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Mapping of Caatinga ecosystems: evaluation of the effectiveness of Vegetation Indexes (NDVI and SAVI) and object-oriented mapping

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Abstract

Based on the most used indices for the production of maps of the Caatinga vegetation cover, this study aimed to characterize the temporal evolution of the land use and cover in a semi-arid mountainous environment, through multitemporal mappings using NDVI and SAVI, using object-oriented classification. From the images of the Landsat 5, Landsat 8 and Sentinel-2 satellites, six (6) classes were identified: Arboreous Caatinga, Shrubby Caatinga, Water bodies, Seasonally dry tropical forest, Bared soil/Housing/Rocks and Agricultural uses/Cashew crop. Sampling of the points to evaluate the accuracy of the maps resulting from the indices accumulated 125 points. The accuracy results for the products from NDVI (37/125) and SAVI (38/125) were considered unsatisfactory, once it was not possible to divide the class "Agricultural uses/Cashew crop". The product generated from object-oriented mapping recognized all classes and had better performance in addition to roads and access roads.
Keywords: Caatinga, Mountain environment, Vegetation index

Resumo

Baseado nos índices mais utilizados para a produção de mapas da cobertura vegetal da Caatinga, o presente estudo teve como objetivos caracterizar as formas e os usos e cobertura da terra na serra João do Vale (RN/PB) por meio de mapeamentos multitemporal, e avaliar os índices de vegetação mais empregados no semiárido (NDVI e SAVI), posteriormente, foi elaborado um mapa valendo-se do mapeamento orientado ao objeto como método de mapeamento alternativo. Para o mapeamento multitemporal, foram utilizadas imagens dos satélites Landsat 5 e o Landsat 8, sendo que para os índices foram empregadas imagens do Sentinel-2. Por meio de baterias de campo, foram identificados 06 (seis) classes: Caatinga arbórea, Caatinga arbustiva, Corpos hídricos, Floreta tropical sazonalmente seca, Solo exposto/ Habitações/ Rochas e Usos agrícolas/ Cajucultura. A amostragem dos pontos para avaliar a acurácia dos mapas resultantes dos índices acumulou 125 pontos. Os resultados da acurácia para os produtos do NDVI (37/125) e SAVI (38/125) são considerados insatisfatórios, uma vez que neles não foi possível segmentar a classe "Usos agrícolas/Cajucultura". O produto gerado do mapeamento orientado ao objeto reconheceu todas as classes e teve melhor desempenho.
Palavras-chave: Ambiente serrano, Caatinga, Índice de vegetação

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I. INTRODUCTION

The mapping of several Caatinga environments has intensified in the last decades in response to the popularization of the most varied methods of obtaining information through remote sensing, including the cartographic production based on vegetation indices (RIBEIRO; SILVA; SILVA, 2016). Prior to this, the floristic and phytosociological surveys of the Caatinga were priorities due to the low level of understanding of this important biome in the early 2000s (CASTELLETTI et al., 2003; GIULIETTI, 2003; LEAL et al., 2005; M. M. A., 2007).

With the advancement of knowledge about the ecology of the Caatinga and with the growing use of remote sensing and geoprocessing techniques, several Caatinga environments experienced an expressive increase of mappings with several purposes, such as for highland environments (e.g. BARBOSA; CARVALHO; CAMACHO, 2017), hydrographic basins (e.g. ALVES et al., 2014), desertification nuclei (e.g. AQUINO; ALMEIDA; OLIVEIRA, 2012) and environments in the Sertaneja depression dotted with mountains (e.g. COSME JÚNIOR, 2011). In this way, the use of vegetation indices in mappings is increasingly widespread, since they allow mapping the Caatinga vegetation cover through its photosynthetic activity, with an increasing number of studies comparing the performance of NDVI - *Normalized Difference Vegetation Index* and SAVI - *Soil Adjusted Vegetation Index* (RIBEIRO; SILVA; SILVA, 2016).

Based on the most used indices for the production of maps of the Caatinga vegetation cover, the goal of this chapter was to characterize the temporal evolution of the land use and cover in the João do Vale mountain range (states of Rio Grande do Norte and Paraíba). Considering the complexity of the semiarid landscapes, the results were obtained by evaluating the NDVI and SAVI values.

II. MATERIAL AND METHODS

Study area

The study area is about 280 km^2 and is located on the border of the states of Paraíba and Rio Grande do Norte (Figure 01), encompassing 4 municipalities (Jucurutu-RN, Triunfo Potiguar-RN, Campo Grande-RN and Belém do Brejo do Cruz-PB).

