Early Warning of Long Channel and Post-controlled Debris-Flow Gully in Southwest China

Jian Huang

Abstract

Closely induced by earthquake, debris flow frequently occurred and had some distinctive features, e.g. long channel and check dams controlled. In mountainous regions of Southwest China, many catastrophic events have already affect local people and became one of the main threats to lives and properties. This paper, presents an early warning method combining rain gauge, ultrasonic sensor and video recording fully adapted to debris flow gullies. A three-level early warning criteria (null, attention, and warning) has is proposed and defined in this paper. Niujuangou gully was selected as a case study to validate the approach, and to demonstrate it's helpful to debris flow occurrences prediction.

Keywords

Post-controlled debris flow • Early warning • Ultrasonic sensor

Introduction

Generally, debris flows occur after a heavy rainfall, and produce rapid mass movements with huge devastating power. They consist in granular solids, water and air (Jan et al. 2002). While debris flow happen, it must cause a great loss including economic and people's lives. Particularly in Southwest China, accelerated economic development and population increase have already increased the risks from debris flows and other kinds of geo-hazards (Huang et al. 2015). However, during recent years several concentrated catastrophic earthquakes occurred in the region, e.g. Wenchuan earthquake on 2008. Earthquakes not only triggered abundant co-seismic avalanches and landslides, but also cracked mountains with large amounts of loose solid materials. All these deposits located in gullies easily developed into debris flows during rainstorms (Shieh et al. 2009). On August 13, 2010, a heavy rainstorm come to the hardest-hit areas including Yingxiu, Longchi, and Qingping town, which caused plenty of unbelievable huge debris flows than before (Xu 2010). For example, the Wenjiagou debris flow in Qingping, Mianzhu, had a total volume of 3.1×10^6 m^3 with a peak discharge of 1530 m^3/s, which caused a great casualties and buried 479 new reconstructed houses, as well as the most of check dams along the catchment (Yu et al. 2013). Another giant debris flow from Sanyanyu gully and Luojiayu gully, happened at Zhouqu, in Gansu Province, Northwest China, on August 7, 2010, which caused 1765 person deaths on the densely urbanized fan (Tang et al. 2011). In the mountainous regions of Southwest China, there are many debris flow like those ones, and the long distance of channel has a tremendously devastating power and causes plenty of property losses. Therefore, great threat and catastrophic debris flow events make the human clearly understand its vulnerability to natural hazards. Effective method and equipment had become an emergent requirement to reduce the hazard and risk. Many researchers have already been working on the forecasting debris flow occurrences and setting up early warning systems. At the beginning, several relations between rainfall and debris flow initiation have been provided from historical, worldwide and regional data (Aleotti 2004; Chien-Yuan et al. 2005; Glade et al. 2000; Guo et al. 2013; Keefer et al.

J. Huang (✉)
State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, 610059, Sichuan, China
e-mail: huangjian2013@cdut.cn

