Mapping of land use and coverage in 2000 and 2010 along the sub-basins of the Seco and Precuá creeks in the municipalities of Bacabeira and Rosário in the state of Maranhão, Brazil

Mapeamento do uso e cobertura do solo nos anos de 2000 e 2010 nas sub-bacias dos Riachos Seco e Precuá, nos municípios de Bacabeira e Rosário – MA

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Abstract
The aim of the present study was to perform a detailed analysis of the spatiotemporal dynamics of land use and coverage in the years 2000 and 2010 in the sub-basins of the Seco and Precuá creeks located in the municipalities of Bacabeira and Rosário in the state of Maranhão, Brazil. For such, geoprocessing methods were used to create a databank with georeferenced information on land use and coverage in the study area for the years analyzed. Images from the Landsat satellite with a special resolution of 30 meters were mapped with the aid of the SPRING 5.0.6 program. The analysis of the information revealed an increase in areas altered by human activities in the two sub-basins in the form of deforestation, urbanization, agriculture, livestock farming and excavation for the implantation of the petrochemical facility in the industrial district of the municipality of Bacabeira. The present findings provide important information to the understanding of the dynamics of geographic space and the chronological identification of environmental changes in the region of the two sub-basins investigated.

Keywords: Geoprocessing, mapping, environmental changes

Resumo
O objetivo deste artigo foi realizar uma análise detalhada da dinâmica espaço-temporal dos padrões do uso e cobertura do solo nos anos de 2000 e 2010 nas sub-bacias dos Riachos Seco e Precuá, localizadas nos municípios de Bacabeira e Rosário – estado do Maranhão. Para tanto, por meio de técnicas de geoprocessamento estruturou-se um banco de dados com informações georreferenciadas, referente ao uso e cobertura do solo nos anos de 2000 e 2010 na área de estudo. Foram utilizadas imagens do Satélite Landsat, com resolução espacial de 30 m, as quais foram mapeadas com auxílio do programa SPRING 5.0.6. A partir das informações geradas no banco de dados foi possível verificar um aumento de áreas antropizadas nas duas sub-bacias, provocadas pelo

desmatamento, urbanização, atividades agropecuárias, extrativismo e pelas atividades de terraplenagem para a implantação de um grande empreendimento do setor Petroquímico no Distrito Industrial do município de Bacabeira. Os resultados apresentados fornecem subsídios importantes no processo de compreensão da dinâmica do espaço geográfico e na identificação cronológica das alterações ambientais no entorno das sub-bacias investigadas.

Palavras–chave: Geoprocessamento, mapeamento, mudanças ambientais.

1. INTRODUCTION

Land use and coverage in a region is an outcome of natural and socio–economic factors and their utilization by man in time and space. Natural environments are constantly transformed and their permanent modifications imply directly in situations of risk and vulnerability, caused mainly by changes in land coverage that need to be controlled for the maintenance of the integrity of ecosystems and their essential ecological processes.

Current demands for natural resources to meet socio-economic goals have increasing produced environmental changes. The resulting pressure and fragmentation of ecosystems has led to the loss of biodiversity. This situation underscores the need for the protection and monitoring of environmental management units. River basins are widely accepted as environmental management units, as rivers and creeks constitute geographically delimited natural systems in which phenomena and interactions can be integrated *a priori* by the input and output of matter and energy (NASCIMENTO; VILLAÇA, 2008).

Studies on the dynamics of land use and coverage in river basins have been developed in many countries to assist in the understanding of how alterations in land use lead to environmental changes and to suggest development strategies designed to ensure sustainability (MENESES et al., 2015). According to the Brazilian Institute of Geography and Statistics (IBGE, 2013, p. 17), “knowledge on land use is relevant due to the need to ensure sustainability with regard to associated environmental, social and economic issues and bring this issue to the foreground in discussions on sustainable development”. The analysis of the spatiotemporal dynamics of land use and coverage in river basins allows the acquisition of information on degrees of conservation, preservation and anthropogenic actions in ecosystems (BARROS et al., 2013), assistance in the recovery of degraded areas (BOLFE et al., 2008), the evaluation of the integrity of Permanent Preservation Areas (REIS et al., 2012; NERY et al., 2013), the mapping of zones of greater erosive potential (SHI et al., 2013; BEZERRA; SILVA, 2014) and the identification of conflicts regarding land use (MELO et al., 2010; PACHECO et al., 2014).

