Geomorphology 276 (2017) 8–15

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Spatial and temporal analyses of post-seismic landslide changes near the epicentre of the Wenchuan earthquake

Wentao Yang [a,*], Wenwen Qi [b], Ming Wang [c,d], Jianjun Zhang [a], Yan Zhang [a]

[a] School of Soil and Water Conservation, Beijing Forestry University, Beijing, China
[b] Beijing Twenty-first Century Science and Technology Development Co., Ltd., Beijing, China
[c] State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing, China
[d] Academy of Disaster Reduction and Emergency Management, Beijing Normal University, Beijing, China

ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form 3 October 2016
Accepted 7 October 2016
Available online 8 October 2016

Keywords:
Post-seismic landslides
Spatial and temporal changes
Remote sensing
Debris flow

ABSTRACT

Major earthquakes in mountain regions have persistent and significant influences on post-seismic landslides but their details have not been well understood. This work uses multi-year high-resolution satellite images and terrain parameters, such as elevation, slope, and aspect, to examine the topographic changes of post-seismic landslides. Despite disturbances during rainy months, landslide areas decreased significantly from 2008 to 2013 in all terrain parameters, indicating that landslide activity near the epicentre has been recovering to the pre-seismic level. The emergence of an increasingly active landslide type shows that landslide debris has been moving from hillslopes to valleys, which could impact post-seismic debris flows. The findings of this work provide important information for post-seismic infrastructure re-construction and disaster prevention in future mountain earthquake events.

1. Introduction

The 2008 Wenchuan earthquake in China triggered thousands of co-seismic landslides over a vast region (Xu et al., 2014). In some areas, co-seismic landslides altered local landscapes by removing vegetation and other land cover types (Cui et al., 2012). It is believed that unstable strata disturbed by earthquakes in mountainous regions can persist for a long time and cause further problems in following years (Huang and Fan, 2013).

Although improved understanding on the mechanisms and distribution of co-seismic landslides and related problems can help us improve preparedness before major earthquakes (Jibson et al., 2000; Wasowski et al., 2011; Chen et al., 2012), the study of post-earthquake landslide evolution is very important for post-seismic disaster reduction. Previous research has shown that mountainous earthquakes have a long-term effect on landslides (Cui et al., 2011). Owing to widespread landslide debris, rainfall-thresholds for initiating debris flows decreased dramatically in the Wenchuan area (Zhou and Tang, 2014). By comparing landslides in 2010 and 2008, Zhang et al. (2014) found some spatial differences between the location of co-seismic landslides and post-seismic rainfall-induced landslides. Yang et al. (2015a) found that landslides that occurred after the Wenchuan earthquake have been evolving into flow-like morphologies and causing significant amounts of damage in areas rebuilt after the Wenchuan earthquake.

Despite the importance of post-seismic landslide changes, some discrepancies exist among studies (Khattak et al., 2010; Saba et al., 2010). By comparing typhoon triggered landslides before and after the Chi-Chi earthquake, Taiwan, Lin et al. (2006) found that the earthquake had a large effect on post-seismic typhoon induced landslides. Saba et al. (2010) found that post-seismic landslide activity after the 2005 Kashmir earthquake was very high for a period of two years and stabilized afterwards. However, Khattak et al. (2010) found that most post-seismic landslides after the Kashmir earthquake had little to no changes within two years. Khan et al. (2013) found that, five years after the Kashmir earthquake, monsoon rainfall did not cause as many landslides as previously expected and vegetation recovered significantly after landslides. After the Wenchuan earthquake, few studies were conducted to study the landslide changes over time (Li et al., 2015). Of these limited studies on this region, Li et al. (2015) found that the occurrence of post-seismic landslides has been decreasing steadily.

Until recently, limited knowledge has been gained regarding spatial changes of landslide distributions after the Wenchuan earthquake. The objectives of this paper are to study the spatial and temporal changes of landslides near the epicentre of the Wenchuan earthquake and to determine the locations where landslides persist. In this work, we use landslides mapped from multi-year high-resolution images to study the spatial and temporal changes of post-seismic landslides.

* Corresponding author.
E-mail address: yang_wentao@bjfu.edu.cn (W. Yang).

http://dx.doi.org/10.1016/j.geomorph.2016.10.010

2. Materials and methods

2.1. Study area

The M_S 8.0 Wenchuan earthquake generated a surface rupture over 200 km long (Xu et al., 2009). Xu et al. (2014) demonstrated that within an area of approximately 110,000 km^2 in the east Tibetan Plateau, the earthquake triggered thousands of landslides, representing a total surface area of approximately 1160 km^2. These co-seismic landslides formed a dense zone in proximity to the surface rupture. The width of this heavy landslide zone differs from south to north: the southwestern section of this zone is wide, ranging from ~25 to 30 km, whereas the northeastern section is narrow, ranging from ~3 to 5 km (Ouimet, 2010).

Yingxiu was selected as the study area (Fig. 1) for two reasons: 1) it was near the epicentre of the 2008 Wenchuan earthquake and therefore experienced the most intense shaking during the earthquake; 2) Yingxiu is located in the southern part of the co-seismic landslides zone, which has the highest density of co-seismic landslides. The study area covers an area of 66 km^2 and has a Modified Mercalli Intensity (MMI) of XI. The study of landslide changes in Yingxiu could have important implications for our understanding of landslide evolution in the Wenchuan earthquake affected area.

