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Land use and land cover mapping of the Saco River's watershed, State of Maranhão, Brazil

Mapeamento do uso e cobertura da terra na bacia hidrográfica do Rio Saco, Estado do Maranhão, Brasil

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ABSTRACT

Land use and land cover mapping benefits landscape understanding and its changes, especially those resulting from anthropogenic actions in the physical environment. The present study aimed at mapping land use and coverage of the Saco River's watershed (located in Codó, state of Maranhão). The area comprises the coconut forest (named *Mata dos Cocais*), a region that encompasses the characteristics of different biomes on the same temporal and spatial scale. The methodology applied was based on remote sensing techniques developed in a Geographic Information System (GIS) environment, processing data from Landsat 8 and supervised classification. The results showed a predominance of dense vegetation in the basin under study, in addition to a reduced occupation by classes of urban area and water bodies. The overall accuracy was 79% and dense vegetation presented a higher user and producer accuracy than the general, with 91 and 87%, respectively. On the other hand, the highest commission and omission errors were those in urban areas and water bodies, which coincided with the lowest occupation classes in the Saco River basin. These results are pioneering for the coconut forest and provide data for strategic planning of environmental actions.

Keywords: Coconut Forest; Landsat 8; geoprocessing; AcATaMa.

RESUMO

O mapeamento do uso e cobertura territorial favorece a compreensão paisagística e as suas alterações, especialmente as decorrentes das ações antrópicas no meio físico. O presente estudo objetivou analisar o uso e cobertura da terra na bacia hidrográfica do Rio Saco (Codó, Maranhão). A área compreende a "Mata dos Cocais", região que abrange características de biomas distintos em uma mesma escala temporal e espacial. A metodologia aplicada baseou-se em técnicas de sensoriamento remoto desenvolvidas em ambiente de Sistema de Informação Geográfica (SIG) com processamento de dados a partir do Landsat 8 e da classificação supervisionada. Os resultados mostraram uma predominância da vegetação densa na bacia em estudo, além de uma reduzida ocupação pelas classes de área urbana e corpos hídricos. A acurácia geral foi de 79%, sendo que a vegetação densa apresentou uma precisão do usuário e do produtor maior que a geral, com 91 e 87%, respectivamente. Em contrapartida, os erros de comissão e omissão mais elevados foram relativos à área urbana e corpos hídricos, o que coincidiu com as classes menos ocupadas na bacia do Rio Saco. Esses resultados são pioneiros para a mata dos cocais e fomentam dados para o planejamento estratégico de ações ambientais.

Palavras-chave: Mata dos Cocais; Landsat 8; geoprocessamento; AcATaMa.

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Introduction

The watershed is the unit for planning and managing water resources in Brazil, according to the National Water Resources Policy (*Política Nacional de Recursos Hídricos*; Federal Law No. 9.433/1997 [Brasil, 1997]). It is, thus, necessary to understand the river basin's hydrological behavior, considering anthropogenic actions, climate change, and the social effects of its use (Silva et al., 2023).

Changes in land use and occupation are among the most important factors that alter the hydrological behavior of a watershed (*e.g.* Medeiros et al., 2019; Poorheydari et al., 2020; Tucci, 2020), since they interfere with surface runoff by altering the processes of infiltration, evapotranspiration, aquifer recharge, and interception (Kibii et al., 2021; Kumar et al., 2022; Duarte et al., 2024). Changes in the landscape mosaic are also factors interfering with hydric erosion (De Araújo et al., 2006; Rabelo et al., 2023).

Geographic Information Systems (GIS) have proven to be viable for monitoring land use and land cover, especially when associated with remote sensing techniques. In this sense, the use of satellite images provides an integrated analysis of the different environmental characteristics of an area, favoring the acquisition of more precise information and facilitating various studies, such as water and vegetation dynamics, and land use mapping, among others. In addition to the synoptic survey, these techniques contribute to the interrelation of information, i.e. they provide environmental data and simultaneously encourage the improvement of methodologies in the field of remote sensing, such as the development of analytical algorithms (Alves et al., 2021; Lopes et al., 2021; Rodrigues et al., 2021; Simplício et al., 2021; Almeida et al., 2023).

