LAND USE ANALYSIS IN KARST REGIONS OF SOUTHEASTERN SÃO PAULO STATE

ANÁLISE DE USO E OCUPAÇÃO EM ÁREAS CÁRSTICAS DO SUDESTE DO ESTADO DE SÃO PAULO

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Abstract

The Remote Sensing and Geographic Information System - GIS are tools that assist in the planning, use and human occupation of sensitive areas like karst terrain. The region between the Guapiara Plateau and Paranapiacaba Range, south of the state of São Paulo presents this geological context that are under constant pressure of the anthropic advancement of several kind of natures, such as mining of carbonate rocks, forestry, agriculture and human occupation itself, inputting a risk to both human lives and preservation of karst systems. The preparation of the map of use and land cover of the area of study is one of the necessary databases themes to be used for land use planning. This work presents the association of remote sensing techniques and the use of GIS information analysis of the use and land cover during the years 2001, 2010 and 2014, through images Landsat 7. Thus, it was possible to map the main land uses in the area, highlighting a wide variability particularly in the Guapiara Plateau. The results demonstrate the advantages of the use of geotechnology in identifying environmental areas of high sensitivity and the possibility of regional planning or establishment of growth vectors towards areas of lower environmental impact.

Key-Words: Territorial planning; temporal analysis; landscape dynamics; karst.

Resumo

O Sensoriamento Remoto e o Sistema de Informações Geográficas – SIG são ferramentas que auxiliam no planejamento, uso e ocupação de áreas sensíveis, como terrenos cársticos. A região compreendida entre o Planalto de Guapiara e a Serra de Paranapiacaba, região sul do Estado de São Paulo, apresenta este contexto geológico, que estão sob constante pressão do avanço antrópico das mais variadas naturezas, como mineração de rochas carbonáticas, silvicultura, agricultura e a própria ocupação humana, colocam em risco tanto vidas humanas quanto a preservação de sistemas cársticos. A elaboração do mapa de uso e cobertura do solo da área de interesse do projeto constitui um dos temas necessários ao banco de dados a ser utilizado para ordenamento territorial. Neste estudo foram adotadas técnicas de sensoriamento remoto e a utilização do SIG, uma análise do uso e cobertura do solo durante os anos de 2001, 2010 e 2014, por meio de imagens LANDSAT 7. Desta forma, foi possível o mapeamento dos principais usos da terra na área, com destaque para uma ampla variabilidade em especial no Planalto de Guapiara. Os resultados demonstram as vantagens do uso das geotecnologias na identificação de áreas de alta sensibilidade ambiental e a possibilidade de ordenamento territorial ou do estabelecimento de vetores de crescimento em sentido às áreas de menor impacto ambiental.

Palavras-Chave*: Planejamento territorial; análise temporal; dinâmica de paisagens; carste.*

1. INTRODUCTION

Karstic regions are areas highly susceptible to environmental and anthropic impacts and the characterization of this type of environment is fundamental for their preservation and optimization of their use, since many people are dependent on them both for housing and the development of various sectors of the economy (LENHARE, 2014).

The economic interest of Ribeira Valley, southeastern of São Paulo state, Brazil, due to the presence of interest ores, mainly the carbonate rocks, exploited for cement and lime, associated to the rapid economic growth and the demand for new mining areas has an advance in the karstic system in the region before any previous basic studies. The local population is in risk due the uncontrolled occupation and difficulty of traditional agricultural practices, consequence of the irregular relief, soil and karstic characteristics, as well as mining that that can erode soil, silt the rivers and lower the groundwater level (SALLUN FILHO et al., 2010, LENHARE; SALLUN FILHO, 2014).

Careful management of sites of occupation, agriculture, disposal of waste, implementation of mining and even protection areas is a means of managing and even minimizing the risks of subsidence, contamination of groundwater and destruction of natural cavities due to the fragility (WILLIAMS, 1993; VAN BEYNEN et al., 2012).

Remote Sensing is a set of activities that allow to obtain information of objects that make up the terrestrial surface without direct contact with them. These activities involve the detection, acquisition and analysis (interpretation and extraction of information) of electromagnetic energy emitted or reflected by terrestrial objects and recorded by remote sensors. The integration of aero-surveys of magnetometry and gamma-spectrometry can unquestionably accelerate basic geological mapping, as well as provide invaluable tectonic information, mineral potential and land use. This is particularly true and highlighted in areas without infrastructure, covered by dense tropical forests and with great territorial extension, as is the case in some regions of Brazil (CARVALHO JUNIOR et al., 2014).

The use of images of this nature in support of geological investigations has been intensifying rapidly. Both techniques, geophysics and remote sensing, are synergistic in several points, from their sample characteristics, by remote sensors, to their finalist application in geological-structural mapping and in the physical and chemical characterization of rocks and soils. Remote sensing and geoprocessing are very effective and advantageous tools in relation to other data collection and analysis methods since they provide a wide panorama of landscape dynamics (TAURA et al., 2011). These tools allow mapping land use and land cover patterns to assess how each landscape element is related to the other spatially and temporally (VAEZA et al., 2010; TAURA et al., 2011).

Previous works have been demonstrate the effectiveness of this set of procedures to aid in the recognition and design of areas of high environmental vulnerability in karstic systems (CARVALHO JUNIOR et al., 2006; FRISCHBUTTER, 2002; ROSA et al., 2009; CHARIF et al., 2013; DOCTOR et al., 2013; de CARVALHO JUNIOR et al., 2014).

