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Flash Flood Incidents in China in 2013:Characteristics, Reasons, and Benefit Analysis of Non-Engineering Measures

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ABSTRACT: Fatal flash flood incidents in 2013 in China were sorted based on statistical data from the Office of State Flood Control and Drought Relief Headquarters and provincial flood reports. Through statistical analysis and field research, the incidents were categorized based on regional distribution, historical comparison, disaster type and level, occurrence time, and composition of fatalities, and national flash-flood-distribution maps drawn according to disaster type and level, and number of deaths. Furthermore, the ratio of deaths by flash floods to total deaths by flooding since 2000 were analyzed, and the situation of flash floods in 2013 compared with 2012. The results showed that of 774 people killed by flooding in 2013, 560 (72.4%) were killed following 181 catastrophic flash flood incidents. Flash flood incidents started in early February, ended in late October, and occurred mainly in July and August, although there were significant regional differences in distribution and severity. Migrant workers, farmers, and tourists were the groups most affected, and the elderly and minors accounted for the largest proportion of total deaths. Extreme heavy rainfall, migrants' poor awareness of flood prevention, and failure of early warning information were the principal reasons for the frequency of flood disasters and number of casualties.

Key Words: flash flood, creek flood , landslide , debris flow , non-engineering measures

1. INTRODUCTION

Flash flood disasters are caused by heavy rainfall in hilly areas, and the landslides and debris flows induced by the flash floods are a threat to the national economy, and people's lives and property. There are 2,058 counties in 29 provinces tasked with flash flood prevention, comprising an area of 4,870,000 km2 and a population of 570 million under threat. Therefore, the issue of flash flood prevention is arduous and difficult. China is located in the East Asian monsoon climatic zone and storms occur frequently in summer. Hilly areas comprise 70% of the total land area within which about 1/3 of the population resides(*Chen 2006*). The impacts of rain, topography, and human activities, result in the frequent occurrence of flood disasters, casualties, and increasing economic losses (*Ma et al., 2008*). From 1950 to 1990, the number of deaths caused by flash floods in hilly areas comprised 67.4% of the total number of deaths from flooding (*Li et al., 2005*). From 1991 to 2006, the proportion of deaths caused by flash floods, in relation to total deaths from flooding, increased significantly. In 2013, in China, the damage caused by floods was lighter compared with the average index since 1990. Furthermore, the affected population was reduced by 30%, deaths were reduced by 70%, and the ratio of direct economic losses to GDP of the previous year was reduced by 0.98%; however, small-river floods and flash floods accounted for a higher proportion of flood-related deaths. In recent years, this proportion has exceeded 70%, meaning that flash floods have become the major cause of natural-disaster-related casualties.

In November 2010, a nationwide county-level project of non-engineering measures for flash flood prevention was launched by the Ministry of Water Resources, Ministry of Finance, and other bureaus in China, financed by a total budget of 7.938 billion RMB. Three years later, flash flood monitoring, early warning, mass prediction and disaster prevention systems covering 2,058 counties had been implemented. It was intended that the flash-flood-prevention project be completed by 2013 and by then, some benefits of disaster prevention and mitigation had actually been achieved. However, there were still weaknesses and it was necessary to implement a subsequent project within the same framework. By categorizing the fatal flash flood incidents of 2013, their characteristics could be analyzed, revealing the national situation in a timely and objective manner. Problems experienced during the process of flash flood prevention could be reflected by analysis of the principal causes of severe flash flood disasters. This could provide detailed and reliable data for decision making for all levels of the flood prevention agencies in China.

Flash flood prevention has become a worldwide problem that poses a significant challenge. Non-engineering measures have been proven the most effective way to overcome these problems. These are defined as any measures not involving physical construction that use knowledge, practice, or agreement to reduce risks and impacts, particularly through the implementation of policies and laws, raising public awareness, training, and education (*Sun et al., 2012*). Under the guidance of this principle, a disaster prevention system was established including monitoring, communication, forecasting, and warning. It was a challenge to evaluate the benefits of the implemented non-engineering measures in 2013, but the frequency of effective early warning information could be considered an important indicator of benefit. It was difficult to determine the exact number of the early warnings issued for each incident, but we collected data on the number of early warnings issued provincially, and the relative benefits of the non-engineering measures in each province could be revealed clearly through joint analysis using both the frequency of warnings and total deaths in each province.