Environmental mapping using satellite products requires the availability of spatial information and is generally supported by auxiliary data such as ground truth and/or *Google Earth Engine* data (GEE) (Gorelick et al., 2017; Souza Júnior et al., 2020). Globally, *World Cover* offers more refined products in terms of resolution. This corresponds to the project dedicated to global coverage characterization led by the European Space Agency (ESA). However, Venter et al. (2022) showed that, despite being widely adopted, the products generated by this platform have inaccuracies and spatial and thematic distortions that vary between biomes, continents, and human occupations. According to these authors, medium spatial resolution makes it impossible to detect and monitor small landscape elements, which are vital for earth system processes on a finer scale and for local land use planning. Therefore, the ideal is to adopt a critical appraisal taking into account the objective of the study above all.

Nationally the *MapBiomas* platform uses integrated algorithms to produce classification maps in multiclass time series (https://mapbiomas.org/). This platform features regular updates and improved computer algorithms for describing the six Brazilian biomes, namely the Amazon, Caatinga, Cerrado, Pantanal, Atlantic Forest, and Pampa (Souza Júnior et al., 2020).

These biomes present a geographical space or biological unit with homogeneous characteristics, defined by a specific macroclimate and phytophysiognomy that have undergone the same landscape formation processes, resulting in a diversity of flora and fauna of their own (*e.g.* Myers et al., 2000). Therefore, despite *MapBiomas*' efforts to map use and occupation in Brazilian biomes, the products generated by this platform may not be satisfactory when attributed to mixed communities and/or transitional areas.

The methodology used by the *MapBiomas* platform consists of creating mosaics of Landsat images (spatial resolution of 30 meters), with each mosaic produced by spatially integrating the different scenes present on each topographic map at a scale of 1:250,000 for each year (MapBiomas, 2000). This configuration is suitable for studies of changes in use and cover in similar phytogeographic domains but not for mapping ecotones, as is the case with the coconut forest.

Located in the Mid-north of Brazil, the coconut forest is under the influence of three climatic types: equatorial, semi-arid, and semi-humid tropical, with a hydrographic drainage system that extends to the North of the state of Maranhão and the far East of the state of Pará. With characteristics of distinct ecosystems (Amazon, Caatinga, and Cerrado), this transition zone, which is still little described in the literature, presents risks, above all due to the opening up of new areas for the development of agriculture activities (Sano et al., 2019).

In this context, the aim of this work was to map land use and coverage in the Saco River basin, located in Maranhão, in the coconut forest ecotone area. This knowledge is fundamental for making decisions regarding environmental management. The results can also stimulate discussion about the fluvial regime of the Itapecuru River basin and its tributaries, as well as water quality modeling studies.

Material and Methods

The study area comprises the Saco River basin, located predominantly in the municipality of Codó, Maranhão, which is characterized by a sub-humid tropical climate with an average annual temperature ranging from 26 to 27°C, and rainfall defined by the Continental Equatorial Regime, with an annual variation between 1,200 and 2,000 mm (Correia Filho et al., 2011).

The Saco River basin drains an area of 1,541 km^2, has a perimeter of 326 km, a total drainage network of 1,619 km, with 101 km of the main river with an outlet at coordinates 9,503,003 S (4°29'44.16" S) and 616,290 W (43°57'10.80" W), as shown in Figure 1.

