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Combining multiple change detection indices for mapping landslides triggered by typhoons

Alessandro C. Mondini [a], Kang-Tsung Chang [b,*], Hsiao-Yuan Yin [c]

[a] Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica, 06128 Perugia, Italy
[b] Kainan University, 1, Kainan Road, Luzhu, Taoyuan County 33857, Taiwan
[c] Soil and Water Conservation Bureau, Nantou County 54044, Taiwan

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ABSTRACT

An important part of landslide research is the interpretation and delineation of landslides, which has increasingly been based on high-resolution satellite images in recent years. Using pre- and post-event FORMOSAT-2 satellite images as the data sources, this study presents a new method that combines four change detection techniques for mapping shallow landslides triggered by typhoons in Taiwan. The four techniques are normalized differential vegetation index (NDVI), spectral angle, principal component analysis, and independent component analysis. We apply the multiple change detection (MCD) technique to map landslides triggered by two typhoons of vastly different magnitudes. Comparisons are then made between MCD results with landslide inventory maps compiled by using a single index (change in NDVI) in one case study and visual analysis in another. Comparison results show that MCD can perform better than change in NDVI in dealing with old landslides and landslides with non-homogeneous spectral responses. MCD is also able to detect small landslides, which are often missed by visual analysis. Additionally, landslide maps prepared by MCD include runout features of sediment deposits from debris flows. A relatively fast processing chain, MCD is expected to become a useful new tool for emergency management after a typhoon event, which occurs on average four to five times a year in Taiwan.

1. Introduction

Landslides are triggered by earthquakes, storms, snow melt, human activities such as timber clearcut or road construction, or a combination of these factors (Aleotti and Chowdhury, 1999). The International Landslide Centre landslide fatality database (http://www.landslidecentre.org/database.htm) shows that landslides cause significant losses of human lives yearly. As an example, Typhoon Morakot (August 5–10, 2009) brought torrential rain to southern Taiwan, set a new rainfall record of 2900 mm, triggered thousands of landslides and debris flows in mountainous areas, and caused 711 fatalities and missing persons, including 500 inhabitants of a village buried by a single landslide (Lin et al., 2010).

Landslides can be classified by morphology, material, mechanism of initiation, and other criteria (Cruden, 1991; Dikau et al., 1996). This paper focuses on shallow landslides. Shallow landslides, either new or reactivated, refer to failures on soil mantled slopes with depths generally less than 2 m. Shallow landslides on steep slopes may evolve into debris flows as geomaterials break up, mix with water, move downslope, and deposit on lowland areas (Takahashi, 1978). Runout is a term that generally describes the downslope displacement of failed geomaterial from landslides. Runouts are often confined within channels but can also be found on open slopes (Chen et al., 2009; Scheidl and Rickenmann, 2010).

Landslide mapping is an important part of landslide research because maps showing observed landslides are the necessary input for calibration and validation of landslide susceptibility models (Guzzetti et al., 2006; Chang et al., 2007; Rossi et al., 2010). For evaluation of the model performance, predicted landslides must be directly compared with observed landslides; therefore, unless observed landslides are correctly mapped, they cannot be used as a basis for comparison. Landslide maps are also used as a proxy for assessing landslide susceptibility at regional scale (e.g., Galli et al., 2008).

Traditionally, landslides are interpreted and delineated manually on stereoscopic aerial photographs by an experienced interpreter using morphologies typical of slope movements such as scarps, deposit zones, disturbed vegetation, and disturbed channels or roads as visual cues (Dikau, 1999; Saba et al., 2010). Manual interpretation, however, is tedious and expensive. Moreover, aerial photographs can cover only small areas and the revisiting interval of aerial coverage is limited and irregular.

In recent years, high-resolution (HR) satellite images have started to replace aerial photographs for mapping landslides (van Westen

* Corresponding author. Tel.: +886 33412500x1021; fax: +886 33413252.
E-mail address: chang@uidaho.edu (K.-T. Chang).

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Table 1
Performance of image analysis techniques for landslide mapping.

Reference	Study area	Method	Image	Accuracy assessment
Nichol and Wong (2005)	Hong Kong	Maximum likelihood classifier	Pre- and post-event SPOT	67–71% landslides detected
Petley et al. (2002)	Upland areas of Nepal and Bhutan	False color composite, PCA, and Abrams ratio	Landsat 7 ETM+	Missing more than 75% of landslides detected by ground mapping
Borghuis et al. (2007)	Mountainous watersheds in southern Taiwan	Unsupervised classification combined with a slope filter	SPOT-5	53–63% area concordance between the unsupervised and manual methods
Tsai et al. (2010)	Mountainous watersheds in southern Taiwan	NDVI and CVA	FORMOSAT-2	9% omission error and 16% commission error
Martha et al. (2010)	Catchment in the High Himalayas	Object-based image analysis	Resourcesat-1	76% of landslides correctly recognized when compared to manually prepared inventory map

Table 2
Specifications of level-4 FORMOSAT-2 satellite images.