M. Mikoš et al. (eds.), *Advancing Culture of Living with Landslides*,
DOI 10.1007/978-3-319-53487-9_17

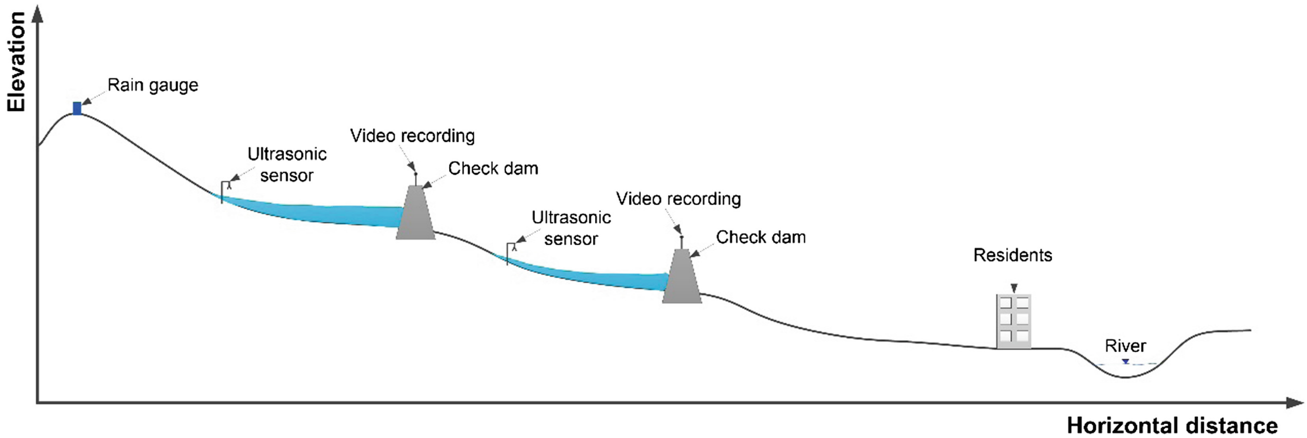

Fig. 1 Schematic diagram of warning method for long channel and post-controlled debris-flow gully

1987; Melillo et al. 2015; Zhou and Tang 2013). Among all rainfall thresholds approaches, the one using intensity–duration threshold (Guzzetti et al. 2007) was perhaps the most popular, which has been proved particularly valid for shallow landslides, and it has also been successfully applied to landslides in general. Baum and Godt (2009) presented a combined threshold including cumulative precipitation, rainfall intensity and antecedent water index or soil wetness for the shallow landslide forecasting. Although widely used in mountainous regions, these methods are still affected by some drawbacks, especially debris flow occurred in gullies with a long channel and check dams already built in.

Consequently, this paper presents a new idea for debris flow forecasting, particularly for which has already been controlled by check dams and has a long channel. The purposes of this paper are to present a simple approach for debris flow initiation prediction and real-time mass movement monitoring.

Methodology

According to the literatures on forecasting debris flow occurrences, rainfall seems to be one of the most important triggering factors. Most of them are concentrated in the relation analysis between rainfall and possibility of debris flow occurrence, e.g. rainfall intensity and duration, antecedent rainfall and so on. So the drawback comes that debris flow early warning is not an imminent hazard but is just regarded as a potential danger, which causes such a complicated problem that the final determination whether to alert local population, and compulsory actions need to be done at once, or a period of time later. Therefore, more devices need to be equipped along the gully to ensure once again, whether debris flow initiation occurrence or not. For example, ultrasonic sensor can monitor the depth of debris flow or flood, and video can see them directly. Then, a collaborative monitoring system and determination process are presented in the following sections, as shown in Fig. 1 and the architecture of data flow in the system shown in Fig. 2.

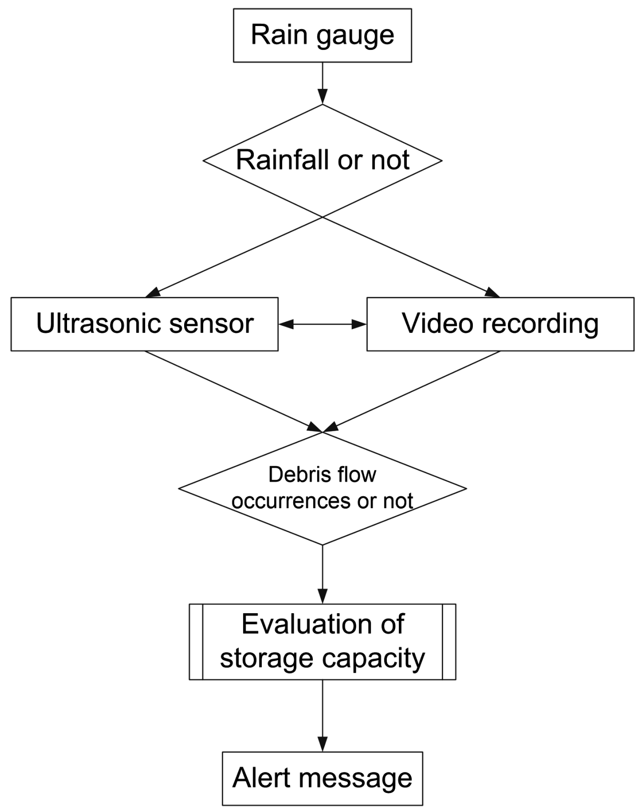

Fig. 2 Data flow of the early warning method

It can be seen in Figs. 1 and 2, the beginning of a rainfall event is the starting of the whole early warning system. That's mean while the rainfall shows begin, ultrasonic sensor and video recording then start to work. Details of each step and method are given as follows.