This paper presents a temporal comparison of Landsat 7 images (2001, 2010 and 2014, which were the best free images avaiable), with the use of the MAXVER-ICM classifier, which, like MAXVER, associates the classes at individual points, but has the advantage of considering spatial dependence in the context of the image to be classified (LEITE; ROSA, 2012; NERY et al., 2013). This analysis can help public policies in the territorial ordering of municipalities located in karst regions.

2. LOCATION OF THE STUDY AREA

The study area consists of carbonate rocks located between the basins of the Almas and São José de Guapiara rivers (Paranapanema River Basin - Guapiara Plateau) and Pilões river (Ribeira de Iguape River Basin – Paranapiacaba Range), in the southeast of the State of São Paulo (Figure 1). The region is located in the context of the "Ribeira Valley", characterized by typical karstic features such as caves, rocky walls, sinkholes, polygonal depressions, cones and karst towers (KARMANN; SANCHEZ, 1979; 1986).

The region comprises carbonate bodies of the Subgroup Lajeado (Neoproterozoic), which occur in the form of continuous bodies and geomorphologically are located between Guapiara Plateau and the Coastal Province (PONÇANO et al., 1981). In the plateau region the relief is more smoothed, with a low hydraulic gradient with predominantly superficial drainage, while in the Paranapiacaba Range the relief is more uneven, providing larger hydraulic gradients in relation to the plateau, besides drainage with superficial sections and underground.

The rivers of the Ribeira Valley allowed people to be transported and goods traded, and economic activities such as gold mining boosted the emergence of towns and cities in the seventeenth century, such as Eldorado and Sete Barras. In the following century, cattle ranching allowed the development of cities, such as Apiaí, in the Upper Vale do Ribeira region. In the first decades of the twentieth century, banana and tea production was important to the region's economy - largely made up of Japanese immigrant workers. It should be remembered that, until the highlight of the port of Santos in the mid-nineteenth century, the port of Iguape played a fundamental role in the flow of products and the economic relevance of the Ribeira Valley region (Seade 2013).

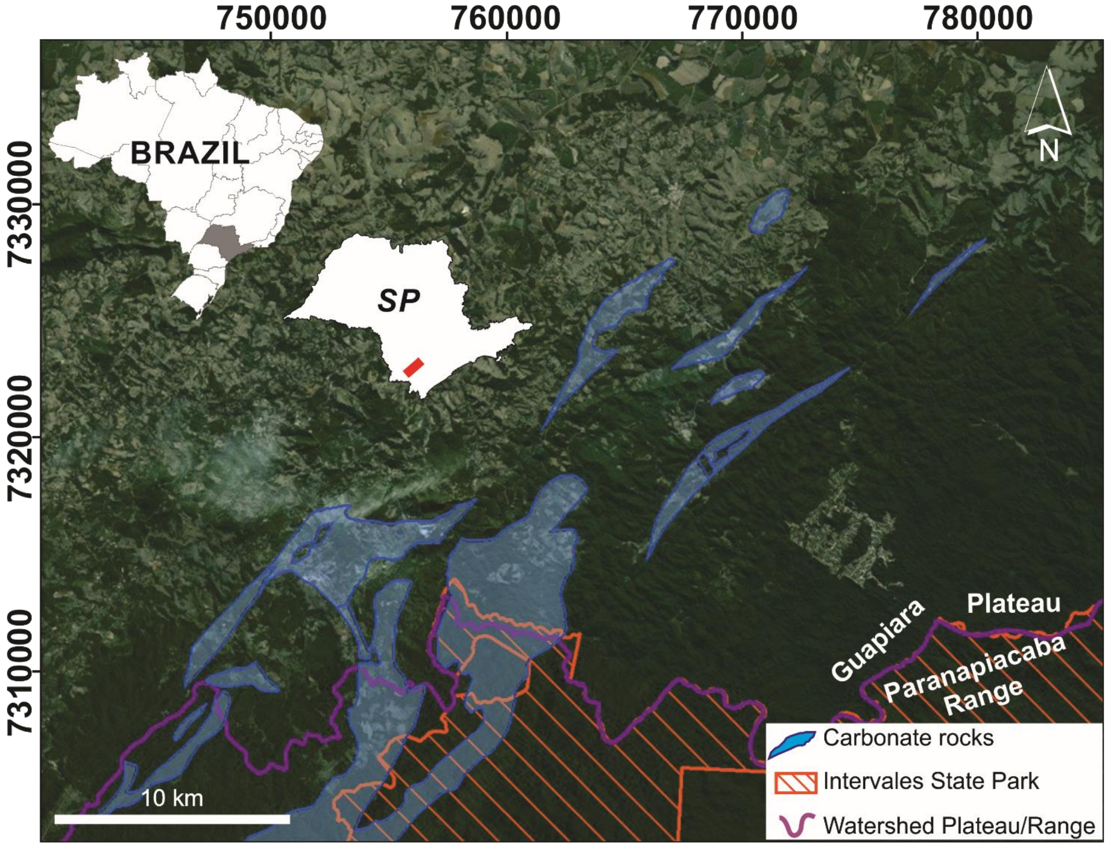

Figure 1: Localization of the area of study.

In the mid-twentieth century, the economic dynamics of the region and, as a result, the population growth of the cities, become stagnant. The decline in mineral reserves and the targeting of other investments in coffee production and marketing to industrialization in other regions of the State are factors that have led to low economic growth in the Ribeira Valley region. In this period, the agriculture of the Ribeira Valley also has a low representativeness for São Paulo agriculture, compared to livestock and sugarcane, which are expanding and consolidating in other regions of the State (SEADE, 2013).