2.2. Data

Two types of data are used in this work: a digital elevation model (DEM) and five remote sensing images. The DEM is derived from a 1:50,000 scale topographic map and has a spatial resolution of 25 m (Gorum et al., 2011). Five satellite images from different sources are used to map landslides before and after the Wenchuan earthquake in Yingxiu (Table 1). These images are multi-spectral and have similar spatial resolutions of approximately 2 m. Taken on June 26th, 2005, the QuickBird image is the only pre-seismic image. An aerial photo taken in June 2008, immediately after the Wenchuan earthquake, is used to map co-seismic landslides in this work. Post-seismic images in 2009, 2011 and 2013 are taken from April to May. Assisted by DEM data, these four post-seismic images are used to map landslides in corresponding years. All of the images have good resolutions and no cloud cover, except the aerial photo in 2008, approximately 10% of which is covered by clouds. To map co-seismic landslides in 2008, we use landslide inventories manually interpreted by Xu et al. (2014).

2.3. Method

Manually interpreting regional landslide distributions is an intensive and time-consuming task. Landslides in 2005, 2008, 2009, 2011 and 2013 for the Yingxiu area were mapped using semi-automatic methods based on Object-Oriented Image Analysis (OOIA). OOIA is an image processing technique that mimics human perception of the world by considering objects rather than individual pixels and uses object attributes for analysis (Martha et al., 2012). An image object is a spatially continuous group of pixels that share similar spectral and textural characteristics. In addition to traditional pixel attributes, the object has spectral statistics and shape, geometry, texture and context attributes. To map landslides, multi-threshold segmentation was applied to produce image objects (Fig. 2).

Image pre-processing procedures are carried out to correct image deformation and mismatching (Mondini et al., 2011). To correct for the effects of terrain during image acquisition, the image is

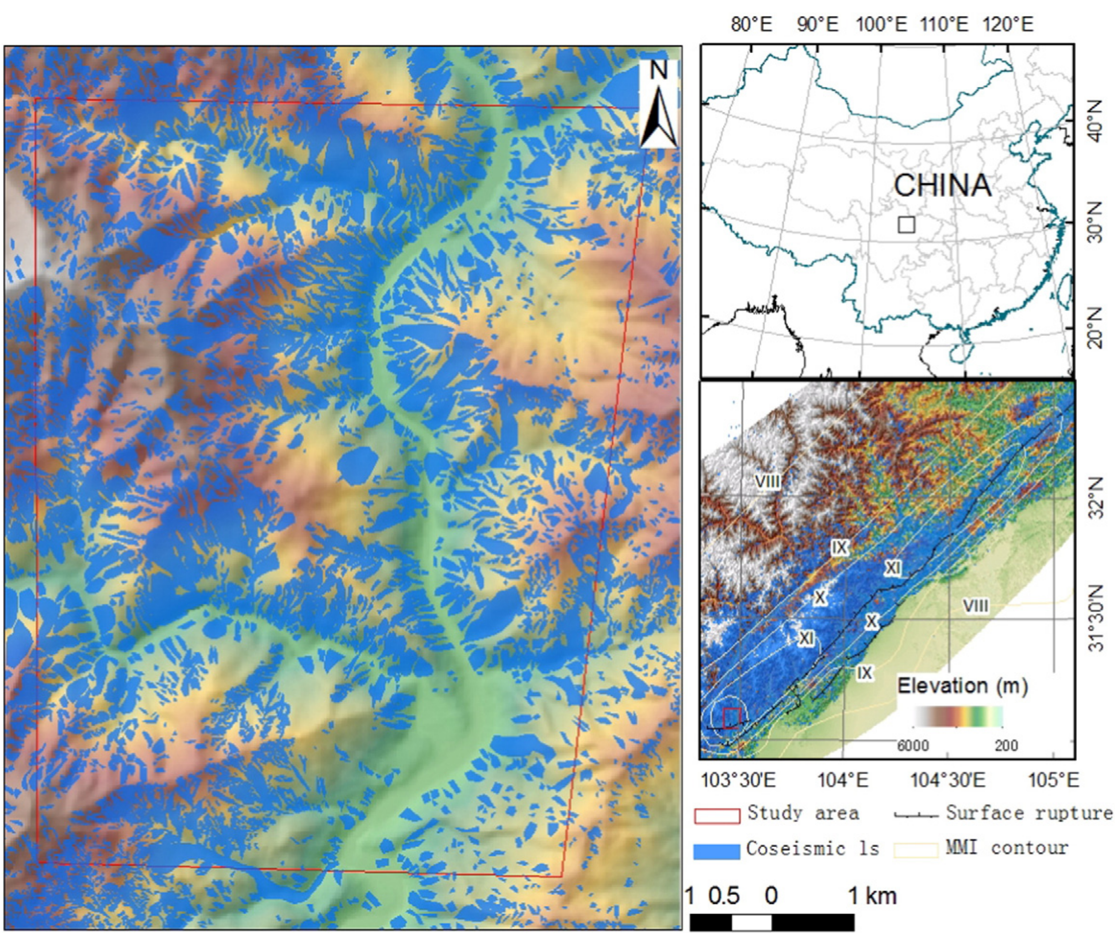

Fig. 1. Geographic location of the study area. MMI, Modified Mercalli Intensity; ls, landslides.