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Characteristics of Lightning Casualties and Vulnerability Evaluation Regionalization in China

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***Abstract*—According to the data of lightning hazards from 1997 to 2010 and lightning observation by TRMM satellite, feature of national injuries and deaths of lightning stroke was analyzed and the results indicates that lightning stroke causes 460 people died and 425 injured every year. The ratio of deaths to injuries is 1:0.92. The mortality rate is 0.36 per one million people and 0.48 per ten thousand square kilometers every year. Three indexes about lightning stroke casualties reports， the number of lightning fatalities per ten thousand square kilometers and the number of lightning fatalities per one million people have good correlativity, Lightning-related casualties have increased for the period of 1997 to 2007 and then began to decrease since 2008 . casualties anomaly percent have positive in 2002、2004、2005、2006、2007, The five years have more frequent lightning fatalities than other normal years, fatalities anomaly percent have maximum value in 2007, the ratio is 78% more than normal years.**

In order to reveal the vulnerability of lightning stroke which lead to injuries and deaths in different region, R-Cluster analysis was used for sifting the 8 indexes that are affected by vulnerability evaluation, and finally 4 indexes—lightning density, casualties frequency, population, and region areas are confirmed. Comparability measures of each sample are calculated by using Euclidean distance, and then the Within method of Q-Cluster is used to analyze and calculate these dates. Finally the result of 6 different kinds of risk zones of lightning stroke that lead to injuries and deaths in China were provide. Guangdong and Hainan pertain to vulnerability evaluation extreme high areas. In these areas, the comprehensive vulnerability evaluation of cluster reaches up to 5.017, whether the average density of lightning or personnel casualty rate is the highest in the six categories. Oppositely, The northwest and northeast of China belong to vulnerability evaluation the lowest areas. Ultimately, Ward's method of Q-Cluster was adopted to explain and testify the result of cluster. Results showed cluster solution is not only stable but also believable, The result of classification is appropriate, and preferably reflects lightning stroke cause people casualties this random event's regional vulnerability evaluation characteristics.

Keywords—Lightning stroke；Casualties；Vulnerability evaluation；Zone

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I. INTRODUCTION

Assessment and regionalization of disaster loss is an important part of disaster science. Natural disasters are essentially extreme geophysical events. The happen of disaster is decided by hazard-formative environment and disaster bearing body. Based on the analysis of the basic characteristics of China's lightning casualties, key indicators of lightning casualty district vulnerability are selected by using R-cluster analysis method. With these key indicators, the various classifications are calculated by Q hierarchical clustering analysis method. In order to validate that the clustering solution is stable and credible, two methods are used to cluster analysis and compare. Then, the result of lightning casualty district vulnerability regionalization is present. This paper is briefly relatively, the work is introduced in detail in our published paper [1].

II. DATA AND METHODS

Data

Chinese lightning disaster database includes lightning disaster accidents reported by all provinces, municipalities and autonomous regions, but not including Taiwan, since 1997. Lightning disaster accident information, such as data, time, location, casualty, damage and so on, has been recorded by the database. The database is used to analyze lightning casualty characteristics from 1997 to 2010 in this paper. It should be noted that the lightning casualty statistic is incomplete because of information omitting and default.

The lightning flash data observed by optical transit detector (OTD) from April in 1995 to March in 2000 and lightning imaging sensor (LIS) from December in 1997 to December in 2005 carried by TRMM satellite is used to calculate cloud-ground lightning density of each provinces, municipalities and autonomous regions by Ming Ma[2]. Their calculation results are used in this paper. Number of population, rural population and the administrative area of each provinces, municipalities and autonomous regions are from the fifth national population census in 2000.

Methods

Table 1 shows the statistical results of average lightning density, lightning disaster accident frequency, casualty frequency, population and administrative area of each provinces, municipalities and autonomous regions, not including Hong Kong, Macao and Taiwan, in China. Firstly, the data in table 1 are standardized. Secondly, the similarity measure of all the eight samples is calculated to get Euclidean distance matrix. Then, according to the matrix, samples are classified by using the hierarchical clustering method. Finally, Ward's method of Q-cluster is adopted to explain and testify the result of cluster.