The study area is located in an equatorial zone, where we can observe the presence of dense vegetation composed mainly of coconut forests, in which the predominant palm is the "babaçu" (*Attalea speciosa*), and also the presence of sparse vegetation characterized as "cerrado", with the predominance of smaller species, often with deciduous foliage. This sparse vegetation is located mainly in the Eastern, Northwestern, and Southwestern regions of the municipality, with pequizeiro (*Caryocar brasiliense*), jatobá (*Hymenaea courbaril*), and andiroba (*Carapa guianensis*), among other fruit trees (Correia Filho et al., 2011).

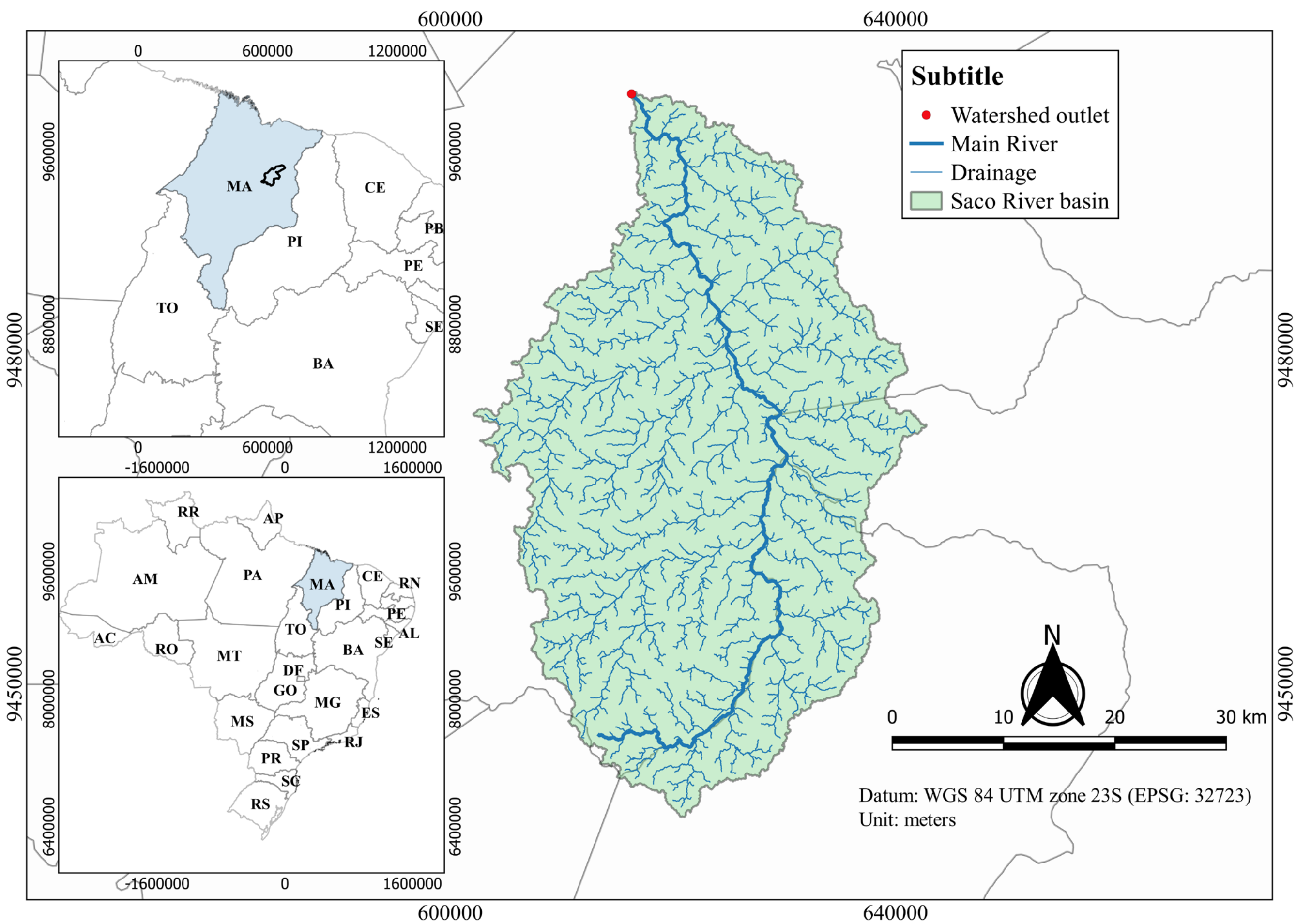


Figure 1 – Saco River's watershed, Maranhão, Brazil.

