Identification of Landslides and Vegetation Recovery Assesment After Hurricane Mitch in La Ceiba and El Porvenir, Honduras.

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ABSTRACT

Hurricane Mitch in Honduras in 1998 produced unprecedented damages throughout the country. Estimations indicate that landslides damaged 70% of the road network and cause nearly 1,000 fatalities. Torrential rainfall from Hurricane Mitch in 1998 triggered many landslides within the counties of La Ceiba and El Porvenir in the Atlantic region of Honduras in a National reserve area. In this study we identify landslides after Hurricane Mitch in La Ceiba and El Porvernir county areas and its vegetation recovery using Landsat satellite images. Multidate Landsat satellite images were acquired previous (1997) and after (1999) the hurricane Mitch. The images were pre-processed and used to determine change detection using Change Vector Analysis (CVA). To eliminate undesirable change pixels and noise, majority filter and slope and were used. The vegetation recovery is estimated using a Vegetation Recovery Rate (VRR) calculated from NDVI derived from satellite images acquired in 2005 and 2011 for Hurricane Mitch. The identification of landslides and the vegetation recovery analysis provides useful information for locating the damage caused by landslides and monitoring their recovery after a Hurricane event. This information helps for different purposes such as relocation efforts of population, urban planning, estimation of damage caused by landslides, and planning the vegetation recovery of the landslides in perturbated protected areas to reduce sediment flows.

1. INTRODUCTION

Hurricane Mitch struck Central America in October 1998, and it will be remembered as the most deadly hurricane to strike the Western Hemisphere in the last two centuries.. The total reported rainfall was 75 inches for the entire storm **(NCDC, 2006).** The rainfall produced devastating floods and landslides that resulted in more than 9,000 fatalities and the displacement of 3 million people. Estimations indicate that landslides caused by Hurricane Mitch damaged 70% of the road network in Honduras and caused nearly 1,000 fatalities **(Harp, 2002).** The landslide areas can be calculated by high-resolution commercial satellites or digital cameras onboard an aircraft **(Maas et al., 1997)** the cost is very high and not suitable for large areas**.** The assessment of landslide for large areas is critical to the mitigation of damages. Quantitative assessment is also essential for activities associated with watershed management and monitoring **(Dhakal et al., 2000).** Remote sensing techniques have been successfully applied to landslide investigations and related studies **(Metternicht et al., 2005; Nichol and Wong, 2005; Peduzzi, 2010; Sarkar and Kanungo, 2004).** Also, sophisticated statistical methods, such as gray level co-occurrence and textural spectrum, are able to discriminate between rough and smooth surfaces and to detect landslides in different environments **(Hervás and Rosin, 1996, 2001; Hervás et al, 1996, Whitworth et al., 2001, 2005).** Change Vector Analysis (CVA) has also been used for landslide detection . The CVA change detection model was used for mapping the 1997 landslides using TM data **(Patton et al., 2003).** CVA may be able to detect possible landslides not clear using the Normalized Difference Vegetation Index (NDVI) **(Tsai et al., 2010).** NDVI is one of the most popular methods for vegetation monitoring **(Lin et al.,2005).** The response of the NDVI becomes saturated when vegetation coverage reaches 100%, thus facilitating monitoring of vegetation recovery. In this research landslides are identified using Multidate Landsat satellite images acquired previous (1997) and after (1999) the hurricane. Majority filter, slope filter were used to eliminate undesirable change pixels and noise. The vegetation recovery was estimated using a Vegetation Recovery Rate (VRR) derived from NDVI calculated for the years 1997, 1999, 2005 and 2011). The results in this study provide the location of landslides after Hurricane Mitch and the vegetation recovery of the previously identified denudated areas for 2 periods after the hurricane.

