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Research Paper

A comparative analysis of pixel- and object-based detection of landslides from very high-resolution images

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ABSTRACT

A comparative analysis of landslides detected by pixel-based and object-oriented analysis (OOA) methods was performed using very high-resolution (VHR) remotely sensed aerial images for the San Juan La Laguna, Guatemala, which witnessed widespread devastation during the 2005 Hurricane Stan. A 3-band orthophoto of 0.5 m spatial resolution together with a 115 field-based landslide inventory were used for the analysis. A binary reference was assigned with a zero value for landslide and unity for non-landslide pixels. The pixel-based analysis was performed using unsupervised classification, which resulted in 11 different trial classes. Detection of landslides using OOA includes 2-step K-means clustering to eliminate regions based on brightness; elimination of false positives using object properties such as rectangular fit, compactness, length/width ratio, mean difference of objects, and slope angle. Both overall accuracy and F-score for OOA methods outperformed pixel-based unsupervised classification methods in both landslide and non-landslide classes. The overall accuracy for OOA and pixel-based unsupervised classification was 96.5% and 94.3%, respectively, whereas the best F-score for landslide identification for OOA and pixel-based unsupervised methods: were 84.3% and 77.9%, respectively.Results indicate that the OOA is able to identify the majority of landslides with a few false positive when compared to pixel-based unsupervised classification.

1. Introduction

Historical collections of high-resolution remote sensing data provides us valuable opportunities to analyze natural hazard events to advance our understanding of the hazard and to minimize its effects (Oommen et al., 2013; Bialas et al., 2016), and help in creating an inventory. Traditionally, remote sensing data have been analyzed using pixel-based classification methods for studying natural hazards, especially landslides. The pixel-based methods rely solely on spectral characteristics of the analyzed image which significantly limits the potential for identification of spatially contiguous areas; often resulting in a speckled appearance in the classification product with many small regions or single pixels classified as hazard events (Sahoo et al., 2007; Stumpf et al., 2011).

A new solution gaining popularity in the field of image processing for landslide studies is Object-Oriented Analysis (OOA). Studies by Barlow et al. (2012), Van Den Eeckhaut et al. (2012), Martha and Kerle (2010), Lahousse et al. (2011), Martha (2011), Stumpf and Kerle (2011), Chang et al. (2012), Blaschke et al. (2014), Moosavi et al. (2014), Wu et al. (2014), and Dou et al. (2015) highlighted advantages of OOA methods for detection of landslides, particularly with medium and low resolution remotely sensed data. The OOA begins with image segmentation, which is a grouping of nearby pixels based on a homogeneity factor. These objects, or segments, can be analyzed further using spatial, textural, contextual, geometric, and spectral characteristics. The additional processing eliminates false positives that are usually missed by pixel-based classification alone (O'Neil-Dunne, 2013; Bialas et al., 2016).

Several studies have assessed the effectiveness of OOA and pixel-based methods (Whiteside and Ahmad, 2005; Yan et al., 2006; Oruc et al., 2004; Chang et al., 2012; Bialas et al., 2016). However, none of these studies assessed the effectiveness of landslide detection with very high-resolution (0.5 m spatial resolution) remotely sensed data.

2. Study area

San Juan La Laguna (14.695°N, 91.287°W) is a community of approximately 10,000 residents located on the shores of Lake Atitlán in south central Guatemala (Fig. 1a–c). Lake Atitlán is a steep-sided caldera lake (Fig. 1d). Three post-caldera active andesitic strato-volcanoes