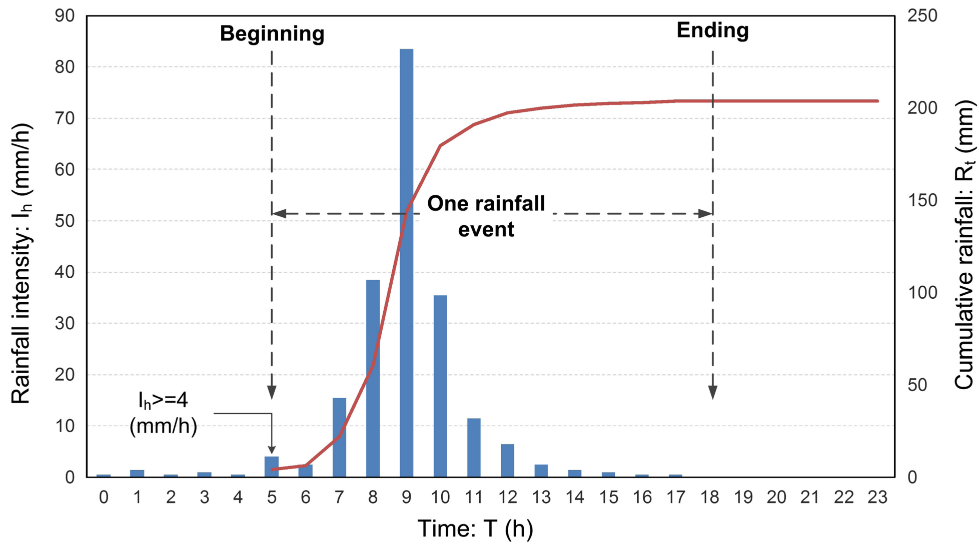

Fig. 3 The definition of a single rainfall event

Definition of a Rainfall Event

Based on the analysis above-mentioned, the start of a rainfall event is very important in the forecasting debris flow initiation occurrences. Based on the research results presented by Jan et al. (2002) and Huang et al. (2015). The beginning of each rainfall event can been defined that is the moment that the hourly rainfall amount is more than 4 mm/h, and the end is when the hourly rainfall amount is less than 4 mm/h, and this should last for at least 6 h, as shown in Fig. 3.

Evaluation of the Storage Capacity

After a rainstorm, whether debris flow occurred or not, there must been having stage changes from the flow along the catchment. So, in order to obtain the continuous monitoring of debris flow or water level, ultrasonic gauges are commonly used devices. Except for recording the stage hydrographs, the ultrasonic sensors provide a way to measure channel erosion or aggradation at the site where they are installed, as shown in Fig. 4.

It can be seen in Fig. 4, ultrasonic sensor hung over the channel measures the distance between the flow surface and the sensor itself, making it possible to record the debris flow hydrographs ($H_t = h_0 - h_t$), average velocity of flow (V) which is a function related to H_t, and even the total volume of single debris flow (Q) which is a function related to V, detail information can be seen from the mitigation standard of debris flow (DZ/T0220-2006). Before the rainstorm, the initial storage capacity (Q_0) of the check dam can be calculated by the topography and height of check dam. The evaluation index of storage capacity, therefore, can be defined by Eq. 1.

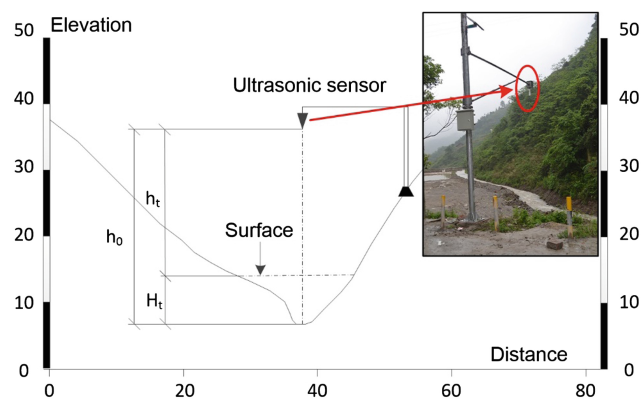

Fig. 4 Schematic diagram of an ultrasonic sensor installed to monitor debris flows

$$ISC = \left(1 - k \times \frac{Q}{Q_0}\right) \times 100\% \quad (1)$$

where ISC is the evaluation index of storage capacity of the debris flow gully, k is the coefficient of deposition by a single debris flow gully, which can be obtained by field investigations and indoor experiments, and others parameters are similar to those mentioned above. Therefore, according to the evaluation index of storage capacity, a three-level early warning system can be proposed for such debris flow gullies with long-distance and post-controlled characteristics in Southwest China, as shown in Table 1.