Data collection was divided into satellite and fieldwork. With regard to satellite images, we used the Landsat 8 multispectral product, Operational Land Imager (OLI) sensor, orbit 220/063, from 18th July 2023, obtained free of charge from the United States Geological Survey (USGS, 2023a) platform (http://earthexplorer.usgs.gov/). The image selection criterion was based on the acquisition date closest to the collection of points obtained on-site and cloud-free coverage (<1% clouds).

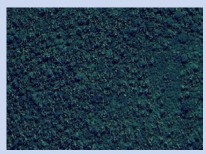
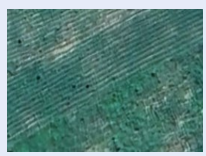
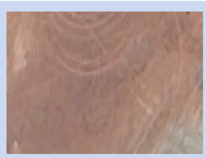
For the field data, 91 points were collected along the Saco River basin using a GPS (Global Positioning System) on July 5th and 9th and August 4th, 2023. For each point collected, the coordinates provided by GPS were recorded and the land use and occupation classification of each class of interest was assigned.

The criteria used to classify the land use and coverage of each point collected were based on Chowdhury et al.'s method (2020). According to this classification, the basin was characterized into five classes: urbanized areas, water bodies, dense vegetation, sparse vegetation, and exposed soil (Table 1). Clouds and cloud shadows were also classified in order to avoid overlapping classes. It should be noted that it was not possible to collect points in agricultural areas, as they were inside private properties that did not authorize entry.

Image pre-processing was carried out in a GIS environment, more specifically in the free software QGIS version 3.16.16, and included applying the scale factor and adding the offset to the Level 2 (C2L2) product of the Landsat 8 image. The seven bands considered in this study (Table 2), according to information on the USGS (2023b) website (https://www.usgs.gov/landsat-missions/landsat-8), were converted from Digital Number (DN) to reflectance using Equation 1. This procedure is conducted to reduce the scattering effects of the Earth's atmosphere on the images of each band.

$$Reflectance = (Band * 0.0000275) - 0.2 \quad (1)$$

Table 1 – On-site land use and land cover classes.

Class	Description	Representative sample of the subject class
Urbanized areas	Areas designated as residential, commercial, industrial, roads and transport.	
Water bodies	Rivers, lakes, ponds, and reservoirs, as well as wet and marshy areas during the wet season and dry areas during the dry season, wet and dry areas during the dry season, perennial marshy areas, and riverside vegetation.	
Dense vegetation	Areas covered by natural vegetation, typical of the region (coconut forest ecotone).	
Sparse vegetation	Areas covered by planted vegetation or short vegetation.	
Exposed soil	Exposed soil and barren area.	

Source: adapted from Chowdhury et al. (2020).

Table 2 – Spectral resolution of the bands used from Landsat 8 - Operational Land Imager sensor.

Bands	Spectral resolution (µm)
Band 1 Coastal Aerosol	0.43–0.45
Band 2 Blue	0.45–0.51
Band 3 Green	0.53–0.59
Band 4 Red	0.64–0.67
Band 5 Near-Infrared	0.85–0.88
Band 6 SWIR 1	1.57–1.65
Band 7 SWIR 2	2.11–2.29

SWIR: short-wave infrared.
Source: United States Geological Survey (USGS) – Landsat Missions.

After pre-processing, the layers were stacked in order to apply the Semi-Automatic Classification Plugin (SCP) to identify the classes (also called regions of interest, see Table 1). These were verified by field observation and with the assistance of Google Satellite, an add-on installed in QGIS.

