SATELLITE IMAGERY FOR LANDSLIDE MAPPING IN AN EARTHQUAKE-STRUCK AREA: A PRELIMINARY STUDY*

Xiaojun Yang[a†] and Liding Chen[b]
[a]Department of Geography, Florida State University, Tallahassee, FL32306, USA; xyang@fsu.edu
[b]State Key Lab for Urban and Regional Ecology, Chinese Academy of Sciences, Beijing 100085, P.R. China; liding@rcees.ac.cn

Abstract

This paper reports our preliminary effort to develop a method for quickly mapping of landslide distribution in connection to a recent major earthquake event. Our study site covers part of the Wenchuan County, Sichuan Province, China, approximately 32 km away from the epicenter of the Sichuan Earthquake that struck on 12 May 2008, estimated at the magnitude of 7.9 and killed 69227 people. Our primary data are from archival satellite imagery series, including two scenes acquired by the Terra's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Landsat 5 Thematic Mapper (TM). These scenes help capture the landscape characteristics before and after the Sichuan Earthquake. We conduct georeferencing and radiometric normalization before further processing the satellite scenes. We compute a Normalized Difference Vegetation Index (NDVI) image from each of the two scenes. Then, we compare the NDVI change before and after the Earthquake. Our initial results indicate that most of the large landslides that occurred after the Sichuan Earthquake can be well detected and mapped. We also discuss our further research efforts in order to improve the accuracy of landslide mapping from remotely sensed data.

Keywords: Landslides, Sichuan Earthquake, Wenchuan, satellite imagery, radiometric normalization, NDVI, change detection

Introduction

Landslides are rock, earth or debris flows on hillslopes due to gravity. They constitute a major type of geological hazards that are widespread, claiming multiple billions of dollars in damages and numerous fatalities every year (Dai *et al*. 2002; Singhroy and Molch 2004; Fourniadis *et al.* 2007; Stone 2008; Huang 2009). Monitoring landslide activities and predicting spatio-temporal slope failures can help understand the nature of terrain failure, formulate mitigation strategies, and ultimately minimize the losses from landslide hazards (Mantovani *et al.* 1996; Singh 1998; Wasowski 1998; Keefer 2002; Switalski *et al*. 2004; Havenith *et al*. 2006; Tarantino *et al*. 2007; van Westen *et al.* 2008; Sato and Harp 2009).

This paper reports our preliminary effort to develop a method for quickly mapping landslides in connection to a recent major earthquake event. This method was mainly based on the use of archival satellite imagery series and image processing techniques. The following sections

---

* Paper presented at the 24th International Cartographic Conference in Santiago, Chile, 15-21 November 2009.

† Corresponding author: xyang@fsu.edu; phone: 850-644-8379

will provide an overview on the case study site, detail our research methodology, analyze the initial results, and discuss our further research plan in order to improve the accuracy of landslide mapping from remotely sensed data.

Study Area

Our case study site covers part of the Wenchuan County, Sichuan Province, China, approximately 32 km from the epicenter of the Sichuan Earthquake that struck at 14:28:01.42 local time (06:28:01.42 Coordinated Universal Time-UTC) on 12 May 2008, estimated at the magnitude of 7.9 according to USGS (2008). Cited as China's most devastating earthquake in more than three decades, the Wenchuan Quake killed 69227, injured 374643, and made 4.8 million people homeless. Figure 1 illustrates the location of the study site, along with the epicenter that was 80 kilometers west-northwest of Chengdu, the capital of Sichuan.

With the focus of 19 kilometers in depth, the Wenchuan Earthquake and its aftershocks created a rupture zone extending more than 200 kilometers. They have triggered more than 15000 incidences of rockfalls, debris flows, and other types of landslides, along with more than 10000 potential rockfall sites (Yin *et al*. 2009). These landslides have been directly responsible for more than 20000 casualties and widespread infrastructure damage.