Conservation measures are adopted when the population exploits a given region for economic progress and local resources are threatened due to uncontrolled, accelerated, predatory

consumption. Thus, the construction of large-scale enterprises, such as the industrial district in the municipality of Babaseira in the state of Maranhão, Brazil, causes social and environmental impacts that need to be monitored and mitigated. The ecosystems around such enterprises undergo pressure from population growth and uncontrolled urbanization, leading to competition for physical space and the risk of the inadequate land use. Thus, there is a need to map these areas with the aid of geoprocessing techniques, which allow the determination of the progression of land use and provide information for decision making with regard to the monitoring and management of environmental resources.

The use of satellite and aerial images in studies on the management of river basins allows the determination of changes in land use and coverage over time (CRUZ, 2009). Remote sensing images allow the identification of the dynamics of human activities along river basins using a Geographic Information System (GIS) for the analysis of the expansion of urbanization and agriculture activities, as well as the negative effects on native vegetation.

The aim of the present study was to map land use and coverage in the sub-basins of the Seco and Precuá Creeks (state of Maranhão, Brazil), using geoprocessing techniques to provide information to assist in decision making regarding environmental management.

2. MATERIALS AND METHODS

2.1. Study area

The Seco and Precuá Creeks belong to the Itapecuru River Basin (Figure 1). The lower courses of these creeks are located in the municipalities of Bacabeira and Rosário in the northern portion of the state of Maranhão, Brazil (02º 56' 01"/03º 02' 17"S and 44º 14' 50"/44º 19' 36" W). Both sub-basins have a circularity index of less than 0.51, demonstrating an elongated shape, with a low tendency toward flooding and a relatively mild topography. Based on the Thronthwaite climatic index, the climate is humid (LABGEO, 2002). Rainfall data in the region demonstrate mean annual precipitation of 1998.8 mm/year between 1975 and 2015. The region has two well-defined seasons. The rainy season spans from January to July and the dry season spans from August to December (INMET, 2015).