For image classification, 210 training samples (regions of interest, ROIs) were selected to represent the seven land use and coverage classes. In addition, the samples were delineated using polygons delimiting the pixels. These were used to record the spectral signatures according to the respective classes. The supervised classification method was based on the minimum distance algorithm. The maximum likelihood method was not used in this study due to the difficulty in establishing representative training areas, which would lead to inaccurate classification (Negri and Mendes, 2020).

Thematic accuracy assessment for SCP classification was carried out using Accuracy Assessment of Thematic Maps (AcATaMa; see Llano, 2018), a complement developed for accuracy assessment proposed by Stehman and Czaplewski (1998) and Olofsson et al. (2014), which is based on three basic elements: sampling design, response design, and analysis.

The sampling design chosen was stratified because, according to Olofsson et al. (2014), this option allows for the best representation of classes, since it generates samples proportional to the size of the classes. The response design establishes the reference land cover classification of a sampling unit (Stehman and Czaplewski, 1998; Olofsson et al., 2014). As for the analysis, a confusion matrix was generated that provides overall accuracy, the user's accuracy for the class and the error of commission, and the user's accuracy for the class and the error of omission (Figure 2).

Results and Discussion

Among the 91 points obtained on-site and used to guide the supervised classification, 19 were sampled for dense vegetation, 11 for sparse vegetation, 29 for exposed soil, 18 for urbanized areas, and 14 for water bodies. The field survey also served as auxiliary data for the general evaluation of classification results accuracy, as mentioned below. Regarding the training samples, 50 polygons were generated for each of the dense vegetation, sparse vegetation, and exposed soil classes; 20 for the cloud class, 15 for the urbanized area and cloud shadow classes, and only 10 for water bodies, totaling 210 training samples. The supervised classification showed a predominance of dense vegetation in the Saco River basin with reduced occupation of urbanized areas and water bodies, as shown in Figure 3.

The algorithm adopted proposed the use of 396 points, randomly distributed as follows: 221 points for dense vegetation, 58 for sparse vegetation, 93 for exposed soil, 9 for urban areas, 8 for water bodies, 4 for clouds, and 3 for cloud shadows (Table 3).

The overall accuracy, which indicates the proportion of the area correctly classified (Stehman and Foody, 2019), was 79%, i.e., of the 396 samples randomly distributed, 313 agreed with the classification. With regard to user accuracy, it can be seen that the classes of dense vegetation (91%), sparse vegetation (71%), and exposed soil (72%) had the best probabilities of the points classified in the SCP image actually representing the reference class on the ground (AcATaMa).

