Article

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MONITORING OF BRAZILIAN SEASONALLY DRY TROPICAL FOREST BY REMOTE SENSING

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Abstract

Among the various characteristics of the Brazilian territory, one is foremost: the country has the second largest forest reserve on the planet, accounting for approximately 10% of the total recorded global forest formations. In this scenario, seasonally dry tropical forests (SDTF) are the second smallest forest type in Brazil, located predominantly in non-forested biomes, such as the Cerrado and Caatinga. Consequently, correct identification is fundamental to their conservation, which is hampered as SDTF areas are generally classified as other types of vegetation. Therefore, this research aimed to monitor the Land Use and Coverage in 2007 and 2016 in the continuous strip from the North of Minas Gerais to the South of Piauí, to diagnose the current situation of Brazilian deciduous forests and verify the chief agents that affect its deforestation and regeneration. Our findings were that the significant increase in cultivated areas and the spatial mobility of pastures contributed decisively to the changes presented by plant formations. However, these drivers played different roles in the losses/gains. In particular, it was concluded that the changes occurring to deciduous forests are particularly explained by pastured areas. The other vegetation types were equally impacted by this class, but with a more incisive participation of cultivation.

Keywords: Mapping, Tropical Dry Forests, Remote Sensing, GIS.

Resumo / Resumen

MONITORAMENTO DA FLORESTA ESTACIONAL DECIDUAL BRASILEIRA POR SENSORIAMENTO REMOTO

Dentre as várias características que o território brasileiro dispõe, uma precisamente se sobressai: o país contempla a segunda maior reserva florestal do planeta, respondendo por aproximadamente 10% do cômputo total das formações florestais globais. Nesse Cenário, as Florestas Estacionais Deciduais (FED) constituem o segundo tipo florestal menos expressivo no Brasil, estando situadas predominantemente em biomas não-florestados, tal como Cerrado e Caatinga. Dessa Forma, sua conservação apoia-se fundamentalmente na sua correta identificação, o qual se torna difícil, uma vez que as áreas de FED são geralmente classificadas como outros tipos de vegetação. Logo, a pesquisa corrente objetivou realizar o monitoramento do Uso e Cobertura do Solo para os anos de 2007 e 2016 da faixa contínua Norte de Minas Gerais - Sul do Piauí, com finalidade de diagnosticar a situação atual das florestas deciduais brasileiras e verificar os principais agentes que afetam seu desmatamento e regeneração. Como resultante, o estudo constatou que o incremento significativo das áreas de cultivos e a mobilidade espacial dos pastos contribuíram determinantemente para as alterações apresentadas pelas formações vegetais. No Entanto, tais drivers desempenharam papeis diferenciados nas perdas/ganhos. Em especial, concluiu-se que as mudanças a qual as florestas deciduais perpassaram foram explicadas particularmente pela pastagem. Os demais tipos de vegetação foram impactados igualmente por esta classe, mas com participação mais incisiva das culturas.

Palavras-chave: Mapeamento, Florestas Deciduais, Sensoriamento Remoto, SIG.

SEGUIMIENTO DEL BOSQUE ESTACIONAL DECIDUO BRASILEÑO POR PERCEPCIÓN REMOTA

Entre las diversas características que el territorio brasileño dispone, una precisamente se destaca: el país contempla la segunda mayor reserva forestal del planeta, respondiendo por aproximadamente el 10% del cómputo total de las formaciones forestales globales. En este escenario, los Bosques Estacionales Deciduales (BED) constituyen el segundo tipo forestal menos expresivo en Brasil, estando situadas predominantemente en biomas no florestados, tal como Cerrado y Caatinga. Sendo así, su conservación debe apoyarse fundamentalmente en su correcta identificación, lo cual se vuelve difícil, ya que las áreas de BED son generalmente clasificadas como otros tipos de vegetación. Logo, la investigación actual tuvo como objetivo realizar el seguimiento del uso y cobertura de la tierra para los años 2007 y 2016 de la banda continua Norte de Minas Gerais - Sur del Piauí, con el fin de diagnosticar la situación actual de los bosques deciduales brasileños y verificar los principales agentes que afectan su deforestación y regeneración. El estudio constató que el incremento significativo de las áreas de cultivos y la movilidad espacial de los pastos contribuyeron determinantemente a las alteraciones presentadas por las formaciones vegetales. Sin embargo, tales controladores desempeñaron papeles diferenciados en las pérdidas/ganancias. Especialmente, se concluyó que los cambios en los bosques han sido explicados particularmente por los pastos. Los demás tipos de vegetaciones fueron impactados igualmente por esta clase, pero con participación más incisiva de las culturas.