2. STUDY AREA

La Ceiba and El Porvenir counties are selected for this research. The importance is that both counties form most of the National Reserve Pico Bonito and are part of the Cangrejal River watershed. The occurrence of landslides in this two counties was very high during Hurricane Mitch and La Ceiba city (third largest in the country) was uncomunicated due to landslide occurrence in the road network. The two counties have an area of 92,435 hectares, and it is located in the northern Atlantic region of Honduras. The area in front of the central portion of the Atlantic coast has a mountainous relief with strong slopes (higher than 40%). Thus, this area has a high probability of landslide occurrence, which became evident after Hurricane Mitch in 1998 **(FUPNAPIB, 2004).**

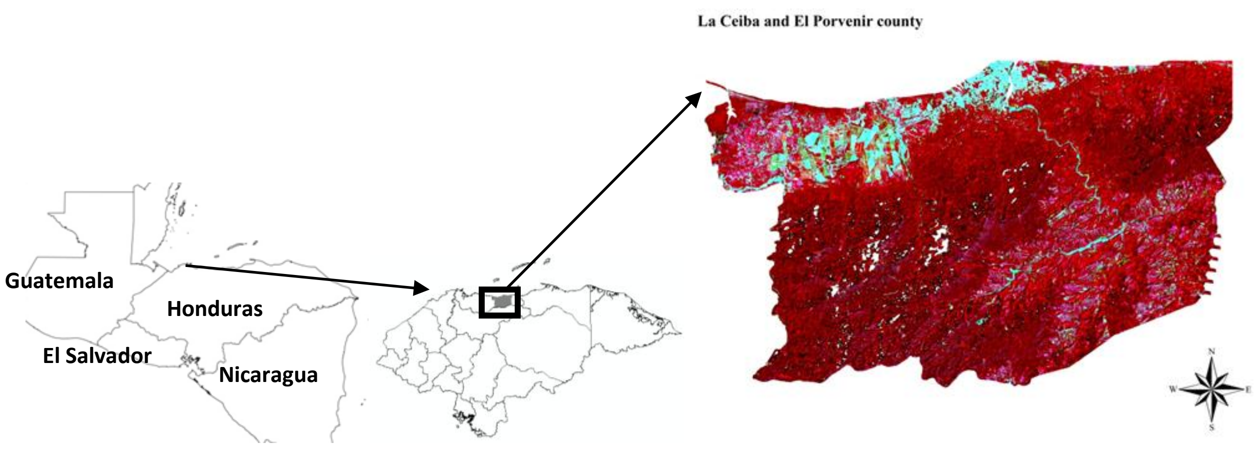


Figure 1. Study area. La Ceiba and El Porvenir counties.

3. MATERIALS AND METHODS

This research has two major final products, identification of the landslide caused by Hurricane Mitch in La Ceiba and El Porvenir counties and vegetation recovery for two periods in these landslide areas. A flowchart of the methodology followed is illustrated in (figure 2).