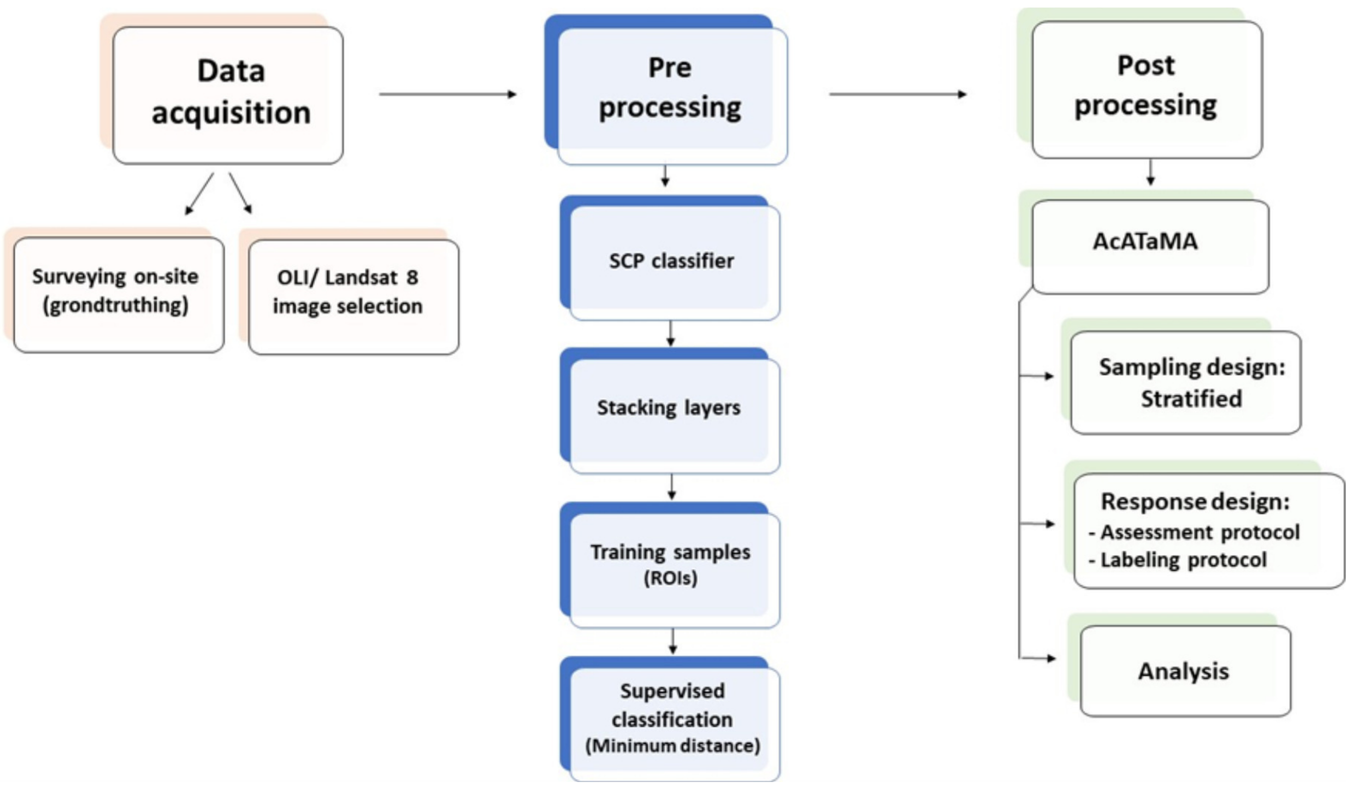


Figure 2 – Methodological flowchart.
OLI: Operational Land Imager; SCP: Semi-Automatic Classification Plugin; ROIs: regions of interest; AcATaMa: Accuracy Assessment of Thematic Maps.

Thus, of the 221 points considered for dense vegetation, 202 were actually categorized in this class, and the remaining 9% were classified as sparse vegetation, exposed soil, and water bodies.

On the other hand, the other classes showed high commission errors, indicating that a point was inadequately included in a land cover class (Llano, 2018). Thus, the urban area and cloud classes showed an error of 100%, since none of the samples were classified in the class they should belong to.

Producer accuracy, meanwhile, refers to the probability of a reference point on the ground being correctly classified (Llano, 2018). In this case, the omission error for the urbanized area coincided with the commission error, which was 100%. The other classes, except for water bodies, were more than 50% accurate, with cloud shadows standing out as 100% correctly classified.

Concerning water bodies, both user and producer accuracy was low (13 and 34%, respectively). This can be explained by the spectral confusion with the shadows produced—by the forests—from different tree strata (Santos et al., 2021), which in the study area is consistent with the mosaic formed by dense vegetation and sparse vegetation.

Another factor that may explain these values is that the Saco River basin has a main river and narrow tributaries. According to Arvor et al. (2018), this fact makes it difficult to detect these targets due to the spatial resolution of Landsat-8 (30 meters) and to accurately separate small and narrow bodies of water. In addition, there is a dense vegetation around these water bodies which makes the spectral shape of the water more similar to the reflectance spectrum of vegetation (Jayawardhana and Chathurange, 2020).

