The impact of human activities on the occurrence of mountain flood hazards: lessons from the 17 August 2015 flash flood/debris flow event in Xuyong County, south-western China

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ABSTRACT

Mountain flood hazards are now among the most studied hazards, given that they cause loss of life and damage to property and infrastructure throughout the world. This paper takes the 2015 Xuyong flash flood/debris flow event as a case study to examine the impacts of human activities on the occurrence and amplification of mountain flood hazards. Field investigations, the interpretation of observational data and mechanistic analyses are carried out as part of a comprehensive analysis of the processes by which mountain flood hazards develop and become amplified, the contribution of excessive sediment supplies to mountain flood hazards and the effects of human activities on mountain flood hazards. Results of this comprehensive analysis indicate that some human activities contribute to the occurrence of the initiation of mountain flood hazards. These human activities fall into two main categories: (1) deforestation and improper construction damage the natural environment and may increase the occurrence of mountain flood hazards; (2) improper choices of residences, local congestion of engineering structures and some other factors may directly amplify the losses caused by mountain flood hazards. Finally, some hazard prevention and mitigation measures for mountain flood hazards are discussed.

1. Introduction

Since ancient times, the world’s population has maintained a sustained growth trend; in particular, during the Industrial Revolution, the population changed tremendously (Calianno et al. 2013; Borga et al. 2014; Goldberg et al. 2016). World population has grown by approximately 4.5 times; it was approximately 1.65 billion at the beginning of the twentieth century and is now over 7.5 billion, leading to larger amounts of
greenhouse gases such as CO₂, NO₂ and CH₄ (Searchinger et al. 2008; Meinshausen et al. 2009; Buchholz et al. 2017). This increase in greenhouse gases has led to an enhancement of the greenhouse effect, causing global warming, accelerating global water cycling and increasing global mean precipitation (Willmott et al. 1985; Ye and Mather 1997; Cox et al. 2000; Huntington 2006; Held and Soden 2010). Extreme weather events and the intensities of catastrophic weather have increased, resulting in a more uneven distribution of precipitation (Li et al. 2012; Marchi et al. 2015). For instance, water-induced hazards (e.g. flash flooding, river flooding and waterlogging) and some secondary hazards (debris flows, landslides and some other events) occur frequently (Iverson 2000; Borga et al. 2014). In addition, human beings become more accustomed to live together with the development of society, leading to regional population concentrations. Human beings living in extreme rainfall regions have been threatened by water-induced hazards many times in history (Miller et al. 2010; Morss et al. 2016). Water-induced hazards can cause loss of life and change into another type of hazard, mountain flood hazards, in the correct geographic environment.

The term ‘mountain flood hazards’ refers to floods, debris flows and landslides caused by rainfall, snowmelt and other factors in mountainous areas. They are considered to include torrents with rapid responses (Camarasa-Belmonte 2016). The natural process of geomorphic change occurs in response to heavy rainfall, the melting of snow and ice, glacier lake outbursts, the locations of mountainous areas and the secondary occurrence of landslides, collapses and debris flows (Joye and Paerl 1993). Mountainous areas account for approximately 20% of the total global land area, and they occupy approximately 67% of the land area of China. The proportions of mountainous areas provide major potential for mountain flood hazards, which cause considerable economic losses and large numbers of casualties. Mountain flood hazards, which integrate water-induced hazards, the geological and hydrological conditions, have become a global issue and have been focused on especially for the mountainous areas of south-western China.

According to the statistical data presented in Figure 1(a), at least 5675 people were killed or went missing due to water-induced hazards in China from 2010 to 2014, of which the percentage caused by mountain flood hazards was nearly 80%. The original data were collected from the bulletin of flood and drought disasters in China for the years of 2010–2014; these bulletins are released by the Ministry of Water Resources of the People’s Republic of China (http://www.mwr.gov.cn/). Of these five years, 2010 reflected the most serious hazards situation due to the abnormal climate events (Tang et al. 2011; Wang 2013). Besides, mountain flood hazards were mainly concentrated in south-western China during 2010–2014 (as shown in Figure 1(b)), and this region accounted for nearly 70% of persons killed and missing. This serious outcome represents a complex natural problem driven by earthquake-exacerbated fractured rock, severely weathered bedrocks and extreme weather events.