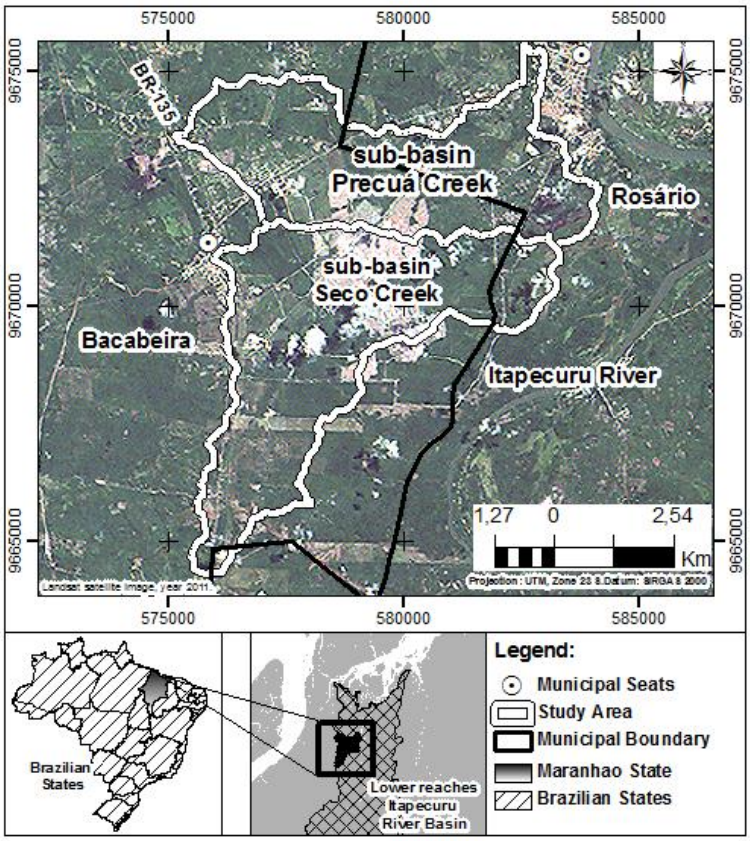

Figure 1 - Location of Seco and Precuá Creeks, state of Maranhão, Brazil

2.2. Materials

A database of preexisting images, maps, software programs and charts was used for the creation of a digital cartographic base. The cartographic materials employed for the creation of the maps were represented in simplified flowchart (Figure 2).

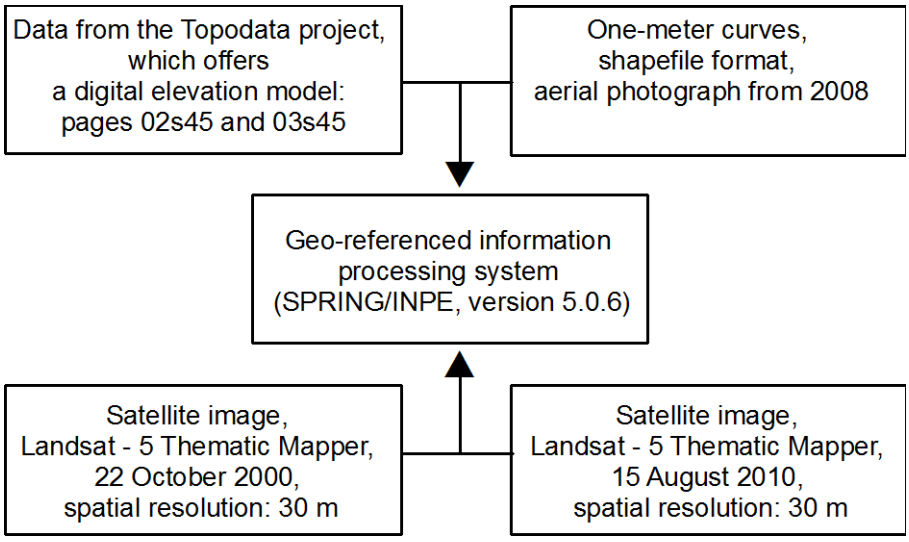

Figure 2 - Simplified flowchart of materials used in study

2.3. Acquisition and structuring of database

The digital cartographic data were obtained from the Brazilian geo-morphological database TOPODATA (INPE, 2008) and the Brazilian Institute of Geography and Statistics and entered into the SPRING program for the creation and modeling of the database. The limits of the study area, cartographic projection and other cartographic variables that comprise the Universal Transverse Mercator were defined; land models in DATUM – SIRGAS 2000; zone 23M; southern hemisphere.

2.4. Definition of limits of sub-basins and digitalization of drainage

The sub-basins and drainage were delimited based on altitude data generated by the Shuttle Radar Topography Mission (SRTM) and refined in the TOPODATA project, which allowed improving the spatial resolution to 30 meters. One-meter curves in shapefile format were also used with the aid of Aerofoto (2008). On the SPRING program, curves at five-meter altitudes were generated and united with one-meter curves for the precise definition of the limits of the sub-basins and drainage network.