Palabras-clave: Cartografía, Bosques Deciduales, Percepción Remota, SIG.

INTRODUCTION

The United Nations Food and Agriculture Organization’s assessment of global forest resources FAO / UN (2010) points to a decrease in the global yearly deforestation rate when comparing the decades of 1990-2000 and 2000-2010. About 16 million hectares of forest were lost in the first decade, while in the latter the amount fell to 13 million hectares/year. According to the UN report, this reduction is certainly due to the fall in forest loss rates recorded in Brazil and Indonesia. It is noteworthy that according to the report, of the estimated four billion hectares of forest on the planet, about 67% are concentrated in just ten countries, seven of which have areas greater than 100 million hectares. This information is pertinent as the three countries with the highest deforestation rates in the decades in question are on the list of the ten most forest-rich territories. This is particularly the case in Brazil, which ranks second among the countries with the largest territorial area of forest and has the highest recorded deforestation figures on the planet.

The information above is apposite, as it draws attention perfectly to the clear and imperative concern that should exist, given the sequential losses of forest that have been registered. The study on the Deforestation of the Brazilian Amazon Forest by Fearnside (2005) emphatically corroborates this statement by placing the loss of soil productivity and biodiversity, changes in the hydrological regime, and greenhouse gas emissions among the possible harmful consequences to the environment caused by the deforestation process. Therefore, as he stresses, mitigation and control strategies and measures must be thought out and implemented, given that losses at the ecosystem level are too real to be disregarded.

In line with the above, the Atlantic Forest and the Amazon stand out in the Brazilian territory because within the scope of the Brazilian vegetation classification system (IBGE 2006a and 2006b) they are the biomes with the highest proportions of forest vegetation (rain and seasonal forests), accounting in total for more than 75% of these subclasses. In this context, the Atlantic Forest is particularly noteworthy as the biome has a higher percentage of secondary or regenerating vegetation of any Brazilian biome (IBGE, 2006a; IBGE, 2006b), containing approximately 80% of the total. Also, the Forest Remnants Atlas of the Atlantic Forest Technical Report from 2012 to 2013 indicates that there are only 12.5% of forest remnants in the Atlantic Forest (SOS Mata Atlântica / INPE, 2014).

This Foundation has been monitoring the forest remnants of native vegetation in the Atlantic Forest since 1985, and the aforementioned report shows that there has been a considerable reduction in annual deforestation rates. However, as well as the quantitative aspect of the phenomenon, they reported that the municipalities with the most deforestation in 2013-2014 are those that have Seasonally Dry Tropical Forests – SDTF, an ecosystem that accounts for less than 4% of the Brazilian territory (IBGE, 2006a). The occurrence of deforestation in these areas is especially worrying as, in the long run, it may culminate in the complete elimination of the biome.

Given the above, bearing in mind Brazil’s well-known share in total global forest stocks and, not least, the reduced proportion of forest remnants of the Atlantic Forest’s native vegetation, in particular the SDTF, this research carries out a spatial-temporal analysis of Land Use and Coverage for the years 2007 and 2016 in the continuous stretch of Seasonally Dry Tropical Forest that extends from the North of Minas Gerais - Jequitinhonha to the South of Piauí, to evaluate the temporal evolution of deciduous forests and identify the main factors affecting losses and gains. The area was chosen because it is entirely covered by Law 11.428 of 2006 (BRASIL, 2006) which rules on the use and protection of native vegetation in the Atlantic Forest biome. To this end, LUC mapping was used through the application of the Geographic Information System – GIS and Digital Image Processing – DIP. This complex procedure is described in the section of this paper that deals with materials and methods.