In addition, the impact of human activities is also a key factor. The increasing demand for wood leads to deforestation, destroying the automatic adjustment ability of natural world (Bawa and Dayanandan 1997; Lean and Warrilow 1989). Natural hazards, particularly mountain flood hazards, increase frequently due to lack of forest vegetation to anchor topsoil (Zhou et al. 2008). Some engineering measures range
from projects designed to control individual floods (i.e. through retaining or dredging), to complex engineering systems for preventing and controlling mountain flood hazards (Chen et al. 2014). Although ample time and money have been devoted to studies and construction projects, people still suffer considerable harm from mountain flood hazards. Given the number of people who die or go missing annually, how

**Figure 1.** Statistical results for casualties due to water-induced hazards and mountain flood hazards in China and their proportions: (a) deaths caused by water-induced hazards and mountain hazards, and the percentage of water-induced hazard deaths due to mountain flood hazards; and (b) deaths and missing persons caused by mountain flood hazard events and the percentage occurring in the western region.
to evaluate the engineering systems used to prevent and control mountain flood hazards has become a question that requires thoughtful consideration.

In this study, the flash flood/debris flow event that occurred in Xuyong County on 17 August 2015 is taken as a case study to examine the impacts of human activities on the occurrence of mountain flood hazards. The organization of this study is as follows. Section 2 presents the geological and hydrological conditions in Xuyong County that tend to cause mountain flood hazards. Section 3 describes the mechanism by which hazards develop and how human activities amplified flash flood/debris flow events in Gaofeng Village and the village downstream of the Jintou Gully. Section 4 describes the formation of mountain flood hazards and the mechanisms underlying their dynamic evolution. Section 5 details the new pattern of mountain flood hazards, the negative effects of human activities, and mitigation measures and warning systems. Section 6 consists of a summary and conclusion.

2. About Xuyong County

Xuyong County is located in a low mountainous area between the Sichuan Basin and the transitional margin of the Yunnan–Guizhou Plateau (as shown in Figure 2(a)). It is bounded by the east longitudes of 105°03’ and 105°40’ and the north latitudes of 27°42’ and 28°31’. The total area of Xuyong County is 2977 km², and the total population was 731,000 in 2013.

Figure 2. The geological and geomorphic conditions of Xuyong County: (a) the location of Xuyong County; (b) the geological conditions in Xuyong County; (c) the three-dimensional terrain of the study area (Bailamiao Township); and (d) the geographic position of the Paotong Gully and the Jintou Gully.
2.1. Geological and geomorphic conditions

Several high mountains and deep gullies are located in Xuyong County, leading to complex geographic and geomorphic conditions. As shown in Figure 2(b), the main stratum exposed in the Xuyong County is dominated by continental sediments, and the strata exposed their range from Cambrian (500 million years ago) to Quaternary (1 million years ago) in age. In addition, Xuyong County is a mountainous region at the margin of the Sichuan basin, and the elevations there gradually increase from north to south.

There is a township named Bailamiaozu Township in the southern part of Xuyong County (the study area, as shown in Figure 2(b)), and Figure 2(c) illustrates its three-dimensional terrain. This township is 33 km from the seat of government of Xuyong County, and a village access road enables the villagers to reach the county seat more easily. There are many gullies in this township, and in this paper, the Paotong Gully (which has a length of approximately 5000 m and an elevation difference of approximately 800 m) and the Jintou Gully are the main objects of study. Figure 2(d) shows the locations of these two gullies. The Jintou Gully is located approximately 1.5 km from the Paotong Gully, and there is an adjacent gully that is very close to the Jintou Gully. Moreover, at the mouth of the Paotong Gully, there is Gaofeng Village, which has a population of approximately 3600. Similarly, there is a village at the mouth of the Jintou Gully (the downstream village). On the edge of these two villages, there is the Qingshui River, which meets the needs of the people for water.