2.5. Processing of satellite images for definition of land use and coverage

The evaluation of land use and coverage was performed based on the mapping of satellite images: LANDSAT - 5 Thematic Mapper; orbit/point 220/62; bands 3, 2 and 1; 15 August 2010 and 22 October 2000 (acquired free of charge from the Brazilian National Institute of Spatial Research). For the mapping, the following classes of land use and coverage were employed: areas modified by human activities, artificial lakes, pasture or plantation, bush vegetation, cloud and cloud shadow. These data were acquired through the interpretation of the images and field validations through sampling of the target areas with the aid of a global positioning system and subsequent analysis with the aid of the SPRING 5.0.6 program. SPRING 5.0.6 was used for the georeferencing and geoprocessing of the images. This program incorporates digital image processing and specific geoprocessing functions in a single application. Contrast functions were employed to enhance the images. Contrasting of the images was performed to highlight classes of land use and coverage of the selected areas. The best composition was composed of Bands 1, 2 and 3 of the 321/RGB model. According to the INPE (2009), this contrast highlights the natural color of an image and vegetation appears in green tones.

3. RESULTS AND DISCUSSION

The sub-basin of Precuá Creek has an area of 20.59 Km^2 and a perimeter of 35.58 Km. Its main course extends 11.73 Km and it is considered a fourth-order river based on its drainage hierarchy. Mean altitude is 23.41 m, with an amplitude of 34.98 meters, ranging from 10.00 meters to 44.98 meters. This creek is found in the municipalities of Bacabeira and Rosário. The sub-basin of the Seco Creek has an area of 24.45 Km^2 and a perimeter of 39.36 Km. Its main course extends 14.26 Km and it is also considered a fourth-order river based on its drainage hierarchy. Mean altitude is 25.03 m, ranging from 6.6 meters to 49.91 meters. This creek is found in the municipalities of Bacabeira, Rosário and Santa Rita (Figure 3).