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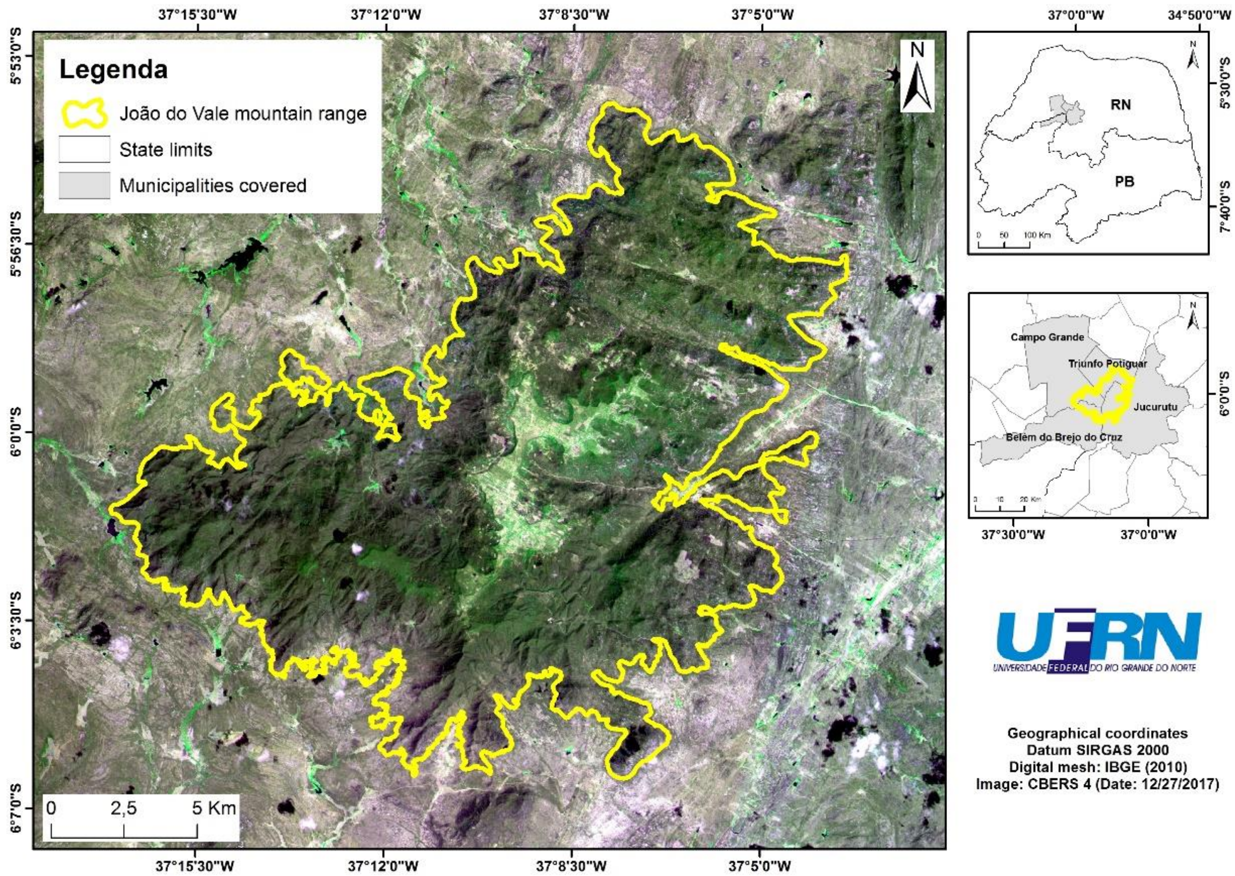

Figure 01: Localization map. Source: Prepared by the author.

Multitemporal mapping

For the multitemporal mapping, we used images of the Landsat 5 satellites (TM sensor with a spatial resolution of 30 meters) made available by the National Institute for Space Research (INPE) and Landsat 8 (OLI/TIRS sensor with a spatial resolution of 30 meters) made available by the United States Geological Survey - USGS. The dates of the Landsat 5 images are as follows: 11/11/1985, 20/09/1995 and 10/01/2005. In turn, for Landsat 8, the date of the image was 10/29/2015. The scenes Landsat 5 and Landsat 8 undergo a pre-processing, where radiometric calibration techniques would be applied.

This initial pre-processing was performed according to the procedures described by Chander; Markham; Helder (2009), which use radiometric calibrations according to (For Landsat 5). In turn, for Landsat 8, radiometric calibration applied followed made by USGS[1].

After radiometric calibrations, the scenes of Landsat 5 and Landsat 8 went to the next stage, atmospheric corrections, using the correction by Dark-Object Subtraction - DOS (CHAVEZ-JR, 1988). The scenes were

[1] Available at <http://landsat.usgs.gov/Landsat8_Using_Product.php> Accessed on September 18, 2017.

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processed with the softwares ENVI v. 4.7 and ArcGIS Pro software (license n° 0cca8e7c4a620601a0e5423e82a3ab81). The pre-processing stage of the satellite images ended with the conversion of their respective coordinate systems to the Datum SIRGAS 2000 Zone 24 S. The mapping with Landsat imagery had decadal interval, in the following years: 1985 - 1995 - 2005 - 2015.

Mapping of current vegetation cover

The classification of the vegetation cover and other classes was supported by a preliminary field survey, in which 06 (six) were identified: Arboreous Caatinga, Shrubby Caatinga, Water bodies, Seasonally dry tropical forest, Bare soil/Housing/Rocks and Agricultural uses/Cashew crop. For vegetation classes, patterns were defined as to physiognomy (Caatinga and forest), stratum (tree and shrub) and location regarding relief (slopes, ridges and plateaus) and altimetry (m).

The satellite images used in this study were from the Sentinel-2 satellite, with 10-meter spatial resolution (Date: 21/04/2018, Tile number: T24MYU and MSI sensor). The images underwent radiometric calibration and atmospheric correction using the correction by Dark-Object Subtraction - DOS (CHAVEZ-JR, 1988). The pre-processing was performed in a GIS environment using the Semi-Automatic Correction plugin from QGIS v. 3.0 (Essen/GNU - General Public License©) (QGIS TEAM, 2015).

Based on the Sentinel-2 images, the NDVI (Normalized Difference Vegetation Index) and SAVI (Soil Adjusted Vegetation Index) was calculated, which are values referring to the photosynthetically active vegetation (HUETE, 1988). In which, optimum values of L (in this study, L = 0.5) (HUETE; JACKSON; POST, 1985). The NDVI and SAVI products were segmented into 12 classes (Natural Breaks, ArcGIS) which were later grouped into their probable classes seen in the field. After class segmentation and land use mapping based on NDVI and SAVI results, these products were subjected to global map accuracy analysis through a Confusion Matrix. The confusion matrix is widely used to quantify the accuracy of a map (CONGALTON, 1991; PONZONI; SHIMABUKURO; KUPLICH, 2012). The Confusion Matrix was proposed by Congalton (1991) and consists of a matrix where information collected in the field is compared with the classes assigned by the user to the map.