The study area is currently comprised of the presence of several conservation units, such as the Interval State Park (PEI) and the High Ribeira State Tourist Park (PETAR), which together with other conservation units (Paranapanema Nascentes State Park - PENAP , Xituê Ecological Station, Carlos Botelho State Park, and APA of Serra do Mar), form an extensive corridor of environmental protection areas, the ecological continuum of the Serra de Paranapiacaba. The presence of these conservation units allows the preservation of the karst system, but inhibits the economic development of the region (SALLUN FILHO et al., 2010; VAN BEYNEN et al., 2012).

3. GEOLOGICAL E GEOMORPHOLOGICAL CONTEXT

The carbonate rocks where the studied karst is currently developed belong to the Açungui Supergroup which is composed of lithostratigraphic units that reflect sedimentary and volcanic environments, arranged in bands with predominant NE direction (Figure 2a).

The carbonate rocks belong to the Lajeado Subgroup, deposited in an open sea plataformal environment composed of an alternation of clastic and carbonate rocks (CAMPANHA; SADOWSKI, 1999). This unit is subdivided into seven others, and those of interest for this study are the Bairro da Serra formations (metacalcarenites and impure calcitic and dolomitic metacalcilutites), Furnas Mine (metacalcarenites and laminated calcilutites) and Passa Vinte (dolomitic metacalcarenites) (CAMPANHA et al., 1987; CAMPANHA, 2002). The karst system in question belongs to the Ribeira Speleological Province (KARMANN; SANCHEZ, 1979; 1986).

The geomorphological context of the study area is the transition from the Guapiara Plateau to the Coastal Province (Paranapiacaba Range), as well as a small portion of Peripheral Depression (Paranapanema Depression) (Figure 2b) (PONÇANO, 1981; LENHARE; SALLUN FILHO, 2014).

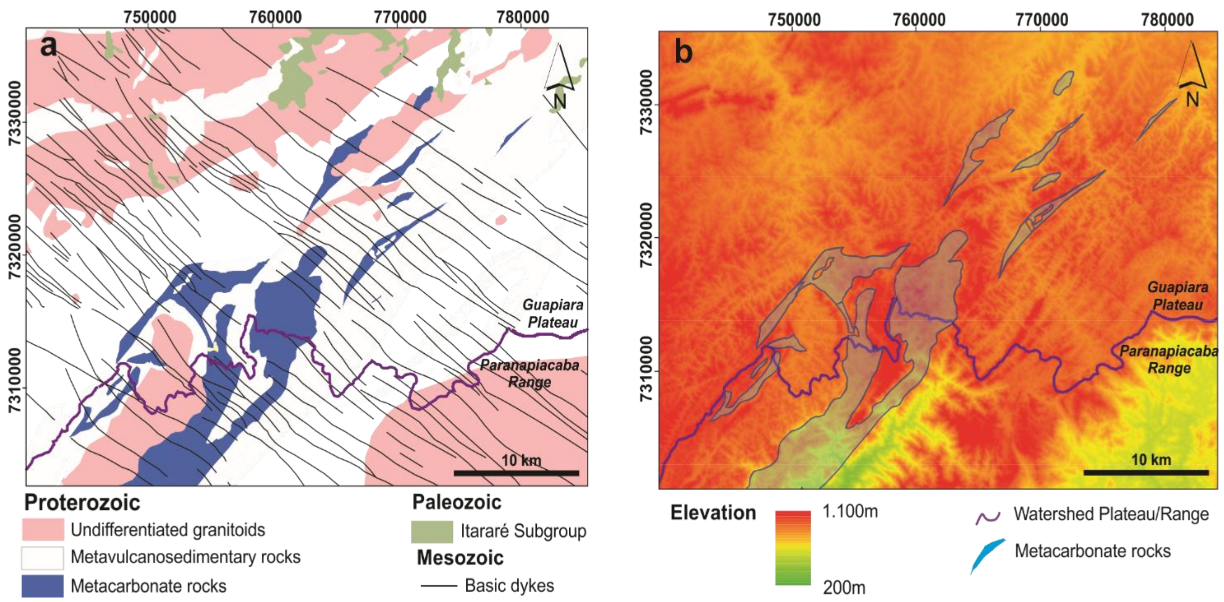

Figure 1: a: simplified regional geological context of the study area with emphasis on metacarbonate rocks (CAMPANHA, 2002); b: regional geomorphological map showing the main units covered by the study area (PONÇANO et al., 1981).

4. MATERIALS AND METHODS

The analysis of the evolution of land use and occupation in the region between Paranapiacaba Range and Guapiara Plateau used the interpretation of satellite images associated with remote sensing techniques and data compilation in a GIS environment.

The images used are the TM sensor of the LANDSAT 7 Satellite, with spatial resolution of 30 meters in the panchromatic and in the spectral of 7 bands. Images from the 220/77 band were used, form the years 2001, 2010, 2014, with cloud coverage below 1% in the total scene. The images were obtained free of charge from the INPE website and newer images are not available for download.

The images were processed using ArcGIS 10.5, with image processing modules with algorithms that integrate raster and vector formats in the same environment. After the images were selected, they were cropped to the limit of the study area. Then, a band composition that was adequate to the analysis of land use and cover was stipulated. The final band operation of each year selected for presentation and interpretation was established in: 1 - R: Band 4 - G: Band 5 - B: Band 7.

