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ORIGINAL PAPER

Lightning casualties and damages in China from 1997 to 2009

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Abstract Lightning-related fatalities, injuries and property damages reported in China from 1997 to 2009 are summarized by using the National Lightning Hazards Database. Therefore, characteristics of the incidents including 5,033 deaths, 4,670 injuries and 61,614 damage reports are analyzed. For the spatial distribution of lightning disasters in China, the eastern costal and southern areas have more frequent lightning disasters than the western areas. Lightning disasters mainly occur in summer months from July to September, while fewer damages occur in winter months from October to March, which correlate significantly with the temporal variability of lightning frequency in China. Lightning-related casualties and damages in China have increased for the period of 1997 to 2007 and then began to decrease since 2008. The national fatalities and injuries per million people per year are 0.31 and 0.28, respectively. Rural people account for 51 and 29% of all lightning fatalities and injuries, which makes residents in agricultural and rural area the major lightning victims. Characteristics of lightning disasters and correlative factors are also studied, including hazard-affected industries and locations. The results show that civil industry has the worst property loss and farmland is the largest category in lightning-caused casualty locations.

Keywords Lightning · Fatality · Casualty · Damage · China

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1 Introduction

Lightning is one of the severe hazards to people and infrastructure in the world. Hundreds of casualties and millions of dollars in damage to buildings, power lines, electrical systems are caused by lightning every year. A worldwide of 24,000 deaths and 240,000 injuries from lightning per year was estimated (Holle and López 2003). Lightning is near the top of the list of all types of weather-related deaths in the United States, only fatalities from flash and river floods rank higher (Curran et al. 2000). The deaths due to lightning during 1940 to 1973 in the United States is higher than the number caused by tornadoes and hurricanes together (López et al. 1993). Therefore, a complete national description of lightning casualties and damages is essential to improving awareness of this hazard. Such information is critical for understanding the risks of lightning to general public and sensitive industries, sectors and activities. It is also essential for evaluating the effectiveness of monitoring and warning information and associated short- and longer-term responses (Mills et al. 2008). Studies on lightning-related casualties and damages have been carried out in many countries (López and Holle 1998; Coates et al. 1993; Elsom 2001; Dlamini 2009). Focus of these studies is mainly on quantifying lightning fatality and injure statistics, identifying human injury mechanisms (Lewis 1997; Walsh et al. 2000) and giving suggestions to lightning protection.

Observations from the space-based instrument showed that South and Southeast Asia contributed strongly to the vernal peak of global lightning (Christian et al. 2003). China is located in temperate and subtropical climate regions and has a mean total lightning density of 4.22 fl/km^2/a (Ma et al. 2005). Greater frequency of lightning occurs typically during the warm months from May to September, and at south and east China. With the optical transient detector (OTD) and lightning imaging sensor (LIS), Ma et al. (2005) found the maximum lightning density (31.44 fl/km^2/a) is distributed over the eastern humid region in China and is higher than the global mean value at the same latitude, while the low values are distributed over the western frigid and arid region. In order to investigate lightning climatology and do severe weather forecasting, China began to setup the national lightning detection network since 2004 and now forms a network with 237 stations. The national network is essential for lightning observation, and its data have been applied to understand lightning frequency and climatology in China. Moreover, the lightning nowcasting and warning system developed by the China Meteorological Administration (CMA) has been promoted to operational use to estimate potential lightning risk and issue warnings (Meng et al. 2008).

The objective of this article is to investigate the characteristics of lightning hazards in China from 1997 to 2009, and to improve understanding of the impact of lightning in terms of fatalities, casualties and property damages. The first section of the article is an overview of lightning hazards studies and its significance. The second section introduces the data sources and lightning-reporting methods in China. Then, characteristics of lightning casualties and damages in China are described, with respect to time, space, rural and urban, circumstances and locations. Finally, the article concludes with a summary of results and recommendations for future work.