2. DATA SOURCES AND DATA PROCESSING

2.1 Data Source

The information collected included flood disaster statistics initiated by the Office of Flood Control and Drought Relief Headquarters, Ministry of Water Resources, and provincial reports of disasters, hydrological and rainfall data, and disaster information and pictures of major flash flood incidents obtained via field investigations. Hong Kong, the Macau Special Administrative Region, and Taiwan were not included. Additionally, Shanghai and Jiangsu Province were excluded because they were not part of the flash-flood-prevention task. Only incidents with casualties were included in the study.

2.2 Data Processing Principles

The statistical work was performed under the guidance of the Office of Flood Control and Drought Relief Headquarters and specialists from the National Flash Flood Prevention Project Team were assigned to the statistics of the flash flood incidents with help from provincial flood prevention agencies. Decryption processing was performed and the information screened in accordance with the principles of flash flood incidents. The incidents were well organized in terms of time and place, and the information was verified twice monthly during the flood season.

A number of principles were applied to the description of the flash flood incidents. Incidents that occurred at the same time in the same county, but in different towns, could be identified as one incident and the number of deaths aggregated. Different types of disaster that occurred in the same place at the same time could be identified as different incidents. Similar types of incident in the same location within an interval of 1–2 days, could be identified as one incident, the occurrence time defined as the beginning date, and the number of deaths aggregated. Only landslides and debris-flow incidents induced by rainfall could be included.

The principles behind the flash flood disaster levels refer to the geological disaster classification requirements in Article 4 of the "Geological Disaster Prevention Regulations" (State Council Decree No. 394). Incidents for which the number of dead and missing people was 30 or more, were defined as giant, 10 to 29 dead and missing were classified as large, 3 to 9 were medium, and less than 3 were small.

3. RESULTS AND ANALYSIS

The statistics of the flash flood incidents reveal there were 181 flash floods in 24 provinces (autonomous region or city, excluding Beijing, Tianjin, Shandong, Hainan, Jilin, and Bingtuan), in which 560 people died and 221 were reported missing. Overall, 774 people died because of floods and thus, the proportion of deaths from flash floods was 72.4%; this reached 100% in five provinces (regions) (Hebei, Shanxi, Liaoning, Heilongjiang, and Fujian), and exceeded 70% in 15 provinces. Therefore, most flood-related deaths were caused by flash flooding.

There were two giant (7.10 Dujiangyan; giant high landslides, 8.16 Fushun; giant flash flood) and six large flash flood incidents in 2013 that resulted in 203 deaths; the number of deaths accounted for 53.4% of the total number. In addition, 173 medium and small incidents killed 357 people.

3.1 Spatial Distribution and Comparison

The distribution of incident disaster levels is shown in Figure 1. The large flash flood incidents are located mainly in Liaoning, Sichuan, Inner Mongolia, Shaanxi, Gansu, and Qinghai provinces (regions), among which Sichuan Province suffered most severely from three large (including one giant) flash flood disaster incidents.