In order to obtain the accuracy of the map, the values of the diagonal column of the Matrix are added, which refer to the points that corroborate with the classes of the map in the field, and then these values are divided by the total sampling of points, followed by conversion in percentage (CONGALTON, 1991; PONZONI;

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SHIMABUKURO; KUPLICH, 2012). Next, Table 01 lists an example of applying a Confusion Matrix with hypothetical values.

Table 01: Confusion matrix according to Congalton (1991).

Confusion matrix					
Classified classes	C	SE	AS	CH	Total
CH	**X11**	X21	X31	X41	AC = Σ (X11...X41) = %
SE	X12	**X22**	X32	X42	AC = Σ (X12...X42) = %
AS	X13	X23	**X33**	X43	AC = Σ (X13...X43) = %
CH	X14	X24	X34	**X44**	AC = Σ (X14...X44) = %
Total					**AM = Σ (X11...X44) = %**

Source: Adapted from Congalton (1991).

Where:
C = Caatinga;
SE = Bare soil;
AS = Agrosystems;
CH = Water bodies;
Σ = Summation;
% = Percentage result;
AM = Map accuracy;
AC = Class accuracy.

In order to evaluate the results of the Confusion Matrix, a comparison will be done between Matrix data and the Kappa Index (Equation 01). This procedure is recommended by Congalton (1991) to better evaluate the accuracy and quality of the map produced.

$$K = \frac{\left(N \sum_{i=1}^{c} xii - \sum_{i=1}^{C} (xi + x + i)\right)}{\left(n^2 - \sum_{i=1}^{c} xi + x + i\right)} \quad (01)$$

Where:
K - is an estimate of the Kappa coefficient;
Xii – is the value on line *i* and column *i*;
X*i* - is the sum of line *i;*
X+ i – is the sum of column *i* of the confusion matrix;
n – is the total number of points and *c* is the total number of classes;

To assess the quality of the Kappa Index, Landis; Koch (1977) elaborated a Table containing index values and their respective qualities with respect to the accuracy of the maps (Table 02).

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Table 02: Values and their respective Kappa Index.

Kappa index values	Classification quality
< 0.00	Very bad
0.00 – 0.20	Bad
0.21 – 0.40	Reasonable
0.41 – 0.60	Moderate
0.61 – 0.80	Good
0.81 – 1.00	Excellent

Source: Adapted from Landis; Koch (1977).

The sampling of the points to evaluate the accuracy of the maps resulting from the indices accumulated 125 points, which were stored in electronic spreadsheets of OpenOffice.org Calc/Apache OpenOffice v. 4.1.5 (2013 GNU Lesser General Public License v.3®). Subsequently, they were analyzed for sampling adequacy in the software PAST v. 3.0 (HAMMER; HARPER; RYAN, 2001), where the JackKnife 1 estimator was adopted. The software used to make the maps was ArcGIS Pro software (license n° 0cca8e7c4a620601a0e5423e82a3ab81).

With the intention of presenting an alternative mapping for the study area, the present study presents a product of segmentation of classes based on medium resolution images. This mapping was aided by the 125 sampling points.

The Ecognition Developer (Trimble®) software, which supported class segmentation, was used to classify land uses and land cover, using the *multiresolution segmentation* algorithm and scale factor 10, which proved to be the most appropriate. The input image was the panchromatic band of the satellite CBERS 4, (spatial resolution of 5 meters, Orbit: 149, Point: 107, and Date: 12/27/2018). The segmentation was aided by a CBERS 4 image composed by bands R3G4B2 (10-meter spatial resolution, Orbit: 149, Point: 107, and Date: 12/27/2018). Upon classification, the tonality, geometry and location of the groupings resulting from the segmentation were taken into account, so that each one of them was correctly classified in the pre-established classes. Figure 02 sets out the criteria for the classification of forms of land uses and occupations.

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BRIEF DESCRIPTION OF THE CLASS

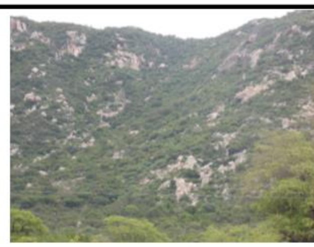
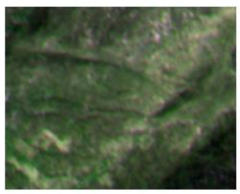
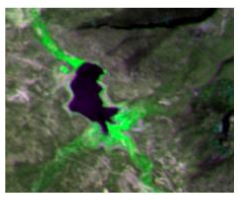
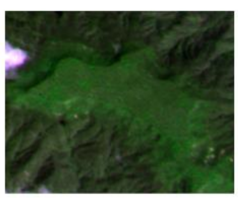
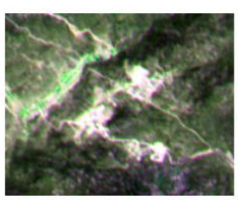
Classes	In satellite image	In the field	Classification criteria
Arboreous caatinga			Its physiognomy ranges from 6 to 10 meters, is mainly located on slopes and ridges at altimetric heights below 600 meters. In the images, it has green / brown shade, marked by drains.
Shrubby caatinga			Its physiognomy ranges from 2 to 6 meters, is mainly located on slopes and ridges at in altimetric heights below 6 meters. In the images, it has green shade, marked by irregular features with light tones.
Water bodies			Located in drainages and next to housing. It has small proportions and in the images, it has shades ranging from black to dark blue.
Seasonally dry tropical forest			Its physiognomy ranges from 6 to 15 meters, is mainly located mainly on the plateaus and on slopes at altimetric height below 600 meters. In the images, it has green shade.
Bare soil/Housing/ Rocks			They are bare areas with no vegetation cover. In the satellite images, they are characterized by varied shapes and light to gray shades, which can also be housing or exposed rocks.
Agricultural uses/ Cashew crop			They are cashew cultivation areas (cashew crops) and other seasonal crops, which are found amidst the cashew plantations. In the satellite images, they are rectangular in shape and have shades from green to light green.

