Modern Environmental Science and Engineering (ISSN 2333-2581)
December 2016, Volume 2, No. 12, pp. 809-814
Doi: 10.15341/mese(2333-2581)/12.02.2016/007
Academic Star Publishing Company, 2016
www.academicstar.us

Measuring Land Cover Changes Caused by Surface Mining Expansion Using Lands at Data at Camaquã Mines, Brazil

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Abstract: The multi-temporal image analysis is one of the most convenient and useful ways to determine how specific attributes of a particular area have changed between two or more regular intervals, comparing aerial photographs or satellite images of the study area taken at different times. This study examined the impact of the expansion of degraded areas through the mineral production and subsequent changes in natural vegetation after leaving the area over a period of 26 years in a region affected by copper mining over a century generating environmental, social and economic impacts atCamaquã Mines, southern Brazil, using geographic information system (GIS) and remote sensing (RS) techniques. A series of Landsat images were classified by normalized difference vegetation index (NDVI) to produce three land cover maps of the region. From comparisons between these maps and areas with no vegetation cover, it was possible to quantify the variation that occurs in the landscape, identifying the evolution of changes in natural vegetation area. It has been observed that between 1985 and 1996 the degraded area has increased 8%, however, in 2011 (the last year analyzed), there was greater vegetation cover than in the first reporting period, resulting in vegetation recovery of 26% when compared to 1985.

Key words: remote sensing, GIS, mining, land cover, NDVI

1. Introduction

After the advent of the first remote sensing satellite (Landsat 1), in 1972, the preparation of accurate reports about the use and land use, changes in vegetation cover, environmental monitoring, natural resource management and urban development have become relatively simple, enabling the making of numerous studies combining field research and satellite data in many areas, such as urban and agricultural areas. In the case of inaccessible areas, the only method of obtaining data for the application of geographic information system (GIS) and remote sensing (RS) techniques in the observation of periodic changes on the surface of the Earth [1].

Although this technology has been available for many years, the use of remote sensing for monitoring of mining activities has rarely been applied, although, according to K. Koruyan et al. (2012) [2], this tool has been proven valuable in the management and planning of some aspects in the operation of mining projects.

Change detection in remote sensing is described by Singh (1989) [3] as “the process of identifying differences in the state of an objector phenomenon by observing it at different times”, determining how specific attributes of a particular area changed between woor more regular intervals, comparing aerial photographs or satellite images of the area taken at different times. In general, the detection of changes in the characteristics of the earth’s surface, according to

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Lu et al. (2011) [4], provides the basis for a better understanding of the relationships and interactions between human and natural phenomena, assisting in the management and use of resources; and invariably this involves the application of multi-temporal image analysis.

In this case study, we have examined the impact of expansion of degraded areas for mineral production and subsequent changes in natural vegetation over a periodof 26 years in a region affected by copper surface mining for over a century, causing environmental, social and economic impacts in Minas do Camaquã, in the municipality of Caçapava do Sul, Rio Grande do Sul, Brazil (Fig. 1). Using remote sensing techniques, degraded and recovered vegetation areas post-mining activity were measured and calculated based on multispectral and sequential analysis of satellite images of normalized difference vegetation index (NDVI).

It was adopted as image selection parameter: (1) the period in which it had data availability (the Landsat 5 satellite was launched in 1984 and closed in 2013), (2) image quality that would allow the application of the vegetation index and (3) representativeness in relation to historical events in the region.

(1) 1985: Four years after mining company starts modern and mechanized operation;

(2) 1996: year of deactivation and abandonment;

(3) 2011: one year before starting ecotourism activities.

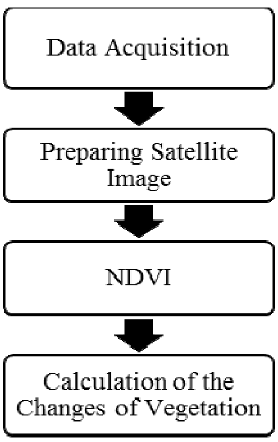

Fig. 1 Flowchart of methodology.