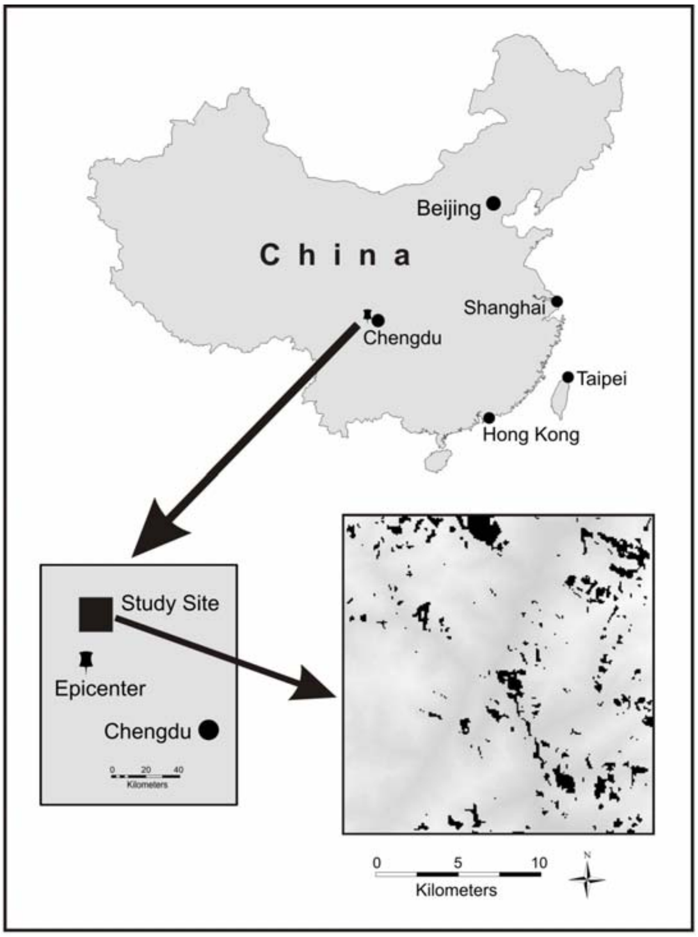

Figure 1. Location of the study site. Note that the epicenter of the earthquake struck on 12 May 2008 is shown (lower left). The study area is about 32 km away from the epicenter. The lower right is a digital elevation model derived from the Shuttle Radar Topography Mission (SRTM) data, covering the entire study area.

Research Methodology

The research methodology adopted here consisted of five major components: data collection, image preprocessing, image transformation, change detection, and the production of final landslide distribution map (Figure 2). This section focuses more on the first four components while the last one will be discussed in the next section.

Data Collection

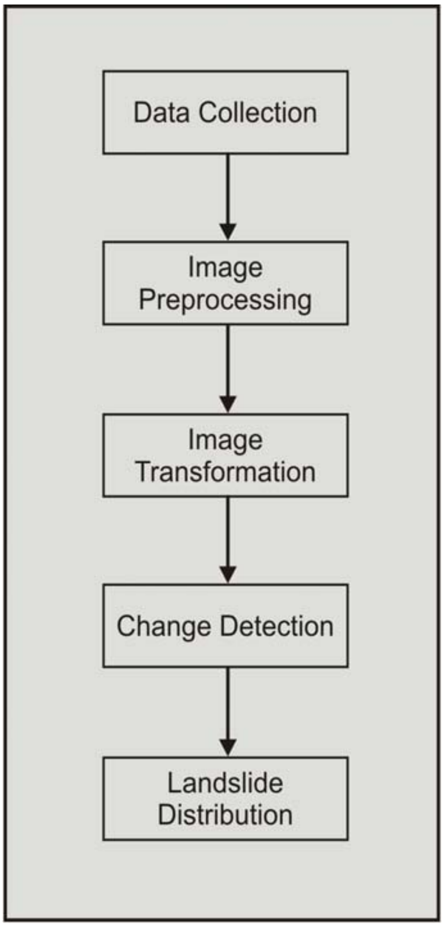

Figure 2. Flowchart of the working procedural route adopted in this study. Note that only major procedures are illustrated here.

The primary data used here were from archival satellite imagery series, including two dates of image scenes acquired by the Terra's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Landsat Thematic Mapper (TM). The ASTER scene was acquired at 3:57:00 UTC on 23 May 2008, 11 days after the Wenchuan Earthquake; while the TM scene was acquired at 3:32:14 UTC on 18 September 2007, slightly more than eight months before the Quake. The actual image area for our further analysis was free from clouds, covering 18630m by 19230m. These scenes helped capture the landscape characteristics before and after the Wenchuan Earthquake.

In addition to the above remote sensor data, we also collected diverse geospatial data sets, including the epicenter location, administration boundaries, digital elevation model (DEM) data derived from the Shuttle Shuttle Radar Topography Mission (SRTM), geological maps, socio-economic data, and so on. These geographically referenced data layers were used for different purposes, including our further research that intends to correlate landslide distribution with some possible controlling factors.

We also conducted a limited field work in Wenchuan for collecting the first-hand data concerning the earthquake impacts and landslide development. This part of work has been quite helpful for our further processing and interpretation of the remote sensor data.

Image Preprocessing

Both georeferencing and radiometric normalization were conducted for image preprocessing. The two dates of image scenes were geometrically rectified by the data providers, namely, USGS EROS Data Center and NASA. Here, each scene was further georeferenced to the UTM map projection (Zone 48N), the WGS 1984 horizontal datum, and the WGS 1984 ellipsoid. Note that the thermal bands of both the ASTER and TM scenes were excluded for further analysis due to their coarse spatial resolution. Other geospatial data layers were also georeferenced similarly so that further integration and analysis can be possible.