The next step, class classification, was defined based on the visual interpretation, assigning for each spectral range defined in the previous step, a predefined class. The predominant classes of use in the study area were selected based on prior knowledge of the study area. The following classes of land use and land cover were used to classify the time series:

1. Tree cover: dense vegetal cover, with high bearing;
2. Pastures/crop: pastures and crops;
3. Bare soil: cultivation of eucalyptus (*Eucalyptus*) and pine (*Pinus elliottii*);

The images were classified through supervised classification, based on the use of algorithms for pixel determination. To obtain the classes, the MAXVER-ICM classifier was used. While the MAXVER classifier associates classes by considering individual points of the image, while the MAXVER-ICM classifier (Interated Conditional Modes) also considers the spatial dependence in the classification. In a first phase, the image is classified by the MAXVER algorithm assigning classes to the "pixels", considering the values of digital levels. The algorithm assigns classes to a given "pixel", considering the neighborhood interactively. This process is terminated when the % change (percentage of "pixels" that are reclassified) defined by the user is satisfied (NERY et al., 2013).

After classification, the classes were converted from matrix to vector. The area calculation of each class was calculated in square kilometers, after the area calculation the obtained data were tabulated and applied in tables. Finally, a thematic map of the use and coverage was developed using ArcGIS software, where other aspects of land use and occupation were compiled, such as data from mining processes and conservation units.

5. RESULTS

The geoprocessing techniques used in the LANDSAT 7 TM images highlighted some land use characteristics in the region. These techniques prioritized forested, non-forested areas and various uses of the soil (Figures 3, 4 and 5). Images from different years were used to allow an analysis of the evolution of land use and cover. In the left row of Figures 3, 4 and 5 are represented the image processed with natural color, while the right row the interpreted results for land use.

These differences between the images, the data from the geoprocessing were vectored, allowing the area calculation of each discriminated class. After the vectorization the data were grouped and tabulated for analysis of the temporal panorama of the situation of each of the target classes of study (Table 1).

In the analysis of the image of the year 2001 (Figures 3a and 3b) it is possible to observe that the forested areas predominate in the scene, however the Bare soil class stands out, mainly in the north and northwest portions, where there is a greater presence of villages and crop areas, occupying 2.8% (6.7 km^2), of the carbonate rocks. The Forest class comprises natural vegetation (primary or secondary) comprising 52.4% (126.1 km^2), while the Pastures/crop class covers 44.8% (108.0 km^2).

In the image of the year 2010 (Figures 4a and 4b), there is an increase of areas of the Forest class covering 49.6% of the area of the selected scene, comprising 119.5 km^2 of the carbonate rocks area. Pastures and crops represent 106,1 km^2 (44.0%). The bare soil class showed a increase of most than 100% in relation to the year 2001, making 6.5% (15.6 km^2) of the carbonate rock area.

Figures 5a and 5b show the situation of the study area in the year 2014. In this scenario, it can be observed that the Forest class presented a significant increase in relation to the year 2010, representing 52.5% (126.6 km^2) of the carbonate rock area. Pastures and crops, on the other hand, stayed at the same levels compared to the years 2001 and 2010, accounting for 44.9% of the area (108.2 km^2). The bare soil class shows the largest fall in the analyzed years. According to the analysis, in 2014, it was 2.6% (6.4 km^2).

After the analysis of the images by geoprocessing techniques, a thematic map of the region was elaborated on how the use and coverage situation is based, based on the image of 2014. In addition to the classes analyzed, the mining data and also of Conservation Units. Through the analysis of the images by geoprocessing techniques, it was produced a thematic map of the region on how the use and coverage situation is based, based on the image of 2014. In addition to the classes analyzed, the mining process data has been entered. These data refer to which phase the mining process is in, i.e., from its application for studies, authorization for mineral prospecting and research, the request for mining and the authorization of mining (Figure 6).

6. DISCUSSION

The analysis of the karstic landscape must consider several factors, some external to the karst itself, and which should be evaluated and weighted together with anthropic and environmental factors (VAN BEYNEN; TOWNSEND, 2005; VAN BEYNEN ET AL., 2013; DOCTOR ET AL., 2013; LENHARE; SALLUN FILHO, 2014). Research, analyzes and interpretations of land use and occupation and geoenvironmental dynamics collaborate in a consistent way with the in-depth knowledge of a region (COLLARES, 2000; GARATUZA-PAYAN et al., 2001; SILVA et al., 2005; VAEZA et al., 2008). The growing concern about land use and occupation has led governments to take interest in studies that address this issue (MEDEIROS; PETTA, 2005).

The search for gold and other minerals of economic interest, such as lead and silver, as well as arable land stimulated occupation in the region between the Paranapiacaba Range and the Guapiara Plateau since the 17th century. In the middle of the twentieth century, the economic dynamics of the region and, consequently, the population growth of the cities, are stagnant. The decline in mineral reserves and the targeting of other investments in coffee production and marketing to industrialization in other regions of the State are factors that have led to low economic growth in the Ribeira Valley region. In the same period, the agriculture of the Ribeira Valley has a low representativeness for São Paulo agriculture, compared to livestock and sugarcane, which are expanding and consolidating in other regions of the State (LEPSCH et al., 1999; SEADE, 2013).