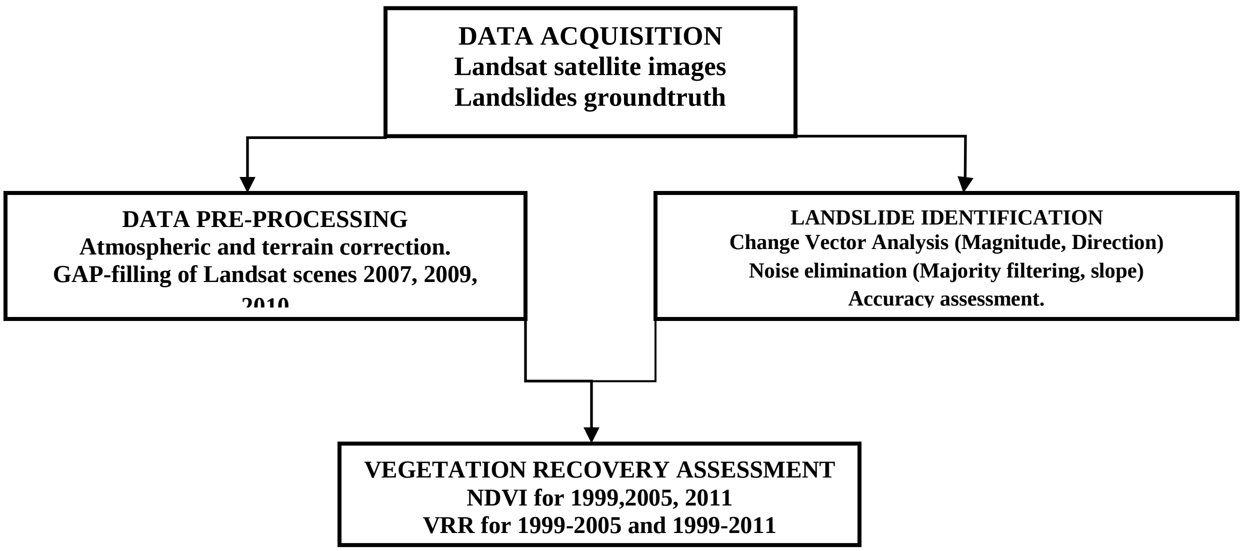


Figure 2. Flowchart of methodology

3.1 Data acquisition

Mutitemporal Landsat satellite images were used to extract the landslides after hurricane Mictch and to estimate the Vegetation Recovery. The Landsat satellite images acquired before and immediately after the Hurricane for the landslide identification. For the Vegetation recovery other images were acquired for 2 different periods (1999-2005 and 1999-2011)**.** Landslide inventory prepared after the Hurricane Mitch was used as ground truth for this research.

3.1 Landslide identification

To develop the landslide identification a Pre Hurricane Mitch Landsat scene and a Post Hurricane Mitch scene is used. The method is developed using CVA applied to pairs of multiband data. CVA identifies changed and unchanged pixels in multi-temporal images based on spectral change vectors calculated from different bands, which may be able to detect possible landslides. Firstly we measure the magnitude of change and secondly the direction of that change. To measure the magnitude of change between the two dates, we must use an approach that accommodates the multiband imagery available. Taking the red and infrared bands for each date, we can imagine that each pixel has a "position" in each of the two bands. The difference between the pixels can then be expressed as the Euclidean distance between them in space:

$$S = \sqrt{(Red\ B + Red\ A)^2 + (NIR\ A + NIR\ B)^2} \qquad (1)$$

Where S= the magnitude of change vector, Red B, A= Red band of images, NIR B, A= Near Infrared Band of image B, A. Threshold was established by interactive examination of the change layers and the groundtruth site polygons. The direction is also estimated to assign the type of change occurred and eliminate change from bare soil to vegetation.
Majority filter and slope filter were used to eliminate undesirable change pixels and noise. The majority filter was used to eliminate the salt and pepper effect and to smooth the edges of landslides. The slope filter was used to eliminate undesirable change pixels as landslides usually occur in high slopes **(Martin and Franklin, 2005).** The identified landslides that fall into area that is under 10° were filtered out.

3.2 Vegetation Recovery Rate

Monitoring the vegetation recovery of the landslides identified after Hurricane Mitch for three different periods was another objective of this study. The two periods selected were 1999-2005 and 1999-2011 for the Pico Bonito National Reserve study area. To develop this analysis, a Vegetation Recovery Rate (VRR) is used **(Lin et al., 2005).** The VRR is calculated from the multi-temporal NDVI in landslide areas. The equation to estimate VRR is:

$$VRR\ (\%) = \frac{NDVI\ 2 - NDVI\ 1}{NDVI\ 0 - NDVI\ 1} \text{x}100 \tag{3}$$

where *NDVI* 0 is the landslide area taken before the hurricane, *NDVI* 1 is calculated soon after the hurricane, and *NDVI* 2 is for the period of evaluation for vegetation recovery. If the VRR value is less than 0, the vegetation recovery condition of the landslide is worst. If the VRR value ranges from 0 to 100, the vegetation recovery of the landslide is increasing. If the VRR value is greater than 100, the vegetation recovery condition of the landslide is better than before the hurricane.

4. RESULTS

The landslides that occurred are 742 landslides with a total area of 1563 Has. The largest landslide is has an area of 30.3 Has. To assess the accuracy of the landslide identification, ground truth was used. User and Producer Accuracy reached 65 % and 77% respectively for landslide class, and overall accuracy reached 84%.

