Slips of scars characterization for image processing in Nova Friburgo - RJ

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Abstract: Natural disasters, such as landslides, are a common problem in many places of the world, and studies about this topic have been increased since they lead to life and economic losses. Remote Sensing data can be used for mass movement studies, and for identification of landslides scars. So, this work identifies and characterizes landslides scars in Nova Friburgo – RJ, through digital processing satellite images of Landsat-5. To enhance the spectral and special quality, in order to facilitate the visual analysis and provide more information, the images were processed by removing clouds cover, selecting bands and obtaining color composition and performed a subtraction between bands. The Normalized Difference Vegetation Index (NDVI) was used to identify and mapping the landslides. A map of environmental fragility, based on Ross (1994) classification, was made to analyze the fragility in study area. Geological, geomorphologic and pedological data were researched to deepen the analysis. The results shows that the heavily rainfall in combination with multiple factors such as geology, geomorphology, soil saturation and high declivity, were the trigger to the 2011 landslide in the study area.

Keys-words: Remote Sensing, landslides, image processing, environmental fragility.

1. Introduction

Natural disasters have been increasingly studied since they lead to life and economic losses. The latest natural disaster of great proportion in Brazil occurred in the mountainous region of the state of Rio de Janeiro - reaching, especially the cities of Nova Friburgo, Teresopolis, Petropolis, Sumidouro and São José do Vale do Rio Preto - in January 2011, when more than 900 people died and 18,000 others were left homeless. It is considered one of the biggest mass movements in Brazil.

According to Guidolini et al. (2012), the main cause of landslides on January 11 and 12, 2011 in the mountainous region of Rio de Janeiro was the heavy rainfall in a short period of time. According to the National Institute of Meteorology (INMET), the affected region had a cumulative total in 24 hours 326 mm of rain, while expected for the month of January is 209 mm.

Remote Sensing data can be used for mass movement studies in the detection of these cases (scarring due to the removal of vegetation and exposure of subsurface soil layers) by identifying indicators. These indicators are related to changes in vegetation cover, due to previous landslides (difference in density and type of vegetation), land use (removal of anthropic action by vegetation in areas prone to landslides), morphology (form strands) and relief (KING and VONDELPONT, 1993; BERGER, 1996).

The resolution of the characteristics of the orbital sensors and the character of the data captured by these systems allow the observation of landscape features related to landslide processes (KING and VONDELPONT, 1993; WALSH et al, 1998). Landslides cause the removal of vegetation cover and consequent exposure of soil or rock in addition to the deposition of material transported along the slope downstream. These factors result in differences in tone, color, hue and texture in the image scene by the sensor, and present specific features, allowing its interpretation.

However, topographical and morphological characteristics and vegetation cover (texture, differences in the image due to high variation in hue caused by the removal or supply of vegetation), suggest the occurrence of these processes in the image scene. Variations in vegetation and texture are easier to be identified in sensor data with finer spatial resolution (AUGUSTO FILHO, 1994; WALSH and BUTLER, 1997).

The objective of this work is to identify and characterize landslide scars through digital processing satellite images of Landsat - 5. The study area is the municipality of Nova Friburgo, in the mountainous region of Rio de Janeiro, which is very susceptible to these processes. Highlighting the features were carried out to identify these landslide scars. The results were compared to the slope of the study area according to the method of Ross (1994) in order to identify susceptible landslide areas.

2. Methodology

2.1 Study Area

Nova Friburgo is located in the mountainous region of the state of Rio de Janeiro at an altitude of 846 m, between 22°16'S and 42°31'O coordinates (Figure 1). According to IBGE (2010), the city has 182,082 inhabitants, distributed in an area of 933.4 km². The municipality of Nova Friburgo is part of the Fluminense Saw, in the central region of the state of Rio de Janeiro. According to the Geomorphological mapping of the state of Rio de Janeiro, the city is located in the degradation of relief system in mountainous areas, the reverse of the Serra do Mar, with very rough terrain. The strands are predominantly straight to concave, steep, crested tops aligned sharp or slightly rounded. Cities in the mountainous region as Nova Friburgo, Petropolis and Teresopolis, have areas of low thick soils and leached (DANTAS, 2001).