Figure 02: Basic criteria for defining each class.
Source: Prepared by the author.

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Finally, in order to guide the selection of satellite images for mappings, rainfall data were collected in the João do Vale mountain range. As this highland environment does not have rainfall stations of official institutions, it was used data of a J. Prolab manual rain gauge with a maximum recording capacity of 130 mm (710.831,63E and 9.337.640,00S, 458 meters altitude), located on a windward slope. For this study, the input images for the generation of NDVI and SAVI were chosen giving priority to their availability in months that mark the end of the rainy season, in this case, the month of April.

III. Results and discussions

Temporal dynamics of the forms of use, cover and occupations between 1985 and 2015

Based on the images of Landsat 5 and Landsat 8, multitemporal maps of the forms of land use and occupation of the massif studied were generated, such maps refer to the years of 1985, 1995, 2005 and 2015. Figure 03 provides the distribution of classes mapped for each year in the study area. Figure 04 illustrates a graph showing the temporal variation of the area occupied by each class.

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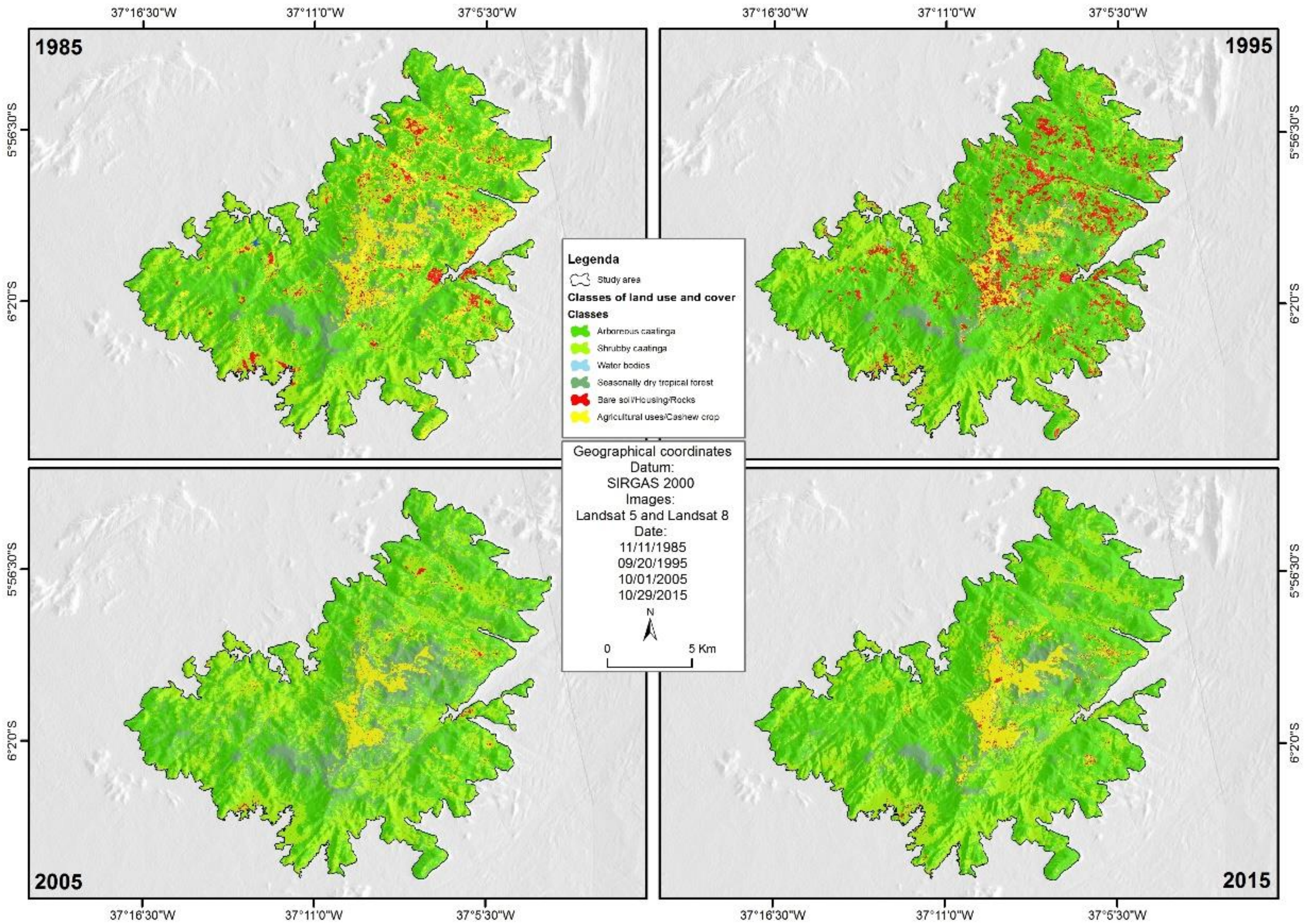

Figure 03: Map of location of classes of land use and cover.
Source: Author's collection.