Case Study

Niujuangou gully located at the south of Yingxiu town, Wenchuan County, Sichuan Province, nearly 0.5 km, right bank of Minjiang River. This gully has a catchment area of

Table 1 Recommended warning levels and activates

Warning level	Judgement (ISC)	Response
Blue (null)	70–100%	Real-time monitoring data are checked per hour during the rainfall event
Yellow (attention)	30–70%	Real-time monitoring data are checked per half-hour during the rainfall event. Authority and expert are alerted. Preparing for alarm
Red (warning)	<30%	Real-time monitoring data are checked all the time during the rainfall event. Local people are alerted

10.7 km^2 and a 3.9 km long mainstream, as shown in Fig. 5. The elevation of this case study region ranges from 850 to 1780 m above sea level, and the valley has a deep slope (35°–45°) at the upstream. The average yearly temperature of about 15 °C, and the climate is mild semi-tropical and moist with abundant rainfall, almost of which is concentrated in three months from July to September, causing lots of flood before in this areas. The epicenter of Wenchuan earthquake was near the outlet of the gully, which triggered so many co-seismic rock fall material and finer landslide deposits along this gully that are easily transformed into debris flows during rainstorm. On August 13, 2010, a huge debris flow trigged by a heavy rainfall in this gully. Fortunately, no people has been hurt because the reconstruction

