

The Use of Image Analysis to Understand Brazil's Worst Natural Disaster

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ABSTRACT

The worst natural disaster in Brazil's history occurred in January 2011 and directly affected the mountainous region of the State of Rio de Janeiro. With the use of ArcGIS 10.2's new image analysis tools, including Slider, NDVI and Difference, together with Landsat 5 images and a model interpolated with real terrain data, a 3D Web Scene was generated for public visualization. The results, provided in an interactive web interface, allowed a better understanding about the consequences of the tragedy and the configuration of the vegetation and land occupation in the region, before and after the event.

INTRODUCTION

On January 11th and 12th, 2011, a devastating tropical storm hit the mountainous region of the State of Rio de Janeiro, Brazil, located at elevations varying from 900 to 1800 meters above the sea level. It was recorded a volume of 180 mm of rainwater in 30 hours, resulting in flooding and mudslides. According to authorities' reports, more than 29,000 persons were displaced, about 700 injured and about 900 deaths (PEREIRA, 2011). One year after the disaster, the number of dead and missing people increased to 1,300.

Sequential land/mud slides struck different geographic areas affecting more than 800,000 inhabitants in three cities: Nova Friburgo, Teresópolis and Petrópolis. The result of the slides and the incredible volume of rainwater over a short period of time resulted in devastating floods that uprooted trees, telephone and electric poles, damaging water and fuel lines, and blocking and destroying streets, roads and bridges. Communications were heavily affected by the lack of electricity and mobile phones lost their signals (PEREIRA, 2013).



Fig 1: Location and limits of Teresópolis county, Rio de Janeiro, Brazil.

Between the affected areas was the *Parque Natural Municipal Montanhas de Teresópolis* (PNMMT) and its neighborhood region at Teresópolis, a touristic city in the mountainous region of the State of Rio de Janeiro, Brazil, with a population of 163,805 people and located at 100 km away from the city of Rio de Janeiro (figure 1). The city is known as the home of Brazilian National Soccer Team. The uncontrolled growth of Teresópolis and other cities of the region near Rio de Janeiro led to the construction of a great number of houses in mountainous terrain or on the banks of rivers.

This fact, together with a 30-hour rainfall that exceeded what was expected for the entire month of January 2011, caused a series of floods and mudslides. The event was considered the worst weather-related tragedy in Brazilian history.

Created in July 2009, the PNMMT is a natural park located in the northwestern portion of the county (figure 2). It has an area of 4,500 acres and is considered the largest municipal park in the State of Rio de Janeiro, being the result of a participatory and democratic process that created the first Unit of Conservation with integral protection established by the municipality. It represents an important step for biodiversity conservation in the mountainous regions of the State (SMMADC, 2009).

The objective of this study was to identify the areas affected by the natural disaster using image analysis and ArcGIS 10.2. A 3D virtual model was generated using a hydrologically consisted DEM, orthorectified aerial photographs and field data collected in the park using GPS, to visualize and understand more broadly the consequences of the tragedy, and the configuration of the vegetation and land occupation in the region before and after the event. Satellite images of August 2010 and August 2011 were also used for the NDVI calculation.

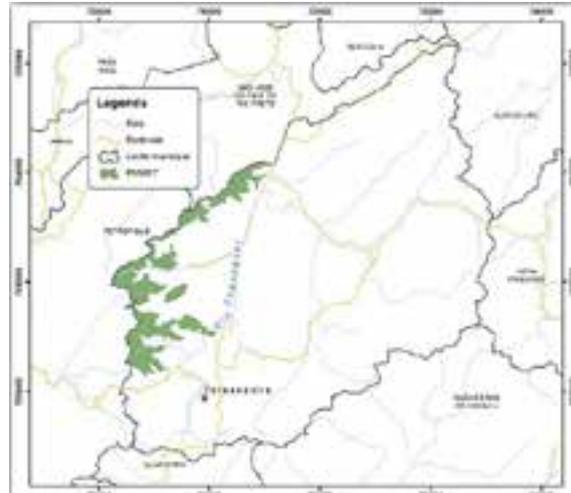


Fig 2: Parque Natural Municipal Montanhas de Teresópolis (PNMMT) and its neighborhood region at Teresópolis.

DEVELOPMENT

In order to generate the virtual 3D model, a Digital Elevation Model (DEM) was interpolated using Contour, Point Elevation, Streams and City boundary data and the *Topo to Raster* tool. To compose the model, orthorectified aerial photographs of the region were placed over the generated DEM. Other data with relevant information such as access roads, tracks and points of interest acquired in field survey were also included.