TABLE I. THE LIGHTNING DISASTER STATISTIC FOR PROVINCES IN CHINA FROM 1997 TO 2010

Order	Province	Lightning density/ (km^{-2}•a^{-1})	Frequency of lightning disaster accidents/ (N•a^{-1})	Frequency of lightning casualty/ (P•a^{-1})	Population/ (ten thousand people)	Area/ (10^4•km^2)
1	Beijing	8.93	87.5	4.64	1382	1.68
2	Tianjin	9.73	18.79	1.36	1001	1.13
3	Hebei	7.94	289.64	25.5	6744	18.77
4	Shanxi	5	33.36	6	3297	15.63
5	Nei Monggol	3.6	50.36	14.43	2376	118.3
6	Liaoning	6.37	113.57	15.86	4238	14.59
7	Jilin	4.54	69.36	10.71	2728	18.74
8	Heilong jiang	4.12	47.93	11.43	3689	45.46
9	Shanghai	7.43	24.07	6.5	1674	0.63
10	Jiangsu	8.52	319.57	33	7438	10.26
11	Zhejiang	8.19	542.64	35.57	4677	10.18
12	Anhui	8.09	130.21	22.93	5986	13.96
13	Fujian	8.53	347.43	33	3471	12.14
14	Jiangxi	9.72	199.86	61.14	4140	16.69
15	Shandong	8.15	248.5	32.21	9079	15.67
16	Henan	6.56	112.71	23.64	9256	16.7
17	Hubei	7.01	151.93	41.14	6028	18.59
18	Hunan	8.12	407.57	42.14	6440	21.18
19	Guangdong	16.64	1395.57	121.86	8642	17.79
20	Guangxi	12.62	149.79	50.07	4489	23.6
21	Hainan	15.99	53.14	21.93	787	3.39
22	Chongqing	8.49	42.64	13.07	3090	8.24
23	Sichuan	4.73	133.21	46.43	8329	48.5
24	Guizhou	10.2	82.64	30.86	3525	17.6
25	Yunnan	5.98	160.07	49.86	4288	39.4
26	Tibet	1.74	14.29	15.14	262	122.84
27	Shaanxi	3.48	29.14	19.43	3605	20.56
28	Gansu	2.59	10.71	32.43	2562	45.4
29	Qinghai	2.05	18.43	23.5	518	72.12
30	Ningxia	2.99	4.57	16.64	562	5.18
31	Xinjiang	1.33	8.43	26.21	1925	165

III. CHARACTERISTICS OF LIGHTNING CASUALTY

The numbers of lightning disaster accidents and lightning disaster accidents with casualty from 1997 to 2010 in China are showed in figure 1. There are 74167 lightning disaster accidents reported from 1997 to 2010. The average number of lightning disaster accident is 5298 every year. The number of lightning disaster accident with casualty is 6355 in the 14 years which is 8.6% of the total lightning disaster accident, and the average number of lightning disaster accident with casualty is 454 every year. As you can see from Figure 1, both the numbers of lightning disaster accident and lightning disaster accident with casualty are approximately on the rise before 2007, but after 2007, the trends are opposite.

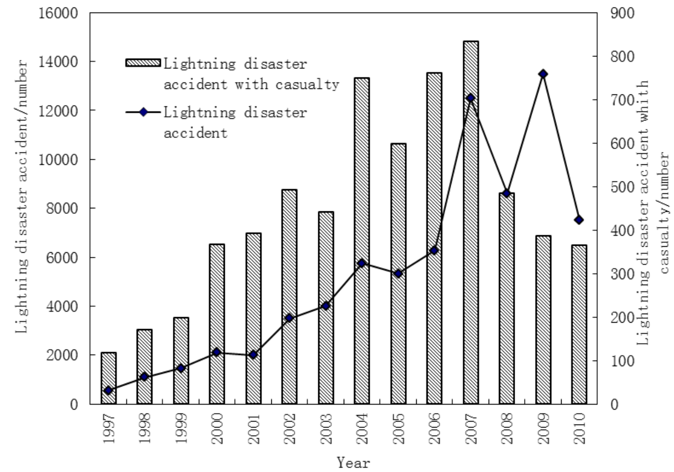

Fig. 1. Compare accident number of lightning disaster with casualties in China from 1997 to 2010