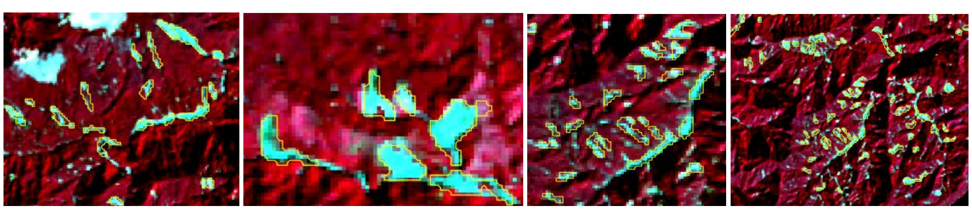
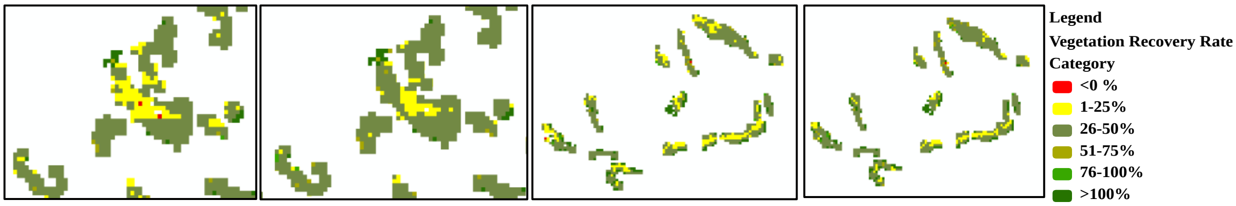


Figure 3. Landslide samples after event at La Ceiba and El Porvenir areas.

The VRR results for the the high, very high and excellent for the landslides calculated in 2005 is 45.6%, and it continued its rise to 79% in 2011. Samples of results for VRR are illustrated in figure 4 and the total analyzed results are listed in table 1 and plotted in figure 5.



(a) (b) (c) (d)

Figure 4. Classified VRR. (a) and (c) VRR 2005, (b) and (d) VRR 2010

Table 1. Vegetation Recovery Rate (VRR)

Class	**VRR (%)**	**1999-2005**		**1999-2011**	
		Area (has)	**(%) of total landslide area**	**Area (has)**	**(%) of total landslide area**
No recovery	**0**	105.0	6.72	3.9	0.25
Low	**0-25**	307.8	19.69	148.2	9.53
Average	**25-50**	436.4	27.92	178.4	11.39
High	**50-75**	296.3	18.96	488.3	31.29
Very high	**75-100**	274.5	17.56	528.3	33.78
Excellent	**>100**	143.0	9.15	216.0	13.76
Total		**1563**	**100.00**	**1563**	**100.00**

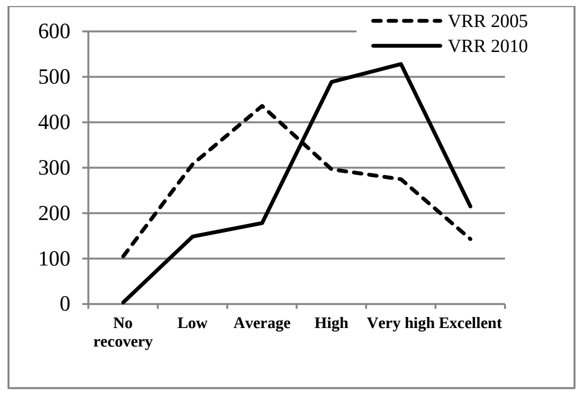


Figure 5. VRR 2005, 2010 study area.

5. CONCLUSIONS

The objectives of this study were to identify landslides caused by Hurricane Mitch and to estimate the vegetation recovery rate for 2 periods after the event. A method that uses multi-temporal satellite images to estimate the CVA in magnitude, direction with the elimination of undesirable change pixels is proposed. The results show an overall accuracy of 84%. This method can complement ground surveying and photo interpretation techniques for landslide identification, and it can be used nation wide for fast assessment using satellite images available freely. Using the NDVI, VRR is estimated and provides a quantitative method for monitoring and assessing the vegetation recovery for the landslides triggered by Hurricane Mitch. The VRR derived from the NDVI calculation revealed a stable plant growth and vegetation recovery tendency for denudation sites. From 11 years of vegetation recovery monitoring, the VRR in the landslides reached in 2011 78.8% for high, very high and excellent recovery in the study area. This result shows that nature has a high possibility to naturally regenerate vegetation on landslides, although artificial vegetation recovery is still required in some priority areas to accelerate the process of recovery. The climate conditions in this area are proper for the landslide occurrence, although the natural regeneration of a disturbed area is very generous and does not need major investment. However, the VRR in the category of excellent is low. This is because La Ceiba and El Porvenir areas have an important national reserve hence a very dense vegetation, which makes it very difficult for the landslide areas to have a better condition than before Hurricane Mitch. The results can support the decision to concentrate efforts to recover the landslide areas where the recovery is still in the very low and low class. If actions are not taken, the risk will be latent and will increase due to the lack of vegetation.

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