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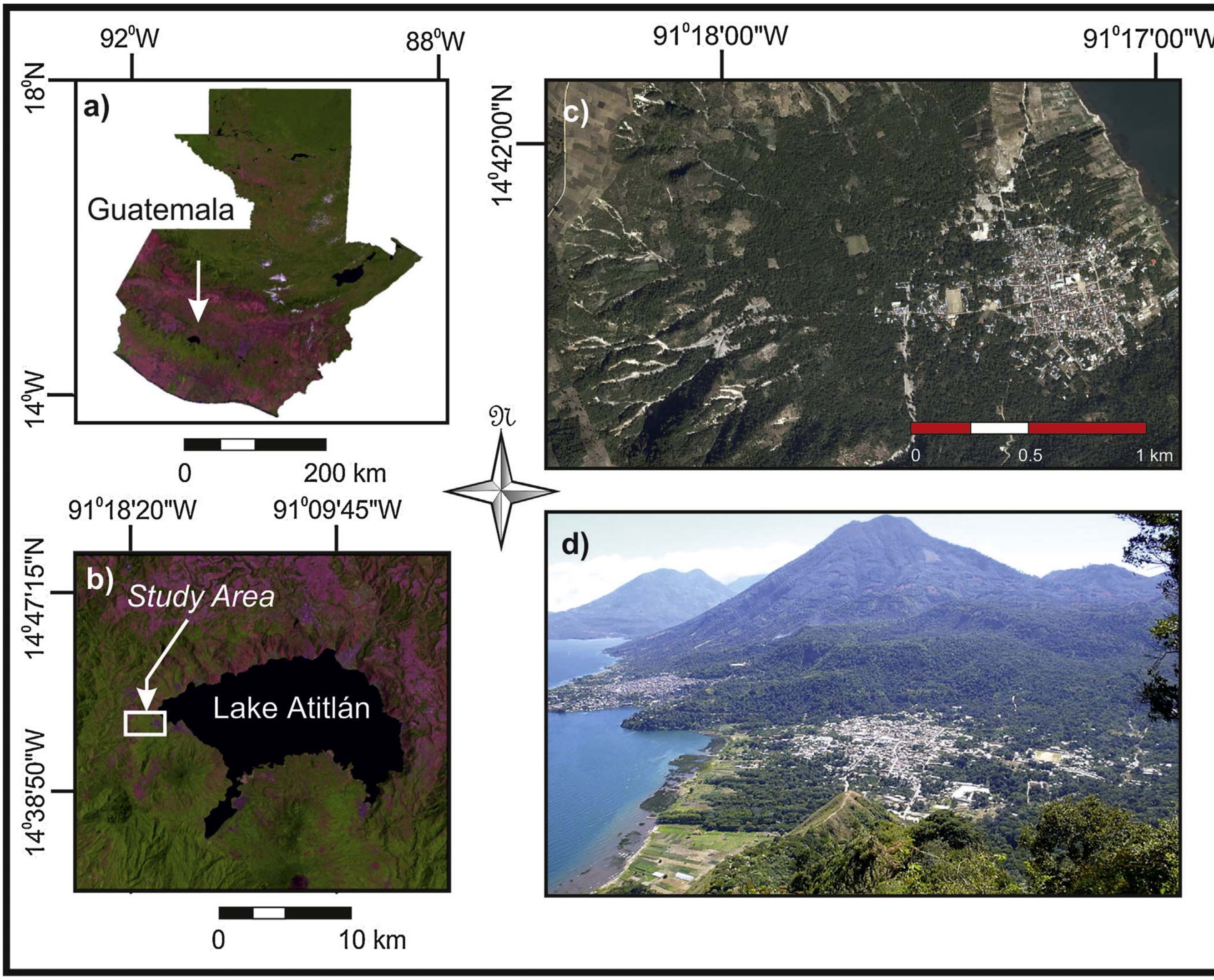

Fig. 1. Location of San Juan La Laguna study area on western shore of Lake Atitlán, Guatemala (a) Map of Guatemala showing the location (white arrow) of Lake Atitlán (b) Lake Atitlán and study area (c) Actual study area and reference image used for processing (d) Terrestrial photograph showing San Juan (Photograph faces the south).

() form the southern margin with San Pedro being the closest to San Juan La Laguna (Newhall et al., 1987). A major eruption in the Atitlán III complex occurred 84,000 years BP resulted in the creation of Lake Atitlán. Quaternary tephra units cover most of the highlands with thicknesses exceeding ~15 m, and unconsolidated Quaternary ash deposits have filled most of the basins of western Guatemalan highlands and in places are thicker than 200 m (Newhall et al., 1987).

The geomorphology of the Atitlán caldera is related to the volcanic activity of the area and the different geologic units reflect various eruptive stages of the volcanoes and landscape dynamics of the sediments (Luna, 2007). The topographic elevations increase from 300 m on the surrounding coastal plain to 1562 m at Lake Atitlán and 3535 m at the summit of Volcano Atitlán (Fig. 1b–d). The volcanic events have produced a steep sided and often unstable crater rim with intermittent deep canyons ranging in depth between 200 and 500 m. Downhill of the rim are located several villages that are susceptible to landslides and lahars. At San Juan La Laguna, slopes might be as steep as 80° and are covered with a thin layer of clay and organic rich soil. This thin veneer, of approximately one meter of soil, creates a very unstable setting, which in the event of a heavy rainfall is likely to fail (Luna, 2007; Smith et al., 2015; Kern et al., 2016).

On 4 October 2005, Hurricane Stan provided the heavy rainfall (297.5 mm) needed to mobilize significant sections of the crater rim. Thousands of landslides occurred along the steep crater walls culminating in the destruction of communities and the loss of hundreds of lives in nearby Panabaj. The destruction significantly affected the fragile state of the predominantly subsistence farming community. Despite the enormous toll on the local population, very little scientific effort was expended in mapping landslides (Luna, 2007; Cobin et al., 2017). Without a comprehensive record, the evidence may soon be covered by vegetation and forgotten, leading to a future reoccurrence.

The steepness of the terrain and the larger number of landslides make field-based mapping a daunting task. We propose and evaluate herein the object-oriented approach to identify landslides. The performance of this approach is compared to the more conventional pixel-based approach.

3. Data and methodology

A detailed schematic of the method followed in this study is presented in Fig. 2. A field-based inventory of landslide initiation points was created by the Instituto Nacional de Sismologia, Vulcanologia, Meterologia, e Hidrologia (INSIVUMEH) after Hurricane Stan (Geológicos del Mundo (GM), 2009; Supplementary material-Appendix A). This inventory together with the remotely sensed high-resolution orthophotos taken shortly after the event in early 2006 was highly beneficial in identifying landslide locations. The multi-spectral (red, green, and blue bands) orthophotos (GM, 2009) with 0.5 m spatial resolution