Figure 2 shows the numbers of people of death, injury, and casualty because of lightning in China from 1997 to 2010. The total number of lightning casualty is 12392 during the 14 years, on average 885 casualties every year. The number of lighting casualties appears double peak characteristics in 2004 (1527 casualties) and 2007(1528 casualties), respectively. Before 2004, lightning casualties is increasing on the whole. After 2007, lightning casualties is decreasing. Lightning deaths and injuries also have such characteristics. The total deaths is 6446, the average of deaths is 460 every year which is 52% of lightning casualties. The ratio of death and injury is 1:0.92 which is higher than 1:2.54 of the USA [3].

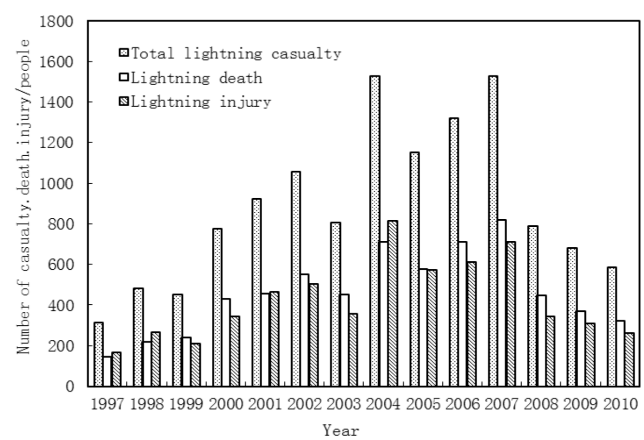

Fig.2 Annual number of lightning casualties, deaths and injuries in China from 1997 to 2010

The anomaly percent of lightning deaths and injuries is revealed in Figure 3. The people of lightning deaths and injuries are 460 and 425 respectively on average every year in China. The anomaly percent of casualty are positive in the years of 2002, 2004, 2005, 2006 and 2007. The most anomaly percent lightning death in 2007 is 78% more than normal years. The most anomaly percent lightning injury in 2004 is 92% more than normal years, which is maybe related to statistical method, thunderstorm days and change of temperature [4].

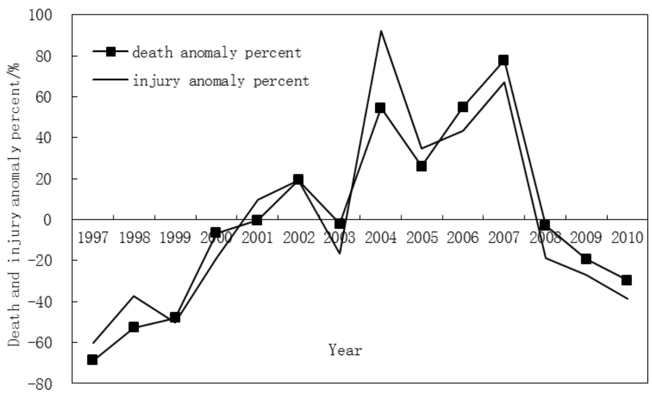

Fig.3 Deaths and injuries anomaly percent in China from 1997 to 2010

As shown in figure 4, there is a significant correlation between average lightning deaths per one million people every year and average lightning deaths per ten thousand square kilometers every year, and both of them are roughly rising from 1997 until the peak year 2007, then descending since 2007. The phenomenon maybe concerned with improved lightning forecasting and warning accurate rate, enhanced public lightning protection, and better medical emergency level [5].

The lightning death rate is 0.36 per one million people every year in China from 1997 to 2010. But for different periods ,The average lightning death rate is 0.42 for American, 1.7 for Singapore, 0.001 for Australian, 6 for South Africa, 15.5 for Swaziland, per one million people every year.[3,6]

According to Figure 5, lightning casualty rate is 0.48 per ten thousand square kilometers every year in China from 1997 to 2010, the highest value is 10.32 in Shanghai, and the lowest value is 0.12 in Nei Monggol and Tibet.