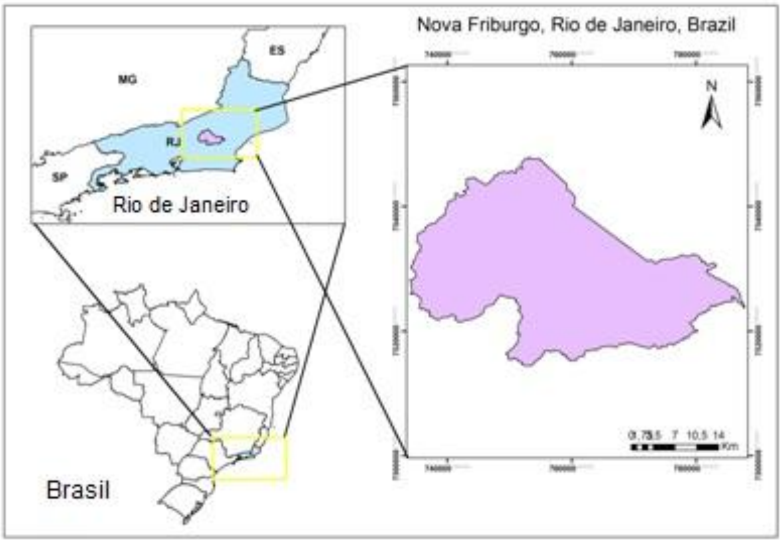

Figure 1. Study area localization map.

The area has a high density of drainage, with variable pattern. There is a predominance of altitude differences greater than 400 meters. The original vegetation was composed of rock formations, evergreen forest, alpine pastures (in the high peaks of the mountainous region, which are still present), and agricultural activities occupy the storm plains and lesser steep slopes (DANTAS, 2001).

2.2 Characterization of slip scars

Landslides produce scars with a well-defined geometry, are usually elliptical or conical, being formed by the head (where it starts slipping), the body (along the stretch affected by the removal and transport equipment) and the base (where deposits the conveyed material) (HANSEN, 1984; IPT, 1989). Furthermore, the slips usually occur along rivers drainage channels and on hillsides, the load carrying eroded material from the drainage channels and also slides adjacent to these channels. Often up originate in drainage headwaters, located on 35 degrees slopes forming, downstream debris cone. In this context, through the interpretation of direct and indirect elements it is possible to identify points in land, which are susceptible to landslides.

2.3 Image Processing

In this work we applied processing enhancement features of interest to the objectives of the study, facilitating the interpretation of the features caused by landslides. The images have been provided in surface reflectance value with the corrected atmospheric effects, and also georeferenced. To selected the study area, a cut in the image were necessary.

Images from satellite Landsat 5 TM sensor, September 4th, 2010 (path / row 216/076) and August26th, 2010 (path / row 217/075) to cover the study area at a time above, but as close as possible to the sliding events and scenes of June 19^{th,} 2011, (path / row 216/076) and May 9th, 2011 (path / row 217/075) to cover the study area after sliding events were selected. The intraband balancing technique colors of the overlapping areas was applied.

The image of May 9th, 2011 had a cloud over the study area, and to remove it, were used spectral math. We assigned the values zero and one, for cloudy and not cloudy pixels, respectively, multiplying the clouds image by the original image without cloud. These areas had to be taken from 2010 images not to infer in the comparison test results between images.

2.3.1 Selection of bands and obtaining color compositions

Colored compositions were tested to highlight features of interest based on spectral responses of the targets and the images statistical analysis such as mean, variance-covariance and correlation between bands. In this context, the statistical parameters were instrumental in the decision of the bands for the generation of colorful compositions and processing, as well as assist the analysis of the results.

The best compositions were obtained by bands 1, 2 and 3, and they showed very different from one scene to another, in relation to the sliding areas.

An RGB false color composition with the intersection of images from 2010 and 2011 was performed. For this, the corresponding bands of each image in different color channels, facilitating the visual analysis of sliding features were related. Through high-resolution images from Google Earth, slip and then areas were identified, held the spectral analysis of these areas before the landslide events (images 2010) and after the occurrence of landslides events (2011 Images).

2.3.2 Image enhancement techniques and characterization of mapped landslides

The enhancement of images was performed by subtraction technique between bands. This technique allows the identification of subtle differences in the spectral behavior of certain targets, reflected by differences in the gray levels of each band. The biggest difference bands and these differences of images were selected and added, creating a new image containing the sum of the differences. With this new image, it was possible to detect the coverage patterns change as the removal of vegetation caused by landslides.

It was used NDVI (Normalized Difference Vegetation Index) associated with the slope map to characterized the study area.

For the composition of this work, the softwares *Envi 5.0* and *ArcGis 10.2* were used.

2.4 Analysis of the environmental fragility

In this work were used TOPODATA project data (geomorphometric Database Brazil), which are SRTM data 90m, which were refined by kriging to 1 arc second (approximately 30 m) (VALERIANO, 2008). So it was generated slope to the city of Nova Friburgo. This geomorphometric variable is important in the interpretation and analysis of relief.