THEORETICAL FRAMEWORK

Unlike the vegetation studies dating from the beginning of the nineteenth century (WHITTAKER, 1980), studies of Seasonally Dry Tropical Forests are mainly restricted to the last three decades. Linares-Palomino (2006) unambiguously attributes the first specific study on seasonally dry tropical forests to Hueck (1959), who gathered the main information about this type of vegetation in South America. On the other hand, Hueck’s contemporaries such as Smith and Johnston (1945), Beard (1955) and Holdridge (1967), and more recently Sarmiento (1975), Murphy and Lugo (1986), Gentry (1995), Janzen (1988), Prado (2000), Pennington, Prado, and Pendry (2000), Olson et al. (2001), Eva et al. (2002), Linares-Palomino, Pennington and Bridgewater (2003) and Sánchez-Azofeifa et al. (2005) are also notable references of studies related to vegetation mapping.

In this scenario, Murphy and Lugo's (1986) relevant studies of the extension of Dry Forests point out that about 40% of the tropical and subtropical terrestrial area is predominantly composed of closed and open forests, with dry forests accounting for 42% of this area, followed by moist forests and wet and rain forests.

Although the predominance of dry forests in the tropics is well-known and supported by various authors, little attention has been paid to them. This relative neglect of the subject is clearly contradictory, considering that this type of vegetation is one of the most threatened ecosystems on the planet (SÁNCHEZ-AZOFEIFA et al., 2005). This finding is ascribed by Miles et al. (2006) to Janzen (1988), who stressed that Seasonally Dry Tropical Forests are the tropical forest biome under the greatest level of threat. Janzen (1988) highlights the fact that when the Spaniards reached the West, dry forests covered around 550,000 km² of Mesoamerica, whereas today only 0.09% of this forest has conservation status and less than 2% is primeval vegetation. Likewise, Janzen (1988) reiterates that these circumstances are not unique to Mesoamerica, pointing out that the dry tropical forests of Australia, Southeast Asia, Africa, and parts of South America are in a similar condition.

Corroborating the above, Portiollo-Quintero and Sánchez-Azofeifa (2010) argue that in the tropics the anthropic pressure on SDTF ecosystems is patently evident, given that these areas are sites endowed with climatic and edaphic characteristics that encourage human occupation, which directly stimulates their depredation. Parallel to this, the authors state that scientific conservation efforts in tropical forests mainly take place in tropical rain forests, however, scant attention is paid to dry forests.

Miles et al. (2006) stress that the evaluation of dry forest conservation relates primarily to the knowledge of its extension and this definition depends on how this type of vegetation is before conceptualized. The definitions present in the literature on SDTFs, which are the main objective of this topic, point to the existence of several concepts and terms associated with Tropical Dry Forests. In general, scholarly attention has converged on a specific group of studies that have directed and supported the understanding of the extent and conceptual limits of the SDTFs. As already mentioned, Beard (1955), Holdridge (1966), Olson et al. (2001), and Eva et al. (2002) are the authors whose parameters are mostly used in the preliminary identification of SDTF areas. However, our research does not make use of these approaches or classification systems, since they have broad connotations that differ spatially and conceptually from the proposal herein[1].

Concerning the above, Mooney, Bullock, and Medina (1995) maintain that the extension of tropical forests is a difficult subject to discuss, since the conceptual and physical limits of the "Dry Forests, Woodlands and Savannas" are interpenetrating, making it relatively complex to distinguish among them. On the other hand, as a definition is needed, these authors point out that in general terms Tropical Dry Forests are found in areas of the tropics that have a prolonged dry season, lasting for several months, which is absolute in some cases.

More specifically, Murphy and Lugo (1995), Gentry (1995), and Pennington, Lewis, and Ratter (2006) point out that Seasonally Dry Tropical Forests are generally found in areas with average annual rainfalls below 1600mm/year, with the dry season lasting for five to six months. They also point out that although they occur in climatic conditions similar to savanna areas, dry forests have well-known different structural and edaphic properties. In effect, the structural arrangement of dry forests is dominated by trees and they are located on more fertile soils, whereas savannas do not have continuous vegetation cover and their lower layer is composed of fire-resistant xeromorphic herbaceous vegetation.