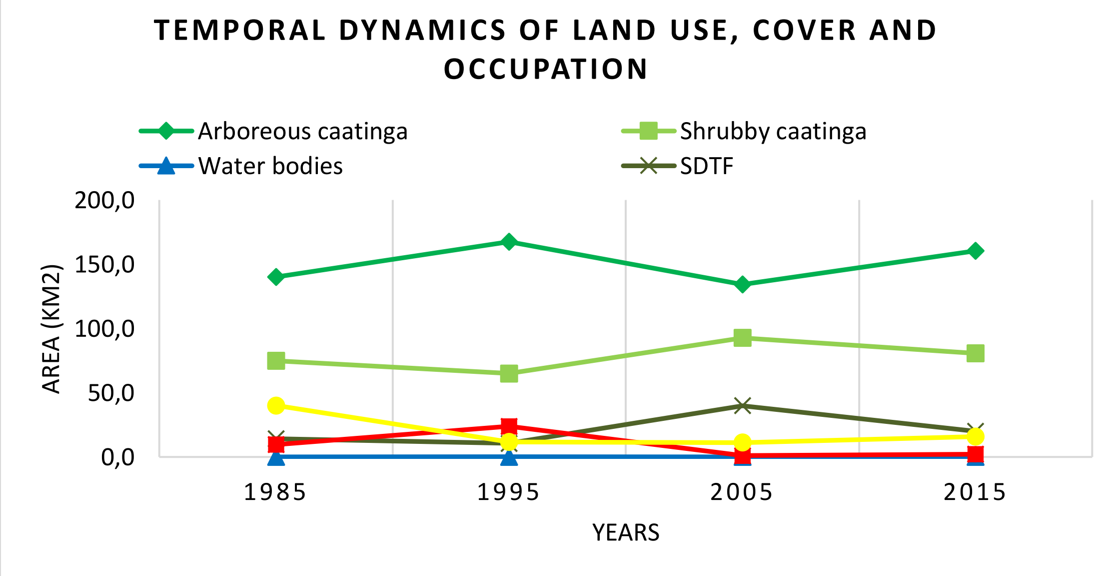

Figure 04: Multitemporal graph of the forms of use and occupation.
Source: Prepared by the author.

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Arboreous Caatinga was the dominant class in terms of occupied area, the highest values observed for 1985 (140 km^2/50.2%), 1995 (167.4 km^2/60%), 2005 (134.2 km^2/48.1%) and 2015 (160.3km^2/57.5%). Such superiority is due to the resolution of the image (medium resolution) and also due to the steepness of the slopes, making difficult the withdrawal of the arboreal individuals. The shrubby Caatinga class was the second largest in area, being closely related to the arboreous Caatinga, being noticed that when there is expansion of the first, the second retracts, as registered for the interval 1995 - 2005.

Seasonally dry tropical forest had a timid distribution, never exceeding 15% study area. Its location may explain its small occupied area, being close to the classes "Agricultural uses" and "Bare soil/Housing/Rocks". The conversion of areas with FTSS and arboreous caatinga in the study site can be explained by the use of tree components for the construction of houses, fencing for private and public land delimitation and also for domestic use. As for the forest physiognomies that cover semiarid highland environments, it is observed a fall in the occupied area to other highland environments, such as the Araripe plateau (PE/CE) (e.g. SILVA NETO, 2013), Martins-Portalegre mountain range (RN) (e.g. BARBOSA; CARVALHO; CAMACHO, 2017) and in the Borborema plateau (PB/PE) (e.g. LIMA, 2013).

Due to the more favorable environmental conditions for the implementation of agricultural crops, the massifs present in the northern Northeast no longer have their primary vegetation cover, the one without alteration, pristine (SOUZA; OLIVEIRA, 2006). In several studies on vegetation cover and/or uses and occupations in highland environments, the results show alteration or uses of the woody components present in each studied massif/inselberg (e.g. SOUZA; OLIVEIRA, 2006; FREIRE; SOUZA, 2007; LIMA, 2013; SILVA NETO, 2013; GUEDES, 2016; BARBOSA; CARVALHO; CAMACHO, 2017) and for the João do Vale mountain range, the results presented herein confirm changes in the vegetation cover of the studied massif.

The agricultural uses were significant for the analyzed moments (reaching a maximum of 41.1 km^2/14.4% in 1985), however, the location of this class was concentrated massively on the plateau, where there is presence of more developed soils (Latosols) and where the most significant tree physiognomies are developed (due to the better soil and climate conditions). In this way, agricultural uses eventually degrade environments previously (possibly) occupied by the arboreous caatinga and FTSS (the beginning of the time series already includes agricultural uses).

Finally, the class "Bare soil/Housing/Rocks" had a dynamics inversely proportional to the shrubby Caatinga, because as shown in Figure 03, when there was growth of the area occupied by the shrubby Caatinga,

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the decrease of the area with Bare soil exposed/Housing/Rocks. Such dynamics can be attributed to both deforestation of shrubby Caatinga in some areas and colonization of species and development of secondary communities. In turn, water bodies registered are referred to “small dams” with low water storage capacity.

Results and cartographic products obtained via NDVI and SAVI

Between the years of 2014 and 2018, the João do Vale mountain range presented rainfall concentrated in the months that compose the Northeast rainy season (from January to April). For Sentinel-2 images, rainfall registered in April 2018 was 498 mm. In the case of rainfall in December 2017 (CBERS-4 image month for this study), no rainfall was recorded.

Prior to the segmentation of vegetation index products, field surveys were carried out for the purpose of recognizing land use and land cover classes. After, the progress was made with the segmentation of the classes and later collection of control/evaluation points to analyze the performance of the indices used.

The data obtained from the NDVI and SAVI indices showed similar trends regarding the distribution of the values by the land cover classes: the highest pixel values correspond to the vegetation cover classes of seasonally dry tropical rainforest and arboreous caatinga, with decreases for classes with rarefied presence or absence of photosynthetic activity, such as Water bodies and Bare soil/Housing/Rocks. The “Agricultural uses” class was not segmented into any of the indices, as well as the “Access roads” class was not segmented in any of the indices. Next, Table 03 lists the values that each class presents in both indices.

Table 03: Classes of land cover and their respective values according to NDVI and SAVI.