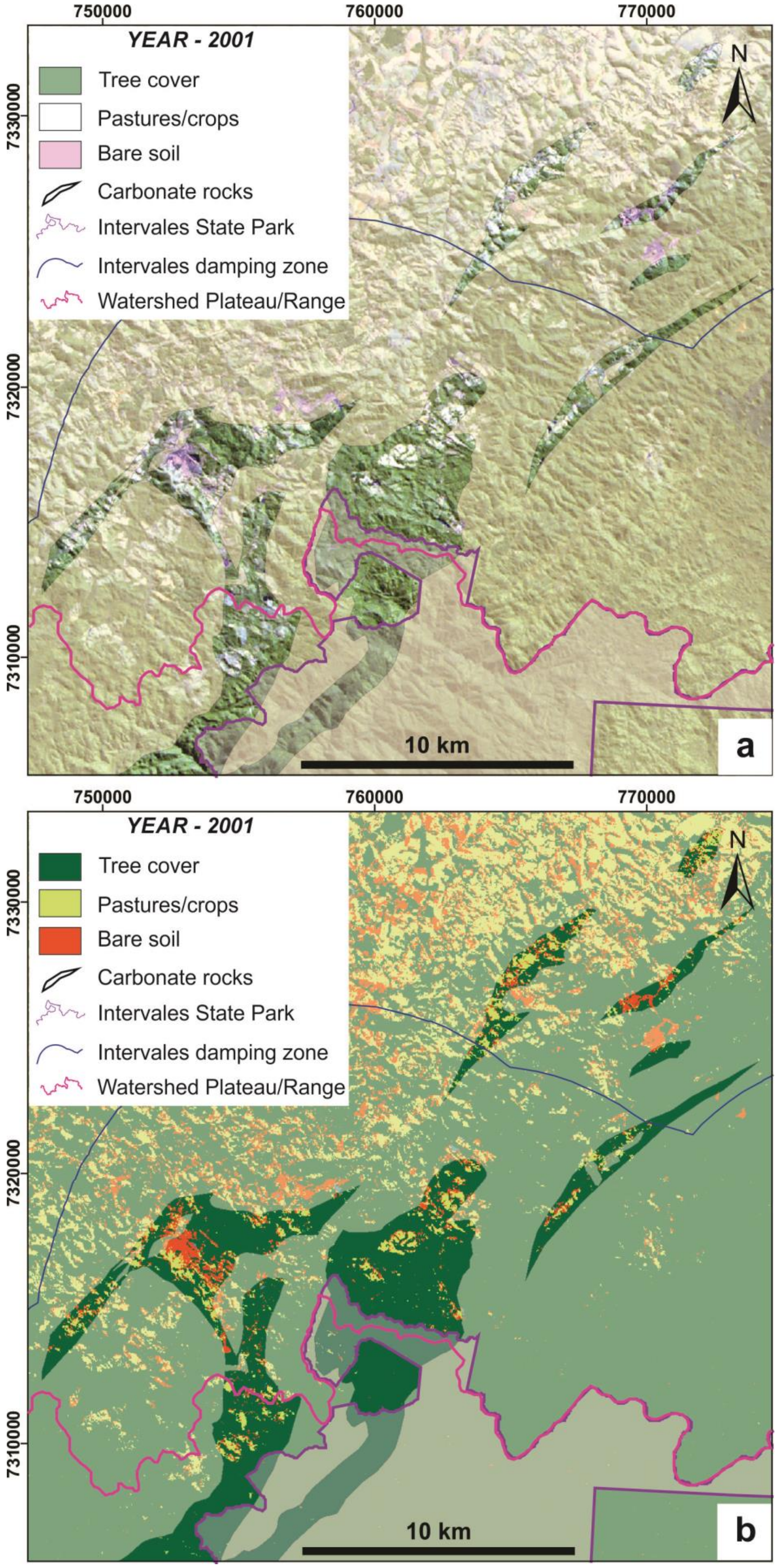

Figure 2: LANDSAT 7 TM image (RGB 457) processed with false color (a) and interpreted with the land use (b), related to the year of 2001.