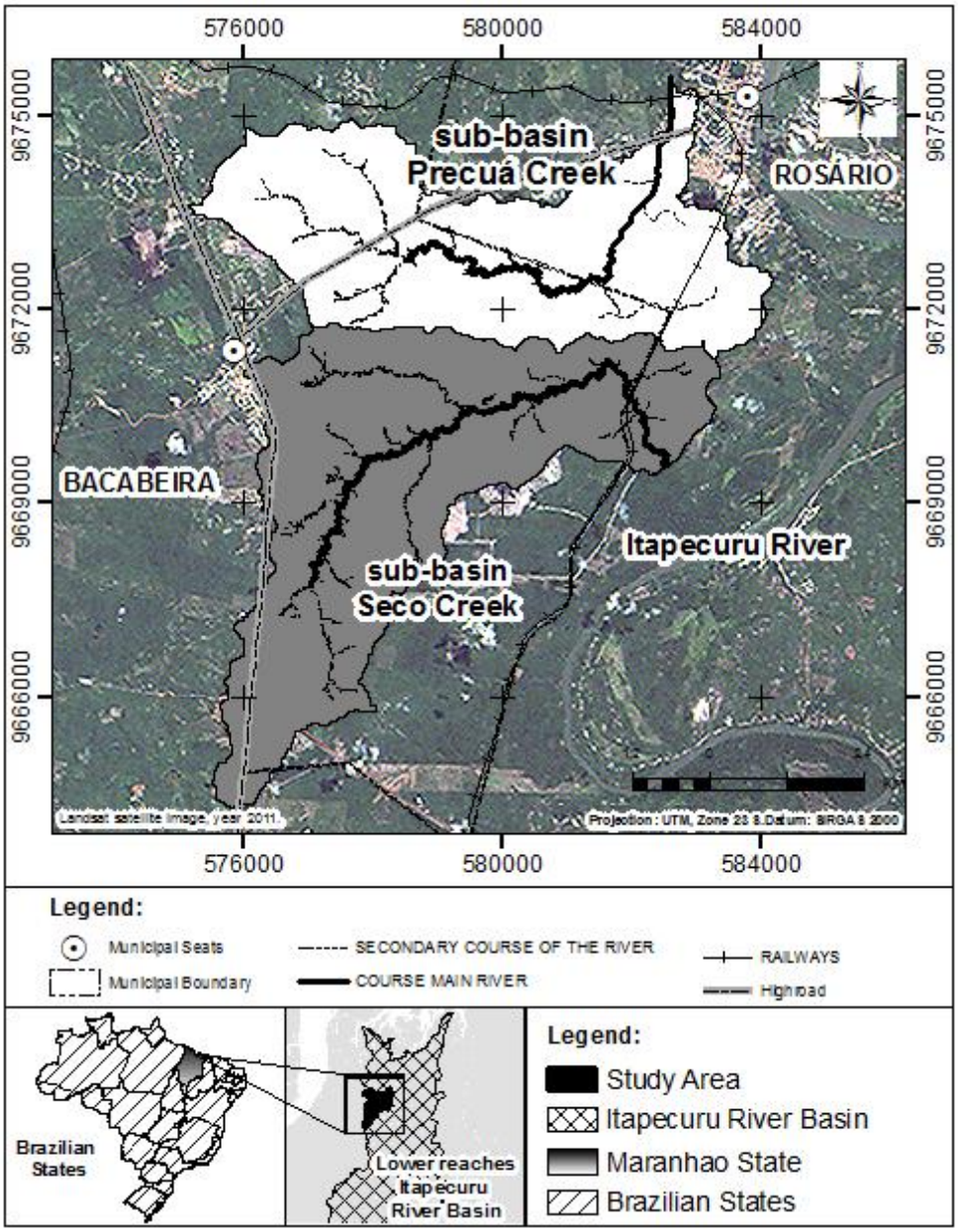

Figure 3 - Limits and order of sub basins of Precuá and Seco Creeks, state of Maranhão, Brazil

The temporal analysis of the images of the Thematic Mapper sensor of the Landsat satellite from the years 2000 and 2010 allowed the determination of the dynamics of changes in land use and coverage in the study area. The areas in the mapped classifications were converted to percentage values to allow the comparison of the sub-basins of the Precuá and Seco Creeks (Table 1). Figures 4 and 5 illustrated the changes in each of the typological features of land use and coverage mapped in the present study.

Table 1 - Percentage of land use and coverage in sub-basins of Precuá and Seco Creeks in 2000 and 2010, state of Maranhão, Brazil

Land use and coverage	Sub-basin Precuá (%) 2000	Precuá (%) 2010	Seco (%) 2000	Seco (%) 2010
Cloud	0.49	0.03	0.15	2.56
Cloud shadow	0.56	0.00	0.15	3.83
Dense urban occupation	0.89	1.59	0.00	0.00
Medium urban occupation	4.45	16.81	0.00	11.62
Low urban occupation	3.84	0.00	9.65	0.00
Exposed soil	2.96	10.27	4.40	20.41
Water tank or reservoir	0.66	1.22	0.86	0.89
Pasture or plantation	0.00	0.35	0.00	1.62
Sparse vegetation	18.75	10.80	18.44	0.86
Medium to dense vegetation	67.39	58.93	66.36	58.20
Total	100.00	100.00	100.00	100.00

In the year 2000, medium to dense vegetation accounted for 67.39% of the sub-basin of Precuá Creek and 66.36% of the sub-basin of Seco Creek. In 2010, these typological features accounted for 58.93% and 58.20% of the sub-basins of Precuá Creek and Seco Creek, respectively (reduction of 8.46% and 8.16%, respectively).

Batista & Dias (2008) state that environmental degradation occurs through the construction of buildings, roads and services, followed by the establishment of the population and its activities of daily living. According to Pereira (2006), humans have been occupying geographic spaces indiscriminately, with no prior knowledge of the vulnerabilities and potentialities of the local environment.