2 Methodology

The data source used in this study was from the National Lightning Hazards Database (NLHD), which includes lightning-related reports from 31 provinces in Mainland China. The NLHD employs a province-municipality-county three-level reporting system. The

county level weather bureaus are the basic reporting departments. When lightning strike occurs, working staffs of county weather bureaus are sent to scene for investigation and verification and record the detail information. Each county weather bureau reports lightning-related fatalities, injuries and damages to its municipal weather bureau every month, and the municipal weather bureaus then compile all the reports occurring within the area of responsibility and report to its provincial weather bureau. Finally, the 31 provincial weather bureaus report to the CMA, and the CMA compiles the reports in the whole country in that month. At the end of each year, different level weather bureaus make a supplementary report if there is any missing report in monthly reports. After that, all the reports from 31 provinces in that year are combined by headquarter in CMA and then added to the NLHD. The advantage of these records in the database is that they are derived from every county weather bureau throughout the country and compiled by CMA headquarter with consistent principle and standard. The records consist of not only fatalities and injuries, but also property damages by lightning strikes. The following information is required in each lightning strike report: (a) year, month, day and time of the event; (b) locality of the event; (c) number and location of fatality/injury; (d) direct/indirect economic loss of the damage. The following information is optional: (e) gender and age of fatality/injury; (f) industry of the damage; (g) circumstances/activity during incident; (h) degree/type of injury. In total, the NLHD contains 5,033 fatalities, 4,670 injuries and 61,614 damage reports from all provinces in China from 1997 to 2009.

Lightning-related casualties and damages generally spread out during the year and throughout the nation, so they receive less attention than the large-impact events and are usually underreported. A few researchers have attempted to estimate the underreporting by evaluating data from multiple sources. López et al. (1993) found that *Strom Data* underreported lightning deaths by 28% and injuries by 42% in the period 1980–1991 in Colorado. Mogil et al. (1977) found 33% more lightning deaths in Texas than reported in *Storm Data*. Mills et al. (2008) indicated the mortality underestimation in the United States ranges from 17 to 33%. Lightning may consistently cause more damage than any other weather phenomenon when other unquantified losses are considered (Curran et al. 2000). In China, underreporting of lightning-related fatalities and injuries mainly result from the traditional beliefs and superstition on lightning casualty, particularly in rural and small urban areas. Nevertheless, the NLHD is a consistent data source on lightning incidents in meteorological department in China for its standardized reporting protocol and coding for all variables.

3 Results and discussion

3.1 Variations by province

From 1997 to 2009, the total number of lightning-related fatality, injury, casualty and damage report are 5,033, 4,670, 9,703 and 61,614, respectively. Table 1 shows the number and rank of lightning-related reports from all provinces in China. Guangdong has the highest fatalities, casualties and damage reports, while Yunnan has the most lightning injures. Both of the provinces locate in south China. Figure 1 shows the rank of lightning-related casualties (Fig. 1a) and damages (Fig. 1b) by step of 8 in rank. For lightning causalities, the top 8 provinces are Guangdong, Yunnan, Jiangxi, Guizhou, Guangxi, Hunan, Sichuan and Hubei, all of which are in the south and have higher lightning frequency than other provinces. For damage reports, Guangdong has the highest number and

Table 1 Number of lightning fatalities, injuries, casualties and damage reports and their ranks for Mainland China from 1997 to 2009

Province	Fatalities		Injuries		Casualties		Damage reports	
	No.	Rank	No.	Rank	No.	Rank	No.	Rank
Anhui	159	12	140	13	299	13	1,728	12
Beijing	17	29	46	23	63	26	1,007	16
Chongqing	55	23	95	16	150	20	425	22
Fujian	255	6	175	10	430	9	4,585	4
Gansu	33	27	27	27	60	27	130	29
Guangdong	595	1	518	2	1,113	1	17,098	1
Guangxi	248	7	273	6	521	5	1,735	11
Guizhou	301	4	345	3	646	4	937	17
Hainan	143	14	199	9	342	11	639	19
Hebei	125	16	85	18	210	16	3,045	7
Heilongjiang	61	21	44	24	105	23	443	21
Henan	136	15	152	12	288	15	1,456	14
Hubei	244	8	251	7	495	8	1,800	10
Hunan	221	10	300	4	521	6	4,968	2
Inner Mongolia	92	18	66	20	158	19	482	20
Jiangsu	238	9	104	15	342	12	3,263	5
Jiangxi	494	2	293	5	787	3	2,448	8
Jilin	63	20	36	25	99	24	758	18
Liaoning	115	17	47	22	162	18	1,384	15
Ningxia	14	31	23	28	37	30	59	31
Qinghai	42	24	84	19	126	21	244	26
Shaanxi	56	22	66	21	122	22	357	23
Shandong	219	11	175	11	394	10	3,188	6
Shanghai	36	25	31	26	67	25	247	25
Shanxi	36	26	16	30	52	28	306	24
Sichuan	261	5	239	8	500	7	1,596	13
Tianjin	17	30	2	31	19	31	236	27
Tibet	75	19	90	17	165	17	190	28
Xinjiang	33	28	18	29	51	29	95	30
Yunnan	491	3	590	1	1,081	2	1,950	9
Zhejiang	158	13	140	14	298	14	4,815	3
Total	5,033		4,670		9,703		61,614	

has more than three times as many as the second rank (Hunan). Lightning caused most damages in the eastern costal provinces and least in the western area in China (Fig. 1b).