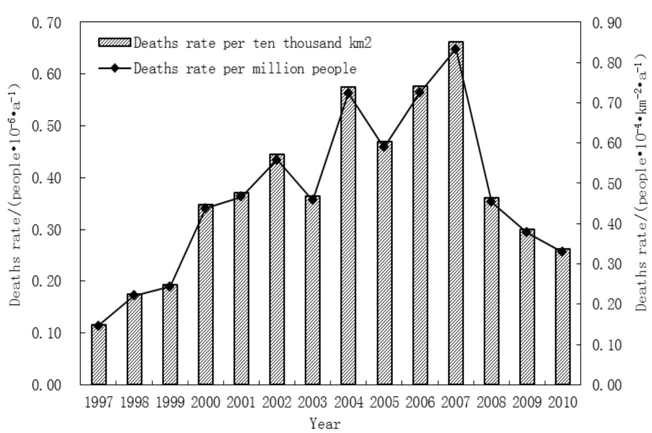

Fig.4 The rate of lightning deaths in China from 1997 to 2010

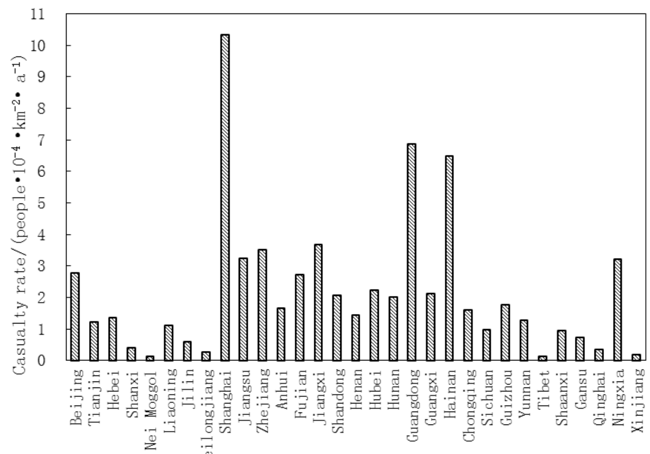

Fig.5 The rate of lightning casualties in China from 1997 to 2010

IV. LIGHTNING CASUALTY VULNERABILITY EVALUATION AND REGIONALIZATION

Lightning casualty vulnerability evaluation index

Features of hazard formative environment and hazard bearing body should be reflected by evaluation index, which can be got by the back stepping method according to the post-disaster damage assessment system, or got by disaster cases using information value method basing on the comprehension of social vulnerability [7]. According to the above principles, eight influencing factors causing lightning casualties have been selected. They are defined as follows. ① Average ground lightning density, Ng (unit: number • km^{-2} • a^{-1}), stand for the number of ground lightning every square kilometer every year. ② Frequency of lightning disaster, F_1 (unit: number • a^{-1}), stand for annual mean of lightning disaster accidents. ③ Frequency of lightning casualty, F_2 (unit: people • a^{-1}), stand for the average number of lightning casualties every year. ④ Number of people, N_1 (unit: ten thousand people). ⑤ Number of country people, N_2 (unit: ten thousand people). ⑥ Density of population, D_1 (unit: people • km^{-2}). ⑦ Density of country people, D_2 (unit: people • km^{-2}). ⑧ Area of zone, A (unit: ten thousand km^2).

Each of the above eight indexes has 31 data samples. Then, these data samples have been standardized. And then, the eight indexes have been filtrated by R-clustering methodology. The result of screening process is credible after testing and verifying by using square sum of deviations method. Finally, four indexes (Ng, F_2, N_1, A) are chosen to be lightning casualty vulnerability evaluation indexes.