Declivity intervals used in this work follow the studies have established the ability to use critical values Ross Geotechnical. They respectively indicate the force of erosion, risk of slipping / slip and frequent flooding. The environmental fragility corresponds to the soil vulnerability to erosion. Faced with the different states of equilibrium and disequilibrium that the environment is submitted, Ross (1994) systematized a nominal hierarchy fragility represented by codes: very low (1), lower (2), average (3), high (4) and very high (5), as we can see in Table 1. These categories especially express the fragility of the environment in relation to the processes caused by diffuse runoff and concentration of rainwater.

Table 1. Slope classification proposed by ROSS, 1994.

Classes Hierarchical	Declivity Intervals
1- Very Low	to 6%
2- Lower	6% to 12%
3- Average	12% 20%
4- High	20% 30%
5-Very high	>30%

In this study it was applied to Ross methodology in the study area in order to identify the most likely to slip areas.

3. Results and discussions

In tropical countries like Brazil, most landslides are triggered by heavy rainfall, while geology, geomorphology and pedology also influence this natural disaster.

The events that occurred in 2011 can be explained by high rates of precipitation, which, associated with declivity and soil saturation, triggered one of the deadliest landslides in Brazil. In less than 24 hours, rained 326mm, more than what was expected for a week (National Institute of Meteorology – INMET).

On satellite images, landslides generally show scars in very light tones, as we can see in Figure 4. The light brown colors show the scar where the landslide happened on 11th and 12th of January 2011. The scars from these landslides (Figure 2) coincide with the faults on Rodrigues map (2013).

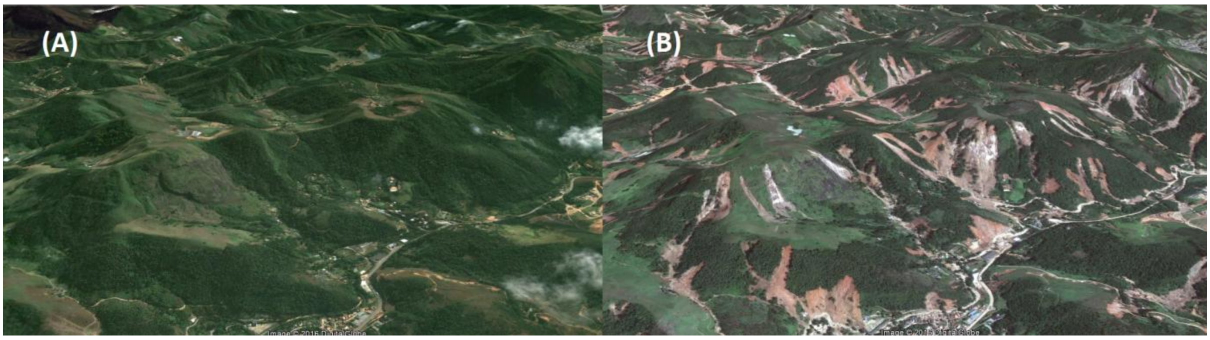

Figure 2. Landslide recognition in high resolution images. A:2010 and B 01/19/2011. Images from Google Earth.

We are able to see the dimension of the landslides in Figure 4, by comparing the image from 2010 and 2011. The mountain in the center of both images, during 2010 shows dark green, which probably refers to an area with vegetation and no soil erosion. But in 2011, after 326mm of rain in a short span of time, the soil saturated with water falls apart. And due to the geomorphology of the mountain, most of the mudslide was directed to the town, killing almost a thousand people.

ISBN: 978-85-17-00088-1

The RGB false color composition was made to facilitate the visual of landslide scars, and the differences on the visible bands (Figure 3.) The light areas shows the where landslides occurred.