Classes of land use and cover	NDVI	SAVI
Arboreous caatinga	0.58 - 0.66	0.35 - 0.43
Shrubby caatinga	0.42 - 0.58	0.26 - 0.35
Water bodies	-0.13 - 0.22	-0.07 - 0.10
Seasonally dry tropical forest	0.66 - 0.77	0.43 - 0.61
Bare soil/Housing/Rocks	0.22 - 0.42	0.10 - 0.26
Agricultural uses/Cashew crop	-	-

Source: Author’s collection.

In order to evaluate the performance of the indices, field surveys were carried out to collect control/evaluation points in the land cover classes in the studied mountain environment. Control/evaluation points (n=125) were plotted, all classes were visited, all of them being representative for analysis. Next, Table 04 lists the number of points that each class concentrated.

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Table 04: Control/evaluation points for classes of land cover.

Classes of land use and cover	**Number of points collected in each class**
Arboreous caatinga	11
Shrubby caatinga	46
Water bodies	9
Seasonally dry tropical forest	11
Bare soil/Housing/Rocks	24
Agricultural uses/Cashew crop	24
Total	**125**

Source: Author's collection.

After making maps based on indices and field surveys, two confusion matrices (one for each index) were assembled to evaluate the accuracy of each map, which will serve to analyze the performance of each index. The construction of the confusion matrix was elaborated from the comparison of the points plotted in the field with the generated products of NVDI and SAVI. Next, Table 05 provides the matrix elaborated for NDVI. Of the 125 sampling points for the NDVI analysis, only 37 were correctly classified, with confusion mainly between the classes, "Arboreous caatinga", Shrubby caatinga", "Seasonally dry tropical forest" and "Agricultural uses/Cashew crop", the latter not recognized by NDVI. Following, Table 06 brings the results of the producer's accuracy and Table 07 brings the user's results, which together provide more detail on the accuracy of each class.

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Table 05: Confusion matrix elaborated for the map produced based on NDVI.

Forms of land use and cover	Arboreous caatinga	Shrubby caatinga	Water bodies	SDTF	Bare soil/ Housing/ Rocks	Agricultural uses/ Cashew crop	Total
Arboreous caatinga	**8**	24	0	6	0	2	40
Shrubby caatinga	2	**9**	0	1	11	13	36
Water bodies	0	0	**8**	0	5	0	13
SDTF	1	13	0	**4**	0	6	24
Bare soil/ Housing/Rocks	0	0	1	0	**8**	3	12
Agricultural uses/ Cashew crop	0	0	0	0	0	**0**	0
Total	11	46	9	11	24	24	
SUM OF MAIN DIAGONAL							**37**
TOTAL NUMBER OF POINTS							**125**

Source: Author's collection.

Table 06: Producer's Accuracy for the NDVI Confusion Matrix.

Classes	Producer's accuracy (%)	Omission error (%)
Arboreous caatinga	72.7	27.3
Shrubby caatinga	19	81
Water bodies	88.8	11.2
Seasonally dry tropical forest	36.6	63.4
Bare soil/ Housing/Rocks	33.3	66.7
Bare soil/ Housing/Rocks	0	100
Total accuracy	**41.73**	**58.26**

Source: Author's collection.

Table 07: User's Accuracy for the NDVI Confusion Matrix.

Classes	User's accuracy (%)	Omission error (%)
Arboreous caatinga	20	80
Shrubby caatinga	25	75
Water bodies	61.5	38.5
Seasonally dry tropical forest	16.6	83.4
Bare soil/ Housing/Rocks	66.6	33.4
Bare soil/ Housing/Rocks	0	100
Total accuracy	**31.61**	**68.38**

Source: Author's collection.

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About 52.1% of the "Shrubby caatinga" class were confused with the "Arboreous caatinga", which contributes to the low performance of the former, as noted by the producer's accuracy, with only 19%. Regarding the "Arboreous caatinga" class, there was a better performance in the producer's accuracy, with an omission error of 27.3%. As the "Agricultural Uses/Cashew crop" class was not recognized by NDVI, the points collected for this class were mostly confused with the "Shrubby caatinga" (54.1% of the points). Seasonally dry tropical forest had about 54.5% of points confused with the class "Arboreous caatinga", having low performance in NDVI.

The land cover class with the best performance in the producer's accuracy was "Water bodies", which had 88.8% producer's accuracy. The class "Bare soil/Housing/Rocks" had low accuracy, registering only 33.3% in the producer's accuracy. Finally, the NDVI performance can be evaluated by the total producer's accuracy, which marked only 41.73%, being this value considered "Moderate", according to the classification of Landis; Kock (1977).

Regarding the user's accuracy, the accuracy values are even lower, with the exception of the "Shrubby caatinga", which had a slight increase (6%), but was considered low. Due to the low performance of the accuracy of the classes in the user's accuracy, the total user's accuracy was only 31.61%, being considered "Reasonable" according to the classification of Landis; Kock (1977).

In order to evaluate the results obtained by means of SAVI, a confusion matrix (Table 08) was assembled, from which the accuracy of the producer (Table 09) and the user (Table 10) were analyzed. Of the 125 control/evaluation points, only 38 were correctly classified.

As in the analysis of NDVI results, there was confusion of the collected points for the class "Shrubby caatinga" with the "Arboreous caatinga", being confused about 52.1% of the points. Thus, the accuracy of the "Shrubby caatinga" class had low performance (17.3%). On the other hand, the "Arboreous caatinga" class had the same performance when compared to the same class in NDVI, showing a 72.7% producer's accuracy, and about 18.1% of its points were confused with the class "Seasonally dry tropical forest". With respect to the class "Seasonally dry tropical forest", this class had 81.8% of its points confused with the class "Arboreous caatinga", culminating with a low performance (9%).