3.2 Variations by province weighted by population

The rate and rank of lightning-related fatalities, injuries, casualties and damage reports from each province weighted by population are shown in Table 2. For lightning casualty rate, the top two are Tibet and Hainan, which were 17th and 11th in number of casualties (Table 1).

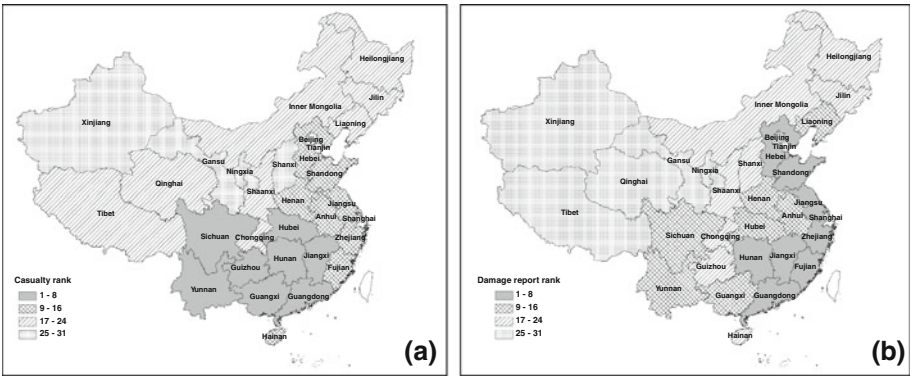

Fig. 1 The rank of each province in number of lightning-related casualties (**a**) and damage reports (**b**) in Mainland China from 1997 to 2009. The names of the 31 provinces are shown in the figure

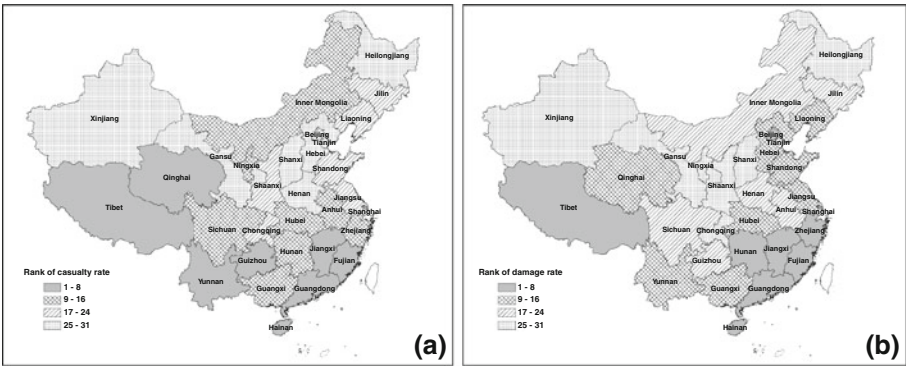

Fig. 2 The rank of each province in the rate of lightning-related casualties (**a**) and damage reports (**b**) in Mainland China from 1997 to 2009

When taking population into account, the maxima shift from southern and eastern provinces (Fig. 1a) to less-populated regions such as Tibet, Hainan and Qinghai in west regions (Fig. 2a). Similar results of casualty rate per population in the Unites States were also shown in Curran et al. (2000). They found the main effect of taking population into account is to shift maxima from populous eastern states as Florida and Michigan to the Rocky Mountain and plains states as Wyoming and New Mexico. The other six provinces in the first class of casualty rate weighted by population are Yunnan, Qinghai, Jiangxi, Guizhou, Guangdong and Fujian. The ranks of populous provinces such as Henan, Shandong and Sichuan degrade, with casualty rank of 15th, 10th, and 7th (Table 1) to 26th, 20th and 15th (Table 2). Except for Tibetan Plateau area, provinces with high casualty rate are located in south China. The ranks of casualty rate in northwest provinces are still low (Fig. 2a).