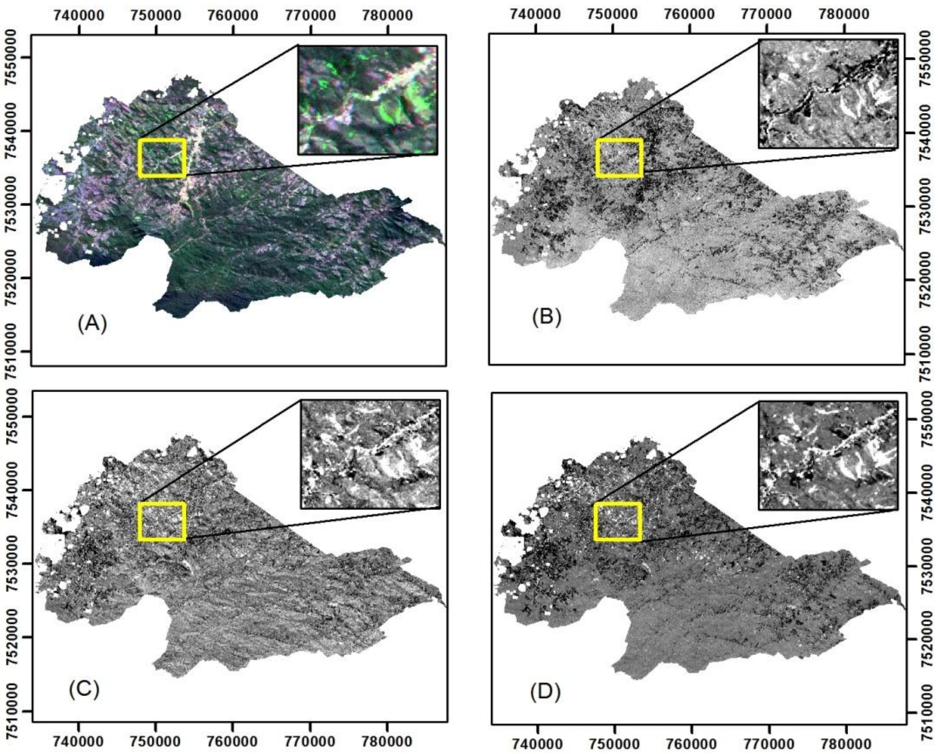

Figure 3. RGB false-color composition. A: R (b1, 2010), G (b1, 2011), B (b2, 2010). B: subtraction b1 (2011-2010). C: subtraction b2 (2011-2010). D: subtraction b3 (2011-2010).

By analyzing the map of the sum of the differences of the visible bands (Figure 4 A), it was verified that the area in green, which remained constant with low reflectance change (-3 to 3%), are related to areas where there were no changes in surface, areas blue represent a significant reduction in reflectance (-3 to 75%) are related to gain density of vegetation and areas of orange and red (3% to 202%) are related to partial or complete removal of vegetation, featuring slip scars and their surroundings. Thus it was set the 3% threshold that led to the mapping seen in the Figure 4 B below.

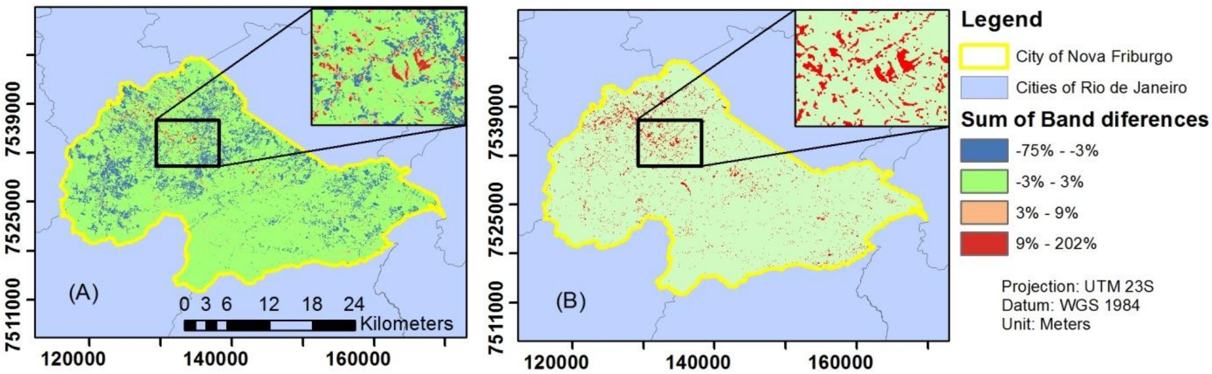

Figure 4. Sum of bands differences (A) and mapping with 3% threshold (B).

The mapping accuracy was verify by sorting 400 points randomly, 150 in the slip scars class and 250 in the no slip scars class, getting a Kappa index of 0.77 and an Overall Accuracy of 89,5%.

As we can see in slope map (Figure 5 A), Nova Friburgo has most of its territory in declivity higher than 30%, which, according to Ross (1994), is an area with high environmental fragility. Already NDVI of 2010 images indicates good vegetation cover in most areas considered at risk by the slope map (Figure 5 B).

