RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

Sentinel-2/MSI images and GEOBIA methodology in mapping land use and land cover in a Seasonally Dry Tropical Forest area in Brazil

Imagens Sentinel-2/MSI e metodologia GEOBIA no mapeamento do uso e cobertura da terra em área de Floresta Tropical Sazonalmente Seca no Brasil

Janaína Silva de Oliveira [*], Eduardo Rodrigues Viana de Lima [**], Bartolomeu Israel de Souza [***], Vinícius da Silva Seabra[****], Mikaella Pereira dos Santos[*****]

[*] Departamento de Geociências, Universidade Federal da Paraíba, jsobio@yahoo.com.br
[**] Departamento de Geociências, Universidade Federal da Paraíba, eduvianalima@gmail.com
[***] Departamento de Geociências, Universidade Federal da Paraíba, bartolomeuisrael@gmail.com
[****] Departamento de Geografia da Universidade do Estado do Rio de Janeiro, vinigeobr@yahoo.com.br
[*****] Departamento de Geografia da Universidade do Estado do Rio de Janeiro, pmikaella2@gmail.com

http://dx.doi.org/10.5380/raega.v59i0.94916

Abstract

Caatinga is an endemic Seasonallly Dry Tropical Forest in Brazil that covers about 10% of the national territory. Characterized by a mosaic of vegetation with predominance of deciduous species adapted to the irregular rainfall and a semi-arid climate, the degradation of that biome has been historically neglected by science and public policies. Despite the advance of geo-technology, such features make mapping of land use and land cover through remote sense a high-complexity task when compared to humid environments. The purpose of this study was to differentiate areas with predominance of exotic woods (*Prosopis juliflora*) from Caatinga's area of Cariri in Paraíba state, Brazil, through remote sense techniques and analyze the occupation of the studied area. By using the MSI sensor of Sentinel-2 Satellite and the Geographic Object-Based Image Analysis (GEOBIA) methodology, the results showed the efficiency in the identification of targets spectrally difficult to individualize, herein represented by the distinction between areas occupied by alien species and native vegetation (dense/rarefied),allowed identify a pattern of distribution of the areas invaded by *P. juliflora* and analyzing the occupation of the studied region, with focus on the conservation of biodiversity and geodiversity local areas. By the innovative results obtained, it´s concluded that GEOBIA was a facilitator in distinguishing targets that are spectrally difficult to be individualized and can be widely used in vegetation monitoring in FTSS by remote sensing.

Keywords:
Caatinga, environmental degradation, environmental conservation.

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

Resumo

A Caatinga é uma Floresta Tropical Sazonalmente Seca endêmica do Brasil que recobre cerca de 10% do território nacional. Caracterizada por um mosaico de vegetação com predominância de espécies caducifólias adaptadas aos eventos irregulares de chuva e ao clima semiárido, a degradação do bioma é historicamente negligenciada pela ciência e pelas políticas públicas. Mesmo com o avanço das geotecnologias, as particularidades da Caatinga tornam o mapeamento de uso e cobertura da terra por sensoriamento remoto uma atividade de elevada complexidade quando comparado aos ambientes úmidos. O objetivo do presente trabalho foi distinguir áreas de vegetação exótica composta predominantemente pela algaroba (*Prosopis juliflora*) na Caatinga do Cariri Paraibano através de técnicas de sensoriamento remoto e analisar o uso e cobertura da terra na região. Com o uso do sensor MSI do Satélite Sentinel-2 e da metodologia *Geographic Object-Based Image Analysis* (GEOBIA), os resultados demonstraram a eficiência na identificação de alvos espectralmente difíceis de serem individualizados, aqui representados pela distinção entre a vegetação nativa (densa/rarefeita) e a algaroba, permitiram identificar o padrão de distribuição dessa espécie invasora e analisar o uso e a ocupação da região de estudo, com destaque para áreas de conservação da biodiversidade e geodiversidade local. Com os resultados inovadores obtidos, conclui-se que o uso da GEOBIA é um facilitador na distinção de alvos espectralmente difíceis de serem individualizados e pode ser amplamente utilizado no monitoramento da vegetação em FTSS por sensoriamento remoto.
Palavras-chave:
Caatinga, degradação ambiental, conservação ambiental.

I. INTRODUTION

Seasonally Dry Tropical Forests (SDTF) present high levels of endemism and provide important ecological services to the society. However, their ecological, social, economic relevance, as well as the efforts to detect changes in the vegetation cover and in the conservation of such environments, are historically neglected, particularly when compared to the humid tropical forests (SANTOS et al. 2011; BEUCHLE et al. 2015; SMITH et al., 2019; LOPES et al. 2020).

Santos et al. (2011), Beuchle et al. (2015), Marinho et al. (2016), Silveira et al. (2018) and Lopes et al. (2020) highlight Caatinga as the biggest SDTF in South America, being characterized by mosaics of herbaceous, shrub and arboreal vegetation, with the dominance of xerophytic and deciduous species. It is a heterogeneous environment, endemic in Brazil, corresponding to approximately 10% of the national territory, with predominant semi-arid climate. However, the intense land use and the lack of environmental threaten the semi-arid region, described as the world's most populous and with the biggest biodiversity.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

According to Marinho et al. (2016), the anthropic pressure in the biome occurs mainly by livestock and deforestation. Many animals are raised freely and feed from native vegetation, which has been replaced by agriculture, pastures and indiscriminate extraction. With the use of traditional techniques and low production levels, Santos et al. (2011), Souza et al. (2015) and Lopes et al. (2020) warn that the transformation of vegetation cover may trigger the desertification process, which impairs the use of soil by changing its physical, chemical, biological and economic properties. According to the authors, it is estimated that almost 20% of Caatinga is under a strong desertification process, being the third most degraded biome in Brazil and one of the most threatened in the tropics.

Degradation is also related to the biological invasion of *Prosopis juliflora*, (Sw.) DC. (Fabaceae), popularly known as 'algaroba' in Brazil. The dissemination of the species in the northeastern semi-arid occurs due to its survival capacity in areas with low precipitation and long dry periods. Even presenting a trend of concentration in the riparian forest domain and deeper soil, little is known about the quantification and distribution of such species in the semi-arid. It is believed that *P. juliflora* occurs in approximately one million hectares, but the area can be even greater because of the easy dispersion of seeds, carried out mainly by grazing animals (ANDRADE et al., 2010; GONÇALVES et al., 2015).

Furthermore, Caatinga also presents exceptional challenges related to the use of remote sense to map and monitor land use and land cover. The difficulty is due to the specificity of the environmental dynamics (SILVEIRA et al. 2018), represented by low indexes of vegetation presence and high reflectance of the soil, the presence of crustose, high spatial heterogeneity in a regional scale, and the unpredictable behavior of the vegetation under the temporal and spatial irregularity of precipitation (SMITH et al., 2019).

Despite the technological advance of remote sense over the last decades, maps that estimate the vegetation cover through satellite images with medium and high spatial resolution in a large scale are recent in that biome – many of those are even limited in historical data from the Landsat series (BEUCHLE et al., 2015; SILVEIRA et al., 2018; LOPES et al., 2020). According to Silveira et al. (2018), recent studies have wasted new opportunities given by technologies to minimize the complexity in mapping Caatinga, such as the use of a higher spatial and spectral resolution provided by the MSI sensor of Sentinel-2 satellite, launched in 2015.