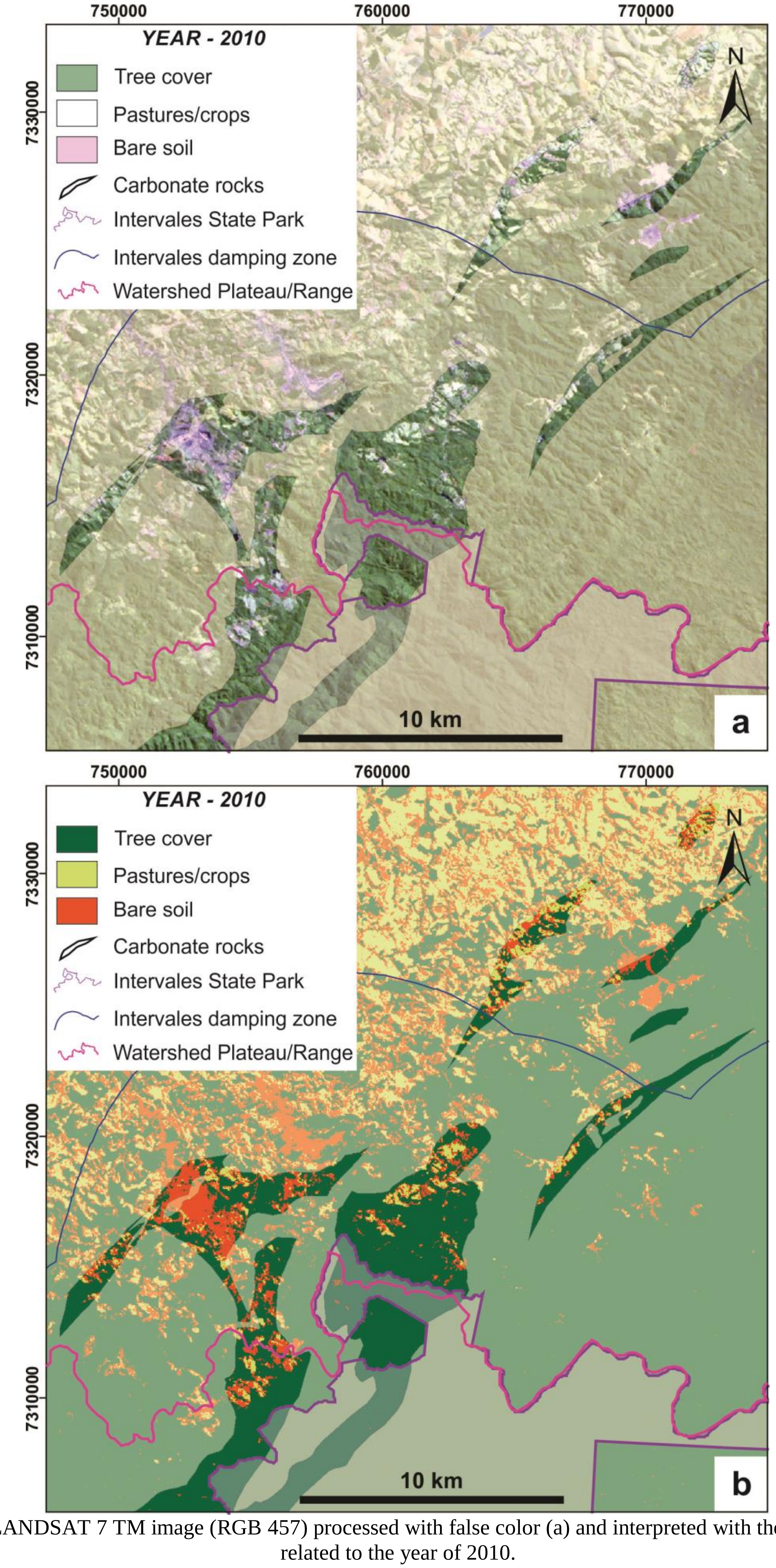

Figure 3: LANDSAT 7 TM image (RGB 457) processed with false color (a) and interpreted with the land use (b), related to the year of 2010.