The national average fatality and injury per year are 387 and 359 (Table 1) in Mainland China from 1997 to 2009, while the numbers in the United States are 90 and 273 from 1959 to 1994 according to Curran et al. (2000). Although lightning-related casualty in China is twice as much as the number in the United States every year, the rate per million people is lower. The rates for fatality and injury per million people per year were 0.42 and 1.26 in the United States for 1959–94 (Curran et al. 2000) and 0.31 and 0.28 (Table 2) in China for

Table 2 Rate per million people per year of lightning fatalities, injuries, casualties and damage reports, and their ranks for Mainland China from 1997 to 2009

Province	Population	Fatalities rate		Injuries rate		Casualties rate		Damage rate	
	(million)	Rate	Rank	Rate	Rank	Rate	Rank	Rate	Rank
Anhui	59.86	0.20	17	0.18	18	0.38	16	2.22	17
Beijing	13.82	0.09	30	0.26	13	0.35	19	5.61	6
Chongqing	30.9	0.14	23	0.24	14	0.37	17	1.06	25
Fujian	34.71	0.57	7	0.39	9	0.95	8	10.16	2
Gansu	25.62	0.10	29	0.08	28	0.18	29	0.39	30
Guangdong	86.42	0.53	8	0.46	8	0.99	7	15.22	1
Guangxi	44.89	0.42	9	0.47	7	0.89	9	2.97	13
Guizhou	35.25	0.66	5	0.75	5	1.41	6	2.04	19
Hainan	7.87	1.40	2	1.95	2	3.34	2	6.25	4
Hebei	67.44	0.14	22	0.10	25	0.24	25	3.47	11
Heilongjiang	36.89	0.13	26	0.09	26	0.22	27	0.92	26
Henan	92.56	0.11	28	0.13	22	0.24	26	1.21	23
Hubei	60.28	0.31	10	0.32	11	0.63	10	2.30	16
Hunan	64.4	0.26	12	0.36	10	0.62	11	5.93	5
Inner Mongolia	23.76	0.30	11	0.21	17	0.51	12	1.56	21
Jiangsu	74.38	0.25	14	0.11	23	0.35	18	3.37	12
Jiangxi	41.4	0.92	3	0.54	6	1.46	5	4.55	8
Jilin	27.28	0.18	20	0.10	24	0.28	23	2.14	18
Liaoning	42.38	0.21	16	0.09	27	0.29	22	2.51	15
Ningxia	5.62	0.19	18	0.31	12	0.51	13	0.81	27
Qinghai	5.18	0.62	6	1.25	3	1.87	4	3.62	9
Shaanxi	36.05	0.12	27	0.14	21	0.26	24	0.76	28
Shandong	90.79	0.19	19	0.15	19	0.33	20	2.70	14
Shanghai	16.74	0.17	21	0.14	20	0.31	21	1.14	24
Shanxi	32.97	0.08	31	0.04	30	0.12	31	0.71	29
Sichuan	83.29	0.24	15	0.22	16	0.46	15	1.47	22
Tianjin	10.01	0.13	25	0.02	31	0.15	30	1.81	20
Tibet	2.62	2.20	1	2.64	1	4.84	1	5.58	7
Xinjiang	19.25	0.13	24	0.07	29	0.20	28	0.38	31
Yunnan	42.88	0.88	4	1.06	4	1.94	3	3.50	10
Zhejiang	46.77	0.26	13	0.23	15	0.49	14	7.92	3
Mainland China	1,262.28	0.31		0.28		0.59		3.75	

Population values are from the fifth national census in China in 2000

1997–2009. The rate of fatality in China is one-fifth the rate of 1.7 in Singapore from 1961 to 1979 (Pakiam et al. 1981), and one-fiftieths the rate of 15.5 in Swaziland from 2000 to 2007 (Dlamini 2009), the highest recorded in the world now. In contrast, the fatality rate of 0.31 in China is much higher than the 0.008 rate in Australia for 1910–1989 (Coates et al. 1993), 0.05 in the United Kingdom for 1993–1999 (Elsom 2001) and 0.17 in France for 1979–1996 (Groubiere 1999).