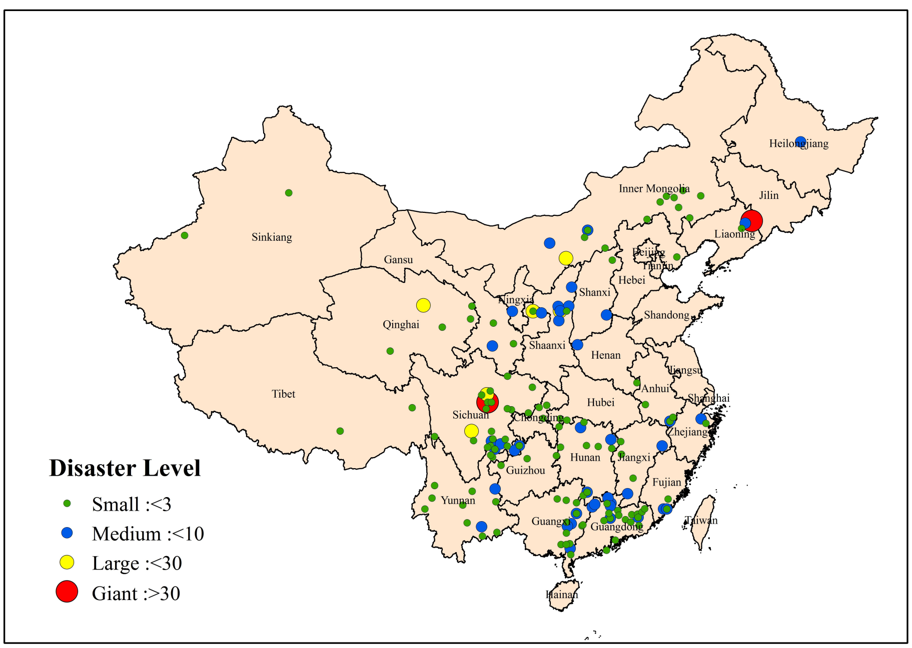

Figure 1. Distribution of flash flood disaster level in 2013

As shown in Figure 2, the different types of flash flood disaster that occurred in 2013 possess different spatial distributions. Creek flood incidents were prone to occur in Guangdong, Inner Mongolia, and

Yunnan provinces (regions), whereas landslide incidents occurred in Guangdong and Guangxi provinces (regions), and debris flow incidents occurred in Sichuan and Guangdong provinces. Three types of flash flood disaster occurred most frequently in Sichuan and Guangdong provinces, causing serious casualties.

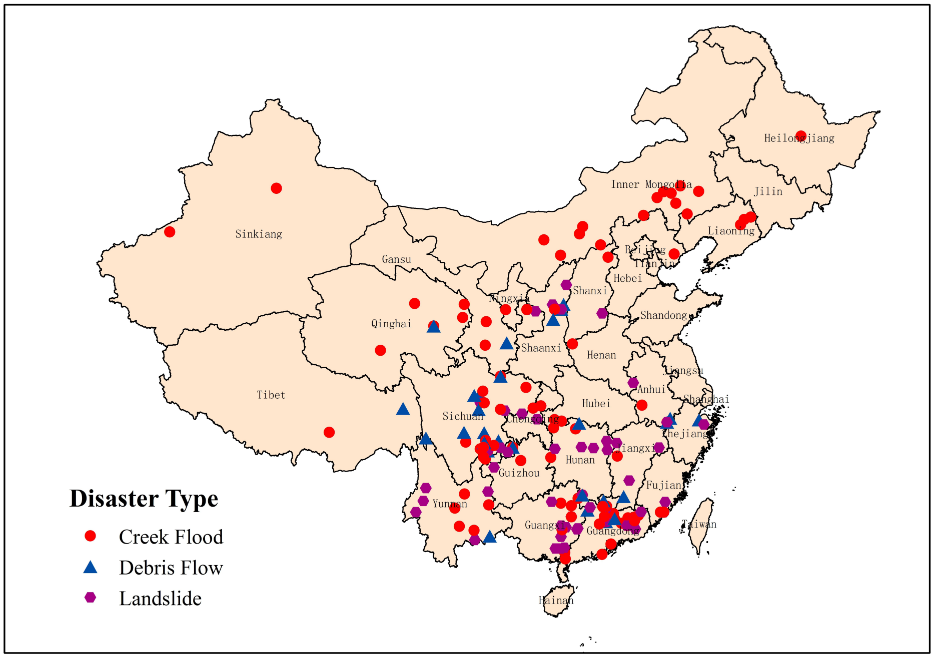

Figure 2. Distribution of flash flood disaster type in 2013

Flash flood deaths and the proportion to total flood-related deaths since 2000 are shown in Figure 3. Before 2008, the number of flash flood deaths was about 1000 with up to about 500 occurring during the rest of the year. Extreme weather incidents with great frequency, intensity, and impact occurred in 2010 causing 2824 flash-flood-related deaths. The proportion to the number of total flood-related dead and missing reached an unprecedented 87.6%. On August 8th, a large debris flow disaster in Zhouqu in Gansu Province, resulted in 1501 deaths and 264 people missing.

Apart from a few years (2000–2002), the proportion of the number of deaths caused by flash floods to the total number of flood-related deaths has remained above 70%. This is partly because of the large scale of deaths in flash flood and partly because the number of deaths caused by giant river floods and the total number of deaths have decreased in recent years. The data showed that since 2008, and especially since the implementation of the non-engineering measures for flash flood prevention, the number of flash-flood-related deaths has remained at a low level, whereas the proportion to the total number of flood-related deaths has been at a higher level.