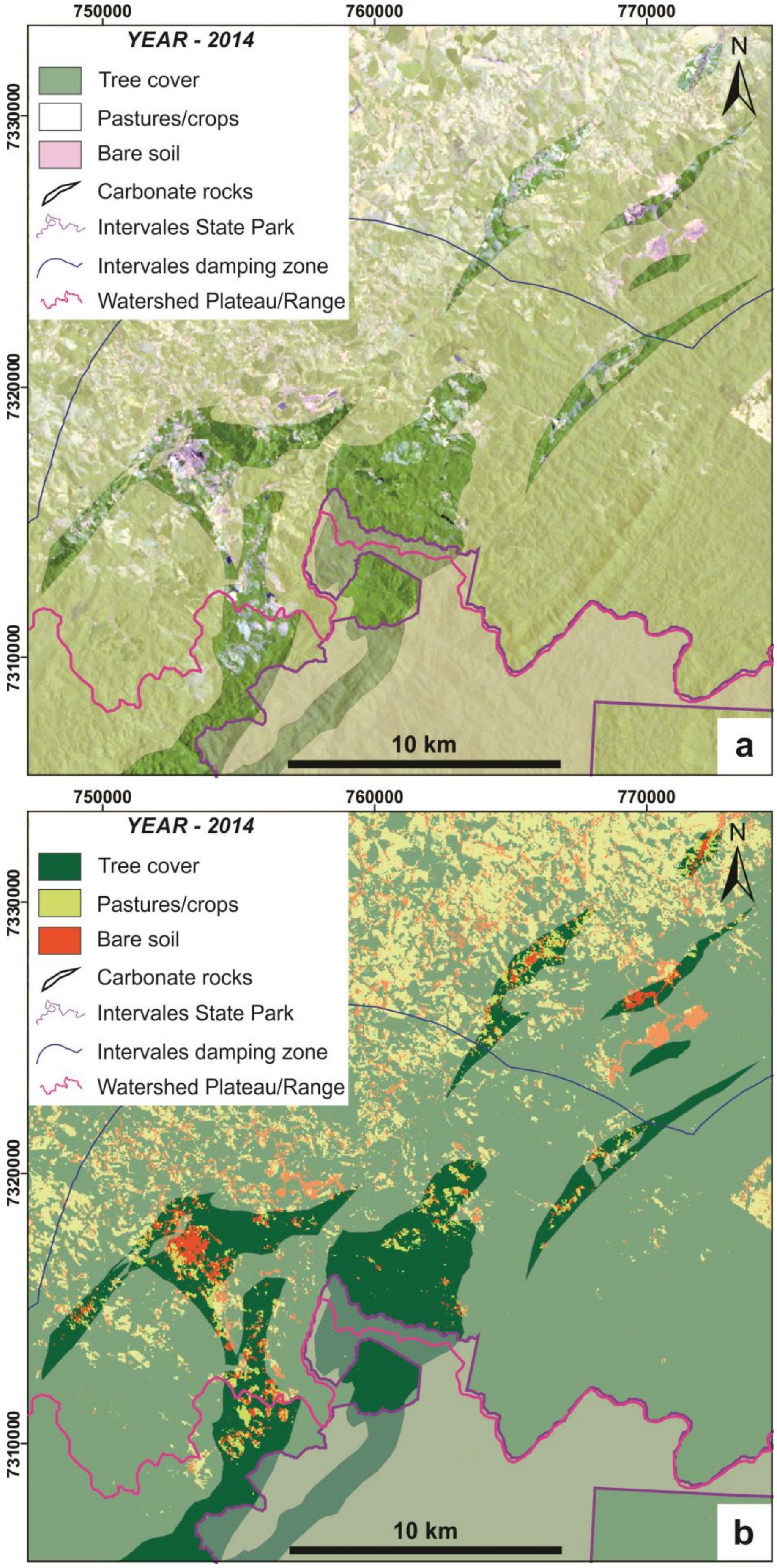

Figure 4: LANDSAT 7 TM image (RGB 457) processed with false color (a) and interpreted with the land use (b), related to the year of 2014.

Table 1: Land use and land cover scenario in the years 2001, 2010 and 2014.

LAND COVER	*2001*		*2004*		*2010*	
	Area (km²)	***Area (%)***	***Area (km²)***	***Area (%)***	***Area (km²)***	***Area (%)***
Tree cover	126.1	52.4	119.5	49.6	126.6	52.5
Pastures/crop	108.0	44.8	106.0	44.0	108.2	44.9
Bare soil	6.7	2.8	15.6	6.5	6.4	2.6
Total	***240.8***	***100.0***	***241.1***	***100.0***	***241.1***	***100.0***

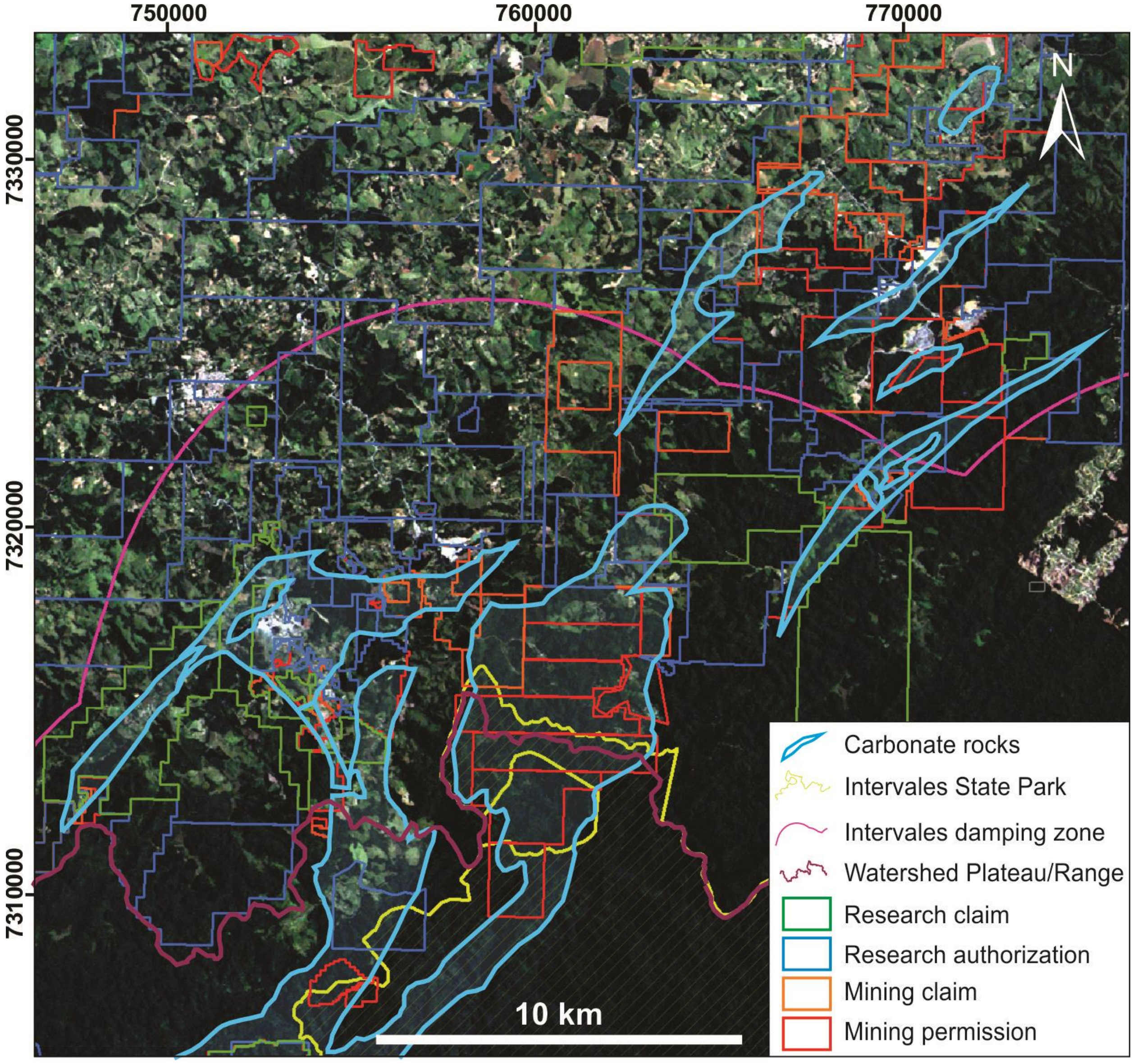

Figure 6: Mining request processes over LANDSAT 7 TM image (RGB 321, true color) in the studied region between the Guapiara Plateau (north of the watershed) and Paranapiacaba Range (south of the watershed).