Also noteworthy was the omission of sparse vegetation (45%) due to confusion over dense vegetation and exposed soil. This is because the Cerrado, one of the biomes where the coconut forest is located, has a complex classification of phytophysiognomies (Sano et al., 2019), which is made even more difficult by the varying management practices that cause different levels of degradation and biomass in the area (Broquet et al., 2024). In this way, some agricultural areas in the region may be higher, such as eucalyptus, with a spectral behavior similar to that of dense vegetation (Ferraz and Vicens, 2019), which can be mistaken for exposed soil when they are clearcut (Luz et al., 2018).

The confusion between sparse vegetation and exposed soil can also be explained by the presence of extensive areas of planted grass pasture. This is due to numerous rural properties in the region that raise cattle, including a large-scale feedlot that houses more than 4,000 heads in intensive production.

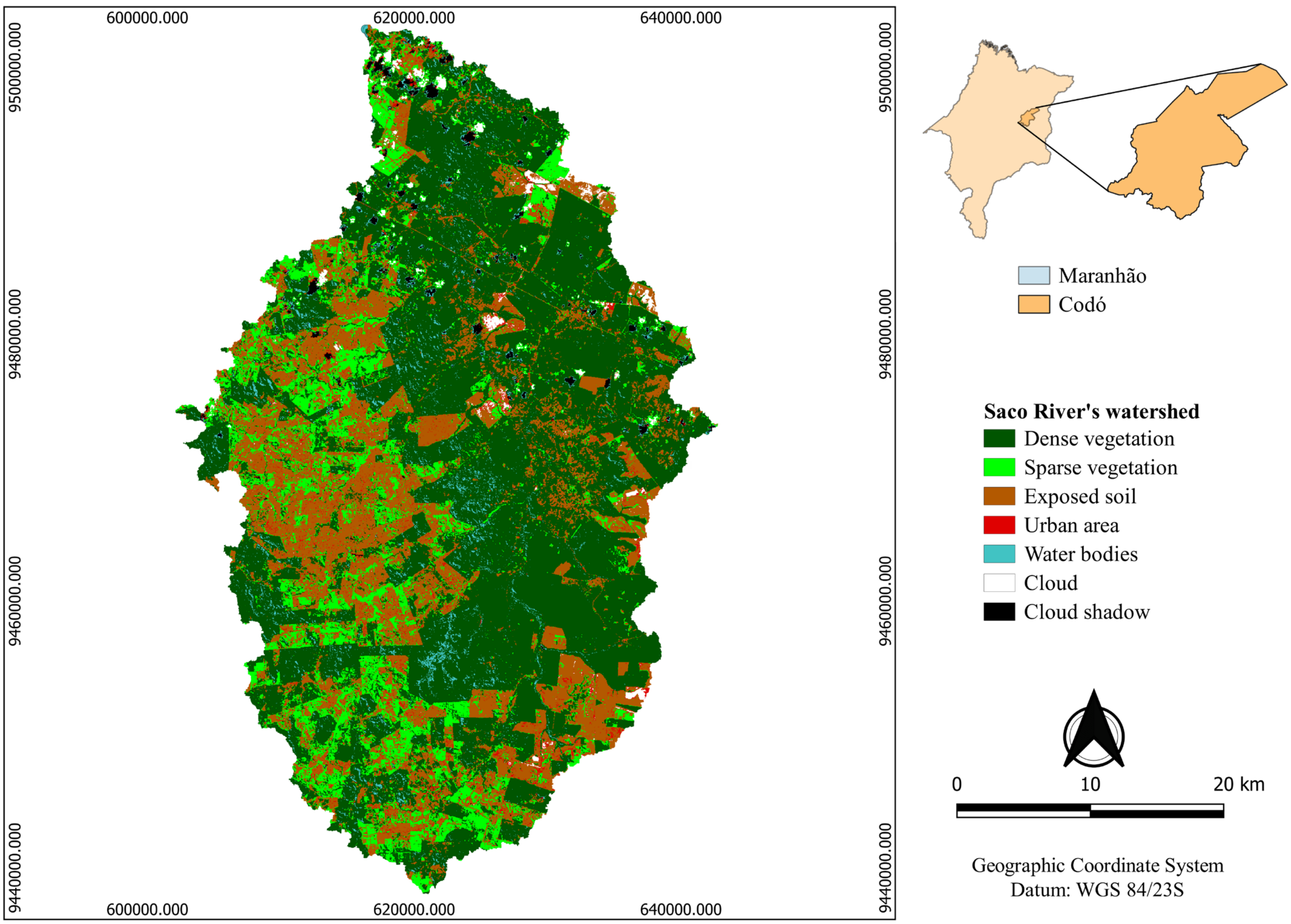


Figure 3 – Supervised classification of the Saco River basin, Maranhão, Brazil.

Table 3 – Post-classification generated by the Accuracy Assessment of Thematic Maps plugin, represented by the confusion matrix.

Class	Dense vegetation	Sparse vegetation	Exposed soil	Urbanized area	Water body	Cloud	Cloud shadow	Total	User accuracy (%)	Error of omission (%)
Dense vegetation	**202**	15	3	0	1	0	0	221	91	9
Sparse vegetation	11	**41**	5	0	1	0	0	58	71	29
Exposed soil	8	18	**67**	0	0	0	0	93	72	28
Urbanized area	0	1	8	**0**	0	0	0	9	0	100
Water body	7	0	0	0	**1**	0	0	8	13	87
Cloud	2	0	2	0	0	**0**	0	4	0	100
Cloud shadow	0	0	0	1	0	0	**2**	3	67	33
Total	230	75	85	1	3	0	2	396		
Producer accuracy (%)	87	55	79	0	34		100	Global accuracy (%): 79		
Error of omission (%)	13	45	21	100	66		0			