Digital processing of satellite images has also improved in the last decades with the improvement of the classification techniques. Santos et al. (2018) consider that the object-oriented classification has shown better performance in recent maps of land use and land cover. Given the specificity of Caatinga and the technical difficulties found in remote sense, Geographic Object-Based Image Analysis (GEOBIA) is a classification

6
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

methodology that allows systematizing and reproducing a specialist's knowledge through Boolean and/or fuzzy models criteria. Under this supervised classification, descriptors are used as object characterization parameters capable of integrating data from multiple sources, scales and variables, such as color, texture, location, context and semantic relationship between classes or objects. Thus, GEOBIA is a facilitator in the distinction of targets spectrally difficult to be individualized (SANTOS et al., 2018; SILVA; CRUZ, 2018; LIMA et al., 2019).

This study purposed to identify and differentiate areas of *Prosopis juliflora* in relation to the remnants of Caatinga during the classification. Additionally, the map of land use and land cover allowed to verify the occupation of the studied area, which is home to particular geodiversity and biodiversity under increasing threat by anthropic pressure, especially farming and vegetation extraction.

The studied area, with 9,207.71 km², covers 21 municipalities of the Cariri region[1] and is partially inserted in the river basin of Paraíba river. According to the Executive Water Management Agency of Paraíba State (AESA, 2019), that area has the lowest precipitation rates in Brazil, with an average of 400-800 mm per year, in a BSh semi-arid climate according to köppen classification. In spite of the low precipitation rates, Seabra et al. (2014) and Lima et al. (2019) stress the importance of that basin for supplying the population of Paraíba. In terms of water resources management, the authors highlight the strategic location of Paraíba river, which, during part of the year, receives water from the transfer of the São Francisco river.

According to Brazilian Institute of Geography and Statistics census (IBGE, 2022), the studied area is home to 146,194 residents, being most of them subsistence farmers. According to the last agricultural census carried out by IBGE in 2017, the predominant products are *Opuntia cochenillifera* (used to feed cattle), corn (*Zea mays* L.) and beans (*Vigna* sp and *Phaseolus* sp). For livestock, it is common to use natural pastures, with special attention to the quantity of animals: 235,947 goats, 161,212 sheep and 72,141 cows.

The lack of economic alternatives intensifies environmental degradation, particularly in the water deficit period. During the long droughts, there is more vegetation extraction, whether for domestic use of rural families, whether for industries, where firewood and charcoal represent the major energy source (Lima et al., 2019). With the anthropic modifications of natural areas, Santos et al. (2011) and Souza et al. (2015) highlight the emergence of biotas characteristic of an environment under a desertification process, found in high levels in Cariri, even if it contrasts with the potentiality of the state in representing the richness of Caatinga's flora.

[1] Although municipality of Boa Vista is located in the microregion of Agreste, it is traditionally referred to as belonging to Cariri.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

In an attempt to organize the sustainable exploitation of natural resources and to ensure ecological balance, the Brazilian law provides for the creation of conservation areas (UC, in the Brazilian acronym) to protect environments with relevant characteristics (Brazil, 2000). However, Lima et al*.* (2019) stress that only 7.7% of the UCs cover areas of Caatinga; and the abiotic nature, frequently represented as a tourist attraction for its scenic beauty, is addressed in a non-important way, without effective legal protection of geodiversity (DIAS; FERREIRA, 2018). In that sense, despite the legislation gap, the initial milestone for geoconservation in the studied area is based on proposals for creating a geopark with eleven geosites and nine geodiversity sites, identified by the Brazilian Geological Service (Lages et al*.*, 2018). In terms of UCs, there are two Areas of Environmental Protection (APA, in the Brazilian acronym) and two Private Reserve of Natural Heritage (RPPN, in the Brazilian acronym).

II. Materials and Methods

The choice of satellite images is a distinction stage in the Caatinga mapping. It was necessary to analyze the temporal and spatial behavior of rainfall in the study area so as not to underestimate or overestimate the vegetation due to the rapid variation in the spectral response to the seasonality of water availability. (SILVA; CRUZ, 2018). According to Almeida and Medeiros (2017), the year-on-year variability of rainfall in the semi-arid is related to the ocean and atmosphere phenomena El Niño and La Niña, which in the more intense years indicate the trends for high or low precipitation, respectively.

According to Climate Protection Center database (CPC, 2019), 2017 was considered as the neutral year closest to the present after the intense occurrences of El Niño in 2015 and 2016; before the most recent years under the influence of La Niña. Data that corroborate the neutrality of precipitation in 2017 were consulted from the National Institute of Meteorology (INMET, 2019). In that year, the mean annual precipitation at the Conventional Meteorological Station of Monteiro was 607mm.

After defining the year, nine scenes were selected from Sentinel-2 to cover the studied area, using as criteria images generated with less cloud cover. Finally, irregular precipitation events were also verified in November in the 21 municipalities that comprise the studied area. According to AESA (2019), only Monteiro and São Sebastião do Umbuzeiro registered precipitations above 8.9 and 5.9 mm, respectively.

The images from Sentinels-2 satellite, MSI sensor, were provided free of charge by the United States Geological Survey (USGS, 2019) with atmospheric correction, eliminating this pre-processing step. Consist of 13 bands, the bands B2 (blue), B3 (green), B4 (red) and B8 (near infrared) have spatial resolution of 10 m; with

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

resolution of 20 m, bands B5, B6, B7 and B8a (red edge) are narrow, and are used for the characterization the vegetation; bands B11 and B12 (SWIR) are applied for the detection of snow, ice, cloud or for assessing moisture stress on vegetation; and bands B1 (aerosols), B9 (water vapor) and B10 (detection of cirrus), with resolution of 60 m, are used mostly for screening of clouds and atmospheric correction.

The diversity of bands of the MSI sensor, together with the radiometric indexes generated by them, aided digital processing of the satellite images. It is a set of techniques characterized by the stages of segmentation, creation of thematic categories, sampling, knowledge modeling, automatized classification and manual edition. Using AcrGIS 10.2 software, the mosaic of bands was built separately, ignoring B1, B9 and B11. Eight radiometric indexes of vegetation and water were applied (Table 1). The results were saved in TIFF image format to be classified using Definiens e-Cognition 8.0.1 software.

Table 1 - Radiometric Indexes of Vegetation and Water.

Índice	**Fórmula**		**Referências**
NDVI	$\frac{(NIR - Red)}{(NIR + Red)}$	NIR = B8; Red = B4	Rouse et al. (1973)
RE-NDVI	$\frac{(NIR - Red\ Edge)}{(NIR + Red\ Edge)}$	NIR = B8; Red Edge = B6	Gitelson e Merzlyak (1994)
GNDVI	$\frac{(NIR - Green)}{(NIR + Green)}$	NIR = B8; Green = B3	Gitelson et al. (1996)
SAVI	$(\frac{(NIR - Red)}{(NIR + Red)} + \mathrm{L}) * (1 + \mathrm{L})$	NIR = B8; Red = B4; L = 0,5	Huete (1988)
SAVI2		NIR = B8; Red = B4; L = 0,3	Huete (1988)
NDWI	$\frac{(NIR - SWIR)}{(NIR + SWIR)}$	NIR = B8; SWIR = B11	Gao (1996)
NDWI2	$\frac{(Green - NIR)}{(Green + NIR)}$	Green = B3; NIR = B8	McFeeters (1996)
MNDWI	$\frac{(Green - SWIR)}{(Green + SWIR)}$	Green = B3; SWIR = B11	Xu (2005)

Source: the authors (2023).