It is worth noting at this point that the attributes above, as well as the distribution of the SDTFs and Savanna areas, are parametric in terms of the extensive knowledge of the areas with the potential to have these vegetation types. However, they are not suitable for the investigations carried out within the scope of our research.

As described by IBGE (2012), the areas of Seasonally Dry Tropical Forests, Deciduous Seasonal Forests - according to the adopted system, are found mainly in the form of disjunctions, with a wide distribution from the north of Minas Gerais to the Northeast of Brazil. According to IBGE (2012) and

Oliveira-Filho, Jarenkow, and Rodal (2006), this area is a transition between the Caatinga and Cerrado biomes/domains. Therefore, adopting the mappings offered as parameters does not directly assist in this research, because although they recognize the difference among “Dry Forests, Woodlands and Savannas”, they do not discriminate against them, despite the evident similarities and intersections among these systems.

Therefore, as detailed below, this research will use the 2012 IBGE Technical Manual of Brazilian Vegetation and the 2004 (pdf format) and 2006 (vector format) Vegetation Maps of the same institution as a parameter to make a preliminary identification for Seasonally Dry Tropical Forests areas, as they differentiate among SDTFs, Caatingas, and Cerrados, albeit on a small scale (1: 5,000,000). Our proposal is similar to that made by Espírito-Santo et al. (2013), which used the IBGE vector base as a parameter, as it specifically describes the spatial differentiation between SDTFs and Caatingas, especially in structural terms.

MATERIALS AND METHODS

CHARACTERIZATION OF THE AREA

Given the above, this section clarifies the fundamental methodological aspects related to the research. Figure 1 shows the limits of the areas considered in this work. The study area consists primarily of the semi-continuous stretch of Seasonally Dry Tropical Forest, with a North-South orientation, covered by the Law Enforcement Area 11,428 of 2006 (BRASIL, 2006). As the cartographic products used to delimit the vegetation formations of the Atlantic Forest are on a scale of 1: 5,000,000 and thus imbricated with generalizations, the mesoregional geographical unit was the spatial criterion used as a parameter to delimit the Study Area (SA) as from this perspective, any SDTF area not covered by the IBGE mapping scale could be identified by the mapping conducted in this research.

Then again, the adoption of the mesoregion as the geographical limit also corroborates our proposal to evaluate any errors in the IBGE mapping, that is, to identify all the additional areas not mentioned by the Institute. Therefore, all the administrative units, or mesoregions, in contact with SDTF areas were targets for land use and coverage mapping, thus reaching a total of ten mesoregions.

Figure 1 identifies the spatial limits of the study area, between the geographical coordinates of 6º 35’ and 18º 44’ latitude S of the Equator and 37º 19’ and 46º 38’ longitude W of the Greenwich meridian. The area includes the Federation Units of Minas Gerais (partially), Bahia and Piauí (partially), comprising 10 mesoregions and 50 microregions which cover 619 municipalities, thus making up 11.1% of the Brazilian municipal network. The area has a total population of 18,249,456 inhabitants, approximately 9% of the Brazilian population (IBGE, 2016). The study area has 143,813km2 of Seasonally Dry Tropical Forest, corresponding to 50.4% of the area of natural and secondary coverage identified by IBGE (2004), and is distributed over three Brazilian biomes: Atlantic Forest (18.3%), Caatinga (39.9%), and Cerrado (41.8%).