Flash flood deaths in 2013 increased slightly compared with 2011 and 2012, but remained at a low level, whereas the proportion of total deaths was still relatively high with a subtle rise compared with 2012; thus, flash floods remained the principal cause of flood-related deaths.

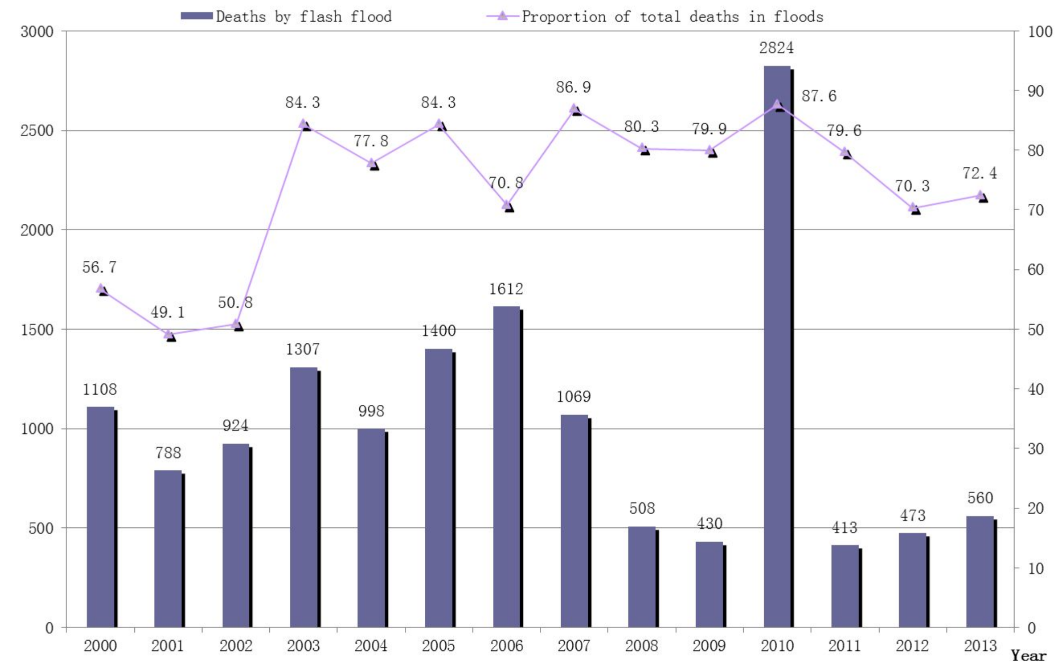

Figure 3. Proportion of deaths caused by flash floods to total flood-related deaths since 2000

(Data source: Bulletin of flood and drought disasters in China, 2012)

Compared with 2012, flash flood incidents and deaths in 2013 increased by 1.7 and 18.4%, respectively (Table 1). The number of deaths caused by a single flash flood incident was 3.1 with a growth of 19.2% compared with 2012. The proportion of foreigners in flood deaths declined slightly, but deaths among the elderly and children increased substantially by 100 people (73.5%) compared with 2012.

Table 1. Comparison of flash flood incidents and deaths between 2012 and 2013

Items	Incidents	Deaths	Deaths per incident	Foreigner	Elderly and children
2013	181	560	3.1	100	236
2012	178	473	2.6	108	136
Increased number compared with 2012	3	87	0.5	-8	100
Rate of increase compared with 2012	1.7	18.4	19.2	-7.4	73.5

3.2 Analysis of Characteristics

3.2.1 Creek floods were the main type of flash flood

There are three types of flash flood considered here: creek floods, landslides, and debris flows. According to the pie chart showing the composition of flash floods in 2013 (Figure 4), 93 creek flood incidents caused 308 deaths (55% of the total) which indicates that creek floods were the principal type of flash floods. There were 59 landslide incidents that caused 164 deaths (29% of the total), and 29 debris flows that caused 88 deaths (16% of the total).

