Outlining a stepwise, multi-parameter debris flow monitoring and warning system: an example of application in Aizi Valley, China

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Abstract: In recent years, the increasing frequency of debris flow demands enhanced effectiveness and efficiency of warning systems. Effective warning systems are essential not only from an economic point of view but are also considered as a frontline approach to alleviate hazards. Currently, the key issues are the imbalance between the limited lifespan of equipment, the relatively long period between the recurrences of such hazards, and the wide range of critical rainfall that trigger these disasters. This paper attempts to provide a stepwise multi-parameter debris flow warning system after taking into account the shortcomings observed in other warning systems. The whole system is divided into five stages. Different warning levels can be issued based on the critical rainfall thresholds. Monitoring starts when early warning is issued and it continues with debris flow near warning, triggering warning, movement warning and hazard warning stages. For early warning, historical archives of earthquake and drought are used to choose a debris flow-susceptible site for further monitoring. Secondly, weather forecasts provide an alert of possible near warning. Hazardous precipitation, model calculation and debris flow initiation tests, pore pressure sensors and water content sensors are combined to check the critical rainfall and to publically announce a triggering warning. In the final two stages, equipment such as rainfall gauges, flow stage sensors, vibration sensors, low sound sensors and infrasound meters are used to assess movement processes and issue hazard

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warings. In addition to these warnings, community-based knowledge and information is also obtained and discussed in detail. The proposed stepwise, multi-parameter debris flow monitoring and warning system has been applied in Aizi valley China which continuously monitors the debris flow activities.

**Keywords:** Debris Flow; Monitoring system; Warning system; Aizi Valley; Rainfall threshold

**Introduction**

Debris flow is a geological disaster which has been extensively and frequently triggered over a broad area. In 2010, large numbers of debris flow disasters have occurred in China resulting in 2900 people either dead or missing, including those in the Sanyanyu gully of Zhouqu and the Wenjia gully in Qingping (Cui et al. 2013; Tang et al. 2012). Similarly in Washington a landslide-induced debris flow caused 45 people dead or missing in 2014 (Iverson et al. 2015). The triggering of extra-large size debris flows indicates that disaster alleviation is still a difficult task. Structural disaster prevention measures, which require huge investments and long timeframes, can help to prevent and alleviate parts of these disasters. However, warning systems, which have a lower cost and shorter construction period, can be more effective and economical compared with conventional structural measures for the disaster reduction (Arattano and Marchi 2008; Papa et al. 2013; Koschuch et al. 2015). Most importantly, warning systems can avoid the large numbers of causalities and permits the timely evacuation of the community.

The success rate of the current debris flow monitoring and warning system still needs to be raised after decades of efforts. For example, the error rate reached 72% in debris flow warning for burned areas in southern California, USA (Restrepo et al. 2008). Because of the limited successful rate of warning systems, the Chinese government had to pay restitution to the residents for prevention and escape in Wenchuan earthquake-induced debris flow sites. China has endured many disastrous debris flows such as that in Zhouqu where 1765 people died or were missing (Cui et al. 2011). Although the monitoring and warning systems are based on the rainfall, new monitoring technology of debris flow based on the acoustic emission and ground vibration detectors are also widely used around the world. In Taiwan, although the warning system issued the alert for typhoon but later intense rainfall recorded at most of the districts in south Taiwan buried the Xiaolin village on August 14, 2009, which caused the loss of 462 people (Wu et al. 2011; Lin et al. 2011).

In Indonesia, a hazardous debris flow event happened on January 4, 2006, which resulted in 210 people dead or missing (Wardhono et al. 2010). All of these cases indicate that it is essential to improve the hazard prediction system with emphasis on monitoring and warning technology to alleviate the hazards. The monitoring and warning of debris flows have been classified into two main types i.e. early warning or prediction based on the triggering factors of the debris flow (Chen et al. 2014; Arattano and Marchi 2008; Stähl et al. 2015) particularly rainfall (Aleotti 2004; Chien et al. 2005; Saito et al. 2010). The real time warning includes the vibration processes (Arattano and Marchi 2008; Abancó et al. 2014), the acoustic emissions (Chou et al. 2007; Schimmel and Hubl 2014; Schimmel and Hübl 2015a; Schimmel and Hübl 2015b) and runoff data (Berti and Simon 2005). It can be seen that early warnings are mainly based on earthquakes, droughts, forest fire and rainfall which may affect the triggering of debris flows (Chen et al. 2014). In order to alleviate debris flow hazards, a more comprehensive and complete approach for monitoring and warning is needed.

Keeping in view the existing problems of debris flow monitoring and warning systems, we developed a stepwise, multi-parameter warning system based on the formation mechanisms and integration of different stages such as early warnings, process warnings. This system addresses parameters including precipitation, mud-line depth, pore pressure, and water content. We chose the Aizi valley, a branch of Jinshajiang River, as a case study for the application of this system (Figure 1).

1 **Key Defects of Debris Flow Warning Systems**

The main defects of current debris flow monitoring and warning systems include the mismatch between the “short lifespan” of monitoring