2. Material and Methods

In order to check the environmental impact and detect the evolution of changes in vegetation cover in an abandoned mining area, remote sensing techniques have been applied in the analysis of a Landsat time series. For the acquisition of data, the coordinates of the study area (described in Study Area topic), satellite images Landsat 5 (which has 30 meters of resolution in the bands of visible and infrared) were collected during three different periods, August 1985, June 1996 and April 2011, and then the impact coverage zones were determined. Finally, the degraded area and in particular the changes in vegetation cover were quantified.

The Fig. 1 shows a sequence of tasks applied in this study, and each step of analysis and image processing are explained in detail in the following topics.

3. Study Area

The study area is located between latitude and longitude -30.908591, -53.446582 and is part of the geological unit “Escudo Sul Rio-grandense”, Caçapava do Sul district. The copper ore discovery in the region is dated 1865 and there were several cycles of operation and decommissioning until the Second World War.

In 1942, the Brazilian Copper Company (CBC) was founded, with the participation of the State Government, the National Lamination Metals and owners and concessionaires of the mines. Its foundation arose from the need to produce strategic materials, including copper, during the war. In 1952 the Pignatari Group took control of the company, selling it to the Federal Government through the National Bank for Economic and Social Development (BNDES), and in 1975 the operation was suspended given the poor conditions of underground mining, which had reached 150 meters of depth, and the deactivation of the metallurgy that used copper produced in Minas do Camaquã. In this period, the CBC has directed its activities to geological research in order to develop the characterization of the ore and expansion of reserves, thus allowing the implementation of the "Camaquã Expansion Project". Mining activities were resumed in 1981 and highly mechanized extraction techniques came to be used both in underground mines and in open-pit mining. In 1987, BNDES assumed the entire bank debt of the company and in 1988 the CBC was put up for auction and has not been sold to any of the companies qualified by withdrawal (the companies qualify by withdrawal? Consider redrafting this bit). As a workaround, the CBC has just been bought by its own employees, who have come to form a new company. The BomJardim SA took over the activities, paid off its debt to the BNDES, before the deadline stipulated in the Protocol of Intentions, and continued to mine copper until May 1996, when the economically viable reserves known became totally depleted [5].

4. Image Data and Processing

For this study we have used Landsat 5 satellite images, obtained at the Brazilian National Institute for Space Research (INPE) website [6]. The images were processed in ArcGis and ERDAS software. The limits of mining and degradation were determined in the time interval using digital image processing. After delimitation and selection of the study area, the vegetation index (VI) tool available on ERDAS was applied.

Fig. 2 Location of the study area.

5. Estimation of Change in the Natural Vegetation

The Vegetation Indexes (VI) are computed and calculated from the numerical value of brightness, this work will be used vegetation index (NDVI), which in addition to map also allows you to measure the quantity and condition.

The NDVI is calculated using the portions of electromagnetic energy reflected by the vegetation in the bands of red (wavelength = 0.6 micrometers) andnearinfrared (wavelength = 0.8 micrometers). It is the product of a function which takes as input parameters from the spectral bands of red and infrared. The reflectance of bands 3 (red-visible) and 4 (infrared-near) of the Landsat 5 sensor, which are determined by the following relationship:

$$\rho_{0,i} = \frac{L_{rad} * \pi}{E_{0,i} * cos\theta * d_r} \quad (1)$$

Where $\rho_{o,i}$ is the spectral reflectance in band i, d_r is the inverse square of the Earth-Sun distance in astronomical unit, $E_{0,i}$ is the average value of exoatmospheric solar irradiance in the band i expressed in $Wm^{-2}\mu m^{-1}$ (solar constant), θ the solar zenith angle (calculated from the solar elevation angle) and L_{rad} is the spectral radiance in band i in $Wm^{-2}sr^{-1}\mu m^{-1}$.

After thatwas carried out the atmospheric correction by the Dark Object Subtraction (DOS) method, using the histogram of each band to select the darkest pixel [7].