The study area is currently comprised of the presence of several conservation units, such as the Intervales State Park (PEI) and the Alto Ribeira Touristic State Park (PETAR), which together with other conservation units (Nascentes do Paranapanema State Park - PENAP, Xituê Ecological Station, Carlos Botelho State Park, and Serra do Mar APA), form an extensive corridor of environmental protection areas, the ecological continuum of Paranapiacaba. The presence of these conservation units allows the conservation and preservation of the karst system, but inhibits the economic development of the region (LENHARE; SALLUN FILHO, 2018).

This negative panorama of economic development often ends up forcing the local population out to places where there is more opportunity. Once the economic situation becomes favorable again there is a resumption of the advance of occupation in the region.

The compartmentalization of the relief is also an important feature to be analyzed. The Guapiara Plateau region presents a smoother relief configuration in relation to the Paranapiacaba Range, which allows a greater expansion of the occupation. This situation can be observed when the selected images were compared between the years analyzed.

The methodology of tree cover analysis did not differentiate forest and afforestation, since this class is understood as one for the purpose of soil protection in karstic terrain (LENHARE; SALLUN FILHO, 2018). The reduction of tree cover percentage values between 2001 and 2010 is related to the cut of eucalyptus or pinus, a very common economic activity in the region. In 2014, the value of the tree cover percentage is related to the growth of a new eucalyptus and pine crop. This fact also explains an increase in the percentage of soil exposed in the year 2010, since between the years of 2001 and 2014 the area covered by this class is practically constant.

Currently, the main activities that can cause imbalance in the karst system are: mining of carbonate rocks (cement and lime production), agriculture (vegetables, fruit growing and forestry) and the disordered human occupation itself. The mining of carbonate rocks can cause lowering of water table, suppression of caves and associated fauna, besides the decrease in area of the karstic environment itself. Agriculture, in turn, may unbalance the speed of the natural process of kartstification by withdrawing plant cover and introducing agrochemicals into the karst hydrological system.

Disordered human occupation can interfere in many ways, such as contamination of groundwater, disposal of domestic and industrial waste inside caves and dolines, construction of buildings in hazardous areas, among others. On the other hand, the presence of Conservation Units (such as PEI and PETAR) is of extreme importance for the conservation and preservation of karstic systems

As already observed, the human presence in the Guapiara Plateau is predominant and the pressure exerted on the karst system is greater when compared to the situation of Paranapiacaba Range, where the existence of conservation units guarantees the preservation of vegetation areas and soil permanence, contributing to the karst cover protection.

In the region of Paranapiacaba Range the presence of conservation units guarantee the preservation and conservation of the karst system. This characteristic emphasizes the importance of the establishment of conservation units in areas considered environmentally fragile. The existence of conservation units may guarantee some preservation of the karst system, but some parks in the region have tourism as their main activity.

Techniques of geoprocessing of images in a temporal series become fundamental tools for the analysis and occupational planning of a region (GARATUZA-PAYAN, et al. 2001; FRISCHBUTTER, 2002; SOUZA FILHO, 2005; VITAL et al., 2005; CARVALHO JUNIOR et al., 2006; SIRI et al., 2009; CHARIF et al., 2013). The compilation of these techniques with data from a variety of sources (geology, geomorphology, mining, agriculture etc.) allows to draw a panorama of the situation of region of study, optimizing anthropic occupation, often with a good safety range.

7. CONCLUSIONS

The occupation in the region between the Paranapiacaba Range and Guapiara Plateau is disorderly since the Brazilian colonial period. The lack of an order in human occupation threatens the physical environment, for example, the karst system that occurs there, and the population that depends on it.

The concept of economy is dynamic in time and depends on several factors that are often independent of the regional economic situation, such as currency fluctuation, mineral supply and demand, proximity to the consumer market, quality of the final product, manufacturing, among others. Historically, the region of study has already witnessed the development of several sectors of economy such as agriculture and mining. All these sectors of primary economy have played a prominent role in some period of the history of regional occupation, but are currently in decline (SEADE 2013).

The geomorphological configuration conditioned the occupation that historically has been more intense in the plateau by its softer reliefs. Thus, the environmental situation of karst is distinct in the sectors to the north and south of the divisor. In the Guapiara Plateau the anthropic occupation is more incisive than in the Paranapiacaba Range, with the presence of mining enterprises in activity, agriculture of various natures, forestry and the establishment of communities.

To the south of the watershed, the karst situation configures areas of environmental protection (PEI and PETAR), and in the PEI there is a Management Plan, which confers an aspect of karst environment protection (SALLUN FILHO et al., 2008).

The karst in the region between the Paranapiacaba Range and the Guapiara Plateau, observed through a temporal series of images and analyzed with geoprocessing techniques, is protected and preserved. There are exceptions, such as mined areas and presence of agriculture (northern portion). However, many of the areas that may be subject to anthropogenic pressure are under the control of management plans and environmental laws, which are not always effective but represent an attempt to conserve and preserve the environment.

Thus, the elaboration of management plans is fundamental to complement the protection of the karst system (SALLUN FILHO et al., 2008; LENHARE; SALLUN FILHO, 2018). However, it should be recognized that, even with existing management plans, such as Intervales State Park, these should be reviewed and adjusted with the updating of environmental laws, economic situation and progress of science.

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