casualties, with a peak in May. Lightning disasters in India (Bhardwaj et al., 2017) peaked in May, and the peak number of casualties occurred in April. The numbers of deaths, injuries and disasters caused by lightning in winter in these areas were the lowest annually.

These results are consistent with the characteristics of local lightning activities (Holle et al., 2016; Holle et al., 2017) and are also related to the peak time of people’s outdoor activities, urban and rural development and other factors. Approximately two-thirds of ground flashes occur in midlatitude summer globally, especially in tropical and subtropical land-sea junctions. However, June to August is the busy farming season, and labor-intensive agricultural activities coincide with frequent lightning strikes in time and space, resulting in a high prevalence
Fig. 2. The rank of each province of lightning-related casualties rate(A), disasters rate(B), fatalities rate(C) in Mainland.
Fig. 3. The rank of each province of lightning-related casualties density (A), disasters density (B) and fatalities density (C) in Mainland China from 2009 to 2018.
of lightning casualties (Curran et al., 2000). At that time, rural areas can provide accurate lightning safety risk warning for people who are most vulnerable to lightning disasters, and formulate effective lightning protection safety measures, which can greatly enhance the ability of lightning protection and disaster reduction in rural areas.

In southern China, sowing in May and dried grain in June and July coincide with the active period of severe convective weather. Farmers often cover their crops with plastic film before thunderstorms or even rain and then retreat home or take shelter in a nearby hut, often resulting in casualties due to lightning strikes.

### 3.5 Distribution of the casualty environment in the lightning disaster

Casualties caused by lightning disasters may be related to the activities of the victims and their location. In this study, the environment in which lightning casualties occurred was divided into 6 categories: inside buildings, outside buildings, farmland, near water, paddy fields, ponds and beside trees. The inside of buildings refers to the interior of simple rural houses, thatched huts, summerhouses or temporary shelters. Outside buildings refers to the exterior of structures, such as under eaves, under the roof top, in yards or on a playground. Farmland mainly refers to non-paddy fields. Near water means close to a river or on a bridge. Paddy ponds refer to paddy fields or fish and shrimp ponds. Beside a tree means around a tree (Fan et al., 2019; Yin et al., 2019a, b).

Fig. 5 shows the proportions of these 6 types of environments in all lightning disaster casualties. As shown in Fig. 5, people working in farmland (35%), paddy fields and ponds (4%), which are all closely related to agriculture, accounted for nearly 40% of the total casualties. The number of casualties inside buildings accounted for 28%. Holle et al.’s statistical results also showed that lightning casualties occurred most often in farmland (25%) and buildings (60%). It can be seen that the lightning casualties in China are similar to those in developed countries in the last century, mainly in rural areas and during agricultural activities.

With the gradual decrease in labor-intensive agriculture and the gradual improvement in lightning protection measures for buildings, lightning casualties occurring in farmland and buildings will rapidly decrease. At present, less than 10% of casualties from lightning disasters occur in farmland and buildings in developed countries (Holle, 2010; Holle and Cooper, 2016a; Raga et al., 2014).

### 3.6 Rural and urban casualties

In this paper, Urban area is a large residential area formed by

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![Fig. 4](image1)

**Fig. 4.** Monthly variations in the percentages of lightning damage reports in China in 2009–2018.

![Fig. 5](image2)

**Fig. 5.** Frequency distributions of the locations of lightning casualties
non-agricultural industries and non-agricultural population. Rural areas, different from cities and towns, are farmers’ settlements engaged in agriculture. A place where laborers mainly engaged in agricultural production live together. Fig. 6. shows the proportion of lightning casualties in rural areas accounted for the total casualties in mainland China from 2009 to 2018. In general, the average number of rural lightning casualties in mainland China in the past ten years accounted for 80.96% of the total number of casualties; this result is less than the number of rural lightning casualties reported by Ma et al., 2008b, which was approximately 97%. However, as shown in Fig. 6, the improvement is not obvious from the annual change trend. The proportion of rural lightning casualties was still 79% in 2018, which was close to the 10-year average and was similar to the proportion of rural lightning casualties in most parts of Africa, the Indian subcontinent, Southeast Asia and other developing regions as well as developed countries in the last century (Illiyas et al., 2014; Dewan et al., 2017).