According to Silveira et al. (2018), the registered reflectance and the indexes that can be generated by the MSI sensor foster mapping Caatinga, since the spectral intervals of red, red edge and SWIR bands are sensitive to the variations of chlorophyll and non-photosynthetic vegetation. Among the vegetation indexes, Lopes et al. (2020) state that NDVI is widely used in studies on dynamics and degradation of vegetation cover in the domain of the Caatingas.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

The mosaics of the bands and the results of the spectral indexes were used as descriptors during the GEOBIA classification through Definiens e-Cognition software, and the delimited quadrant was greater than the studied area (minimal and maximum UTM coordinates: x = 673778 and 832860; and y = 9076585 and 9216154). The first stage of the supervised classification refers to the segmentation of the images, adjusted to the multi-resolution algorithm, with the same weights for all bands used in the process, considering the means and standard deviations of the images with weight 1, similarity parameter 100, form 0.1 and compactness 0.5.

The shape criterion considers the object's geometry at the time of segmentation according to the spectral responses of the targets. A reduced shape value (0.1) was chosen so that the spectral responses of the targets identified were more relevant than the shape at the time of their identification. Compactness contributes to the size of objects discriminated from segmentation. The values defined were selected based on trial and error, in the search for segments consistent with the scale sought in the mapping.

With the segmented images, the pixel groups are transformed in objects and are shown to distinguish seven predetermined thematic categories (Table 2). During the knowledge modeling stage, it is possible to identify features and describe identifying standards through visual interpretation techniques with different resolutions, which performs better than traditional methodologies restricted to the use of spectral attributes (SANTOS et al., 2018; SILVA; CRUZ, 2018; LIMA et al., 2019). Field work during the dry and wet seasons was essential to identify the objects in the image.

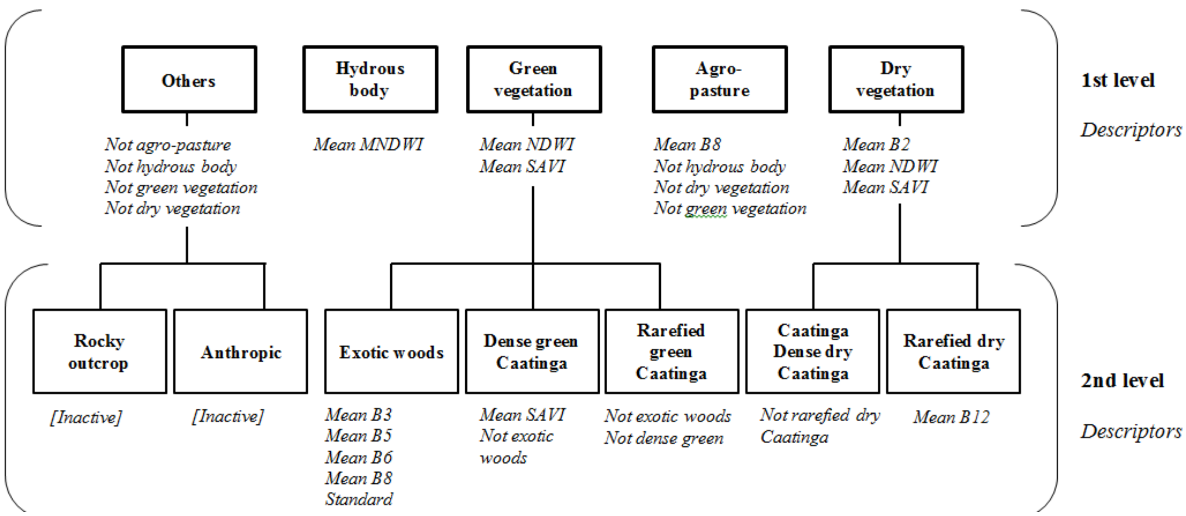
Table 2 - Description of the thematic categories.

Thematic category	Characteristics
Hydrous body	Significant accumulation of water on the surface, whether natural or artificial, mostly represented by reservoirs.
Rocky outcrop	Generally found in the form of flooring and inselbergs.
Anthropic	Represented by the consolidated urban/semi-urban occupation or areas with soil movements caused by anthropic activities.
Exotic woods	Mostly comprised by *Prosopis juliflora*;
Agro-pasture	Areas with high level of degradation of Caatinga due to vegetation extraction, growing areas and/or pastures in the predominant herbaceous vegetation.
Rarefied Caatinga	Comprised of herbaceous, shrub and/or open arboreal vegetation, partially covering the soil.
Dense Caatinga	Comprised of shrub/arboreal vegetation, totally covering the soil.

Source: the authors (2023).

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

In the sampling and knowledge modeling stages, the objects were represented in a top-down decision tree with two hierarchic levels, as shown in Picture 1, which also presents the respective descriptors. The use of inverse models, which include the word NOT, was essential to classify an unclassified object in the same hierarchic level. For example, 'Others' is used when the classification is NOT 'Hydrous body', NOT 'Green vegetation', NOT 'Agro-pasture' and NOT 'Dry vegetation'.



Picture 1 - Hierarchy and descriptors used in GEOBIA classification. (Source: the authors, 2023).

Next, categories 'rocky outcrop' and 'anthropic' were manually edited, which concluded the GEOBIA classification in Definiens e-Cognition software. Then, the results were exported in shapefile format as polygons, and with ArcGIS software, categories 'Dense Caatinga' and 'Rarefied Caatinga' were made compatible to include the same caption value of the respective polygons of 'green Caatinga' and 'dry Caatinga'. Lastly, the post-processing was carried out through ERDAS Imagine software, where geometric generalization was made possible by applying a mode filter and eliminating minimum areas (900 m²) in a 5x5-pixel vicinity.

The map of land use and land cover was validated by field checking. The results obtained in the classification were incorporated in vector format in ArcGIS software, and the centroids of the polygons were extracted. Then, 70 points were created for each category and were submitted to random statistical selection with the subset features tool of Geostatistical Analyst module.

The consistency of the classification was then verified visually both through Google Earth platform and in loco for the 490 generated points. The reliability of the classification was statistically validated through a confusion matrix (CONGALTON, 1991), with the calculation of the coefficients of agreement of overall accuracy (equation 1) and the Kappa index (equation 2), where $-1 \leq K \geq +1$ (Table 3).

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

$$EG = \frac{A}{N} * 100 \tag{1}$$

EG = overall accuracy

A = general match of each sample point of the diagonal

N = total of sample points in each category

$$K = \frac{n\sum_{i=1}^{c} x_{ii} - \sum_{i=1}^{c} x_{i+}x_{+i}}{n^2 - \sum_{i=1}^{c} x_{i+}x_{+i}} \tag{2}$$

K = Kappa coefficient

n = total of sample points (reference pixels)

c = = total of categories

x_{ii} = sum of the diagonal of the confusion matrix

x_{i+} = sum of row i of the confusion matrix

x_{+i} = sum of column i of the confusion matrix

Table 3 - Division of quality classes resulting from Kappa.