2.2. Hydrological and climate conditions

The Yangtze River Basin, which is the third largest river basin in the world, flows through and across the three major economic zones of central and western China. Thirty-three rivers are located within this basin, such as the Yongning River and the Chishui River. The Qingshui River is a tributary of the Yongning River, which flows through Xuyong County. In addition, Xuyong County has a subtropical humid monsoon climate, which is controlled by tropical marine air masses and polar continental air masses. The annual average temperature is 17.9°C, and the annual sunshine is as high as 1170.3 hours. In addition, the total amount of rainfall is large, and the rainfall distribution is uneven from month to month. As shown in Figure 3(a), the total rainfall displays a slightly increasing trend from 2012 to 2015 (2012: 1138.8 mm; 2013: 1134.6 mm; 2014: 1328.4 mm; 2015: 1432.4 mm). Moreover, the monthly precipitation is concentrated from May to August. In particular, in August 2015, the monthly total rainfall increased steeply to 329 mm, and mountain flood hazards occurred.

3. The 2015 flash flood/debris flow event

Mountain flood hazards threatened Gaofeng Village and the village downstream of the Jintou Gully from the night of 16 August to the morning of 17 August. The hazard process can be separated into two parts: the development of the hazards and the amplification of the hazards.
3.1. The development of the hazards

Figure 3(b) illustrates the detailed rainfall history through August 2015. The monthly total rainfall in August was 329 mm. Of this amount, the antecedent rainfall occurred primarily on 4 August, 7 August and 8 August (27 mm on 4 August; 32 mm on 7 August and 41 mm on 8 August). The rainfall reached the rainstorm level (81.9 mm) on 17 August. Under such heavy rainfall conditions, a series of subsequent reactions
occurred, and mountain flood hazards were eventually triggered. At 2:00 am on 17 August, the maximum rainfall reached 146.4 mm in Bailamiaozu Township. The soil soon became saturated, and the rainfall then rapidly produced run-off because of the presence of steep slopes. Finally, the run-off converged at the intersection of every pair of tributaries, turning into a mountain flood. The rapid flow eroded the loose sediments found in the gullies and flushed away parts of the toes of slopes. After the toes of the slopes were washed away, the stability of the banks on both sides was drastically reduced, resulting in partial collapse of the bank slopes. Finally, an abundance of loose material entered the gullies, resulting in an excessive sediment supply. The mountain flood that carried these abundant sediments poured out from the mouths of these two gullies and formed the mountain flood hazards.

3.2. The amplification of hazards and losses

Human activities have an impact on the two parts of mountain flood hazards, initiation and amplification (Chen et al. 2015). The mountain flood would normally have poured directly into the Qingshui River. However, human activities prevented this process in various ways. For example, Gaofeng Village is located at the mouth of the Paotong Gully, and it blocked the path of the mountain flood and the debris flow. As a result, Gaofeng Village was largely destroyed. Figures 4(a) and 5(a) show post-hazards aerial maps of the Gaofeng Village. The sediments carried by the Paotong Gully vary in size (Figure 4(b)). Furthermore, more than 10 houses and vehicles (buses and cars) were partially buried (Figure 4(c,d)). Moreover, four houses were completely buried after the mountain flood, as shown in Figure 4(a). Meanwhile, due to flood erosion of the right bank of the Qingshui River, the foundations of the houses near the riverbank were damaged, resulting in the collapse of several houses (Figure 5(b)). The village access road was badly damaged by caving (Figure 5(c)), and the junction of the road and the bridge was damaged (Figure 5(d)), resulting in the delay of rescue vehicles and medical personnel. The Qingshui River was originally only 20 m wide; however, after passage of the mountain flood, it reached more than 50 m in width (Figure 5(a)).