In relation to the class "Agricultural uses/Cashew crop", this was also not recognized by SAVI, 95.8% of its points were confused with the classes "Seasonally dry tropical forest" (25%), "Arboreous caatinga" (33.3%)

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and "Shrubby caatinga" (37.5%). In turn, the performance of the class "Bare soil/Housing/Rocks" was 54.1% producer's accuracy. The class with the best results was "Water bodies", with 88.8% producer's accuracy.

The overall performance of SAVI can be attested with the total producer's accuracy, which was 40.31%, being considered "Reasonable", according to the classification of Landis; Kock (1977). In this case, the producer's accuracy of NDVI performed better than that recorded for SAVI.

Table 08: Confusion matrix elaborated for the map produced based on SAVI.

Forms of land use and cover	Arboreous caatinga	Shrubby caatinga	Water bodies	SDTF	Bare soil/ Housing/ Rocks	Agricultural uses/ Cashew crop	Total
Arboreous caatinga	**8**	24	0	9	2	8	51
Shrubby caatinga	1	**8**	0	1	9	9	28
Water bodies	0	0	**8**	0	0	0	8
SDTF	2	13	0	**1**	0	6	22
Bare soil/ Housing/Rocks	0	1	1	0	**13**	1	16
Agricultural uses/ Cashew crop	0	0	0	0	0	**0**	0
Total	11	46	9	11	24	24	
SUM OF MAIN DIAGONAL							**38**
TOTAL NUMBER OF POINTS							**125**

Source: Author's collection.

Table 09: Producer's Accuracy for the SAVI Confusion Matrix.

Classes	Producer's accuracy (%)	Omission error (%)
Arboreous caatinga	72.7	27.3
Shrubby caatinga	17.3	82.7
Water bodies	88.8	11.2
Seasonally dry tropical forest	9	91
Bare soil/ Housing/Rocks	54.1	45.9
Agricultural uses/Cashew crop	0	100
Total accuracy	**40.31**	**59.68**

Source: Author's collection.

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Table 10: User's Accuracy for the SAVI Confusion Matrix.

Classes	User's accuracy (%)	Omission error (%)
Arboreous caatinga	15.6	84.4
Shrubby caatinga	28.5	71.5
Water bodies	100	0
Seasonally dry tropical forest	4.5	95.5
Bare soil/ Housing/Rocks	81.2	18.8
Agricultural uses/Cashew crop	0	100
Total accuracy	**38.30**	**61.70**

Source: Author's collection.

For the results obtained by SAVI, the user's accuracy presented values that increased the accuracy of some classes (Arboreous caatinga and Water bodies) and decreased the values of others (Shrubby caatinga, seasonally dry tropical forest and Bare soil/Housing/Rocks). The total user's accuracy presented better results when compared the results obtained for NDVI, being recorded 38.30%, which is considered "Reasonable", according to the classification of Landis; Kock (1977).

Performance of NDVI and SAVI indices in mapping vegetation cover

The results obtained with the confusion matrices elaborated for each vegetation index made it clear that NDVI presented better performance than SAVI. This superiority was not expected, given that the literature that addressed this topic mostly points out that the SAVI results exceed those of NDVI (e.g. ALVES et al., 2014; GUEDES, 2016; RIBEIRO; SILVA; SILVA, 2016). In addition to missed crosses for SAVI, the NDVI also presents lower performance compared to other indices (YANG; WEISBERG; BRISTOW, 2012; LI; JIANG; FENG, 2013).

Although the performance was better, NDVI advantage over SAVI was not so great, and even though the literature points to SAVI as the best index, NDVI still presents a wide application in studies on Caatinga phenology and in mappings with environmental bias (.g. COSME JÚNIOR, 2011; MELO; SALES; OLIVEIRA, 2011; CHAVES et al., 2013; DANTAS, 2013), and in some cases have a satisfactory overall accuracy (e.g. SÁ et al., 2010).

When evaluating the performance of the indices used here, it was observed that the classes "Arboreous caatinga", "Shrubby caatinga", "Seasonally dry tropical forest" and "Agricultural uses/Cashew crop" were the classes that exhibited the most confusion, which can result from a slight deficiency of the indices in recognizing separately the photosynthetic activity of these classes. The vegetation of the Arboreous caatinga, Shrubby caatinga (usually in regrowth) and agricultural crops (commonly perennial in highland environments) show

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similar photosynthetic activity, making it difficult the segmentation, something that the specialized literature has already observed for both NDVI and SAVI in mountainous environments (e.g. GUEDES, 2016; RIBEIRO; SILVA; SILVA, 2016) and in other Caatinga environments (CHAVES et al., 2013).

Finally, the results presented here for NDVI and SAVI are considered unsatisfactory, since good cartographic products based on indices should have classification, according to Landis; Kock (1977), from "Good" to "Excellent", as observed by Guedes (2016) in the mountainous environment of the municipality of Martins, state of Rio Grande do Norte, where the accuracy was classified as "Good", according to Landis; Kock (1977).

Alternative mapping: object-oriented classification based on CBERS 4 images

In response to the low performance of vegetation indices in this study, an object-oriented mapping was performed as an alternative methodological procedure. The object-oriented mapping of land use and cover for the study area proved to be effective in relation to the products from the vegetation indices, since it was not possible to segment the class "Agricultural uses/Cashew crop", which occupies 4.2% of the total (Table 11), besides the impossibility of identifying other features, such as roads and access roads that permeate the studied mountain environment. Figure 05 provides for the distribution of each form of land use and cover.

Table 11: Area occupied by each class of land use and cover.