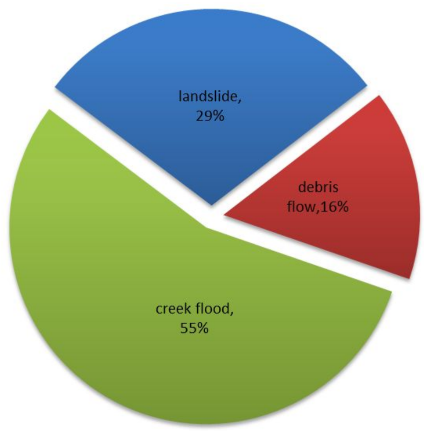

Figure 4. Composition of flash flood disasters in 2013

3.2.2 Large flash flood incidents caused great casualties

There were six giant and two large unexpected flash flood incidents in 2013 (Table 2), in which the rainfall exceeded the region’s historical extreme and river flows in some areas peaked, resulting in significant casualties and loss of property. The giant flash flood disaster that occurred on August 16, in Qingyuan County in Liaoning Province, caused 77 deaths with direct economic losses of 7.634 billion RMB. On July 10, a giant landslide incident in Dujiangyan in Sichuan Province resulted in 45 deaths, 116 people missing, and serious damage to property.

Table 2. Large-scale flash flood incidents in 2013

Time	Place	Type	Rain regimes	Water regimes	Disaster condition		
			Rainfall (mm/h)	Peak flow (m^3/s)	Dead	Missing	Economic loss (million, RMB)
20130630	Erdos City,Inner Mongolia	Creek flood	67mm/3h	156.6	19	/	50
20130704	Simian County, Sichuan	Debris flow	152.5mm/3h	/	11	10	700
20130710	Wenchuan County,Sichuan	Debris flow	30.1mm	/	14	15	3,800
20130710	Dujiangyan City, Sichuan	Landslide	1129mm	/	45	116	/
20130712	Yan’an City, Shaanxi	Creek flood	36.4mm/24h	70	15	/	1,466
20130816	Qingyuan County,Liaoning	Creek flood	425mm/24h	6700	71	84	7,634

20130820	Wulan County, Qinghai	Creek flood	31.3mm/6h	700	24	/	30

3.2.3 Flash flood incidents started early with long duration, concentrated in July and August

In 2013, the flash flood disasters began in early February and ended in late October (Figure 5). The flash flood incidents were concentrated in July and August when 96 incidents (53% of the total) caused 376 deaths (67.1% of the total number of flood-related deaths). Flash floods occurred most frequently in July, and on July 10, five flash flood incidents caused 65 deaths.

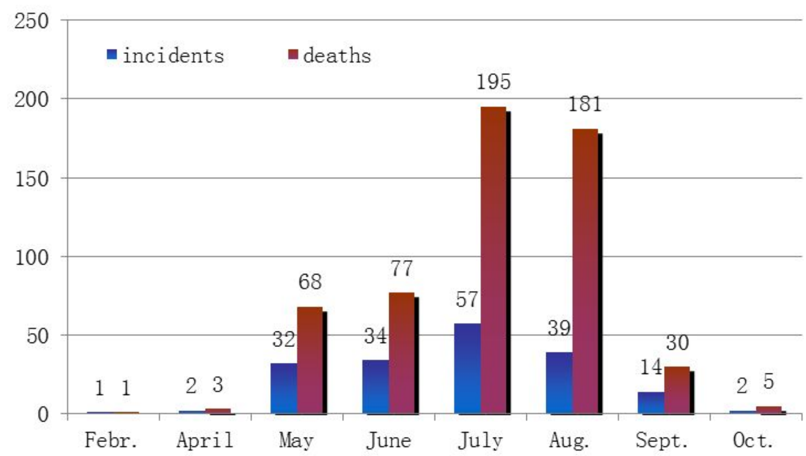

Figure 5. Frequency of flash flood incidents and number of deaths (by month)

3.2.4 There were significant regional differences and severe flash floods hit some provinces

Fatal flash flood incidents occurred in all six regions of China listed in Table 3, and Central South and Southwest China suffered most. Flash floods caused 155 deaths in Southwest China, which accounted for 27.7% of the total, and a further 127 people were reported as missing. There were significant regional differences in the occurrence of flash flood disasters; Southwest China was mostly severely afflicted, whereas North China was affected the least. Creek floods caused the most deaths in Northeast and Northwest China, whereas debris flows and landslides were concentrated in Southwest China, accounting for 45% of total debris flow deaths and 52% of total landslide deaths, respectively (Table 3).