The NDVI was determined by the following relationship:

$$NDVI = \frac{\rho iv - \rho v}{\rho v + \rho v} \quad (2)$$

Where ρiv and ρv represent the reflectance bands in the infrared and red.

As a result of the application of Eq. (2), the product generated is stamped with the values of NDVI ranging within the range -1 to +1, with -1 representing total absence of vegetation and +1 maximum detected the presence of vegetation.

6. Results and Discussions

After the images were processed and generated the NDVI indexes, the cutoff of about 0.30 was set to vegetation and no vegetation. Thus, all above 0.30 was considered as vegetation and all below that was considered as no vegetation.

In Fig. 3 you can see the vegetation dynamics of change in the study area, characterized by a contraction of the same between the periods 1985 and 1996, the mine operation lifetime, and finally, expanding the vegetated area in the period 1996 to 2011, the period after deactivating the mine and abandonment.

Through analysis of NDVI index, which defines thecutat 0.30 wascalculated in the software ERDAS the vegetation pixel count (NDVI > 0.30) and degraded area (NDVI < 0.30), as the satellite has a spatial resolution of 30 meters, the area of each pixel corresponds to 900 m². The measurements of surface mine expansion and vegetation cover area changes are presented in Table1.

The Fig. 4 below shows a graph with the evolution of degraded area in the analyzed period, in which there is a clear recovery of the vegetation on the degraded area between the period from 1996 to 2011.

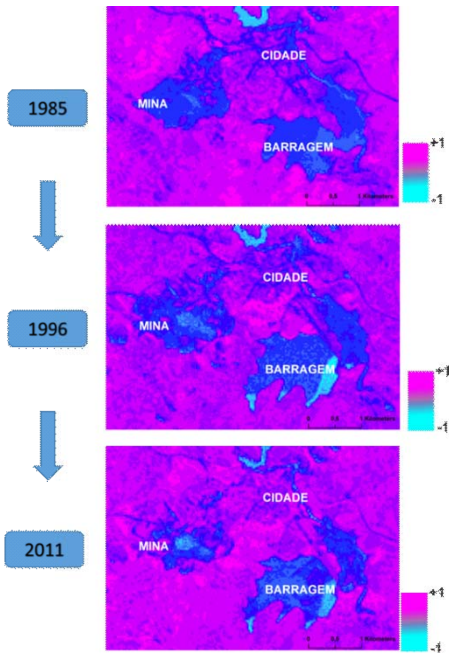

Fig. 3 An example of the land use/cover expansion and effect on vegetation between 1985 and 2011. (+1) Vegetation. (-1) No vegetation. Mine (mina), Town (cidade) and Dam (barragem).

Table 1 Expansion of mining and vegetation cover area.

Area(m²)	2011	1996	1985
Degraded	4,693,500	6,300,000	5,825,700
Vegetation	16,785,000	14,896,800	15,486,300
	DegradedArea		
Period	Variation(m²)	Cumulative(m²)	Rate(%)
1985-1996	474,300	474,300	8
1996-2011	-1,606,500	-1,132,200	-26

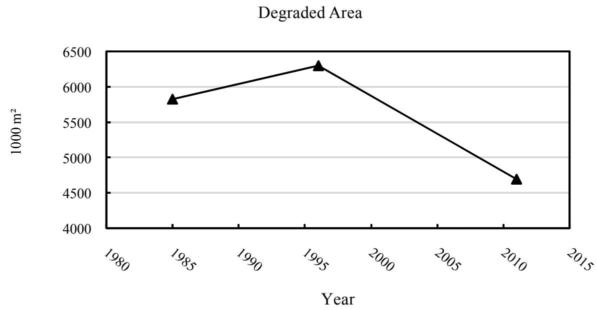

Fig. 1 Expansion of degraded area between 1996 to 2011.

