USE OF A LANDSAT-TM TIME-SERIES FOR MONITORING EROSION FEATURES IN AREAS OF GOLD EXPLORATION, SERRA TEPEQUÉM, RORAIMA STATE, BRAZILIAN AMAZON

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ABSTRACT

This paper discusses the use of a Landsat-TM time series for monitoring erosion features caused by the action of independent miners (*garimpeiros)* in the search for gold. Five free-cloud Landsat-TM scenes acquired in March/87, October/91, November/94, January/96, and January/99 were used to produce maps showing temporal evolution of mined areas in the region of the Tepequém plateau. To produce detailed thematic maps of the degraded areas, images were segmented using a region growing approach, followed by the application of a region-classifier algorithm based on clustering techniques. According to these maps, eroded areas increased by 388% from 1987 to 1994, comprising 107 ha, 255 ha, and 415 ha, in the 1987, 1991, and 1994 images, respectively. Due to a governmental action, combined with the exhaustion of the mineralized alluvial deposits, *garimpeiros* abandoned the region around 1993/1994. As a result, vegetation soon started recovering eroded areas. Images acquired in 1996 and 1999 showed that degraded areas decreased to 366 ha and to 339 ha, respectively. This work shows that Landsat-TM images may be an efficient mean for monitoring erosion features, even under the ecological characteristics of the Tepequém plateau, where eroded areas have low contrast relative to surrounding open grass fields. Additionally, the image processing procedures permitted to save time and to curtail inherent subjectivity involved in the visual interpretation, producing accurate thematic maps of land use/cover change classes.

1. INTRODUCTION

During the late eighties and early nineties, Roraima State, and particularly the region of the Tepequém plateau, was severely exploited by independent miners (*garimpeiros*) in the search for gold (Oliveira, 1995), resulting in several degraded areas along streams. In the search for gold, *garimpeiros* use high-pressure water jets to wash mineralized alluvial deposits. This practice causes removal of the vegetation cover along stream banks, so creating conditions to start erosional process in mined areas. In spite of constituting a serious environmental problem, few attention has been given to study the impact caused by informal gold mining activities (*garimpos*) in the Brazilian Amazon. This kind of activity causes two major environmental problems. The first one is related to the pollution of rivers and streams due to the use of mercury amalgamation for gold recovery. The second problem is the deforestation and erosion along mined streams. This second mining-derived problem may be addressed directly by remote sensing techniques.

Using visual interpretation of Landsat-Thematic Mapper (TM) images, Melo & Almeida-Filho (1996) showed preliminarily that mined degraded areas could be mapped under the physiographic conditions of the Tepequém plateau. More recently, Almeida-Filho & Shimabukuro (1999) showed that the degraded areas in that region could also be identified using orbital radar images acquired by the Japanese Earth Remote Sensing satellite (JERS-1). In this study we use techniques of automatic classification applied to a Landsat-TM time series, aiming at to map and to monitor the evolution of areas degraded by gold mine activities in the Tepequém plateau region, over a twelve-year period, from 1987 to 1999.

2. STUDY AREA

The study area covers a surface of approximately 150 square kilometers, located in the north-central part of the State of Roraima, Brazilian Amazon, close to the border with Venezuela (Figure 1). It includes the Tepequém plateau, being defined by the following geographic coordinates: 61° 48' 15'' - 61° 37' 53'' west longitude and 3° 50' 30'' - 3° 44'20''

north latitude. The region has a tropical climate with a dry season from October to March, and a rainy season from May to September. Mean annual precipitation varies from 1,750 to 2,000 mm, with daytime mean temperatures generally higher than 30° C during the entire year.