KAPPA (K)	MAP QUALITY
< 0.00	Bad
0.00 – 0.20	Poor
0.21 – 0.40	Acceptable
0.41 – 0.60	Good
0.61 – 0.80	Very good
0.81 – 1.00	Excellent

Source: Landis and Koch (1977).

III. Results and discussion

The GEOBIA classification reached excellent results, as shown in Table 4, with global accuracy at 87% and Kappa 0.85 (Table 4). The classification was based on ten descriptors: standard deviation of B7; mean of B2, B3, B5, B6, B8, B12, and spectral indexes MNDWI, NDWI and SAVI (refer to Picture 1).

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

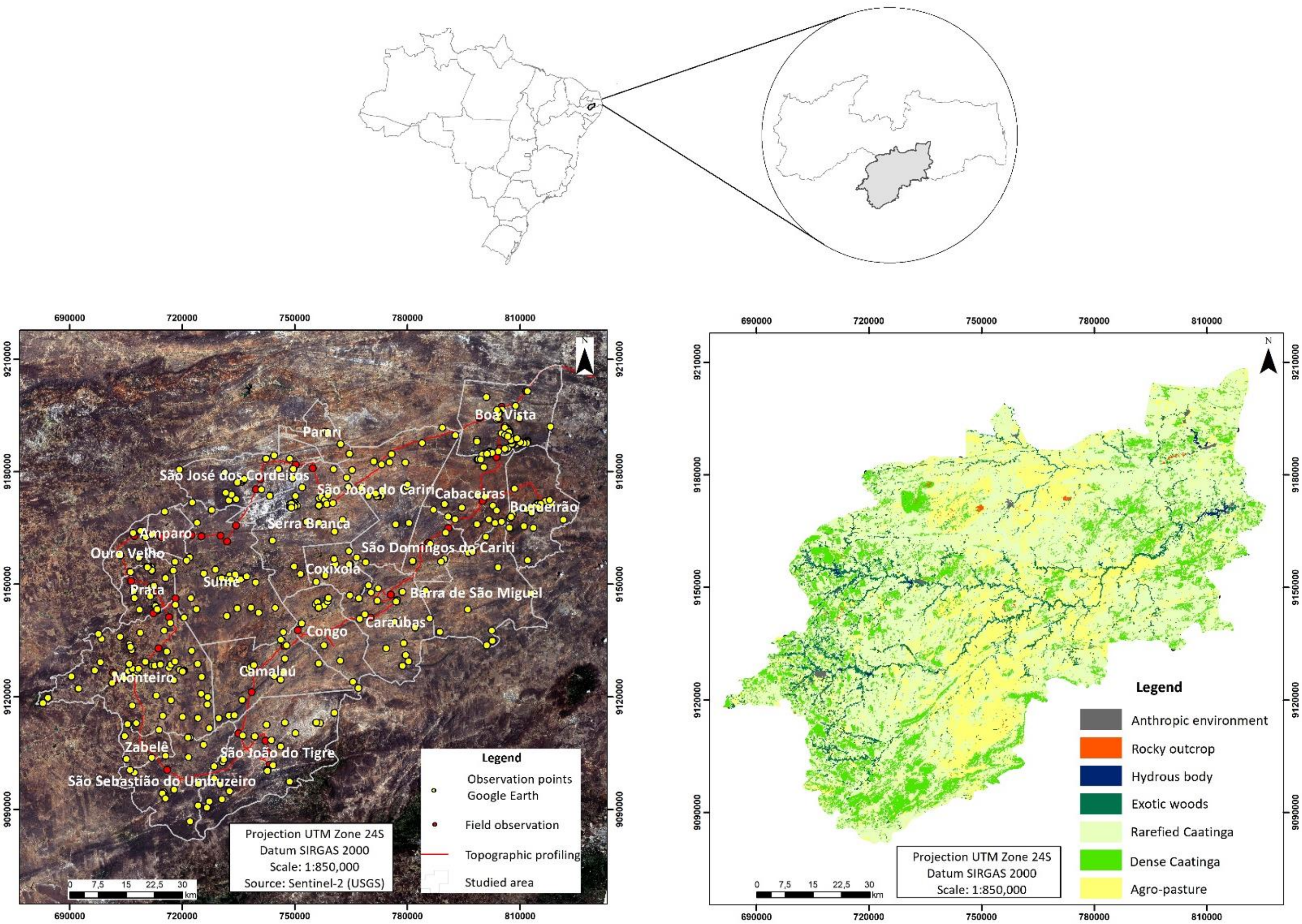
Table 4 – Confusion matrix with results obtained from global accuracy and Kappa index.

	Categories	**Reference Samples**						
		Hydrous body	Rocky outcrop	Anthropic	Exotic woods	Agro-pasture	Rarefied Caatinga	Dense Caatinga
Field checking	Hydrous body	62	0	0	0	0	0	0
	Rocky outcrop	0	54	0	0	0	0	0
	Anthropic	6	7	67	0	0	1	0
	Exotic woods	0	0	0	57	0	1	2
	Agro-pasture	0	7	3	8	61	2	0
	Rarefied Caatinga	2	2	0	0	7	61	4
	Dense Caatinga	0	0	0	5	2	5	64
Global accuracy		**87%**						
Kappa index		**0.85**						

Source: the authors (2023).

The results obtained by GEOBIA with only the indices and spectral bands enabled distinguishing areas of exotic vegetation from native vegetation in an unpublished result for the adopted regional scale. The Picture 2 shows a Sentinel-2 image in RGB 4-3-2 composition used during sampling, the points observed in field checking, the field path and the result of the classification.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916



Picture 2 - Map of land use and land cover generated by GEOBIA classification. (Source: the authors, 2023).

The SAVI proved to be more efficient to differentiate dry vegetation from green vegetation (first level of the decision tree) and from dense green Caatinga in the second level. According to Huete (1998), that index considers the effects of brightness of the exposed soil from constant L, factor used to group lower or greater vegetation density, with values between 0.25 and 1. Here, L=0.25 and L=0.5 were used and the intermediate cover was the most appropriate and stood out as an important descriptor in the Caatinga. Thus, although NDVI is widely used in studies about the dynamics and the degradation of vegetation cover in Caatinga, there is a significant influence of soil on the results, especially in semi-arid regions with low density of vegetation cover (LOPES et al., 2020; SMITH et al., 2019).

In addition to SAVI, the distinction between green and dry vegetation was also based on NDWI, proposed by Gao (1996) as a complementary index that responds to the presence of moisture in the vegetation, particularly in canopies. As for mean B12 (SWIR), it was essential in the differentiation of dry Caatinga to assess

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

the moisture stress in vegetation (SILVEIRA et al., 2018; USGS, 2019). In the second level, the characterization of exotic of the Caatinga occurred only through spectral bands B3, B5, B6, B7, B8.