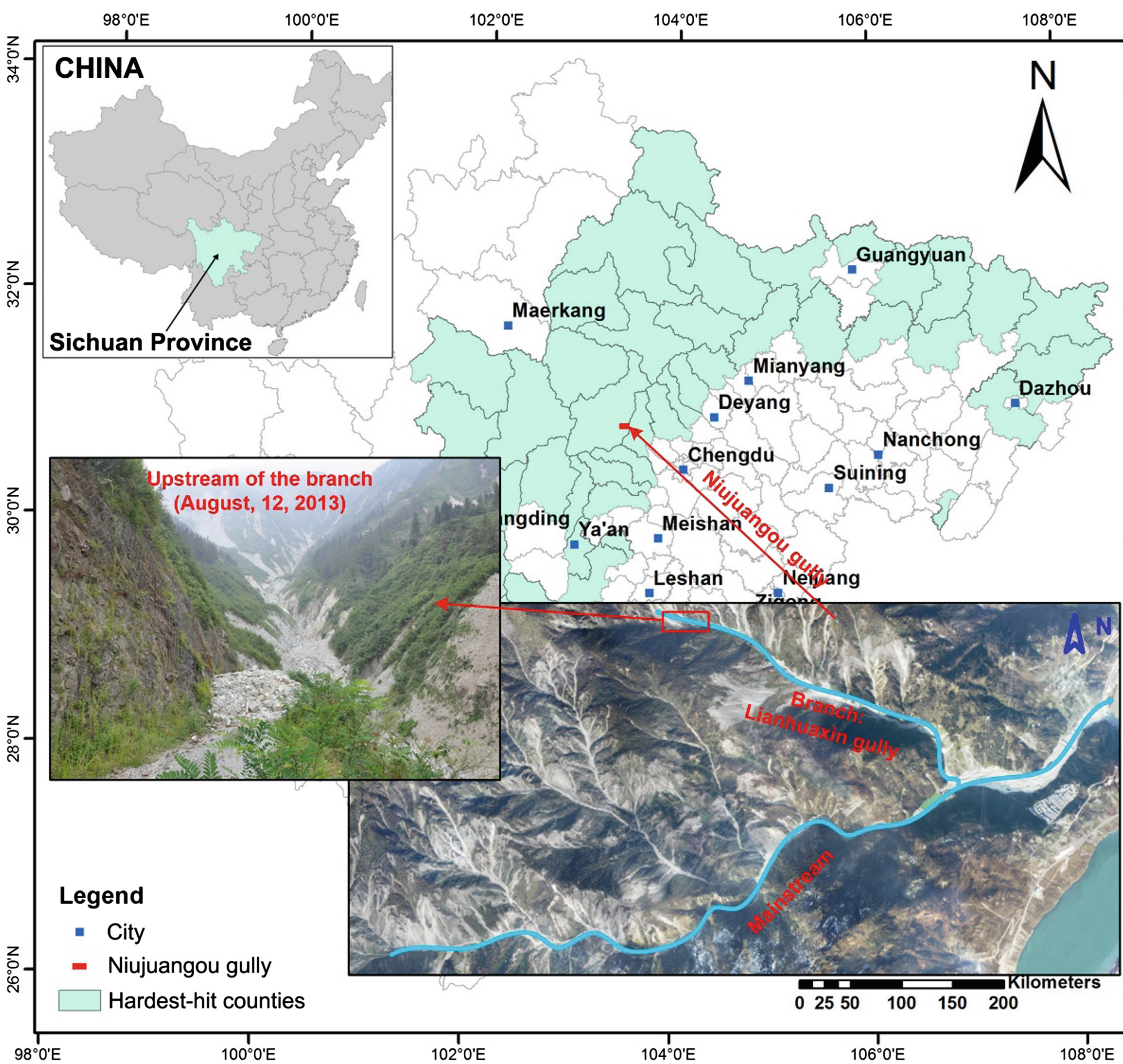

Fig. 5 Location of Niumiangou gully. The *inset image* at the *right bottom* was taken by unmanned aerial vehicle on 7 March, 2011

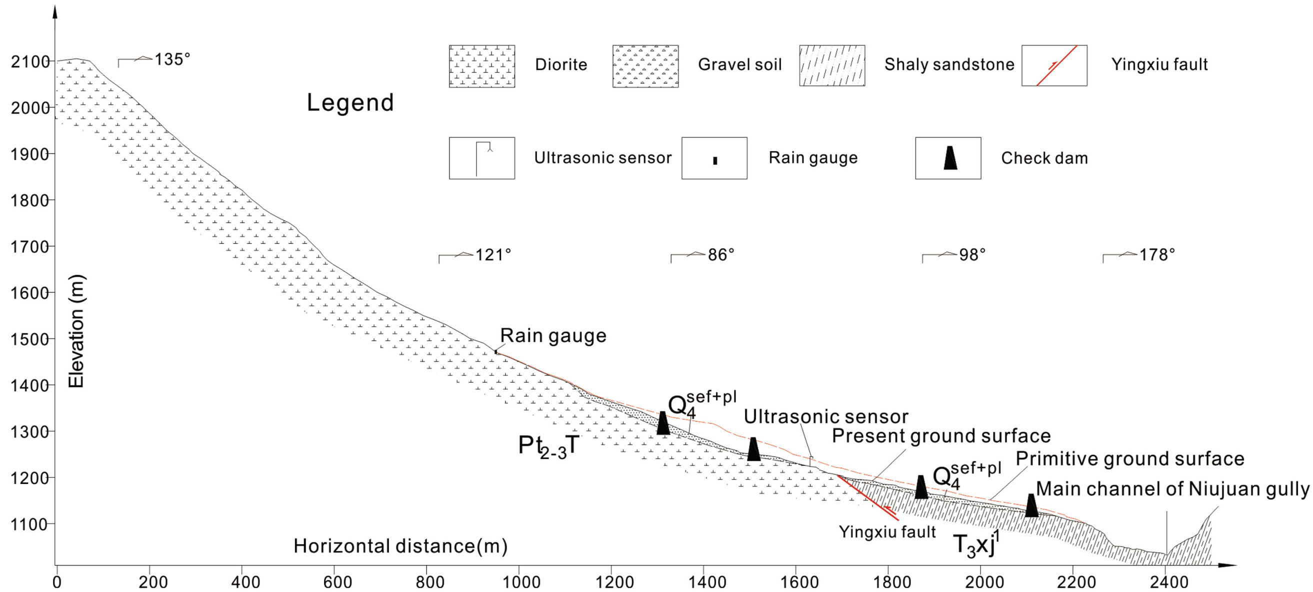

Fig. 6 Check dams and monitoring sensors installed along the Lianhuaxin branch gully

area is far from the risk region after the earthquake, but the bed of Minjiang River has been uplifted and caused a great threat to the upstream of Yingxiu town.