Despite the reduction in medium to dense vegetation in the present study, areas with these features still account for the largest portion of the sub-basins, since such areas are found predominantly in the rural zone of the municipalities of Bacabeira and Rosário. However, a reorganization process of the two sub-basins is underway due to the initial work toward the installation of the Premium I Refinery, which has caused a 9.41% and 18.12% increase in the amount of exposed soil in the sub-basins of the Precuá and Seco Creeks, respectively. Added to this are the figures on low, medium and dense urban occupation, pasture and plantation areas and water

tanks/reservoirs, totaling 30.24% of Precuá Creek sub-basin and 34.81% of the Seco Creek sub-basin.

The expansion of areas of human activities occurs concomitantly to the tendency toward a reduction in green areas. Therefore, the establishment of public policies compatible with urbanization and environmental legislation is fundamental to impeding actions of huge impact (LAGO, 2011).

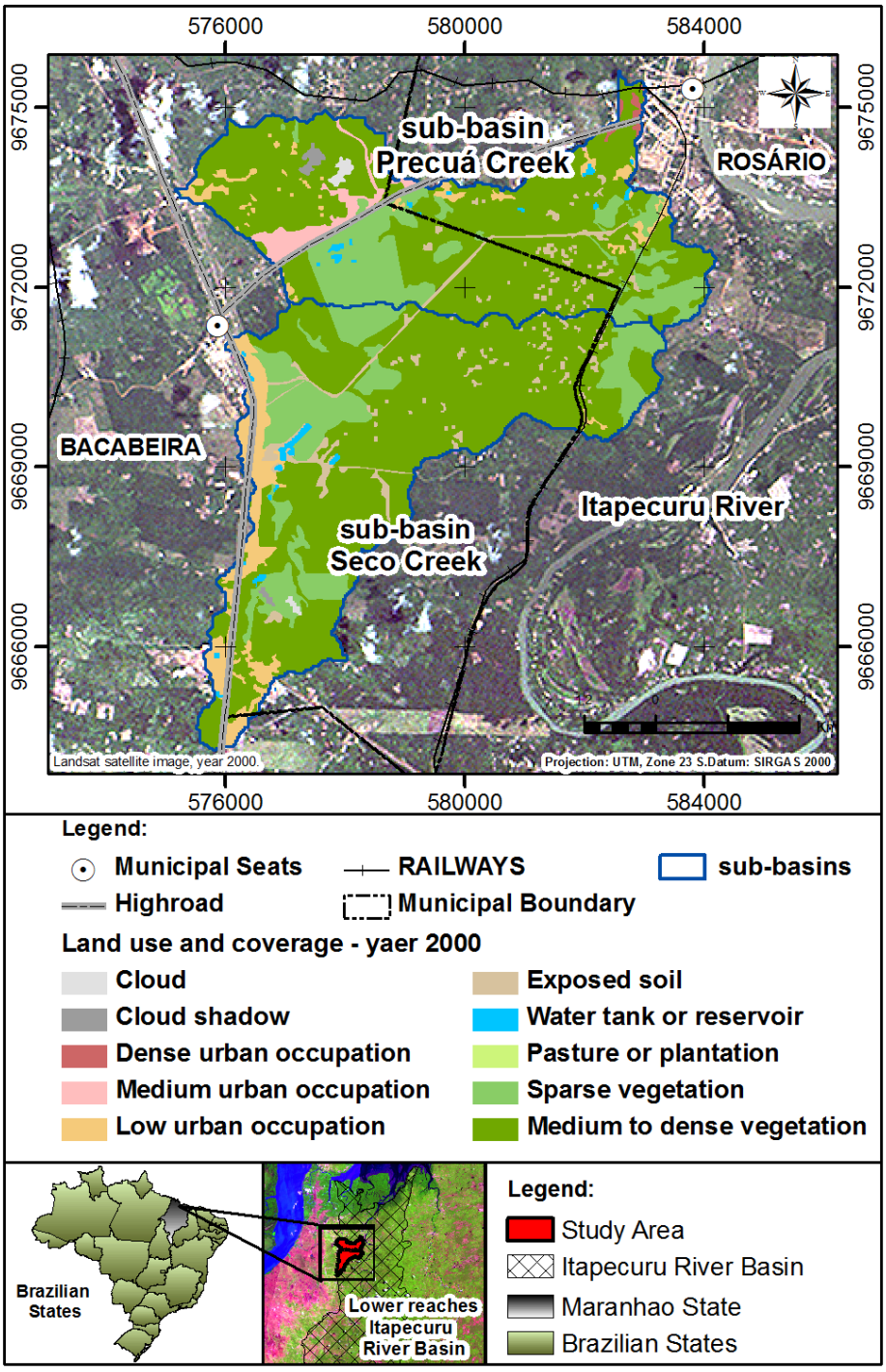

Figure 4 - Map of land use and coverage in sub-basins of Precuá and Seco Creeks in year 2000, state of Maranhão, Brazi