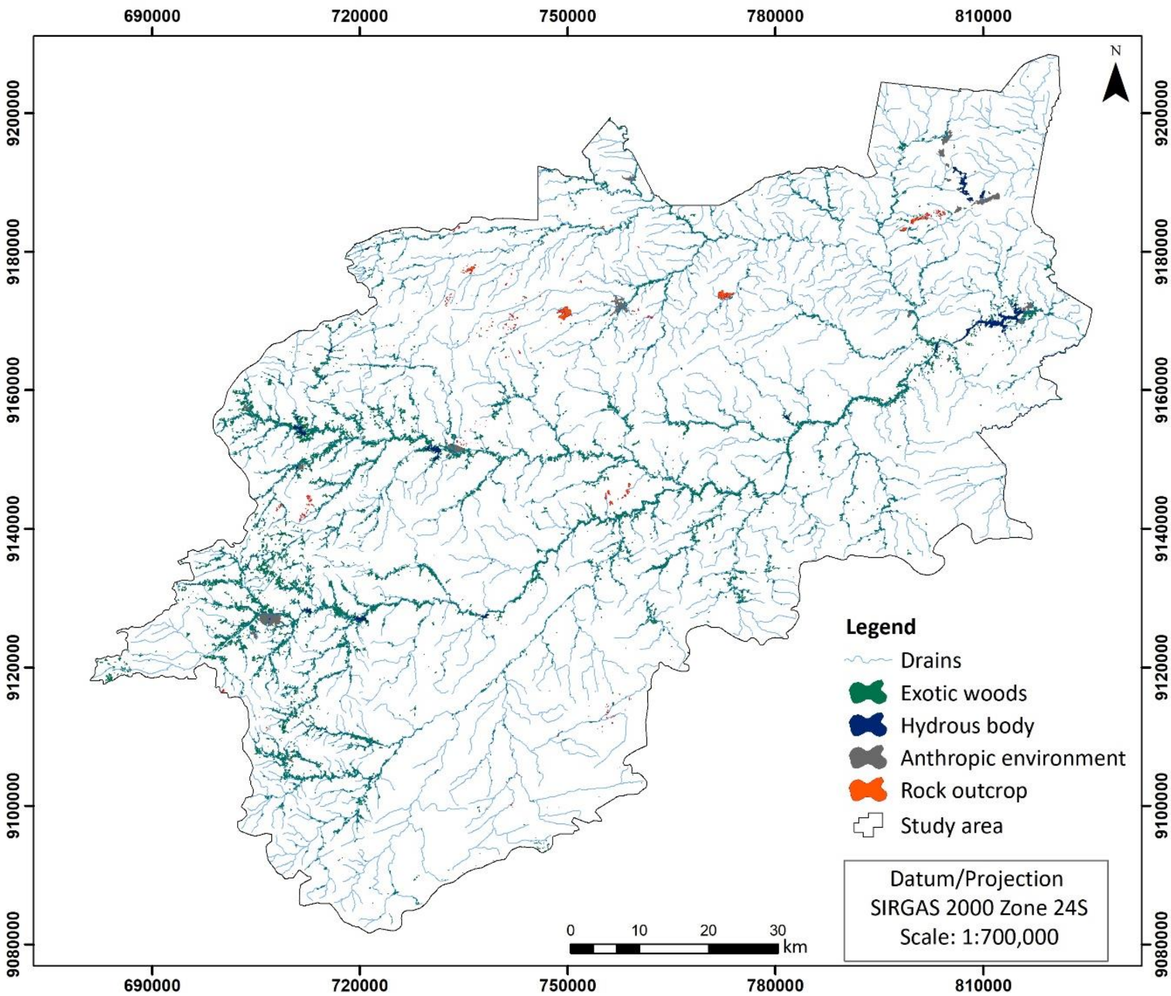
In order to differentiate Exotic woods from Dense and Rarefied Caatinga, SAVI and NDWI indexes were essential, as those allowed identifying the presence of biomass adjusted to the soil and moisture in the vegetation. Lima et al. (2019) could also distinguish Caatinga and non Caatinga with the same indexes, despite the use of other descriptors, such as relief range – since *Prosopis juliflora* tends to follow lower portions of the relief along the drains. The moisture stress in the dry vegetation of rarefied Caatinga was also identified through the mean B12, differentiating green Caatinga from Exotic woods through the mean SAVI index.

In a more detailed area, restricted to APA Cariri, Silva et al. (2019) used the mean reflectance of B2, B3, B4 and B8, geometry and shape, in addition to the drainage system and access roads. The authors distinguished two categories of Caatinga (arboreal and shrub), degraded area, anthropic area, rocky outcrop, plantations on river floodplains, river bodies and reservoirs. Even in more detailed mapping, as carried out by Ballén et al. (2016) at APA Cariri with the use of NDVI and SAVI, the differentiation between areas of dense Caatinga and areas dominated by *Prosopis juliflora* could only be viewed in field. Pereira et al. (2013) could differentiate areas of *Prosopis juliflora* in the map of land use and land cover of the municipality of São João do Cariri with images from Landsat-5/TM and CBERS-2/CCD. For this purpose, the authors used highlight techniques, NDVI, multi-spectral compositions adjusted for similarity segmentation and non supervised classification, according to the Bhattacharya coefficient.

After mapping, each category was quantified to subsidize the analysis of land use and land cover in the Cariri region, state of Paraíba. With a total area of 9,207.72 km², Rarefied Caatinga represents 58.63% of the land (5,398.22 km²), followed by Agro-pasture, with 22.23% (2,046.99 km²), Dense Caatinga with 15.83% (1,457.65 km²), Exotic Woods with 2.90% (266.69 km²), Anthropic with 0.17% (16.01 km²), Hydrous Body with 0.16% (14.31 km²) and Rocky Outcrop with 0.09% (7.84 km²).

When quantifying Exotic Woods, it is possible to think, initially, that it is not representative, for it covers 2.90% of the Cariri region, as well as the low quantitative contribution verified in categories Anthropic, Hydrous Body and Rocky Outcrop. However, Picture 3 illustrates the spatial distribution of those categories, where Exotic Woods reveals to be widespread all over the studied area, following drain areas and forming an "exotic riparian forest".

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916



Picture 3 - Highlight of Exotic Woods overlaid with the existing drains, with the spatial location of categories anthropic, rocky outcrop and hydrous body. (Source: the authors, 2023).

Prosopis juliflora was introduced in Brazilian semi-arid in the 1940s and, in the 1970s, its cultivation was encouraged by governmental actions to replace the original vegetation of Caatinga, particularly for its forage potential and as a source for stakes and firewood (Andrade et al*.*, 2010; Pereira et al*.*, 2013). However, Andrade et al*.* (2010) stress that the invasion of the species interferes in the resilience of the ecosystems and affects the native diversity of Caatinga, which increases environmental vulnerability.

According to Pereira et al*.* (2013), the expansion of the exotic species also results in a greater local socioeconomic vulnerability. The authors identified the continuous occupation of the species in fertile areas, especially in riverbanks. But the radicular system of the *Prosopis juliflora* favors fluvial erosion, reduces agricultural areas because of torrents and makes any consortium activity impossible. Currently, observed cases of suppression in planting areas, where farmers use, empirically, several inefficient control techniques. Among those, the use of fire and herbicides stresses the lack of scientific knowledge to mitigate the advance of the

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

species and the effects of those actions on the human health and on the environment (PEREIRA et al., 2013; Gonçalves et al., 2015).