The presence of cattle in a given area results in low-stature vegetation that serves as a food source for them and, at the same time, exposes the soil due to trampling induced by the animals. This is a major environmental concern, as the basin under study is part of the MATOPIBA—a region made up of mostly Cerrado areas in the states of MAranhão, TOcantins, PIauí, and BAhia (from where the acronym originated). With 73 million hectares, this agricultural frontier is marked by large grain harvests, especially soybeans, corn, and cotton and, despite its economic importance, this region already shows patterns of significant changes in land use and cover related to the conversion of natural vegetation into cultivated pastures and cropland (Sano et al., 2019).

The urbanized area, in turn, had a commission error of 100%, since its accuracy is determined by spectral confusion with the planted area, i.e. sparse vegetation (Santos, et al., 2021), as well as spectral confusion with exposed soil cover.

In general, the methodological approach applied in this study proved to be consistent with the good practice protocol for estimating areas and assessing the accuracy of land cover patterns, since the reference data sources provide sufficient representation to accurately label each class of interest, as proposed by Olofsson et al. (2014).

Conclusions

Our study analyzed the land use and land cover patterns in the Saco River basin in Maranhão, Brazil, and concluded that there is a predominance of dense vegetation, such as the "babaçu" palm tree (*Attalea speciosa*), and that urban areas and water bodies are the least representative in the region.

It is worth noting that this work presents pioneering data for the coconut forest—a biome with a complex phytophysiognomy—and encourages strategic planning of environmental actions, making it possible, among other, to continuously monitor changes in land use and land cover over a given time.

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Authors' Contributions

Feitosa, J.N.A.: conceptualization, data curation, formal analysis, investigation, methodology, writing (original draft). **Coelho**, C.F.: supervision, writing (original draft, review & editing). **Silva**, R.C.C.: data curation, investigation. **Ribeiro**, A.T.: investigation, writing (original draft). **Simplício**, A.A.F.: investigation, methodology.

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