3.3 Year-to-year variations

The year-to-year variations of lightning-related fatalities, injuries and damage reports in Mainland China from 1997 to 2009 are shown in Fig. 3. The number of lightning fatalities and injuries increased from 144 and 169 in 1997 to the maxima of 827 and 718 in 2007 and then decreased to 371 deaths and 310 injuries in 2009. The wide use of electric equipment in modern days caused lightning-damage reports increase all along the period, only with a low value in 2008 (Fig. 3). Lightning casualties and damages were very low from 1997 to 2001. It was likely an underestimate resulting from underreporting in rural areas at that time. The sharp increase in year 2002 could be attributed mainly to the improved reporting procedure, especially in rural areas. Although lightning damage reports increased all along this period, fatalities and injuries began to drop since 2008. The drop of casualties in the last 2 years of the record may owe to improved forecasts and warnings, better awareness of the lightning threat, more substantial buildings available for safe refuge, medical care and emergency communications and other socioeconomic changes (López and Holle 1996; Holle and López 2003).

3.4 Monthly variations

Lightning casualties and damages occur all through the year in China, but most of the events are during summer months from June to August (Fig. 4). Lightning fatalities, injuries and damages in these 3 months account for 72, 67 and 63% of the whole year, and July has the maximum percentage frequencies for all categories. The greatest number of casualties and damages are in July (26 and 21%) with the second most in June (23%) for casualties and August (21%) for damages. The peak months from June to August are also the period of intense thunderstorm activities in China. During the winter months from November to February of the following year, the number of lightning fatalities, injuries and damage reports are the lowest in the year. The monthly variations of lightning casualties and damages in China show the same pattern with that in the United States (Curran et al. 2000).

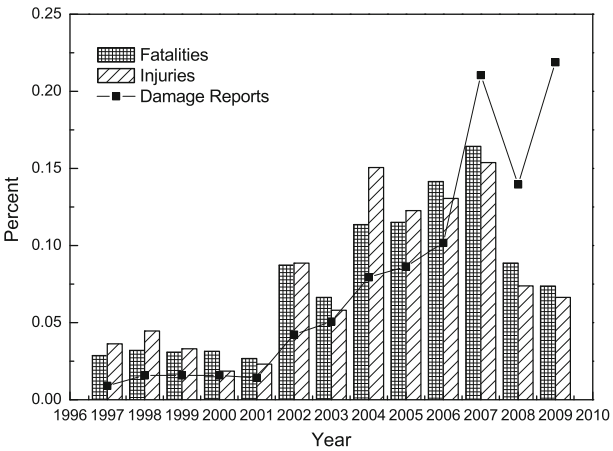

Fig. 3 Year-to-year variations of lightning-related fatalities, injuries and damage reports in Mainland China from 1997 to 2009

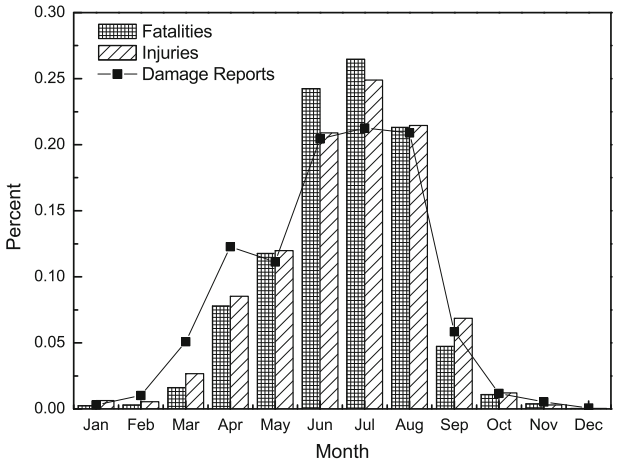

Fig. 4 Monthly variations of lightning-related fatalities, injuries and damage reports in Mainland China from 1997 to 2009

3.5 Rural and urban casualties

López and Holle (1998) found a remarkable agreement of rural population and normalized lightning death per million people in the United States during the twentieth century. The decrease in the population-adjusted lightning deaths occurred throughout the century and closely followed the decrease in percentage of the population living in rural areas. Several factors appeared to contribute the large number of deaths occurred in rural settings, such as the limited number of substantial grounding to homes and buildings; unimproved medical treatment and related communications; low-level lightning education; and absence of meteorological warnings compared to urban areas (Holle and López 2003). Inside houses with little or no grounding is an unsafe location during a thunderstorm. Houses with minimal grounding from such methods as electrical wiring and plumbing increase the risk of personal injury or death. Substantial grounding provides a path for the release of lightning current and decreases excessive voltage resulting from lightning to a safe level and therefore reduces the risk of lightning stroke on people and household appliances inside.