Forms of land use and cover	Area (Km^2)	Area (%)
Arboreous caatinga	39.4	14.1
Shrubby caatinga	191.8	68.5
Water bodies	0.5	0.2
Seasonally dry tropical forest	21.8	7.8
Bare soil/ Housing/Rocks	14.7	5.3
Agricultural uses/Cashew crop	11.8	4.2
Total	**280.0**	**100.0**

Source: Prepared by the author.

In addition to having presented a better performance in the classification and representation of the classes "Arboreous caatinga" and "Shrubby caatinga", it was observed that the class "Seasonally dry tropical forest" was classified correctly according to its distribution seen in the field surveys, as well as in agreement with the 125 points sampled in loco.

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The object-oriented classification in Caatinga environments also showed good results in studies where Landsat 5 images were used as input image (e.g. SEABRA; XAVIER; DAMASCENO, 2014) and also with CBERS 2-B images (e.g. ROCHA, 2011).

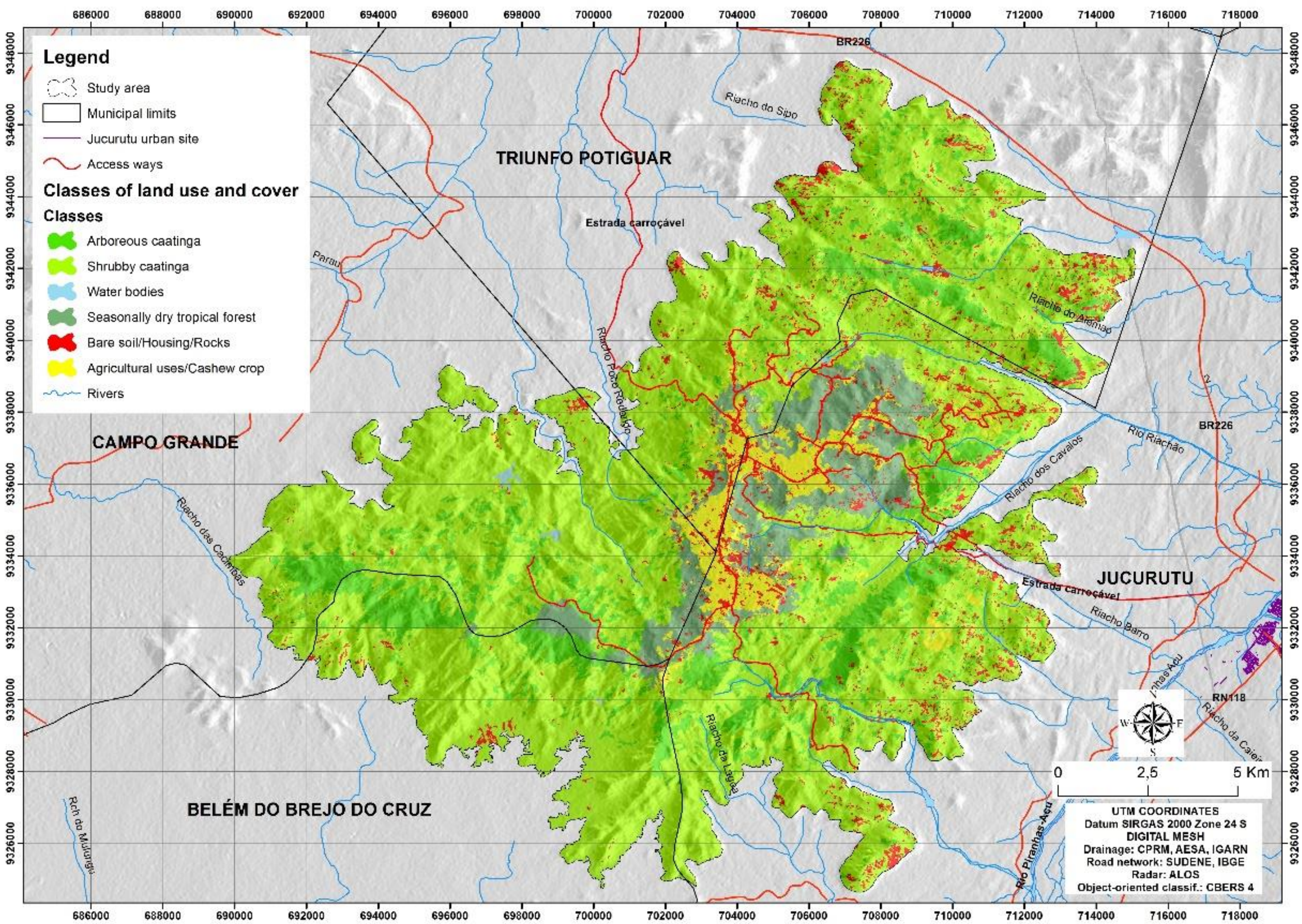

Figure 05: Map of location of classes of land use and cover.

Source: Author's collection.

IV. CONCLUSIONS

Regarding the multitemporal dynamics, the effectiveness of the methodological procedures regarding the processing and construction of cartographic products is confirmed. The dynamic pattern of the distribution of forms of land use and cover has come to the conclusion that the specialized literature points to the semiarid highland environments: advance of devastation of vegetation physiognomies (mainly forests), abandonment of agricultural use and later regrowth, and physiognomies in ecological succession (mainly Caatinga ecosystems).

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Although NDVI and SAVI indices were not efficient enough to map the vegetation cover and the other classes of the studied mountainous environment in the present study, they are efficient and widely applied in vegetation studies and mapping. The object-oriented mapping was able to construct a product that best represented the classes observed in the field, besides corresponding to the sampling points plotted in the field.

A fact to be observed relates to the best results obtained with the object-oriented classification because, in addition to a more detailed segmentation, the panchromatic band of CBERS 4 has a 5.0-meter spatial resolution, whereas the NDVI and SAVI products were generated with images of the Sentinel-2, with 10-meter resolution.

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