A strong characteristic of the tragedy caused by the rains was the occurrence of landslides in many different places. Using the NDVI (Normalized Difference Vegetation Index), an indicator that shows significant results in the detection of changes in green vegetation cover caused by deforestation, fires and landslides (MOREIRA, 2013), it was possible to verify the difference observed between the months of August 2010 and August 2011. The development of the study followed the methodology represented schematically in figure 3.

TM (Thematic Map) Sensor of Landsat 5 was used as the source of images (INPE, 2013) with bands 3 and 4 corresponding to red and near infrared bands of August 2010 and August 2011 images, representing data before and after the tragedy. When working with images from satellite sensors, it is common that each spectrum band came in separated files. As the images used have seven bands, the first step was to make a composition of these bands for each of the images. Using the *Composite Bands* tool of ArcGIS, the seven original files were unified into one. The generated file still have seven separate spectrum bands and for viewing, it should be selected three of these bands to compose the RGB channels. For a composition with natural colors, the bands 3, 2

and 1 were chosen respectively for the R, G and B channels. For the vegetation analysis, was adopted the composition 543 of the RGB channels.

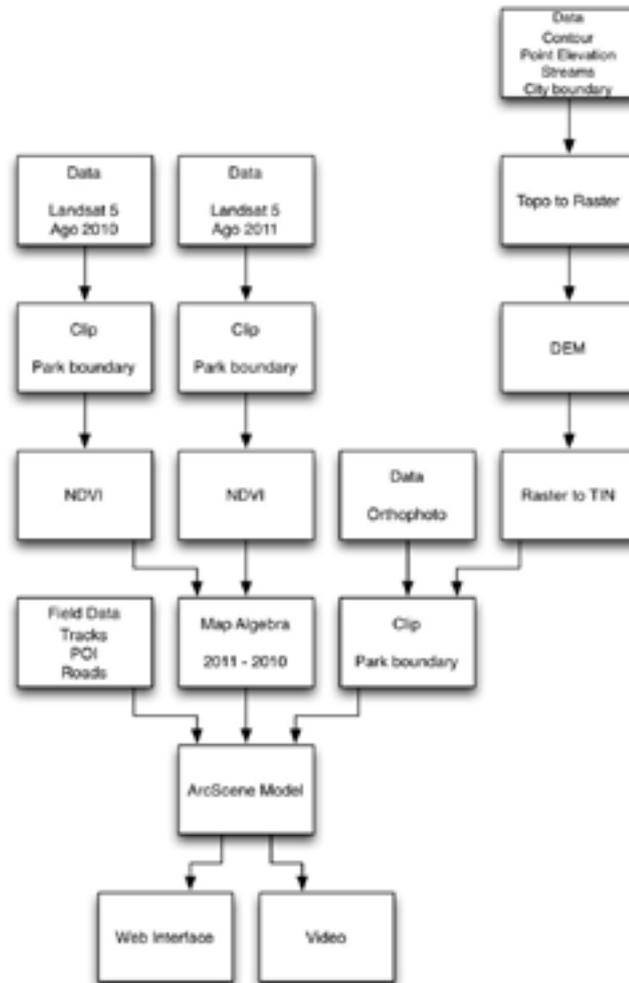


Fig 3: Methodology used, showing the sequence of data preprocessing and NDVI calculation, in parallel with the creation of the 3D model. The integrated results are presented using a Web interface.

The next step was the extraction of the study area (PNMMT) from the images using the *Extract by Mask* tool, where the matrix file to be cut and the layer containing the polygon with the boundary of the Park were indicated. At the end of the processing, only the matrix data contained in PNMMT area for the August 2010 and August 2011 images were represented. After the area definition, the NDVI was calculated for bands 3 and 4 in both images, using the *NDVI* tool. Finally it was calculated the NDVI variation (LILLESAD, 2004), also for both images using *Map Algebra* tool.

The created model was exported as a 3D Web Scene using CityEngine new toolset inside ArcScene (ESRI, 2013). With CityEngine Web Viewer provided by ESRI, the model was made available at the UNIFESO website and can be accessed by the link www.unifeso.edu.br/lpp. The 3D model is planned to receive better images and new data in a future update.

RESULTS AND ANALYSIS

A classificatory symbology was defined to indicate the degree of deforestation or regeneration according to the pixel values of the difference between the 2010 and 2011 NDVI images. As the value of each pixel could range from -200 to 200, it was considered that values within a margin of 10% of that amplitude (-20 to 20) would be neutral. Pixels with values below -20 were considered areas of apparent loss of vegetation coverage, and areas with sensitive regeneration were represented by pixels with values greater than 20. Figure 4 represents the obtained results.