Result of lightning casualty vulnerability evaluation regionalization

According to the four evaluation indexes (Ng, F_2, N_1, A), 31 samples of 31 provinces are cluster analyzed to six classes using Within method. The six classes are ｛Beijing, Tianjin, Shanghai, Chongqing, Hainan｝, ｛Shanxi, Jilin, Shaanxi, Liaoning, Heilongjiang, Gansu, Ningxia, Qinghai｝, ｛Shandong, Henan, Hubei, Hunan, Hebei, Anhui, Jiangsu, Sichuan｝, ｛Jiangxi, Guangxi, Fujian, Guizhou, Zhejiang, Yunnan}, {Guangdong}, {Nei Monggol, Tibet, Xinjiang}. The cluster results of Ward's method are {Beijing, Tianjin, Shanghai, Hainan}, {Shanxi, Jilin, Shaanxi, Heilongjiang, Gansu, Ningxia, Qinghai}, {Shandong, Henan, Hubei, Hunan, Hebei, Anhui, Jiangsu, Sichuan, Yunnan}, {Jiangxi, Guangxi, Fujian, Guizhou, Zhejiang, Liaoning, Chongqing}, {Guangdong}, {Nei Monggol, Tibet, Xinjiang}. Compare with the cluster results of both methods, only Liaoning, Chongqing and Yunnan are belong to different classes. So, the cluster results are stable and credible.

According to the results of Within method, the average lightning casualties per ten thousand kilometers every year of six classes are calculated. Using the calculated results, the cluster results of Within method are adjusted. The final results of cluster analysis are {Beijing, Tianjin, Hebei}, {Shanxi, Jilin, Shaanxi, Liaoning, Heilongjiang, Gansu, Ningxia, Qinghai}, {Shandong, Henan, Hubei, Hunan, Chongqing, Anhui, Jiangsu, Shanghai, Sichuan}, {Jiangxi, Guangxi, Fujian, Guizhou, Zhejiang, Yunnan}, {Guangdong, Hainan}, {Nei Monggol, Tibet, Xinjiang}.

TABLE II. THE COMPREHENSIVE VULNERABILITY EVALUATION OF CLUSTER

Category	Samples	Standardized vulnerability evaluation indexes			Synthesized vulnera-bility value
		Average ground lightning density	**Average lightning casualties (unite area)**	**Average lightning casualties (unite people)**	
1	{Guangdong, Hainan}	1.6851	1.9393	1.3927	5.017
2	{Jiangxi, Guangxi, Fujian, Guizhou, Zhejiang, Yunnan}	0.2459	0.0166	0.3994	0.662
3	{Shandong, Henan, Hubei, Hunan, Chongqing, Anhui, Jiangsu, Shanghai, Sichuan}	-0.1082	-0.1835	-0.8961	-1.187
4	{Beijing, Tianjin, Hebei}	0.1771	-0.2836	-1.1336	-1.240
5	{Nei Monggol, Tibet, Xinjiang}	-1.1689	-0.8341	0.7449	-1.258
6	{Shanxi, Jilin, Shaanxi, Liaoning, Heilongjiang, Gansu, Ningxia, Qinghai}	-0.8309	-0.6547	-0.5074	-1.993

Table 2 is the standardized vulnerability evaluation indexes, such as average ground lightning density, average lightning casualties per ten thousand kilometers every year, average lightning casualties per one million people every year, and synthesized vulnerability value of six classes. Synthesized vulnerability value of {Guangdong, Hainan} is 5.017, their vulnerability of lightning casualty is the highest, they are high lightning casualty hazard risk region. {Guangdong, Hainan} is first class. {Jiangxi, Guangxi, Fujian, Guizhou, Zhejiang, Yunnan} is second class which is the second highest lightning casualty hazard risk region. The third class {Shandong, Henan, Hubei, Hunan, Chongqing, Anhui, Jiangsu, Shanghai, Sichuan} and the fourth class {Beijing, Tianjin, Hebei} are both belong to middling lightning casualty hazard risk region. The fifth class {Nei Monggol, Tibet, Xinjiang} and the sixth class {Shanxi, Jilin, Shaanxi, Liaoning, Heilongjiang, Gansu, Ningxia, Qinghai} are feeble lightning casualty hazard risk region.

V. CONCLUSIONS

Statistical results of lightning casualties in China from 1997 to 2010 indicate that lightning deaths and injuries every year on average are 460 and 425 people, respectively. The ratio of deaths and injuries is 1:0.92. The average lighting deaths per one million people every year is 0.36. The average lightning deaths per ten thousand kilometers every year is 0.48.

The result of lightning casualty vulnerability evaluation regionalization demonstrates that Guangdong and Hainan are the highest lightning casualty hazard risk regions of China. And northwest and northeast of China are belong to weak lightning casualty hazard risk regions.

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