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Post-earthquake landsliding and long-term impacts in the Wenchuan earthquake area, China

Runqiu Huang, Weile Li *

State key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu 610059, China

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ABSTRACT

The Ms 8.0 Wenchuan earthquake on May 12, 2008 triggered tens of thousands of landslides and produced large amounts of loose material. The loose material accumulated in gullies or on slopes provides abundant sources for the consequent debris flows, which will endanger resettled residents and destroy urban reconstruction. During the 5 years following the Wenchuan earthquake event, heavy rainfalls have already induced a great number of debris flows in the earthquake-damaged area, resulting in serious casualties and property losses. The co-seismic landslides and the debris flows induced by rainfalls in the Mianyuan River basin are analyzed using multi-temporal remote sensing images. More than 2000 landslides were triggered and about 4.0×10^8 m^3 of loose material was generated in the Mianyuan River basin, and the volume of erodible material is 6.0×10^7–1.6×10^8 m^3. There were 1.27×10^7 m^3 of bed load sediments and 6.3×10^5 m^3 suspended load sediments transported into the river system in the past 5 years. The active mass movements will last for a long period in the Mianyuan River basin.

1. Introduction

Landslides play an important role in the natural landscape system in dynamic mountain environments which experience constant uplift, though most landslides require a triggering event to initiate (Lin et al., 2006). Large seismic events and high intensity and/or long duration rainfall are main triggers for landsliding. The shaking associated with great earthquakes may trigger extensive landslides and rock falls, even at a distance of more than 100 km from the epicenter (Keefer, 1984). Such co-seismic landslides produce massive amounts of loose material, accumulating in gullies, providing source material for the occurrence of subsequent debris flows induced by rainfalls. In addition, the strong shaking may loosen and shatter the bedrock, facilitating subsequent sliding. This is the reason why the frequency and scale of debris flows triggered by rainfall usually increase markedly after a strong earthquake (Tang, 2010). Thanks to the new developments in investigation techniques, modeling, and data analyses, much progress has been made in understanding of co-seismic hazards, but new lessons are still being learned from historic and recent earthquakes (Wasowski et al., 2011).

In contrast to relatively extensive documentation of co-seismic landslides, little is currently known about the long-term post-seismic landslide hazards or their importance in slope erosion (Keefer, 1994). Keefer (1994) described a quantitative method for determining the amount of earthquake-induced landsliding and used this method to analyze the erosion rates in 12 seismically active regions. Comparisons with other slope processes indicate that earthquake-induced landslides are the predominant agents of slope erosion on the island of Hawaii, in the San Francisco Bay region, and in western New Guinea (Keefer, 1994). Nakamura et al. (2000) studied the landsliding activity for the periods before and after the 1923 M7.9 Kanto Earthquake in Japan, and categorized the development of post-earthquake landslide activity into four stages, i.e., generation, instability, recovery and stability. In particular, the first 15 years immediately after the earthquake are considered as the stage of highest activity. Significantly, the 1999 Mw 7.6 Chi-Chi Earthquake in Taiwan resulted in the world's most extensively studied dataset on co-seismic and post-seismic landslides (Wasowski et al., 2011). Dadson et al.(2004) quantify the geomorphic impact of the Chi-Chi Earthquake. They found that co-seismic weakening of substrate material caused increased landsliding during subsequent typhoons and increased the magnitude and frequency of hyperpycnal sediment delivery to the ocean. Lin et al. (2008) studied the post-seismic landsliding in the Chenyoulan River catchment of central Taiwan hit by the 1999 Chi-Chi Earthquake during 1996 to 2004. They concluded that the amount of sediment discharge at normal flow discharge is affected by supplied sediment volume, which tends to increase with seismic activity. Using a time series of landslide maps and suspended sediment transport data, Hovius et al. (2011) found that the Chi-Chi earthquake was followed by a period of enhanced mass wasting and fluvial sediment evacuation, peaking at more than five times the background rate and returning progressively to pre-earthquake levels in about six years.

The Wenchuan Earthquake triggered more than 50 000 landslides with a total volume of 5–15 billion m^3 (Huang and Li, 2009a, b;

* Corresponding author.
E-mail address: whylwl01@163.com (W. Li).

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Huang, 2011; Parker et al., 2011; Zhang et al., 2011), which introduced a large amount of loose material onto hilly terrains and created numerous quasi-stable cracked slopes. Such materials can become sources of subsequent debris flows. According to the statistics provided by the Department of Land & Resources of Sichuan Province, the earthquake affected areas have been hit by 2447 debris flows and landslides of different scales since the earthquake event (Figure 1 and Table 1). The heavy rainfall on September 24, 2008 triggered 72 debris flows in Beichuan County (Tang et al., 2011a). The old county town of Beichuan was completely buried by 6 to 10 m thick debris (Figure 2). Another rainfall on August 13 to 14, 2010 caused 80 debris flows in Qingping, Yingxiu and Longchi, which were reconstructed after the Wenchuan earthquake and were partially or totally destroyed by the debris flows. The Wenjia gully debris flow in Qingping with the volume of 4.5×10^6 m^3 buried most part of Qingping town (Xu, 2010; Tang et al., 2011b; Xu et al., 2012) (Figure 3).