Several engineering projects have negative effects on mountain flood hazards. In Bailamiaozu Township, a village access road was built for the convenience of the villagers (Figure 2(d)). To reduce the hazards associated with mountain floods, a culvert was constructed under the road to enable the passage of run-off and small amounts of sediment. However, such a hazard mitigation measure cannot completely control all kinds of flood hazards. On the night of 17 August, a huge rock mass separated from its parent mass and fell due to the flood, blocking the culvert. A natural dam was thus produced, and increasing amounts of solid matter was deposited on the upper side of the culvert. Finally, the huge mountain flood, mixed with abundant sediment, flooded the village access road and destroyed the downstream village. As shown in Figure 6(a), a house located at the mouth of the Jintou Gully became buried by up to 5 m of material. In addition, another house was almost buried. Furthermore, the parent rocks became exposed after the scouring of mountain flood. Moreover, soil erosion and the destruction of vegetation also occurred (Figure 6(b)).
Figure 4. Typical traces left behind by the mountain flood hazard in Gaofeng Village: (a) aerial panoramic disaster map; (b) various grain sizes seen in the debris flow deposits; (c) buried houses; and (d) a buried vehicle.
Due to the occurrence of the mountain flood and the excessive supply of sediment, considerable amounts of sediment were discharged into the Qingshui River, which became wider (Figure 6(c)).

4. Mechanisms of formation and dynamic evolution

In general, three main factors (steep terrain, abundant solid matter and short-term heavy rainfall) drive the formation of mountain flood hazards. However, these three factors alone cannot cause serious loss of human life and property. In recent years, the impacts of human activities on mountain flood hazards have received increasing amounts of attention.

4.1. Run-off amplification

Special geographic and hydrological conditions are key factors that affect the initiation of mountain flood hazards (Johnson and Sitar 1990; Chirico et al. 1999; Napolitano et al. 2016). When rainfall reaches the ground, some of the rainwater penetrates the pores of the soil surface, and the remainder moves gradually along the surface from high points to low points. At first, rainfall accumulates in depressions on slopes, and the rainwater then overflows the depressions. The rainwater then rapidly converges and is converted to run-off (Procter et al. 2011; Penna and Borga 2013).

The process of the evolution of rainfall to run-off is mainly divided into rainfall, plant interception, the filling of depressions and infiltration. Furthermore, due to the unique climatic conditions in mountainous areas, the annual rainfall is relatively concentrated and occurs mainly from May to September. The soil is more likely to be in a critically saturated state because of the high frequency of rainfall. Thus, run-off occurs much more easily after heavy rainfall.

When run-off forms, it flows from regions of high topography to low-lying places, due to gravity. Furthermore, the presences of steep slopes reduce the time required for run-off to flow from upland areas to stream outlets. Therefore, short-term heavy
Figure 5. Typical traces left behind by the mountain flood hazard beside the Qingshui River: (a) aerial panoramic disaster map; (b) damaged houses on the riverbank; (c) damage to the village access road due to caving; and (d) a destroyed bridge pier.
rainfall events cause the outlet flow to increase sharply, subsequently causing a series of problems. Human beings cannot take measures in time to protect themselves, given the rapid response of run-off. As a result, lives may be lost and property can be seriously damaged.

4.2. Excessive sediment supply to gullies

Excessive sediment supply occurs under heavy rainfall conditions, and it is also a crucial factor in the initiation of mountain flood hazards (Imaizumi et al. 2006; McGuire et al. 2017). For example, as shown in Figure 2(d), an adjacent gully lies close to the Jintou Gully (approximately 200 m away from the Jintou Gully). These two gullies have similar slopes and geological and topographic conditions and experienced heavy rainfall at the same time. However, the village downstream of the adjacent gully was not damaged, despite the heavy rainfall; instead, the flow simply increased. Although these two gullies have the same geographic and hydrological conditions, the hazard models that threat to downstream villages are different. One reason is that, during the heavy rainfall event, the Jintou Gully was filled by the excess sediment supply (more soil failures occurred in this gully, such as shallow landslides on the slopes and collapses near the gully bottom), whereas the adjacent gully was not.