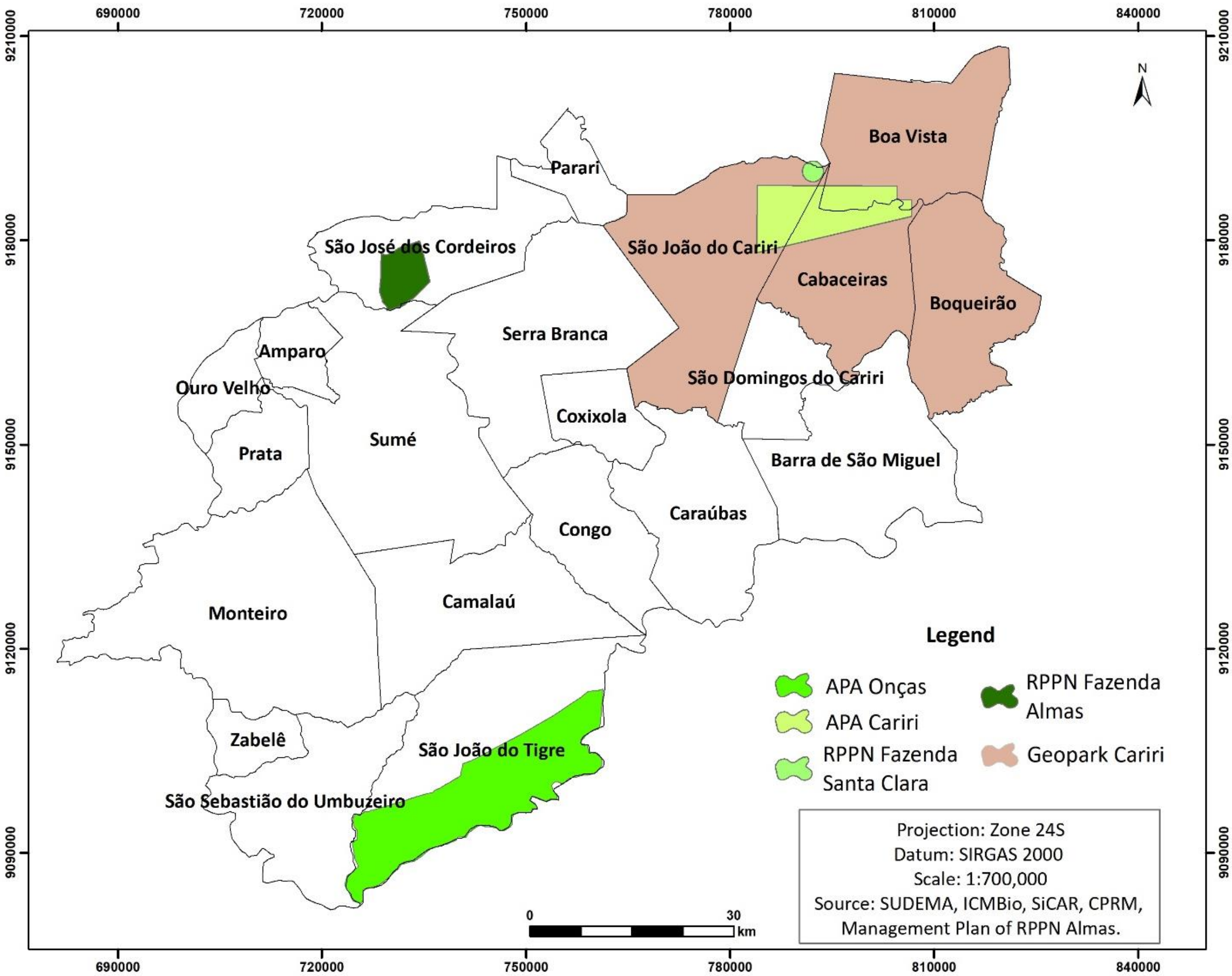
Even with the predominance of small communities and scattered villages, which hamper the identification in the mapping because of the scale, it is worth to highlight the intense anthropic use associated with agriculture and livestock. Included in category Agro-pasture, those represent 22.23% of the studied area, whose coverage may be even greater when considering free-roaming animals that feed on native vegetation. According to Lima et al*.* (2019) and Pereira et al*.* (2020), the environmental degradation derived from that economic activity important in the region tends to extend to areas with plain, slightly corrugated surface, highlighting the importance of the rocky outcrops in the conservation of Caatinga.

The anthropic use has modified the soil and the natural vegetation of the biome, with a close relation between degradation and desertification. In the state of Paraíba, the rarefaction or absence of vegetation cover in Cariri make the region noted for the high levels of desertification. On the other hand, in the areas with small modifications in Caatinga, the floral diversity exceeds other preserved remnants of existing SDTFs (SOUZA et al., 2015).

In the studied area, Rarefied Caatinga represents 58.63% of the region, being the most representative category. Pioneer species are commonly found, which may indicate a modification of the vegetation cover in the past. Marinho et al*.* (2016), when evaluating the effect of land use in the regeneration of the community of woody plants of Caatinga over the past 20 years, identified a relatively high vegetation cover in the areas with low pasturing, which indicates the recover capacity of those environments when the animals are away. As for the Dense Caatinga, it occupies 15.83% of the studied area and is scattered all over the Cariri region, state of Paraíba, being essential in the formation of the biome's characteristic heterogeneous mosaic.

Even with a high representativeness of Rarefied Caatinga and the presence of areas with Dense Caatinga, it is important to remember that the protection of biodiversity and geodiversity in the studied area is incipient. For that matter, to complement the analysis of land use and land cover, the contribution of each thematic category was quantified in the perspective of the four existing UCs and in the proposal for creation of the Geopark (Picture 4).

RA'EGA
O ESPAÇO GEOGRÁFICO EM ANÁLISE
https://revistas.ufpr.br/raega
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916



Picture 4 - Location of the UCs and areas proposed for geoconservation of the studied area. (Source: the authors, 2023).

Located in the municipality of São João do Tigre, APA Onças is the greatest UC in the studied area, with approximately 381 km². According to Borges et al. (2017), the vegetation in APA Onças is characterized by arboreal and shrub Caatinga, both in dense and open forms; and the anthropic activities are based on subsistence farming. In the UC, Rarefied Caatinga corresponds to 42.32%, followed by Dense Caatinga, with 35.99%, and Agro-pasture, with 21.45%. To a lesser extent are Exotic Woods, with 0.22% and Rocky Outcrop, with 0.01%. Categories Hydrous Body and Anthropic are not found. The representativeness of the two categories of Caatinga is noteworthy, and together they represent 75.95% of the UC.

The obtained results are comparable to those by Pereira et al. (2020), who analyzed the influence of relief in land use and land cover in that UC. Although the authors have defined five categories (Sparse Vegetation, Semi-dense vegetation, Dense Vegetation, Exposed Soil and Water) and used mapping techniques that differ from those herein, the three vegetation categories were 77.91%.

18
ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

Furthermore, Borges et al. (2017) proposed a geospatial, graphical and thematic representation of the APA's geodiversity, where they quantified 14 potential geosites for analysis. Even facing the existing potential, Pereira et al. (2020) observed a greater level of environmental degradation in plainer regions with low moisture content, and pointed the fragility of the UC facing the anthropic interference in the local communities.

RPPN Fazenda Almas sits at the border of the municipalities of São José dos Cordeiros and Sumé. It has approximately 51 km², being 60.82% represented by Dense Caatinga, 36.13% Rarefied Caatinga, 2.51% of Agro-pasture, 0.29% of Rocky Outcrop and 0.24% of Prosopis juliflora. It is noteworthy that almost the entire UC (96.95%) corresponds to areas of Caatinga. For Lima and Barbosa (2014), that area is unique in terms of vegetation conservation, with high variety of species, which may be associated to the difficulty of access within the RPPN and to the diversity of micro-habitats capable of minimizing the drought effects, acting as ecological refuges.