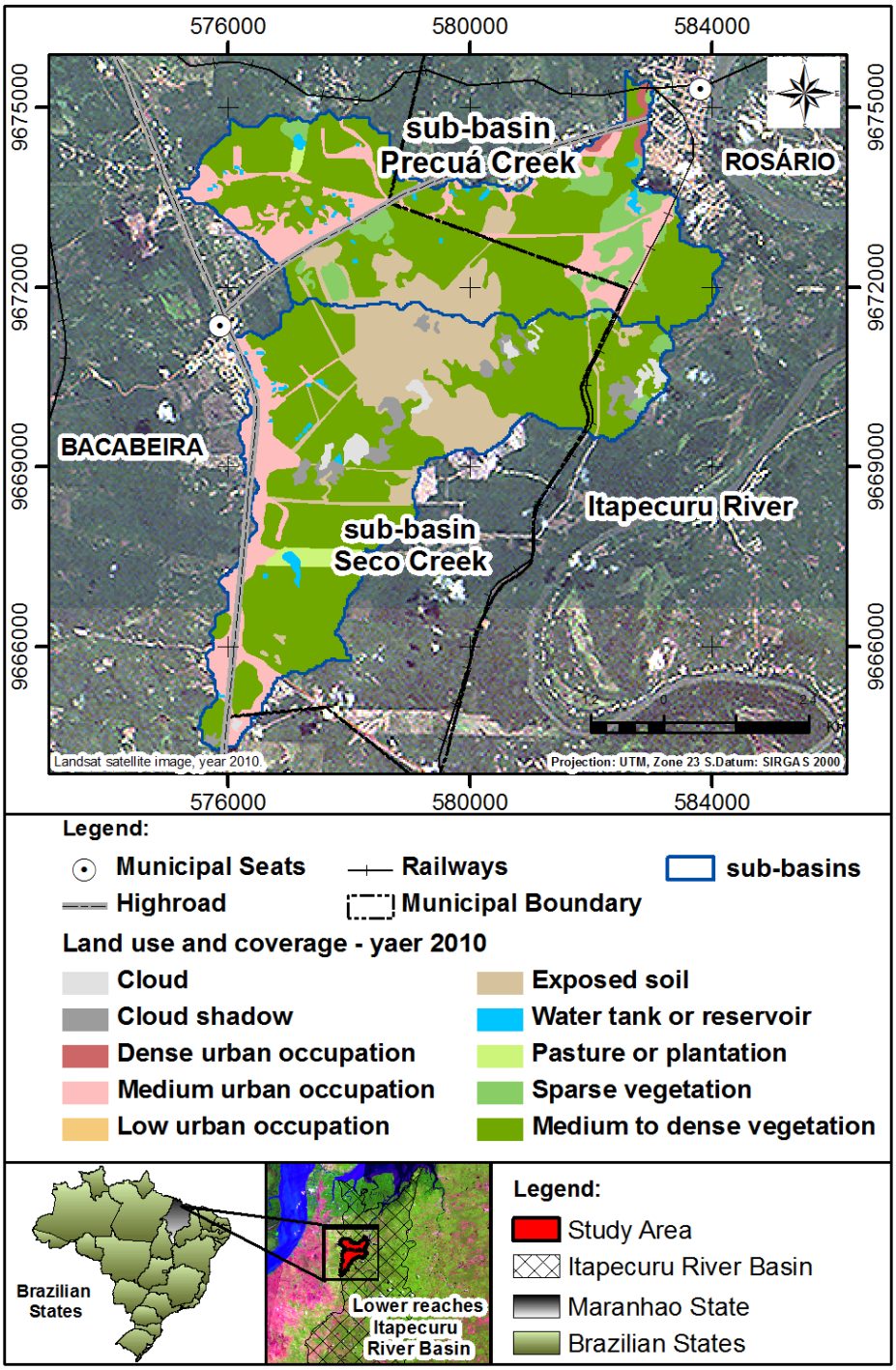

Figure 5 - Map of land use and coverage in sub-basins of Precuá and Seco Creeks in year 2010 state of Maranhão, Brazil

Soares (2016, p. 97) discussed this scenario for the region in which the Precuá and Seco creeks are located:

> Economic projections indicate that port expansion in the city of São Luís will constitute a strong attraction to the arrival of new enterprises, which will potentially be implanted in the lower course of the Itapecuru River, mainly due to the proximity and saturation of the industrial district of São Luís, the existence of areas without human occupation and the proximity of the Itapecuru River (water availability). This scenario will impose growing pressure on natural resources in the study area, with the real possibility of the occurrence of

significant changes in landscape patterns, generating direct consequences on the quality of life of local communities and the functioning of natural ecosystems.

The diagnosis and understanding of changes in land use and coverage patterns is a fundamental component to the establishment of environmental management strategies. Mapping can assist in the creation of proposals aimed at land use management, the indication of protected areas, the containment of erosive processes, the recovery of degraded ecosystems, the guaranty of water quality and, consequently, the maintenance of the characteristics of the landscape and improvements in the quality of life of local communities (SOARES, 2016).

However, the changes evidenced in the patterns of land use and coverage reflect the dynamic process of change along the two sub-basins, which invariably leads to the removal of vegetation for the implantation of urban infrastructure, farming activities and extractivism. Urbanization in the two sub-basins occurs in different ways and at different intensities in each municipality due to diverse