According to field investigation, there are still left a lot of loose material in the gully, especially in the branch Lianhuaxin gully, as shown in Fig. 5. So, controlled measures and monitoring sensors have been carried out in Niujuangou gully for the prevention and mitigation geohazards in the near future (Fig. 6). Four check dams have been built along the Lianhuaxin gully, and one rainfall gauge was installed at the upstream and one ultrasonic sensor was installed in the middle of the check dams, as shown in Fig. 6.

On 9 July, 2013, there was a heavy rainfall in this area, and the ultrasonic sensor has recorded the depth of flow information. After the rainfall, field survey also made sure that debris flow had occurred during the rainfall, as shown in Fig. 7. Based on the single rainfall event definition above-mentioned, this rainfall event started at 4:00 a.m. 9 July, 2013, lasting for 48 h to end at 4:00 a.m. 11 July, 2013. The maximum hourly rainfall was 74.5 mm, and the cumulative rainfall was amount to 450 mm. Accompanied with the rainfall, the stage of the flow (Graph in the middle of Fig. 7.) shown that the channel erosion and aggradation happened at the same time. But the maximum of erosion depth was 0.5 m, and the maximum of aggradation was 2.1 m appeared just three hours later after the maximum hourly rainfall intensity. Unfortunately, the ultrasonic sensor didn't record any data after the 9:00 a.m. 10 July, 2013. Therefore, there were not enough information to see the whole progress of debris flow mass movement in a real-time way. However, the video recording can show that directly.

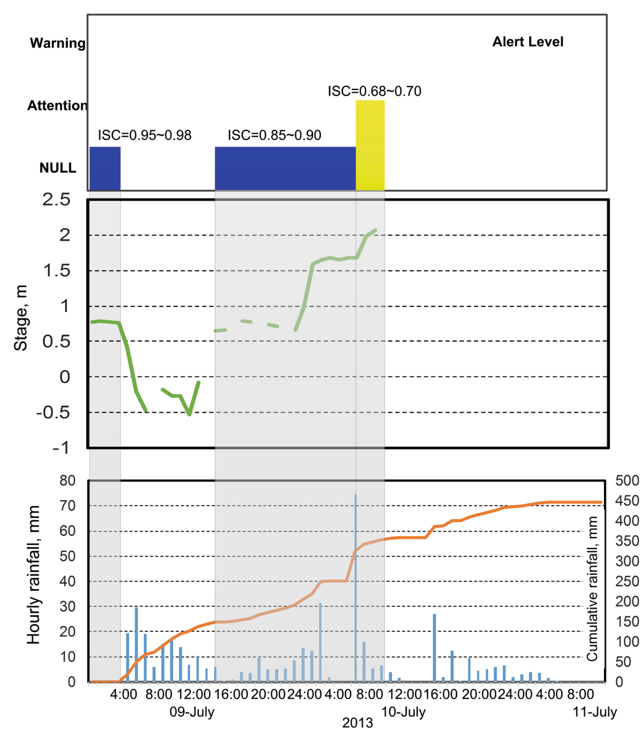

Fig. 7 Real-time early warning for the branch Lianhuaxin gully (from 9 July, 2013 to 11 July, 2013)

Based on the real-time monitoring data, the correspondingly calculated ISC value was very high, as shown in Fig. 7 the first column graph. So, the warning level was only up to the Yellow one (attention), and the total volume of this debris flow was up to 2.96×10^5 m^3, according to the field measurement and topography calculation after the rainfall event.

The case study has shown that the early warning method plays a great function in forecasting debris flow, more accurate and reliable particularly for long channel and post-controlled debris flow gully. However, it's not enough to prove that the method are effective presently because of lack of more successful examples. So, when more information is collected in the future, the presented debris-flow early warning method can be improved to validate the process, then ultimately reducing the losses of lives by this type of geohazrd.

Conclusion

Debris flows cause catastrophic harm both in human and property losses, triggered by heavy rainfall every year in the mountainous regions in Southwest China. These debris flows always have a long channel, even though check dams built along the gully may stop the material deposits, some of them still can go through to the downstream and cause a great threat to the local people living in the downstream areas. Therefore, an urgent requirement for effective methods is needed immediately. In order to present a new early warning method on debris flow risk forecasting, the rain gauge, ultrasonic sensor and video recording sensor have been discussed and used to work together in this paper.