The Serra Tepequém, comprised by Middle Proterozoic sandstones and conglomerates of the Roraima Formation (Borges and D'Antona 1988), constitutes an isolated plateau bounded by abrupt sloping erosion scarps, standing up to 1,000 meters above the surrounding metavolcanic country rocks. Mainly savanna open grass fields constitute the vegetation cover in the plateau, whereas surrounding area is covered by a tropical rain forest (see color composite in Figure 2).
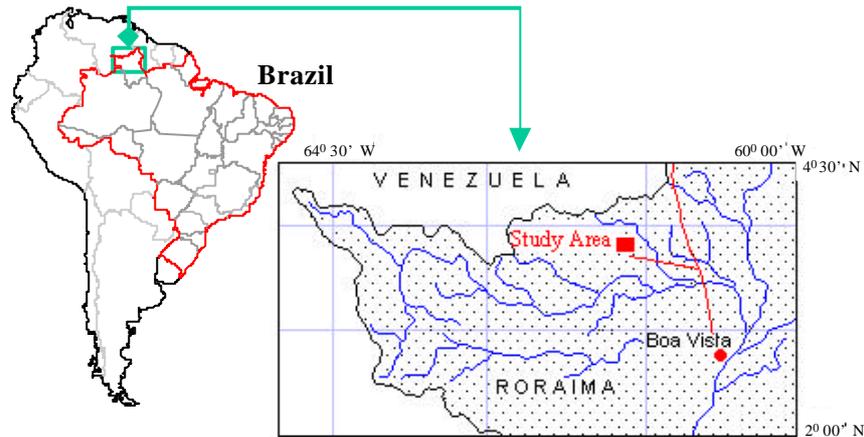
Figure 1. Location of the study area.

3. LANDSAT-TM DATA AND DIGITAL PROCESSING

In this study we used all the available free-cloud Landsat-TM scenes covering the study area (path 233, row 57), acquired in March/87, October/91, November/94, January/96, and January/99. Images were converted to the UTM coordinate system, using common control points extracted from a topographic map at the scale of 1:100,000. This procedure yielded a registration accuracy equivalent to 0.8 pixel. Before processing, digital numbers were converted to reflectance values, and a 1% linear contrast stretch was applied to all the images to adjust grayscale ranges. As an attempt to improve performance of image segmentation, a median filter was applied to smooth the images.

The digital image processing was carried out in a geographic information and image processing system (SPRING) developed by INPE (Câmara Neto et al., 1996). Image segmentation and region-classification techniques were the digital image processing techniques applied to generate thematic maps of the erosion features. Image segmentation permits partitioning off images into homogeneous regions, which may have particular common attributes such as gray level means. The used approach, based on region growing technique, can be described by the following sequential steps (a) segmentation of the image into regions (one or more pixels); (b) comparison of each segment with its neighbors and merging it with the statistically more similar segment, updating the mean gray level; (c) segment continues growing by comparison with the new neighbors until to have no more joinable segments, when a completed region is labeled; and (d) the process moves to the next uncompleted cell, repeating the entire sequence until all cells are labeled (Almeida-Filho et al., 1977).

Landsat-TM band 3 (0.63-0.69 μm) of the different years were selected for segmentation, due to the better enhancement between eroded areas and sparsely surrounding vegetated terrain,. Best definition of the target areas in segmented images were obtained using a similarity threshold (distance to the center of the classes) and an area threshold (number of pixels) of 20 and 10, respectively.

A region classifier algorithm based on clustering techniques was used to classify segmented image. The approach can be described by the following steps: (a) firstly it is created a list of regions ordered by size (number of pixels); (b) the classes present in the regions are detected; and (c) a k-means algorithm is applied to reclassify the regions, based on the class means. In the first step, the regions are ordered in a decreasing order by size. In the second step, the detection of classes is accomplished as follows: the statistical parameters (mean vector and covariance matrix) of the first region are taken as the initial parameters for the class. This region is then removed from the list. Next, given a chi-square threshold and the statistical parameters of the class, a decision surface is defined (in this case an hyperellipsoid). All the regions in the list with mean vector lying inside this hyperellipsoid are marked as not eligible for class detection. Finally, the mean

vector for the class is updated. This second step is repeated until the list does not contain any other region eligible for class detection. In the third step, the regions are classified by using the mean vector of each class as the initial centers for the k-means algorithm. Chi-square acceptance threshold of 99%, 95%, and 90% were tested. Based on visual analyzes of the classified images on the screen, a 90% acceptance threshold was selected as the most appropriate to define eroded areas. Due to the low spectral contrast between eroded areas and natural open grass fields in the Tepequém plateau, ground truth information was very important to define classes in the region-classified images. In this process some classes were regrouped to express more faithfully the terrain features.