Fig. 5 shows the area corresponding to the open pit

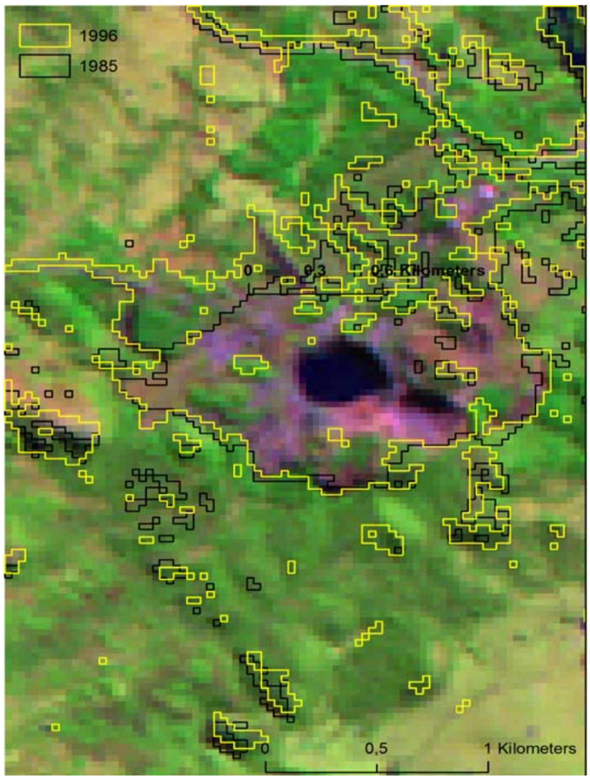

Fig. 5 An example of the expansion of mining activity between 1985 and 1996 (different colours represent mine boundaries related to the years).

mine in isolation from other structures, this analysis is the vectorization of the area marked as degraded from NDVI. This corresponds to the color composition of the year 2011 (RGB 542), in which are represented in yellow the degradation boundaries of the year 1996 and in black the boundaries of the year 1985.

7. Conclusions

A quick literature review shows that remote sensing methods can be used to classify the types of land use in apractical, economic, repetitive and large areas. Although change detection techniques have been widely used in multidisciplinary scientific studies to monitor and evaluate the impacts of natural processes and human activity on the environment, few studies using these tools have been conducted to evaluate changes in areas affected by mining activity.

In this paper, the authors presented an estimate of the expansion of the degraded area and the changes in vegetation associated with mining activity through multi-temporal analysis of the years 1985, 1996 and 2011, applying the NDVI index.

It was observed that the area without vegetation cover increased between 1985 and 1996 and that there was a great expansion of vegetation after the closure of operations and abandonment of the area in 1996, advancing over 26% of the area characterized as degraded, and in 2011 the area with greater vegetation covers the first analyzed date. Total of an area is about 113 ha. It should be noted that this data is from the area affected by mining as a whole, including the construction of the mining town (urban sprawl), tailings dam and open pit. By only analyzing the influence of the open pit region, visually it is possible to notice a big vegetable recoating.

The depletion of mineral resources has been a common event throughout world history, but neglect and impoverishment of these regions is not an inevitable consequence. The use of remote sensing and geographic information system have an increasing role in the management of mining areas. Together, they provide information and statistical data for the evaluation of habitat diversity and changing land cover while the mine is in operation, which may be used to formulate policies and guidelines for the management post-mining and in planning the closure of the mine, environmental reclamation, monitoring, characterization of the landscape and socioeconomic alternatives for rehabilitation of the area in the production system. In this study area, the municipality was adopted in 2012 ecotourism as an alternative to use the area.

As future work, we suggest (1) the classification of different types of vegetation occupying the area, for example: dense vegetation, grassland, scrub, native vegetation and exotic vegetation, etc; (2) multi-temporal analysis in stream subbasin João Dias, in order to identify changes in drought conditions and contamination of sedimentation, as it received the solid waste and liquid effluents from the treatment of copper ore since the nineteenth century until the construction of the tailings dam at the end of 1970; (3) identification of the variation in average vegetation index only in the mine pit area and (4) inclusion of images from different periods in the analysis.

Acknowledgements

The authors are grateful for funding received from the Luiz Englert Foundation (FLE), the Federal University of Rio Grande do Sul and the Department of Mining Engineering.

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