Table 3. Frequency of flash flood incidents and number of deaths (by region)

Region	Flash flood		Creek flood		Debris flow		Landslide	
	Incident	Death	Incident	Death	Incident	Death	Incident	Death
North	19	61	17	50	2	11	0	0
Northeast	4	84	4	84	0	0	0	0
East	15	38	5	14	6	15	4	9

Central South	65	131	28	59	31	54	6	18
Southwest	56	155	26	35	16	74	14	46
Northwest	22	91	13	66	4	10	5	15
Total	181	560	93	308	59	164	29	88

Flash flood disasters were more prominent in local provinces. The individual deaths in Sichuan, Liaoning, Guangdong, Yunnan, Inner Mongolia, Shaanxi, and Qinghai caused by flash floods exceeded 30, and the total number of deaths in Sichuan, Liaoning, and Guangdong provinces reached 246 (43.9% of the total number of deaths). Sichuan Province was the area hit most severely by flash floods (23 incidents with 102 deaths) in 2013.

3.2.5 Foreigners were affected by flash floods; the aged and minors accounted for the largest proportion of total deaths

The nationalities of 477 people killed by flash floods were determined, which revealed that the casualties included 377 locals and 100 foreigners, 79 and 21% of the total number of deaths, respectively. Furthermore, 466 people were identified based on age, which revealed that the casualties included 88 minors (aged below 18), 230 adults (aged between 18 and 60), and 148 aged (older than 60), accounting for 18.9, 49.4, and 31.7% of the total number of deaths, respectively. The aged and minors accounted for just over one half (50.6%) of the total number of deaths.

3.3 Analysis

A tracking survey of large-scale flash flood disasters was performed with the help of local government to reveal the principal reasons for the occurrence of the incidents, under the guidance of the Office of State Flood Control and Drought Relief Headquarters. The principal reasons are presented in the following.

The annual rainfall was 1–2% more than normal in most parts of Northeast and North China, eastern and western parts of Northwest China, northeast parts of Southwest China, and most of South China. The annual rainfall of the Songhua River basin in Heilongjiang Province in the flood season was 30–40% more than average. Heavy rainfall in some areas caused flooding of small rivers and flash flood disasters. The rainfall associated with large-scale flash flood incidents exceeded the historical average precipitation, and in some cases even reached the 1000-year rainfall. Extreme rainfall resulted in serious flash flood incidents in Liaoning, Shaanxi, Qinghai, and other provinces with tremendous economic losses.

During the Qingyuan flash flood incident on August 16, four stations recorded in excess of the 1000-year rainfall and two stations recorded in excess of the 500-year rainfall. In addition, six further stations recorded rainfall of above 300 mm and 21 stations recorded rainfall of over 200 mm. Both the rainfall intensity and hourly rainfall amount attained historical extremes. At Dujiangyan on July 10, a large landslide incident occurred after the total amount of rainfall over a 5-day period reached 1129 mm, as recorded at Xingfu station, Dujiangyan, exceeding the average annual rainfall of 1121 mm.

Therefore, efforts should be strengthened in tracking serious flash flood incidents, especially those resulting in severe loss of life. The collection of rainfall and water data and a thorough investigation of the disaster should be performed as soon as serious incidents occur.

3.3.2 Migrants' poor awareness of flood prevention

The movement of people away from rural areas has become an increasingly serious problem following the rapid economic development in recent years. The pressure on local defense against disaster has increased because of the loss of the local labor force and in addition, the growth of tourism has increased the difficulty of defense (*He et al., 2013*).

On July 10, there was a large landslide at Dujiangyan (45 deaths; 116 missing) and on August 20, at Wulan, there was a flash flood incident (24 deaths). Most of the dead and missing were foreign tourists involved in farm tourism or construction workers. In Lingbao (Henan Province), a flash flood incident killed five foreign non-employees who were picking slag at the Nangou temple mine, who were washed away by floods after they witnessed the rainfall stop. All the deaths caused by flash floods in Inner Mongolia were as a result of people crossing the river on their own.

Migrants' poor awareness of flash flood prevention could be reflected by these incidents. Thus, there is an urgent need to strengthen public education, raise levels of self-help awareness, expand the dissemination of warning information, and send warning information to individuals in regions threatened by flash floods.