factors. The result of this dynamic process is a mosaic composed of varied spatial situations that have in common the excavation activities involved in the implantation of the Premium I Refinery, which was the main agent responsible for changes in the occupation of space in the region in the period analyzed.

4. CONCLUSION

The analysis of land use and coverage in the sub-basins of Seco Creek and Precuá Creek allowed the characterization of the main typological features and the recognition of pressure caused by human activities. This information can assist in the planning of occupation of the area studied.

The mapping on a 10-year scale revealed that medium to dense vegetation accounted for 67.39% in the Precuá Creek sub-basin and 66.36% in the Seco Creek sub-basin in the year 2000, with an 8.46% and 8.16% reduction, respectively, by 2010. Moreover, areas involving human activities corresponded to 30.24% and 34.81% of the Precuá Creek and Seco Creek sub-basins in 2010, demonstrating progressive environmental degradation, as evident by the loss of native vegetation.

The changes detected in the sub-basins occurred mainly due to the removal of vegetation in the excavation step of the implantation of the petrochemical facility and, on a smaller scale, because such changes are directly related to the expansion of company headquarters in the municipalities of Bacabeira and Rosário.

This study demonstrates that the use of remote sensing images with a 30-m resolution offers important information to the understanding of the dynamics of geographic spaces and the

identification of the chronology of environmental changes. Land cover and land use change process and its implication for environmental and ecosystem functioning are important to recognize the services provided by the natural ecosystems, and to come up with a sustainable land use plan.

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