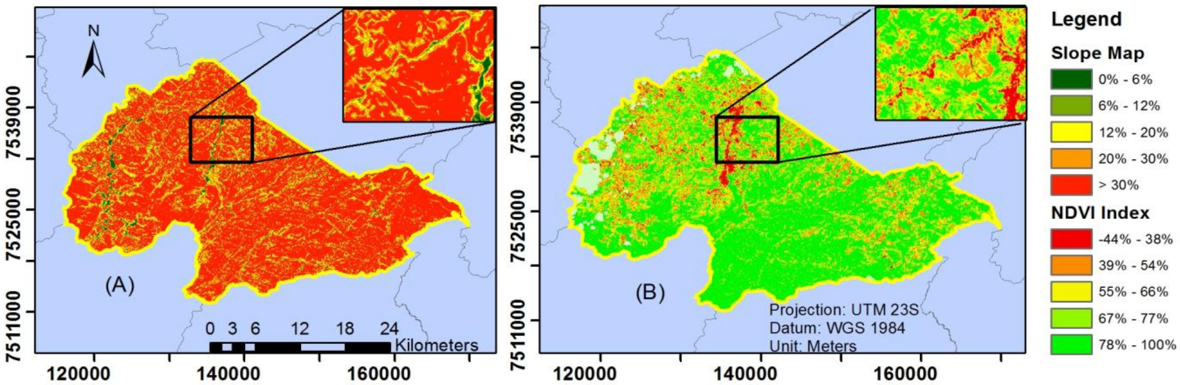

Figure 5. Slope Map (A) and NDVI Index (B).

According to Saha et.al (2005), "The structural discontinuities such as major faults, thrusts and lineaments have in general the most dominant impact on landslide occurrence". And in Rodrigues (2013) research there is a geological map, which shows all the faults in Nova Friburgo.

The characterization of areas mapped as slips made, based on the slope values and NDVI (of 2010 images), shows that more than 68% of the sliding areas had very higher risk (> 30%) but 73% of these same areas had high NDVI indicators (> 60%), showing that the vegetation is not a decisive factor for the sliding when the slope of the land is very high. This behavior can be observed through the slope and NDVI histograms of areas mapped as slip (Figure 5).

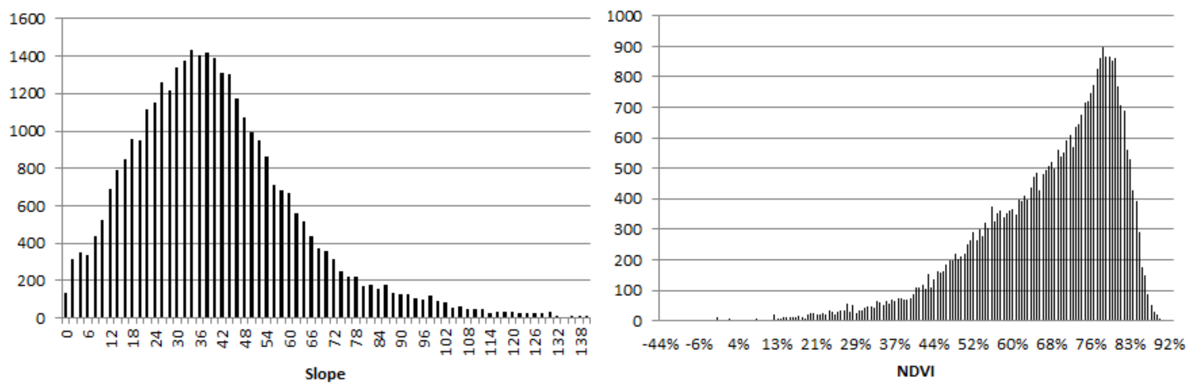

Figure 6. Slope and NDVI histograms of areas mapped as slip.

These hazards happened due to a combination of multiple factors, such as geological structural, soil saturation, high declivity and heavy rainfall. However, the vegetation cannot be considered a trigger factor to landslides, since the images from 2010, show the mountain in dark green color which is vegetation.

4. Conclusions

To characterize slips of scar using Image Processing techniques in Nova Friburgo – RJ, it was necessary to download satellite images from USGS, and process them to enhance the spectral and special quality, to extract information about landslides. The cloud covers over the study area were removed to improve the characterization of landslide scar. An RGB false-color composition was performed to facilitate the visual analysis of sliding scars. And geological, geomorphologic and pedological data were researched to deepen the analysis.

The evidences showed that the large amount of concentrated rain, in a few hours, in combination with multiple factors such as geology, geomorphology, soil saturation and high declivity, were the trigger the 2011 landslide.

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