4. RESULTS AND DISCUSSIONS

Figure 2 shows a color composite and the Landsat-TM time series covering the region of the Tepequém plateau. Hues of magenta and green in the color composites indicate, respectively, areas of open grass fields over the plateau and areas of tropical rain forest in the surrounding. Exception for a few clouds, bright areas in the Landsat-TM band 3 images indicate degraded terrain associated with gold mining activities (images cover 15 x 10 km).
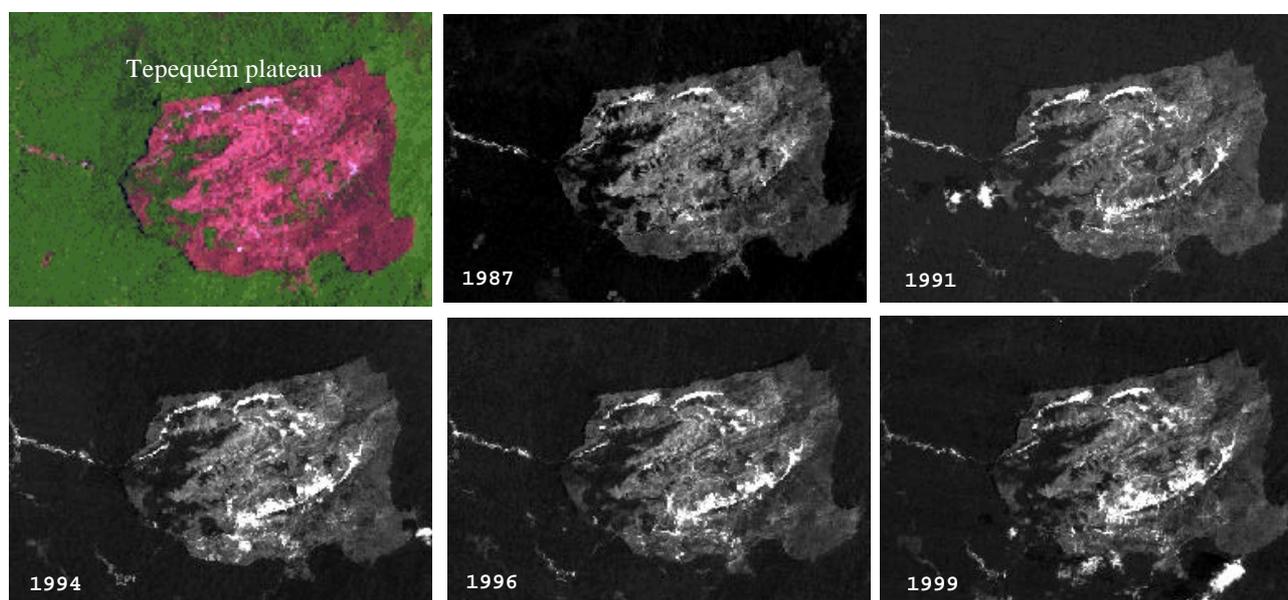

Figure 2. Color composite and Landsat-TM time series of the study area. Hues of magenta and green in the color composite indicate, respectively, areas of open grass fields over the Tepequém plateau, and areas of tropical rain forest in the surrounding; bright areas in the Landsat-TM band 3 images indicate degraded terrain associated with gold mining activities (images cover 15 x 10 km).

Thematic maps showing distribution of degraded areas are showed in Figure 3. Up to 1987, gold mining areas predominated along the stream that drains the northern part of the Tepequém plateau. Small mined areas also occur downstream outside of the plateau, in areas of tropical rain forest. Data from 1991 indicated that mining activities had been extended to streams in both central and south parts of the Tepequém plateau. Such activities continued growing in the region, according to the data from 1994. Based on the maps, degraded areas increased by 388% from 1987 to 1994, comprising 107 ha, 255 ha, and 415 ha, in 1987, 1991, and 1994 Landsat-TM images, respectively.

Due to a governmental action, combined with the exhaustion of the mineralized alluvial deposits, *garimpeiros* abandoned the region around 1993/1994. As a result, vegetation soon started recovering eroded areas. Maps based on 1996 and 1999 TM images showed that degraded areas decreased to 366 ha and to 339 ha, respectively (Figure 3).