Soil erosion and sediment recharge occur naturally (Stancanelli et al. 2017), especially under heavy rainfall conditions. As shown in Figure 7(a), side A is the original surface of the gully before a mountain flood produces rills and loose sediment. When a short-term heavy rainfall occurs, rain falls on the slopes, partly seeping into the soil and partly turning into run-off. As a result, the water depth in the gully rises. Furthermore, sediments located upstream are transported downwards, forming a flow with a high sediment concentration (Figure 7(b)). Subsequently, given the aggregation of run-off in different branches, the speed of run-off increases continuously. The soils between side A and side B are rapidly eroded to lower areas, due to the action of the rapid run-off (Figure 7(b)). As the original deposits and soils erode away, the slope angles on both sides increase and collapse more easily, as shown in Figure 7(c)
Figure 6. Typical traces left behind by the mountain flood hazard in the Jintou Gully: (a) buried houses and exposed parent rock; (b) soil erosion and uprooted vegetation; and (c) discharged sediment and the widening of the Qingshui River.
Moreover, run-off both passes through the gully and constantly erodes the toes of the slopes. Finally, when the stability of the slopes reaches the critical stability value, both sides collapse into the gully (Figure 7(d)). The soils on both sides collapse into the gully, resulting in an excessive sediment supply (Figure 7(e)). Given the effects of rapid run-off and gravity, the excess sediments migrate quickly to lower places and eventually trigger debris flows. Debris flows represent one of the mountain flood hazards that threaten lives and property.

4.3. Effects of human activities

Human activities have a certain impact on mountain flood hazards. For example, human activities have magnified the hazards in the villages downstream of both the Jintou Gully and the Paotong Gully. In Gaofeng Village, as shown in Figure 8, the short-term heavy rainfall changed to large-scale run-off because of the rapid response in this mountainous area (Figure 8(a)). The run-off subsequently passed through and out of the gully, coupled with an excessive sediment supply (Figure 8(b)). Originally, a portion of the sediment was deposited on flat surfaces, and the remainder was

Figure 7. The mechanism leading to excess sediment supply to gullies during heavy rainfall events: (a) the state before heavy rainfall; (b) a flow with a high concentration of sediment develops; (c) the original surface is partly eroded, forming a steep slope; (d) the slide masses reach a critical stability state; and (e) sliding occurs on the slopes on both sides, triggering an excessive sediment supply.
Figure 8. The hazard-producing mechanism in the Paotong Gully: (a) heavy rainfall transforms to run-off; (b) run-off causes soil erosion, resulting in excessive sediment supply; (c) Gaofeng Village blocks the flow path of the mountain flood; and (d) the mountain flood pours into the village, eventually causing a disaster.
transported into the Qingshui River with the run-off water. However, the Gaofeng Village blocks the path of the mountain floods (Figure 8(c)). Thus, the mountain flood rushed from the mouth and directly into Gaofeng Village, damaging houses, roads and vehicles. Finally, it destroyed several houses and killed dozens of people (Figure 8(d)).