3.3.3 Failure of early warning information

Failure of early warning information was one of the most important reasons behind the deaths in 2013. In the August 16 Qingyuan flash flood incident, after warning information was generated by the county-level platform, flood prevention staff could make real-time observations using the county-level flash-flood-monitoring and warning system, and then release warning information via telephone or fax to all townships in accordance with the command of county leaders. However, the external alarm and warning message was not launched by the county-level system, national flash-flood monitoring and early warning information management systems failed to receive any early warning information. During the August 20 flash flood incident in Wulan, the flood occurred in the Siyuangou creek where floods had never occurred before and where there was no flash-flood-prevention warning system, and only a meteorological station in Chaka area. Therefore, efforts should be increased to operate and manage the flash-flood-monitoring and early warning information systems appropriately, such that migrant casualties could be effectively reduced.

3.4 Benefit analysis of non-engineering measures

County-level monitoring and early warning systems for flash flood prevention have been implemented since 2010, through which accurate hydrological information can be monitored and timely early warnings disseminated, thereby reducing casualties and loss of property. Remarkable benefits have been achieved through flash-flood-prevention work in China (*Huang et al., 2010*). According to statistics prepared by the National Flash Flood Prevention Project Group, there were more than 50,000 county-level early warnings issued by 1714 counties in 2013. Furthermore, 22,430,000 warning messages were sent to approximately 1.01 million people with responsibilities for flood prevention. Early warning broadcast stations were started 9 million times to spread warning messages, meaning that 366 million people threatened by flash floods were evacuated to areas of safety, effectively avoiding casualties. Compared with 2012, the number of counties that issued flood warnings, the number of warnings and short messages, and other indicators showed substantial growth in 2013, indicating that some benefits had been derived from the flash-flood-prevention projects in 2013, and that large-scale casualties had been avoided.

In addition, a coupling analysis was performed to reveal the relationship between warning times and deaths caused by flash floods. The results could be divided into four categories, as shown in Figure 6.