5. CONCLUSIONS

The results show that Landsat-TM images can be used to produce detailed maps of degraded areas associated with the activities of independent miners in the Amazon region. Temporal maps obtained from the time-series images constitute

a reliable basis for monitoring evolution of degraded area over time. Additionally, the adopted image processing procedures permitted to save time and to curtail inherent subjectivity involved in the visual interpretation, producing accurate land use maps.
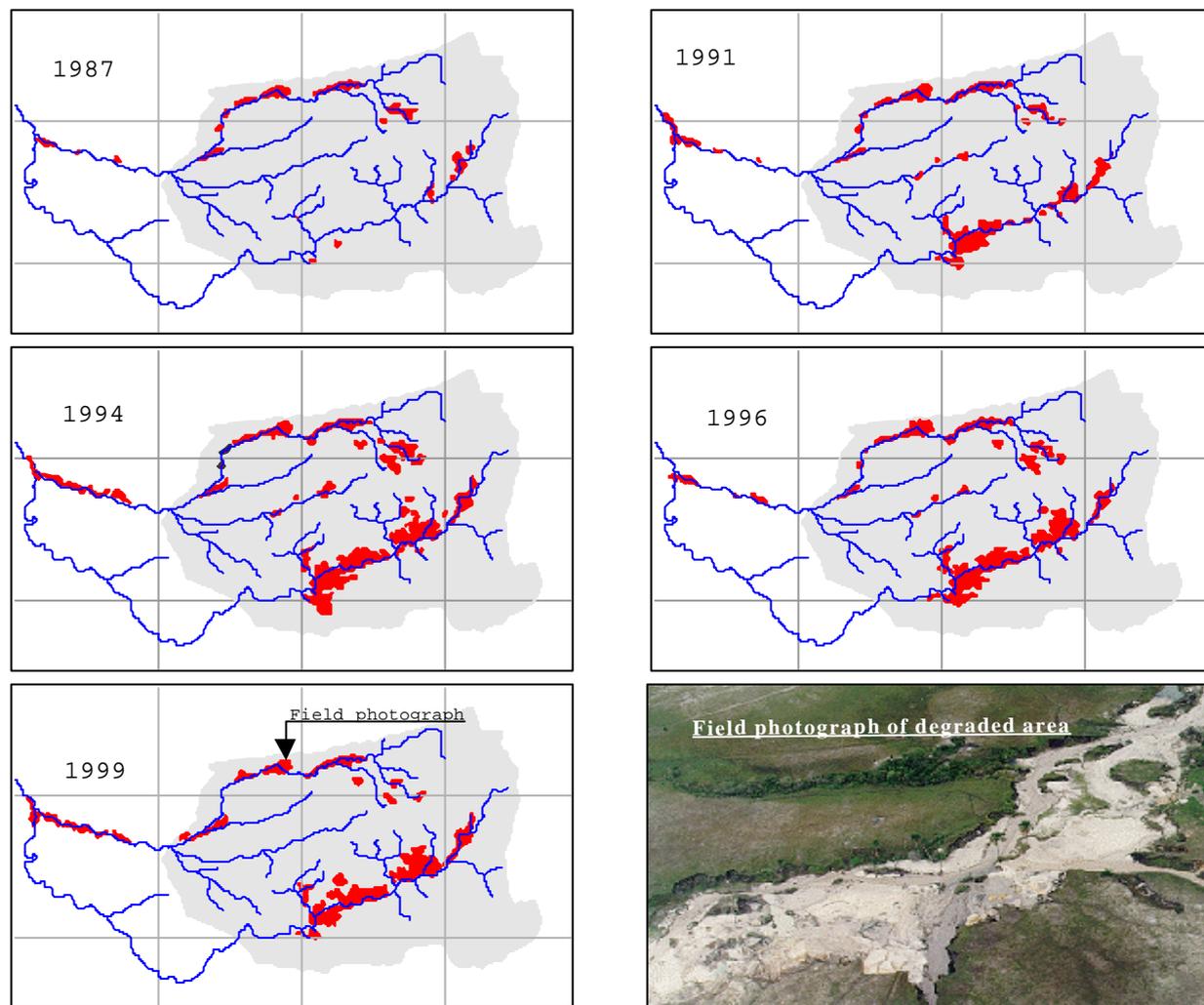

Figure 3. Degraded areas (red) caused by mining activities in the region of the Tepequém plateau increased by 388% from 1987 to 1994, comprising 107 ha, 255 ha, and 415 in 1987, 1991, and 1994 maps, respectively. After *Garimpeiros* left the region (around 1993/1994), vegetation starts recovering degraded mined areas, Maps based on images acquired in 1996 and 1999 showed that degraded areas decreasing to 366 ha and to 339 ha, respectively. Field photograph was taken in 1995 and shows an example of degraded area (see arrow in 1999-map for location).

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