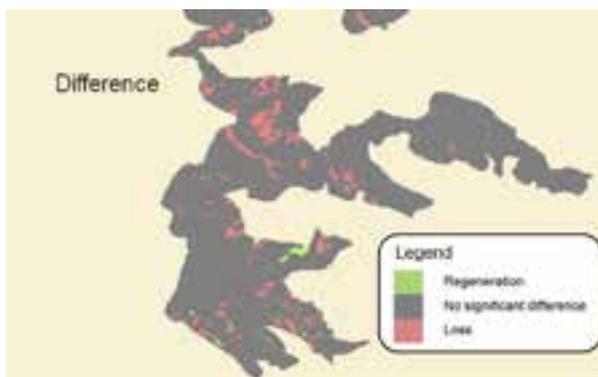


Fig 4: NDVI difference calculation, showing areas of vegetation loss and regeneration inside the PNMMT.

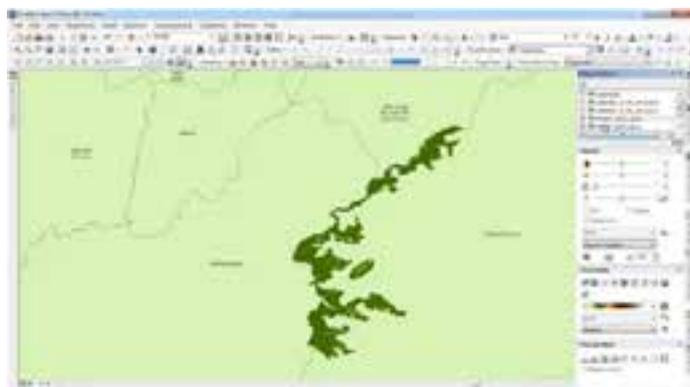


Fig 5: NDVI mapping of the PNMMT area, showing its location related to Teresópolis and neighboring counties.

The ArcMap interface with the NDVI mapping of PNMMT area using 2010 satellite image, processed with image analysis, are presented in figure 5. With the *Slider tool* it was possible to compare the difference in the vegetation coverage between the 2010 and 2011 data. The final 3D model in natural colors in a partial view of the Park area is represented in figure 6. Some details of roads, tracks and the Park boundary are also indicated.



Fig 6: 3D model in natural colors highlighting roads in red, tracks in green, and the boundary of the Park in yellow.

Figure 7 shows the 3D model in Comparison Mode, using ESRI CityEngine Web Viewer interface. In the left side, the NDVI 2010 option was selected and in the right side the orthophoto option was chosen. The options can be visualized in the column *Layers* in the right side of the figure. Using slider, represented by a vertical line and two arrows, it is possible to compare the difference in vegetation coverage between 2010 and 2011, both in NDVI and in Landsat 5 images.



Fig 7: 3D model in Comparison Mode with ESRI CityEngine Web Viewer interface.

CONCLUSIONS

To analyze the changes of the vegetation coverage in PNMMT caused by the action of rain tragedy and also by deforestation, this study was done using the *Normalized Difference Vegetation Index* (NDVI). The analysis presents significant results in the detection of changes of the green vegetation coverage that can be seen in the 3D model of the park using ESRI Web Visualization tool. Using ArcGIS 10.2's new Image Analyst features NDVI, Difference and Slider, combined with Landsat 5 public images, a 3D virtual model was generated and made available to visualization with an interactive Web Interface. Based on the mapping carried out, environmental policies aimed at reforestation and regeneration of degraded areas could be implemented.

The final product could also be used for other studies and dissemination of the PNMMT, serving also as an important management tool. Among other possibilities, the 3D Virtual Model could be used for:

- (a) production of thematic maps that facilitate analysis for the establishment of new areas with potential related to ecotourism;
- (b) dissemination of existing areas inside the Park designated for that purpose, using cartographic products and the web;
- (c) environmental education and awareness of the local population in order to preserve the biodiversity in the park area.
- (d) terrain relief analyses including modeling of water flows and mass movements.

In further research and future implementations, besides the use of better satellite images allowing more refined analysis, this study can follow the natural path towards the Web GIS, with the provision of information for the general community through portals of public institutions and/or higher education institutions web sites. Through a collaborative GIS, ordinary citizens could also feed the database with information from their everyday life, and participate more actively in the public management. Such collaboration could provide a new era for the citizens in their dealings with public managers and with the municipality where they live, also contributing to the environmental education and awareness in order to mitigate the impacts of future disasters like that one occurred in January 2011.

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