Spatial resolution (m)	Panchromatic	2 m
	Multispectral (R, G, B and NIR)	8 m
Wavelength (μm)	Panchromatic	0.52 to 0.82
	Blue	0.45 to 0.52
	Green	0.52 to 0.60
	Red	0.63 to 0.69
	NIR	0.76 to 0.90
Footprint (km)		24×24
Spectral resolution		8 bits pixel^{-1}
Revisit time		Daily
Viewing angle	Along and across track	±45°

et al., 2008; Saba et al., 2010). Various techniques, including visual analysis, image differencing, change vector analysis, the maximum likelihood classifier, the normalized differential vegetation index, principal component analysis, and object-based image analysis, have been used to interpret landslides from satellite images (Petley et al., 2002; Cheng et al., 2004; Haeberlin et al., 2004; Nichol and Wong, 2005; Rosin and Hervás, 2005; Restrepo and Alvarez, 2006; Borghuis et al., 2007; Martha et al., 2010; Tsai et al., 2010). The accuracy of these image analysis techniques varies in terms of landslide classification (Table 1).

Classification accuracy is typically used in the literature as the main criterion for evaluating an image analysis technique. However, in practice, there are three other important considerations. 1) The time required to interpret and map landslides is critical for emergency management purposes. 2) Ideally the technique must be equally effective for interpreting and mapping landslides triggered by events of different magnitudes. 3) It will be an additional advantage if the technique can distinguish new from old landslides and also map runout features.

This paper uses a multiple change detection (MCD) technique, a data processing chain, which makes use of HR satellite images and combines four change detection techniques to semi-automatically

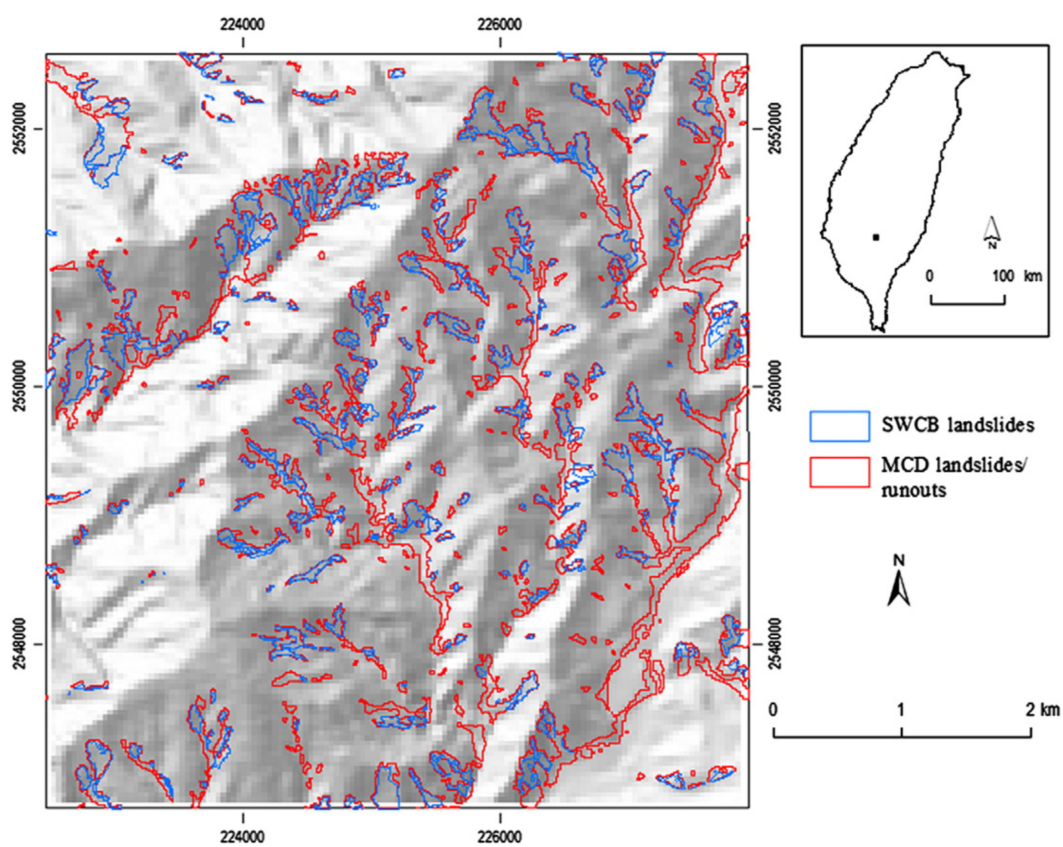

Fig. 1. Location map of the area of Case study 1 and comparison between landslides mapped by MCD and those from the SWCB inventory map. The projected coordinate system is TWD97, measured in meters.