It is noticed that a large number of fatalities and injuries occur in rural areas in China (Fig. 5). Rural regions account for 51 and 29% of all lightning fatalities and injuries reported from 1997 to 2009. Lighting casualties in urban areas only account for 6%. If taking no account of unknown factors (14%), rural regions account for 93% of all lightning casualties. The large proportion of casualties is attributed to the working style, living environment and medical treatment in rural settings in China. First, rural people in China continue to rely on labor-intensive agriculture, where people are more exposed to the lightning threat. From the analysis of lightning-related locations, the largest proportion of fatalities and injuries in China occurs when people are working on farms (Fig. 8). Second, dwellings in rural regions are often poorly grounded and built in exposed areas, which increase the chance of direct lightning strikes on people. Furthermore, considerable lightning strikes in rural regions occur in remote mountainous areas, where communication and transportation are underdeveloped and lack of resuscitation techniques. According to Cooper (1980), nearly 75% of those who suffered cardiopulmonary arrest from lightning

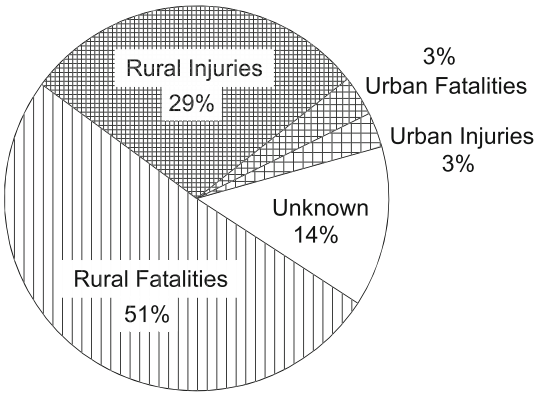

Fig. 5 Frequency distribution of lightning casualties in rural and urban regions in Mainland China

injuries died, many because cardiopulmonary resuscitation was not attempted. All the factors above result the large casualties in rural regions and high death/injury ratio in China compared to other part of the world in Cherington et al. (1999).

3.6 Economic losses

Lightning causes millions of dollars property losses in China every year. Figure 6 shows the annual variations of direct economic losses caused by lightning. Direct economic losses increased from 50 million RMB (about 7.4 million US dollars) in 1997 to 450 million RMB (about 66 million US dollars) in 2007 and then began to decrease in 2008. Direct economic loss per damage decreased during this period, which indicated the increase in lightning damage reports, same with the results shown in Fig. 3. In order to see which industry has the most severe damages by lightning, lightning damages with economic losses are classified into nine categories: civil use, power, education, manufacture, communication, petro-chemistry, finances, transportation, agriculture and forestry (Fig. 7). Lightning-caused damage on structures and appliances for civil use has the largest

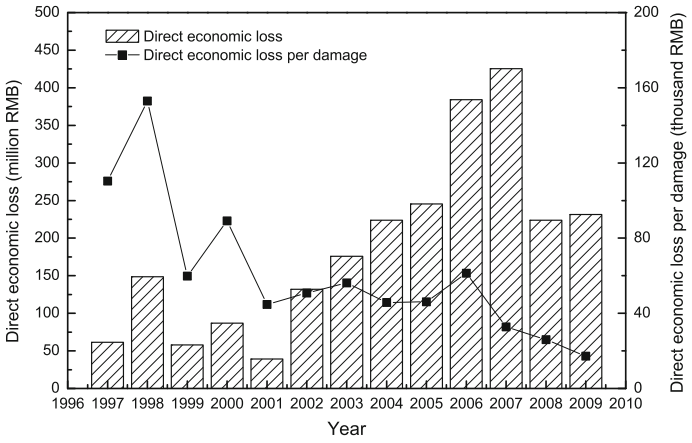

Fig. 6 Annual variations of direct economic losses caused by lightning in Mainland China from 1997 to 2009