The top five proportion of rural casualties in China are Gansu (100%), Xinjiang (100%), Shanxi (96%), Hebei (95.5%) and Heilongjiang (95%). These provinces are general low economic developing level. Most people are engaged in animal husbandry, farming and other labor-intensive outdoor work in the daytime. Lack of lightning protection measures in buildings and buildings in residence, life and work. Lightning safety education and training needs to be improved. This is the main reason why most of the lightning casualties occur in rural areas of developing countries (Holle, 2010; Holle and Cooper, 2016a; Raga et al., 2014).

3.7 Gender

This study obtained data of 1546 lightning casualties with gender information from 2009 to 2018. Fig. 7 shows the gender distribution of the victims. As shown that the proportions of male and female casualties from lightning disasters are approximately the same, although male casualties are slightly more common than female casualties. This indicates that males are slightly more likely to be exposed to lightning hazards than females. However, in the rural areas no matter what kind of activities people engage in, everyone is at risk of lightning safety. As a result, men and women of all ages are vulnerable to lightning disaster. This is similar to the statistical results of the gender distribution of lightning casualties in India, Bangladesh and some countries in Africa.

4. Conclusion and advise

In this study, based on the analysis of lightning disaster casualty data from the 2009 to 2018 National Lightning Disaster Compilation, the statistical characteristics of 1904 lightning disaster are provided. Among these disasters, the casualty and injury tolls were 1789 and 1552, respectively. The southern region with frequent lightning strikes has the largest number of lightning disasters. The regional distribution of lightning disasters was generally greater in the southeast than in the northwest. Lightning disasters in southern China accounted for 82.98% of the total number of disasters, and casualties in southern China accounted for 82.94% of the total number of
casualties. 53% of lightning casualties in China involved males.

Considering population weighting, the annual casualty rate and injury rate of lightning disasters per million people in China were 0.13 and 0.12, respectively. The lightning casualty rate is in line with the trend of transferring from the south-east area with concentrated population to the west area with less population. Considering area weighting, it is in line with the trend of moving from larger provinces (western regions) to smaller provinces (southeast regions).

From 2009 to 2018, national lightning disaster casualties mainly occurred from May to August. The number of deaths, injuries and disasters caused by lightning disasters in these four months accounted for 84.8%, 79.45% and 82.77% of the annual total, respectively. The number of lightning disasters and deaths peaked in July, accounting for 24.37% and 25.43% of the annual total, respectively, while the number of lightning injuries peaked in June, accounting for 27.00% of the annual total. However, June to August is the busy farming season, and labor-intensive agricultural activities coincide with frequent lightning strikes in time and space, resulting in a high prevalence of lightning casualties.

During 2009–2018, the number of rural casualties caused by lightning disasters accounted for 80.96% of the total number of casualties caused by lightning disasters in mainland China. Especially in provinces where agriculture is the main industry, the proportion of lightning casualties in rural areas can reach 100% of the total number of lightning casualties in the province. An analysis of human activities and the locations of lightning casualties found that farmland (35%) and paddy fields or ponds (4%), two types of environments that are closely related to agriculture, accounted for nearly 40% of the lightning casualties in rural areas.

The lightning protection and disaster reduction measures in rural areas should be the focus of governmental decision makers. With the widespread expansion of agricultural mechanization and the rapid development of urban and rural economies, lightning protection measures for buildings will be improved, and lightning disaster casualties caused by exposure to these environments will be reduced gradually. Five suggestions are as follows:

1. The popularization of lightning protection safety: 30–30 Rule. The first 30 refers to the number of seconds between seeing lightning and hearing its associated thunder; a 30-second interval refers to six miles (10 km). The second 30 refers to the number of minutes to wait until resuming outdoor activity after the last lightning or thunder within a specific range.

2. The period of busy farming is a period of high incidence of lightning disaster. Meteorological Department can provide accurate lightning safety risk warning for Rural area people who are most vulnerable to lightning disasters.

3. The training of lightning protection safety should be more popular for young-adult people. During outdoor farming, grazing or activity, people should understand the lightning protection awareness and correct methods of avoiding strikes before thunderstorms.

4. The main reason for the serious lightning casualties in rural areas is the lack of lightning protection measures. When making rural security policy, the government should consider improving the lightning protection measures for rural residents, work and activity places.

5. Improve the training and popularization of cardiopulmonary resuscitation (CPR). This method is the most effective medical rescue measure after lightning strike. 80% of lightning victims can survive.

Data availability statement

Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions.

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