The provided process: rainfall is the only starting factor, after that the ultrasonic sensor and video recording begin to work together. Meanwhile, expert judgements are still needed in the final determination. The Niujuangou gully was selected as a case study for a detailed explanation of the presented method, and the results show that it is worth the effort to research continually in the future.

Acknowledgements This study was financially supported by the Fund for International Cooperation (NSFC-RCUK_NERC), Resilience to Earthquake-induced landslide risk in China (Grant No. 41661134010), and National Natural Science Foundation of China (Grant Nos. 41521002 and 41302242), Specialized Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20135122130002), and State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection (Chengdu University of Technology) (Grant No. SKLGP2013Z007).

References

Aleotti P (2004) A warning system for rainfall-induced shallow failures. Eng Geol 73:247–265. doi:10.1016/j.enggeo.2004.01.007

Baum RL, Godt JW (2009) Early warning of rainfall-induced shallow landslides and debris flows in the USA. Landslides 7:259–272. doi:10.1007/s10346-009-0177-0

Chien-Yuan C, Tien-Chien C, Fan-Chieh Y, Wen-Hui Y, Chun-Chieh T (2005) Rainfall duration and debris-flow initiated studies for real-time monitoring. Environ Geol 47:715–724. doi:10.1007/s00254-004-1203-0

Glade T, Crozier M, Smith P (2000) Applying probability determination to refine landslide-triggering rainfall thresholds using an empirical "Antecedent Daily Rainfall Model". Pure Appl Geophys 157:1059–1079

Guo X-j, Cui P, Li Y (2013) Debris flow warning threshold based on antecedent rainfall: a case study in Jiangjia Ravine, Yunnan, China. J Mt Sci 10:305–314. doi:10.1007/s11629-013-2521-z

Guzzetti F, Peruccacci S, Rossi M, Stark CP (2007) Rainfall thresholds for the initiation of landslides in central and southern Europe. Meteorol Atmos Phys 98:239–267. doi:10.1007/s00703-007-0262-7

Huang J, Huang R, Ju N, Xu Q, He C (2015) 3D WebGIS-based platform for debris flow early warning: a case study. Eng Geol 197:57–66. doi:10.1016/j.enggeo.2015.08.013

Jan CD, Lee MH, Huang TH (2002) Rainfall threshold criterion for debris-flow initiation. National Cheng Kung University, Tainan, pp 9104–9112

Keefer DK, Wilson RC, Mark RK, Brabb EE, Brown WM, Ellen SD, Harp EL, Wieczorek GF, Alger CS, Zatkin RS (1987) Real-time landslide warning during heavy rainfall. Science 238:921–925

Melillo M, Brunetti MT, Peruccacci S, Gariano SL, Guzzetti F (2015) Rainfall thresholds for the possible landslide occurrence in Sicily (Southern Italy) based on the automatic reconstruction of rainfall events. Landslides. doi:10.1007/s10346-015-0630-1

Shieh C-L, Chen Y, Tsai Y, Wu J (2009) Variability in rainfall threshold for debris flow after the Chi-Chi earthquake in central Taiwan, China. Int J Sedim Res 24:177–188

Tang C, Rengers N, van Asch TWJ, Yang YH, Wang GF (2011) Triggering conditions and depositional characteristics of a disastrous debris flow event in Zhouqu city, Gansu Province, northwestern China. Nat Hazards Earth Syst Sci 11:2903–2912. doi:10.5194/nhess-11-2903-2011

Xu Q (2010) The 13 August 2010 catastrophic debris flows in Sichuan Province: characteristics, genetic mechanism and suggestions. J Eng Geol 18:596–608

Yu B, Ma Y, Wu Y (2013) Case study of a giant debris flow in the Wenjia Gully, Sichuan Province, China. Nat Hazards 65:835–849. doi:10.1007/s11069-012-0395-y

Zhou W, Tang C (2013) Rainfall thresholds for debris flow initiation in the Wenchuan earthquake-stricken area, southwestern China. Landslides 11:877–887. doi:10.1007/s10346-013-0421-5