The impact of human activities on mountain flood hazards occurs through the construction of both human dwellings and engineering works. In the Jintou Gully, the process by which mountain floods form closely resembles that of the Paotong Gully (the rapid transition from heavy rainfall to run-off is shown in Figure 9(a) and the development of an excessive sediment supply is shown in Figure 9(b)). However, the mountain flood hazards in the Jintou Gully were mainly caused by engineering projects. As mentioned above, a village access road extends through Bailamiaozu Township, and the road intersects the Jintou Gully at right angles (Figure 2(d)). Engineers constructed a culvert under the village access road to pass run-off and to reduce the probability of mountain flood hazards. There is no doubt that it is useful to build culverts. However, these manmade constructions cannot bear all kinds of hazards, and this particular structure finally became a hazard-producing construction. On the night of 16 August, run-off carrying large amounts of sediment flowed down from regions of high topography. A mixture of water and solid matter was deposited on the platform, which lay several meters above the culvert (Figure 9(b)). A boulder with a diameter larger than that of the culvert blocked the culvert and the path of the mountain flood (Figure 9(c)). A natural dam subsequently formed, and increasing amounts of the sediment–water mixture were deposited behind the natural dam. The amount of mountain flood material behind the dam increased rapidly. After a few minutes, the slope between the platform and the culvert was partly buried. The mixture, which was deposited on the platform and behind the natural dam, poured down. The fence along the village access road was washed away. Ultimately, the mixture flowed over the road and destroyed the village downstream (Figure 9(d)).
Figure 9. The hazard-producing mechanism in the Jintou Gully: (a) heavy rainfall transforms to run-off; (b) run-off causes soil erosion, resulting in excessive sediment supply; (c) a boulder blocks the culvert; and (d) the mountain flood pours over the village access road, eventually causing a disaster.
5. Discussion

5.1. Evolution of the pattern of hazards

The pattern of the development of mountain floods changes when human activities play an important role in forming such hazards. Figure 10(a) illustrates the complex relationships between human activities, natural conditions and mountain flood hazards. There are interactions between each pair of these factors. The extreme weather events and the intensities of catastrophic weather have increased, resulting in a more uneven distribution of precipitation (Jiang et al. 2008; Mistro et al. 2017). Furthermore, many engineering projects are constructed, and some of them have an adverse effect on natural conditions. For instance, water supplies, shipping and other functions often determine the locations of cities. In addition, the combination of human activities and natural conditions trigger mountain flood hazards (Sala 2003). Mountain flood hazards also affect human activities and natural conditions. For example, mountain flood hazards cause soil erosion in the Jintou Gully and the Paotong Gully, eventually changing the soil slope. They also cause heavy damage and human casualties (Silvestro et al. 2016). Thus, measures are taken to minimize damage, such as relocating the local people to other places or building hazard-preventing structures. A new set of interactions between human activities, natural conditions and mountain flood hazards subsequently develops.

5.2. The impacts of human activities on hazards

The impact of human activities on mountain flood hazards includes two main aspects: indirect effects and direct effects (Figure 10(b)). The indirect effects are mainly reflected by the damages to natural environmental conditions. The natural environment has been damaged by hydrological and geological processes, causing mountain flood hazards to increase in frequency. First, due to the population
explosion, greenhouse gases have increased and the greenhouse effect is becoming more severe, resulting in a warmer global climate. As a result, the global atmospheric water cycle intensifies, leading to increases in extreme weather and severe extreme weather events. Thus, uneven distributions of precipitation develop, leading to hydrological damage. Second, as population increases, the daily demands of human beings for convenience increase. Thus, humans take actions to address this problem. For instance, people cut down trees to get wood and construct engineering projects (e.g., roads and railways) for increased convenience. In mountainous areas, deforestation and engineering construction projects lead to reductions in vegetation. Thus, the slopes are less protected by vegetation, and weathering causes the soil on the slopes to become loose gradually. As a result, the stability of slopes sharply decreases. Landslides and collapses occur frequently when earthquakes occur. Abundant sediment is subsequently deposited in the gullies, resulting in geological damage. The

Figure 10. Human activities impact mountain flood hazards in terms of (a) new patterns of mountain flood hazards and (b) the direct and indirect effects of human activities on mountain flood hazards.
combined effects of hydrological damage and geological damage lead to frequent mountain flood hazards.

The direct effect is mainly manifested in the amplifying effect of human activities on mountain flood hazards. For self-protection, human beings take many measures to mitigate mountain flood hazards. Forest planting is one of the most effective methods, given that it directly restores environmental conditions. In addition, engineering mitigation measures are also useful, especially in rapid hazard management. However, not every engineering project can prevent all kinds of mountain flood hazards. Some of them can amplify the hazards, such as the culvert at Jintou Gully. The impact of human activities on mountain flood hazards is also manifested in many aspects and worth considering.