APA Cariri covers approximately 157 km², 76.33% of which represented by Rarefied Caatinga, 16.45% by Dense Caatinga, 3.71% by Agro-pasture, 2.64% by Exotic Woods, 0.81% by Rocky Outcrops and 0.07% by Anthropic. Silva et al. (2019) analyzed the degree of anthropic intervention within the UC by using a map that considered the size of the vegetation and socio-environmental variables. The results obtained by the authors show the predominance of shrub Caatinga (61%) and high levels of environmental transformation motivated by the extraction of betonite and farming activities.

Despite the vulnerability presented, it is stressed that the APA is also associated with geoconservation, which should include five geodiversity sites, seven geosites of national relevance and one of international relevance. The consolidation of those environments becomes one more tool to promote local sustainable development, which should integrate the interests of the community, of the mining companies and of the UC management.

RPPN Fazenda Santa Clara is the smallest UC in the studied area and presents more lack of scientific studies in its area, despite having been created in the 1990s. Without an official border or a management plan, the area was measured by Chico Mendes Institute of Biodiversity through coordinates inserted in the RPPN Computer Monitoring System. The area covers approximately 6.34 km², being 62.05% Rarefied Caatinga, 36.32% Dense Caatinga and 1.63% Agro-pasture.

In a study on the floral composition of vascular plants in the RPPN, Queiroz et al. (2017) identified two types of vegetation according to the density and size of the vascular plants: open formation and closed formation, which may be related to categories Rarefied Caatinga and Dense Caatinga. The open formation was

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

characterized by the low density and diversity of species, with higher number of xerophile features, related to the higher dryness at the area and to the anthropic action intensified by the presence of cattle.

IV. Conclusion

Mapping through remote sense in Caatinga is extremely complex due to the spectral behavior of the vegetation, very much influenced by the irregularity of the precipitation events. Here, the map of land use and land cover in the regional context of Cariri in the state of Paraíba differentiated areas with the predominance of *Prosopis juliflora* (Exotic Woods) from those of native remnants of Caatinga (Dense and Rarefied). It is an unpublished result that has much to contribute in the measurement of degraded and native areas, thereby subsidizing studies for the conservation of a biome historically neglected by public administrators. The use of the techniques herein may subsidize new studies for the detection of the vegetation cover of Seasonally Dry Tropical Forests and serve as a basis for continuous improvements in the use of geo-technology for the conservation of environments with particular features.

V. References

AB'SABER, A. N. Caatingas: o domínio dos sertões secos. In: AB'SABER, A. N. Os Domínios de Natureza no Brasil: potencialidades paisagísticas. São Paulo: Ateliê Editorial, 2011. 6ª ed., 160p.

AESA - Agência Executiva de Gestão das Águas do Estado da Paraíba. Disponível em: <http://geoserver.aesa.pb.gov.br/geoprocessamento/geoportal/mapas.html>. Acesso em 09 de agosto de 2019.

ALMEIDA, H. A.; MEDEIROS, E. A. Variabilidade no regime pluvial em duas mesorregiões da Paraíba e sua relação com o fenômeno El Niño Oscilação Sul. Journal of Environmental Analysis and Progress, v. 02, n. 03, p. 177-185, 2017. https://doi.org/10.24221/jeap.2.3.2017.1340.177-185

ANDRADE, L. A.; FABRICANTE, J. R.; OLIVEIRA, F. X. Impactos da invasão de Prosopis juliflora (sw.) DC. (Fabaceae) sobre o estrato arbustivo-arbóreo em áreas de Caatinga no Estado da Paraíba, Brasil. Maringá, v. 32, n. 3, p. 249-255, 2010. https://doi.org/10.4025/actascibiolsci.v32i3.4535

BALLÉN, L. A.; SOUZA, B. I.; LIMA, E. R. V. Análise espaço-temporal da cobertura vegetal na Área de Proteção Ambiental do Cariri, Paraíba, Brasil. Boletim Goiano de Geografia, v. 36, n. 3, p. 555-571, 2016.

BEUCHLE, R.; GRECCHI, R. C.; SHIMABUKURO, Y. E.; SELIGER, R.; EVA, H. D.; SANO, E.; ACHARD, F. Land cover changes in the Brazilian Cerrado and Caatinga biomes from 1990 to 2010 based on a systematic remote sensing sampling approach. Applied Geography, v. 58, p. 116-127, 2015. https://doi.org/10.1016/j.apgeog.2015.01.017

BORGES, U. N.; PACHECO, A. P.; MARIANO, G. Uma contextualização espacial e temática da Geodiversidade: APA das Onças/PB/Brasil. Estudos Geológicos, n. 27, p. 143-160, 2017.

BRASIL. Lei n° 9.985 de 18 de julho de 2000. Regulamenta o artigo 225, § 1º, incisos I, II, III, VII da Constituição

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

Federal, institui o Sistema Nacional de Unidades de Conservação da Natureza e dá outras providências. Diário Oficial da União: Brasília, 2000.

CPC – CLIMATE PREDICTION CENTER. Disponível em: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Acesso em 09 de agosto de 2019.

CONGALTON, R. G. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment, v. 37, n. 1, p. 35-46, 1991. http://dx.doi.org/10.1016/0034-4257(91)90048-B

DIAS, L. C.; FERREIRA, G. C. A Geoconservação sob a ótica legislativa: uma análise comparativa de leis nacionais e internacionais sobre a proteção do patrimônio geológico. Revista Geociências UNESP, v. 37, n. 1, p. 211-223, 2018. https://doi.org/10.5016/geociencias.v37i1.11186

FRANCISCO, P. R. M.; CHAVES, I. B.; CHAVES, L. H. G.; LIMA, E. R. V.; SILVA, B. B. Análise espectral e avaliação de índices de vegetação para o mapeamento da caatinga. Revista Verde de Agroecologia e Desenvolvimento Sustentável, v. 10, n. 3, p. 01-12, 2015. https://doi.org/10.18378/rvads.v10i3.3046

GAO, B. NDWI: A normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment, v. 58, n. 3, p. 257-366, 1996. https://doi.org/10.1016/S0034-4257(96)00067-3

GITELSON, A.; MERZLYAK, M. N. Quantitative estimation of chlorophyll-a using reflectance spectra: experiments with autumn chestnut and maple leaves. Journal of Photochemical and Photobiology B: Biology 22: 247-252. 1994. https://doi.org/10.1016/1011-1344(93)06963-4

GITELSON, A. A.; MERZLYAK, M. N.; LICHTENTHALER, H. K. Detection of red edge position and Chlorophyll. Journal Plant of Physiology 148: 501-508. 1996. https://doi.org/10.1016/S0176-1617(96)80285-9

GONÇALVES, G. S.; ANDRADE, L. A., XAVIER, K. R. F.; SILVA, J. F. Métodos de controle de Prosopis juliflora (Sw.) DC. (Fabaceae) em áreas invadidas no semiárido do Brasil. Ciência Florestal, n. 25, p. 645-653, 2015.

https://doi.org/10.5902/1980509819615

HUETE, A. R. A soil-adjusted vegetation index (SAVI). Remote Sensing of Environment, n. 25, p. 295-309, 1988. https://doi.org/10.1016/0034-4257(88)90106-X

IBGE – Instituto Brasileiro de Geografia e Estatística. Disponível em: https://cidades.ibge.gov.br/. Acesso em 09 de dezembro de 2023.