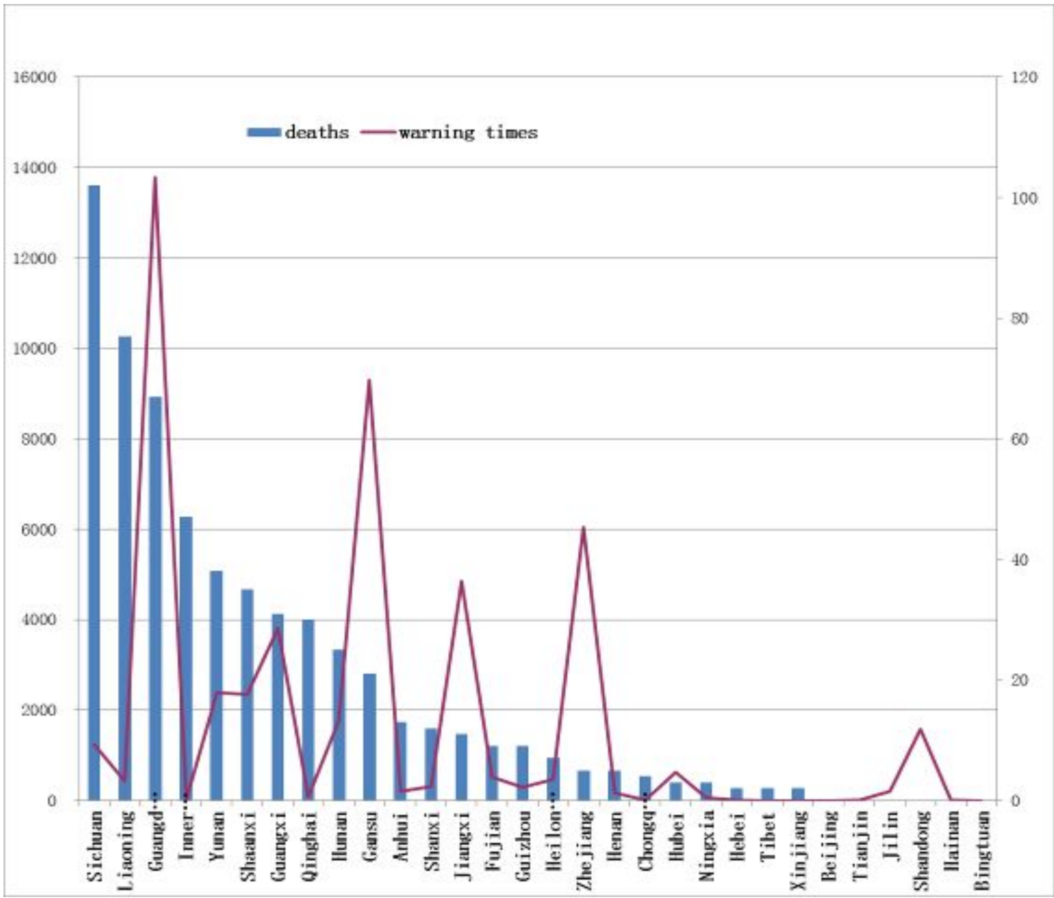

Figure 6. Relationship between warning times and deaths caused by flash floods

The areas with the most deaths, but fewest warnings are in Shanxi, Inner Mongolia, Liaoning, Sichuan, Qinghai, Anhui, Fujian, and Guizhou provinces (regions). The areas with most deaths, but more warnings are in Guangdong, Yunnan, Shaanxi, Guangxi, Hunan, and Heilongjiang provinces (regions). The areas with fewer deaths and more warnings are in Gansu, Jiangxi, Zhejiang, Shandong, and Jilin provinces (regions). The areas with fewer deaths, but also few warnings are in Hebei, Chongqing, Henan, Ningxia, Tibet, and Xinjiang provinces (regions).

The relationship between deaths and warnings is complicated, because some warnings were false and others ineffective at providing information for avoiding death. However, the relative relationship is clear that the non-engineering measures could be improved to enhance the effectiveness of the warning information.

The reason for the relationship of “more deaths but fewer warnings” indicates the problems of sharing and disseminating monitoring information, which must be improved in the monitoring and early warning system. With regard to the relationship of “more deaths and more warnings”, this reveals the great difficulty in examining the relationships, which should be analyzed for specific flash flood incidents. The reason for the relationship of “fewer deaths, but more warnings” was partially because of incorrect or missing warning information; therefore, the accuracy and effectiveness of the warning information should be checked and analyzed for specified flash flood incidents. The problem of untimely and missing warning information also existed for the situation of “fewer deaths and fewer warnings”; this was especially so when no warning information was issued, but deaths were caused. Therefore, the warning system should be checked to ensure the veracity of the warning information, especially when a disaster occurred.

4. CONCLUSIONS AND DISCUSSIONS

Because of the frequent extreme weather in 2013, the number of flash-flood-related deaths and incidents increased slightly compared with the previous 2 years. However, the deaths remained at a low level compared with the average since 2000. Large incidents caused greater casualties. Extremely heavy rainfall, migrants' poor awareness of flood prevention, and failure of early warning information were the principal reasons for the frequency of flood disasters and significant casualties. The monitoring and early warning systems implemented in case of emergencies provided some benefits in 2013 through the avoidance of deaths.The data and related statistical results have already been applied in disaster information management by the Office of Flood Control and Drought Relief Headquarters, which has received great attention by the provincial flood control agencies. However, a number of problems have been identified in this work, and great efforts should be made to overcome them.

First, all flash flood incidents, not just those that cause death, should be tracked with field investigations, such that the overall results could be more reliable. Furthermore, incidents in which non-engineering measures have an effect should be given greater attention to verify the efficacy of the warning system.

Second, monitoring and early warning systems should be enhanced and improved with regard to information sharing and dissemination, especially in those areas identified as having a relationship of "more deaths but fewer warnings" (Shanxi, Inner Mongolia, Liaoning, Sichuan, Qinghai, Anhui, Fujian, Guizhou province or region). In these areas, supervisory efforts should be strengthened to identify the reasons for failures, and to ensure sound and effective early warning information that can play an important role in flash flood prevention.

Third, the management of migrants (workers, farmers, and tourists) should be improved, and a system of responsibility for flash flood prevention should be implemented. Furthermore, for the migrants themselves, an awareness of flood prevention and techniques for self-help should be encouraged. In addition, warning information should be sent to individuals in areas threatened by flash floods as quickly as possible, by exploiting technology and thus, achieving a greater range of publicity.

Finally, more work should be performed on seeking proper indicators to evaluate the benefits of non-engineering measures, and a benefit-analysis-indicator system, evaluation methods, and reliable data resources should be exploited to accomplish this work.

5. ACKNOWLEDGMENTS

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