5.3. Mitigation measures and warning systems

Mountain flood hazards have received an increasing amount of attention because they cause substantial loss of life and property (Mazzorana et al. 2012). How to mitigate mountain flood hazards has been considered by scholars from all over the world. As shown in Figure 11(a), collective relocation is the best means of ensuring the safety of residents living in particular areas (such as Gaofeng Village). However, collective relocation is very hard to achieve, due to many factors. For instance, the costs of relocation are enormous, and local people are reluctant to move to unknown places. In addition to collective relocation, a series of hazard mitigation measures should be adopted in areas prone to mountain floods. The example of the Jintou Gully indicates that local congestion should be avoided (Figure 12(a)). For example, a bridge can be built instead of a culvert, as shown in Figure 12(b). The bridge can pass greater amounts of water–solid mixtures (approximately 10–20 times as much as a culvert), reducing the possibility of mountain flood hazards. Figure 13 illustrates that building a small dam could prevent the local people from being hurt in Gaofeng Village. Such a dam could increase the evacuation time for the local people, thereby reducing the threat posed by mountain flood hazards (Catane et al. 2012).

In addition to some governance measures, the establishment of rainfall observations and forecast-based warnings is also very important (Morss et al. 2016). In the study of rainfall conditions, rainfall threshold values have been investigated by many scholars in China and in other countries, and intensity–duration–frequency (IDF) relationships have been identified (Iadanza et al. 2016; Miao et al. 2016). However, the relationship exhibits high variability within each catchment (Bezak et al. 2016). Thus, intensity–duration–frequency relationships receive additional attention. In addition, in situ monitoring is another effective method; it can directly reflect the degree of occurrence of the hazards (Feng et al. 2014). As shown in Figure 11(b), monitoring is divided into landslide monitoring, rainfall monitoring and soil saturation monitoring. This information can be transferred to an information processing platform before being transferred to a hazard release platform to determine what actions to take. At the same time, messages can be sent, phone calls can be made, and broadcasting can be carried out to warn people to take protective action in advance (Calianno et al. 2013). Moreover, site-specific information can be sent to local people in real time to
enable them to make their own judgments. It is also necessary to establish an official warning institution, and a global exchange of information regarding mountain flood hazards should be established to create a better early-warning model. The information from individual sites and the rainfall thresholds that induce mountain flood hazards should be placed on the cloud.
Figure 12. The influence of culvert construction and bridge construction on discharge: (a) the maximum flow area of the culvert; and (b) the maximum flow area of a bridge.
6. Conclusions

In this paper, the 2015 Xuyong flash flood/debris flow is taken as a case study and used to study the impacts of human activities on the occurrence of mountain flood hazards. The impacts of human activities, the mechanisms by which mountain flood hazards form and dynamically evolve, and the corresponding hazard mitigation measures and forecasting systems for mountain flood hazards are analyzed. The following useful conclusions can be derived:

a. In addition to the impacts of steep terrain, short-term heavy rainfall and excessive sediment supply, human activities also have a significant impact on mountain flood hazards.

b. Human activities indirectly affect the occurrence of mountain flood hazards by causing damage to natural conditions. In addition, the direct impact of human activities is manifested as its amplifying effect on mountain flood hazards.

c. Humans sometimes build engineering projects to mitigate hazards; however, these mitigation measures sometimes lead to additional hazards.

d. Collective relocation represents the best means of mitigating these hazards. However, its costs are unacceptably high. In addition, hazards investigations (which suggest that local congestion must be avoided) and mountain flood warning systems can also reduce loss of life and property.

Figure 13. Disaster prevention and control measures: the construction of small dams.
e. The establishment of mountain flood hazard forecasting systems requires the monitoring of all relevant aspects, including rainfall monitoring, landslide monitoring and soil saturation monitoring. Moreover, global information exchange is also particularly important.

Mountain flood hazards have attracted more and more attention, and people have implemented many hazard reduction projects. However, do such human activities eventually become one of the factors that produce hazards? This question still deserves further investigation.

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