The above-mentioned facts suggest that the landsliding activity and its impacts on the earthquake-affected areas have increased significantly compared to the pre-earthquake period. The Mianyuan River basin is one of the worst-hit areas during the Wenchuan earthquake. Its area is about 0.4% of the whole Wenchuan earthquake area, but the number and area of co-seismic landslides took up 4% and 6.8%, respectively of the whole Wenchuan earthquake area (Li et al., 2010). The second largest landslide, Wenjia gully landslide, was located in the basin. The largest Daguangbao landslide was also located close to the basin. The post-earthquake landsliding is very active in the Mianyuan River basin and is taken as a case study to investigate the mechanisms and impacts of post-earthquake landslides.

2. General characteristics of post-earthquake landslides

2.1. Remarkable increase in the frequency of landslides occurrence

Fig. 4 shows the number of catastrophic landslides induced by rainfall in 39 severely affected counties in Sichuan province during the eight years just before the earthquake and five years immediately after the earthquake. It can be observed that the number of landslides has risen rapidly for 4 consecutive years after the earthquake, going from 114 in 2008 up to 823 in 2011 followed by a drop to 747 in 2012.

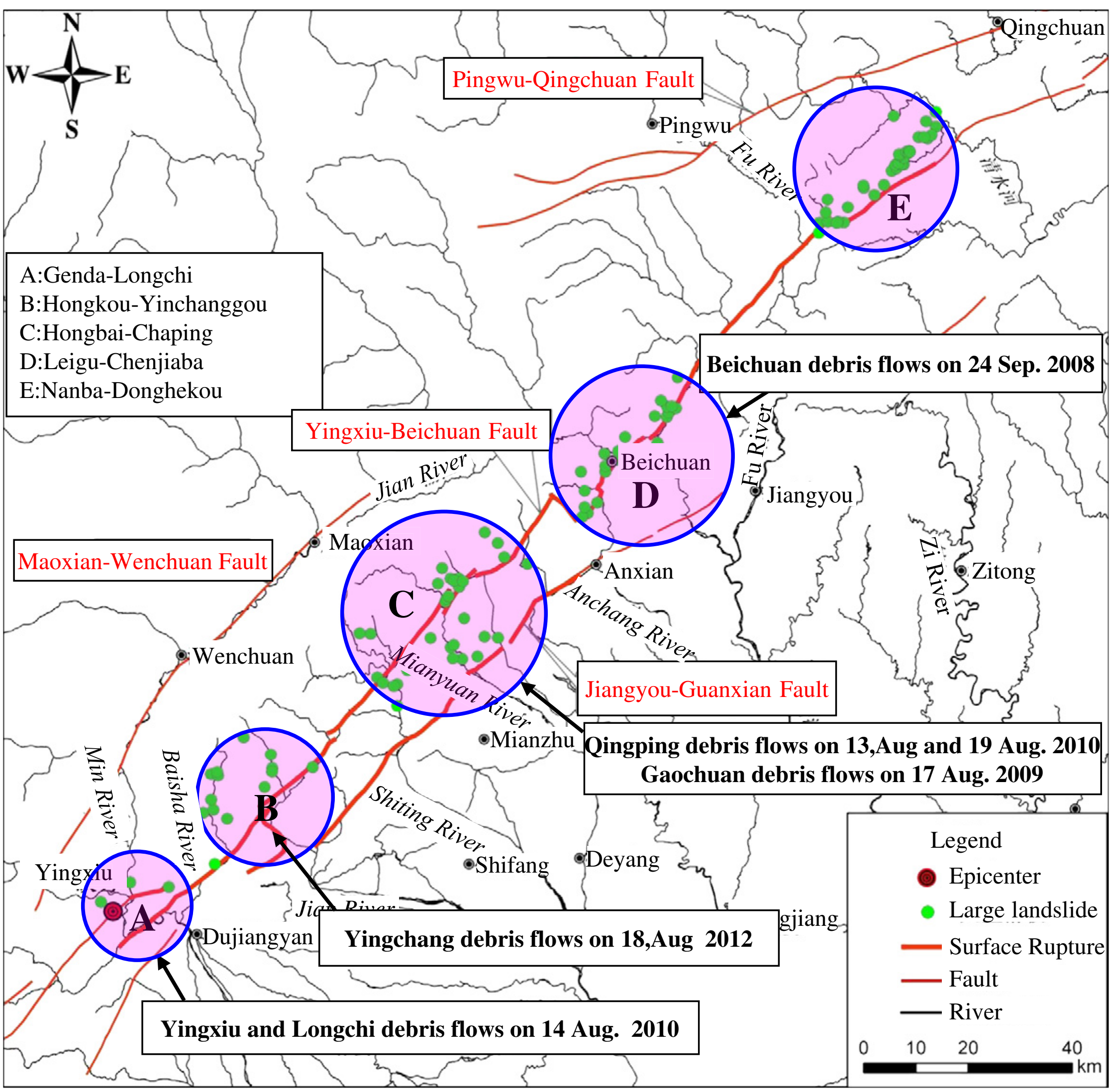

Fig. 1. Distribution of large-scale landslides (surface area > 50000 m^2) triggered by the 2008 Wenchuan earthquake and debris flows induced by post-earthquake rainfalls. A–E are five fault segments: A = the Genda (Wenchuan County)–Longchi (Dujiangyan County) segment, B = Hongkou (Dujiangyan County)–Yinchanggou (Pengzhou County) segment, C = Hongbai (Shifang County)–Chaping (Anxian County) segment, D = Leigu (Beichuan County)–Chenjiaba (Beichuan County) segment and E = Nanba (Pingwu County)–Donghekou (Qingchuan County) segment.