INMET – Instituto Nacional de Meteorologia. Disponível em: http://www.inmet.gov.br/portal/index.php?r=home/page&page=rede_estacoes_conv_graf. Acesso em 10 de outubro de 2019.

LAGES, G. A.; FERREIRA, R. V.; MENESES, L. F. NASCIMENTO, M. A. L.; FIALHO, D. Geoparque Cariri: proposta. CPRM, 2018. 59p. Disponível em https://rigeo.cprm.gov.br/xmlui/handle/doc/20244

LANDIS, J. R.; KOCH, G. G. The Measurement of Observer Agreement for Categorical Data. Biometrics, v. 33, n. 1, p. 159-174, 1977.

LIMA, F. S.; ALMEIDA, N. V. Dinâmica espaço-temporal da cobertura vegetal na Área de Proteção Ambiental (APA) do Cariri, Paraíba-PB, Brasil. Revista Brasileira de Geografia Física, v. 10, n. 3, p. 699-721, 2017.

LIMA, I. B.; BARBOSA, M. R. V. Composição florística da RPPN Fazenda Almas, no Cariri Paraibano, Paraíba, Brasil. Revista Nordestina de Biologia, n. 23, p. 49-67, 2014.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

LIMA, V. R. P.; SEABRA, V. S.; XAVIER, R. A.; DORNELLAS, P. C. Análise do Padrão Espacial do Uso e Cobertura do Solo e da Fragmentação e Conectividade da Vegetação no Semiárido do Nordeste Brasileiro: Bacias Dos Rios Taperoá e Alto Paraíba-PB. Revista de Estudios Andaluces, v. 37, p. 25-49, 2019.

https://doi.org/10.12795/rea.2019.i37.02

LOPES, R. J. C.; SANTOS, A. M.; ZLATAR, T.; LIMA JÚNIOR, C. Uso de índices de vegetação por sensoriamento remoto para estudos da Caatinga: uma revisão sistemática. Gaia Scientia, v. 14, p. 104-116, 2020. https://doi.org/10.22478/ufpb.1981-1268.2020v14n1.48862

MARINHO, F. P.; MAZZOCHINI, G. G.; MANHÃES, A. P.; WEISSER, W. W.; GANADE, G. Effects of past and present land use on vegetation cover and regeneration in a tropical dryland forest. Journal of Arid Environments. v. 132, p. 22-33, 2016. https://doi.org/10.1016/j.jaridenv.2016.04.006

McFEETERS, S. K. The use of the normalized difference water index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, v. 17, p. 1425–1432, 1996. https://doi.org/10.1080/01431169608948714.

PEREIRA, R. A.; ALCÂNTARA, C. R.; NETO, J. D.; BARBOSA, E. M. Análise Espaço-Temporal da Cobertura Vegetal e do Avanço de Prosopis juliflora (SW) DC numa área de Caatinga. RA'EGA, v. 28, p. 154-180, 2013.

PEREIRA, V. H. P.; CESTARO, L. A. Corredores ecológicos no Brasil: avaliação sobre os principais critérios utilizados para definição de áreas potenciais. Caminhos da Geografia, v. 17, n. 58, p. 16-33, 2016. https://doi.org/10.51359/2238-6211.2020.245694.

QUEIROZ, R. T.; MEDEIROS, J. R.; TREJO, I. Levantamento Florístico das Plantas Vasculares da RPPN Fazenda Santa Clara – São João do Cariri (Bioma Caatinga). In: Abílio, F.J.P. (Org.), Educação Ambiental em Unidades de Conservação do Bioma Caatinga. Editora UFPB, João Pessoa, 2017. p. 291-329.

ROUSE, J.; HAAS, R.; SCHELL, J.; DEERING, D. Monitoring Vegetation Systems in the Great Plains with ERTS. Third ERTS Symposium, NASA, p. 309-317, 1973.

SANTOS, A. A. B.; COSTA, E. C. P.; LOURENÇO, J. S. Q. Mapeamento do Uso e Cobertura da Terra do Litoral Leste Fluminense. In: SEABRA, V. S.; AUGUSTO, R. C. (org). Dinâmicas Ambientais e Geoprocessamento no Litoral Leste do Estado do Rio de Janeiro, 2018. 137p. p. 69-98.

SANTOS, J. C.; LEAL, I. R.; ALMEIDA-CORTEZ, J. S.; FERNANDES, G. W.; TABARELLI, M. Caatinga: the scientific neglicence experienced by a dry tropical forest. Tropical Conservation Science, v. 4, n.3, p. 276-286, 2011. https://doi.org/10.1177/194008291100400306

SEABRA, V. S.; XAVIER, R. A.; DAMASCENO, J.; DORNELLAS, P. C. Mapeamento do Uso e Cobertura do Solo da Bacia do Rio Taperoá: Região Semiárida do Estado da Paraíba. Caminhos de Geografia, v. 15, n. 50, p. 127-137, 2014. https://doi.org/10.14393/RCG155024249

SILVA, D. V. P.; CRUZ, C. B. M. Tipologias de Caatinga: uma revisão em apoio a mapeamentos através de sensoriamento remoto orbital e GEOBIA. Revista do Departamento de Geografia, v. 33, p. 113-120, 2018. https://doi.org/10.11606/rdg.v35i0.142710

SILVA, L. F.; SOUZA, B. I.; BACANI, V. M. Intensidade da ação antrópica na Área de Proteção Ambiental do Cariri Paraibano. Caminhos de Geografia, v. 20, n. 71, p. 364-385, 2019. https://doi.org/10.14393/RCG207145788

SILVEIRA, H. L. F.; GALVÃO, L. S.; SANCHES, I. D.; SÁ, I. B.; TAURA, T. A. Use of MSI/Sentinel-2 and airborne LiDAR data for mapping vegetation and studying the relationships with soil attributes in the Brazilian semi-arid region.

ISSN eletrônico 2177-2738
RA'EGA, Curitiba, PR, V.59, p. 3 – 22, 4/2024
http://dx.doi.org/10.5380/raega.v59i0.94916

International Journal of Applied Earth Observation and Geoinformation, n. 73, p. 179-190, 2018. https://doi.org/10.1016/j.jag.2018.06.016

SMITH, W. K.; DANNENBERG, M. P.; YAN, D.; HERRMANN, S.; BARNES, M. L.; BARRON-GAFFORD, G. A.; MOORE, D. J. P.; NAGLER, P. L.; REED, S. C.; RUTHERFORD, W. A.; SCOTT, R. L.; WANG, X.; YANG, J. Remote sensing of dryland ecosystem structure and function: Progress, challenges, and opportunities. Remote Sensing of Environment, v. 233, 111401, 2019. https://doi.org/10.1016/j.rse.2019.111401

SOUZA, B. I.; ARTIGAS, R. C.; LIMA, E. R. V. Caatinga e Desertificação. Mercartor, v. 14, n. 1, p. 131-150, 2015. https://doi.org/10.4215/RM2015.1401.0009

USGS – United States Geological Survey. Disponível em: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-sentinel-2?qt-science_center_objects=0#qt-science_center_objects. Acesso em 10 de agosto de 2019.

XU, H. Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int. J. Remote Sens, 27, 3025–3033, 2006. https://doi.org/10.1080/01431160600589179