In addition to georeferencing, a radiometric normalization procedure proposed by Hall *et al.* (1991) was implemented to the two dates of satellite scenes in order to suppress their radiometric differences caused by the variations among atmospheric conditions, sensor-target-viewing geometry, vegetation growing seasons, and phenological characteristics (Yang and Lo 2000). With the TM scene dated on 17 September 2007 as the reference, the ASTER scene dated on 23 May 2008 as the subject scene was then radiometrically rectified by using radiometric control sets (see Hall *et al.* 1991; Yang and Lo 2000).

Image Transformations

In this study, we used the image-to-image comparison approach to help pinpoint the spatial occurrences of landslides. To this end, a Normalized Difference Vegetation Index (NDVI) image was computed from each of the two satellite scenes. Note that the normalized ASTER scene was used for this computation and the outputs should not be rescaled into the unsigned 8-bit data type.

Change Detection

An image-differencing change detection procedure was implemented by using the NDVI image derived from the TM scene as the Before image and the NDVI image from the ASTER scene as the After image. This created an image difference file. With this image, we further created a landslide distribution map (Figure 3) by highlighting the pixels with a decrease of at least ten percent in their brightness value as a direct result of the subtraction. The determination of ten percent as the threshold was made through an interactive process using a visual image interpretation method. In our further research, we will conduct a standard accuracy assessment by using the procedure recommended by Congalton (1991).

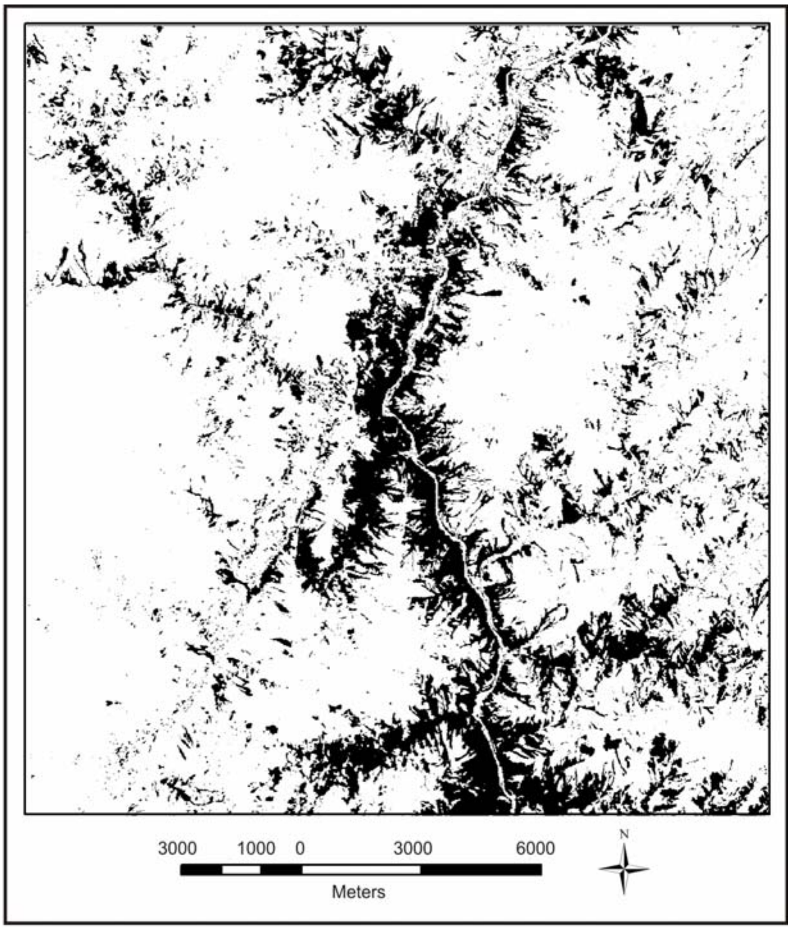

Figure 3. Spatial distribution of the landslides triggered by the earthquake struck on 12 May 2008. Note that most of these landslides (black patches) occurred along the Mingjing River and its major tributaries.

Results

Figure 3 illustrates the spatial distribution of landslides after the Wenchuan Earthquake. By using the original satellite scenes and the Google Earth, we visually examined the landslide distribution in relation to other geographic features such as stream networks, terrain slope, and road networks. We found that most of the landslides occurred along the Mingjing River and its major tributaries (black patches in Figure 3). Also some landslides occurred around mountain submits and ridges, indicating the seismic shaking was quite strong during the Wenchuan Earthquake and its aftershocks. This distribution pattern was also observed by other investigators such as Sato and Harp (2009) and Yin *et al*. (2009).