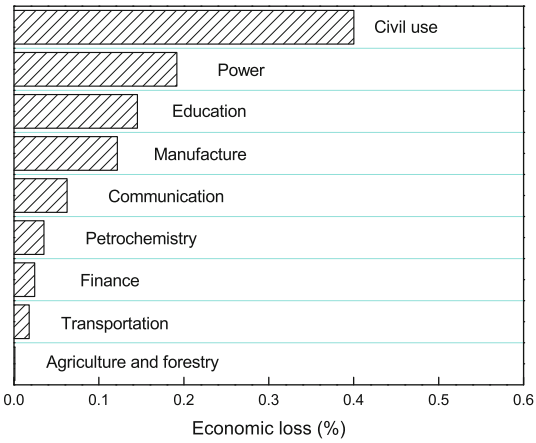

Fig. 7 Frequency distributions of economic loss in different fields

economic loss and accounts for 40% of total losses. Lightning damage on power lines has the second largest (19%) economic loss. Education field is the next largest category with destruction of buildings and appliances in schools.

3.7 Locations

Lightning-related deaths and injuries are mainly determined by the activity and location of individuals during the thunderstorm. In this study, locations of lightning casualties are divided into nine categories: farm, open fields, water area, in buildings, factories and building sites, mountains, trees, telephones and radios, bikes and motorcycles (Fig. 8). "Farm" is the largest category for 37% were struck whilst working on farm. "Open fields" is the next largest category and accounts for 14% casualties. "Water area" (e.g. rivers, lakes, fish farms and reservoirs) is the third largest group and accounts for 9% casualties. Fig. 8 points to the fact that the majority (79%, sum of farm, open fields, water area, mountains, trees, bikes and motorcycles) of lightning casualties occurs outdoors in open areas in China, similar with the results of Mills et al. (2008) in Canada.

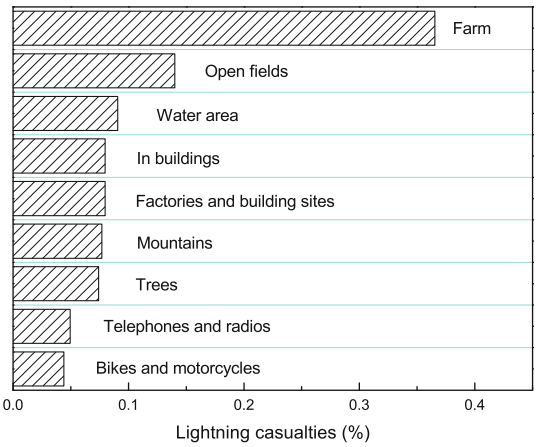

Fig. 8 Frequency distributions of the locations of lightning casualties

4 Conclusion

Lightning is a common meteorological hazard in China that leads to fatalities, injures and large amount of economic losses. Based on the National Lightning Hazards Database, lightning-related fatalities, injures, casualties and damage reports from 1997 to 2009 were summarized. Large casualties and damage reports were located in south and east China. When taking population into account, the maxima shift from southern and eastern provinces to low population provinces such as Tibet, Hainan and Qinghai and the ranks of populous provinces such as Henan, Shandong and Sichuan degraded.

The number of lightning fatalities and injuries increased from 1997 to 2007 and began to decrease since 2008. While the damage reports showed an increase all along the period, only with a low value in 2008. The peak months of lightning fatalities, injuries and damages were from June to August, which was also the period of intense thunderstorm activities in China. July maxima were reached by all types of lightning reports. The number of lightning fatalities, injuries and damage reports were lowest between November to February of the following year.

Rural regions accounted for 51 and 29% of all lightning fatalities and injuries. A majority of fatalities and injuries occurred when rural people were doing field work. Direct economic losses by lightning increased from 50 million RMB (about 7.4 million US dollars) in 1997 to 450 million RMB (about 66 million US dollars) in 2007 and began to decrease in 2008. Direct economic loss per damage decreased during this period, which indicated increase in lightning damage reports. Civil field had the largest economic losses, and power industry was the second category. A significant number (79%) of lightning casualties occurred outdoors in open areas, with 37% working on farm, 14% in open fields and 9% in water area.

The annual worldwide number of lightning injuries is probably 5 to 10 times the annual number of deaths, while the injury/deaths ratio in China is about one. Future work will focus on further analysis of the high death/injury ratio in China and investigate the impact factors. In addition, comparisons of casualties and damages with ground-lightning flash-density data detected by the National Lightning Detection Network in China, and improvement of a better lightning reporting protocol that will include all the variables discussed above will also be included. This can help reduce the underestimation of lightning casualties and damages and develop a more concise national lightning hazard database.

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