Conclusions

In this preliminary study, we have demonstrated how satellite imagery can be used to map the spatial distribution of landslides in connection to a major earthquake event. Critical to this study has been the acquisition of the two dates of satellite scenes with one obtained before the Earthquake and the other after the event. Ideally, these scenes should be acquired by the same sensors at approximately the same season but this is not always possible due to many other environmental or logistical constraints. The image-differencing change detection method adopted here was contingent upon the radiometric normalization of the satellite series. We found that most of the large landslides occurred along the Mingjiang River and its major tributaries. Some landslides occurred around mountain submits and ridges, suggesting the strong impacts of seismic shaking during the Wenchuan Earthquake and its aftershocks.

Meanwhile, we also note the limitations of this preliminary study. In particular, many small-scale landslides were not represented because of the image spatial resolution used. Some additional field work is needed in order to determine the types and nature of the landslides. Our further research will assess the accuracy of the landslide distribution map and develop more robust methods for improving landslide mapping from remotely sensed data.

Acknowledgements

This research was partially supported by the Florida State University Council on Research and Creativity and the Chinese Academy of Sciences through the International Partnership Project 'Ecosystem Process and Services'. Thanks are also due to the Global Land Cover Facilities for sharing their data collection for the 2008 China Earthquake.

References

Congalton, R. G. (1991) A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37, 35-46.

Dai, F. C., Lee, C. F. & Ngai, Y. Y. (2002) Landslide risk assessment and management: an overview. *Engineering Geology*, 64, 65-87.

Fourniadis, I. G., Liu, J. G. & Mason, P. J. (2007) Landslide hazard assessment in the Three Gorges area, China, using ASTER imagery: Wushan-Badong. *Geomorphology*, 84, 126-144.

Hall, F. G., Strebel, D. E., Nickeson, J. E. & Goetz, S. J. (1991) Radiometric rectification - toward a common radiometric response among multidate, multisensor images. *Remote Sensing of Environment*, 35, 11-27.

Havenith, H. B., Torgoev, I., Meleshko, A., Alioshin, Y., Torgoev, A. & Danneels, G. (2006) Landslides in the Mailuu-Suu Valley, Kyrgyzstan - Hazards and impacts. *Landslides*, 3, 137-147.

Huang, R. Q. (2009) Some catastrophic landslides since the twentieth century in the southwest of China. *Landslides*, 6, 69-81.

Keefer, D. K. (2002) Investigating landslides caused by earthquakes - A historical review. *Surveys in Geophysics*, 23, 473-510.

Mantovani, F., Soeters, R. & VanWesten, C. J. (1996) Remote sensing techniques for landslide studies and hazard zonation in Europe. *Geomorphology*, 15, 213-225.

Sato, H. P. & Harp, E. L. (2009) Interpretation of earthquake-induced landslides triggered by the 12 May 2008, M7.9 Wenchuan earthquake in the Beichuan area, Sichuan Province, China using satellite imagery and Google Earth. *Landslides,* 6, 153-159.

Singh, R. B. (1998) Land use cover changes, extreme events and ecohydrological responses in the Himalayan region. *Hydrological Processes,* 12, 2043-2055.

Singhroy, V. & Molch, K. (2004) Characterizing and monitoring rockslides from SAR techniques. IN SINGH, R. P. (Ed.) Monitoring of Changes Related to Natural and Manmade Hazards Using Space Technology.

Stone, R. (2008) An unpredictably violent fault. *Science,* 320, 1578-1580.

Switalski, T. A., Bissonette, J. A., DeLuca, T. H., Luce, C. H. & Madej, M. A. (2004) Benefits and impacts of road removal. *Frontiers in Ecology and the Environment,* 2, 21-28.

Tarantino, C., Blonda, P. & Pasquariello, G. (2007) Remote sensed data for automatic detection of land-use changes due to human activity in support to landslide studies. *Natural Hazards*, 41, 245-267.

USGS (2008) Magnitude 7.9 - eastern Sichuan, China: 2008 May 12 06:28:01 UTC [Online] (Updated 22 May 2009) Available at: http://earthquake.usgs.gov/eqcenter/eqinthenews/2008/us2008ryan/us2008ryan.php [Accessed 10 July 2009].

van Westen, C. J., Castellanos, E. & Kuriakose, S. L. (2008) Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview. *Engineering Geology*, 102, 112-131.

Wasowski, J. (1998) Understanding rainfall-landslide relationships in man-modified environments: A case-history from Caramanico Terme, Italy. *Environmental Geology*, 35, 197-209.

Yang, X. J. & Lo, C. P. (2000) Relative radiometric normalization performance for change detection from multi-date satellite images. *Photogrammetric Engineering and Remote Sensing*, 66, 967-980.

Yin, Y. P., Wang, F. W. & Sun, P. (2009) Landslide hazards triggered by the 2008 Wenchuan earthquake, Sichuan, China. *Landslides*, 6, 139-152.