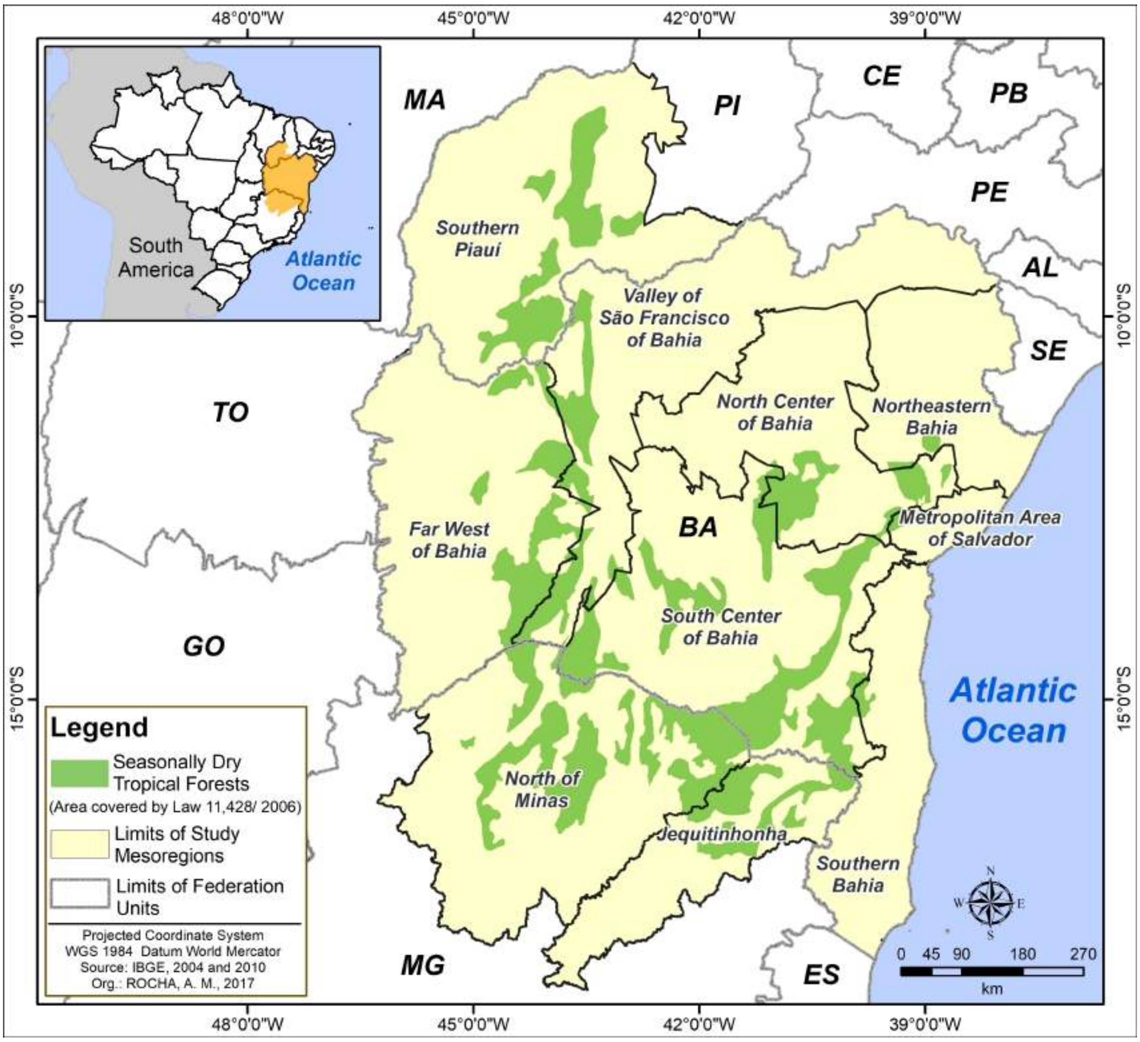


Figure 1- Location of the Study Area

METHODOLOGY

The information below presents the image packages, operational procedures, and software utilized in this research. In STEP 1, the LUC mapping started with the acquisition of satellite images, and to determine the image package of the satellite/sensor that contributed most efficiently to the spectral differentiation process, which was selected as the parameter. This criterion was used as the study area is composed of several types of vegetation, with different structural and phenological properties. Therefore, based primarily on the study by Liesenberg, Ponzoni, and Galvão (2007) on the seasonal dynamics and spectral separability of some phytophysiognomies of the Cerrado Biome, the present research mostly used images from the MODIS sensor, especially because of this sensor's potential in the spectral differentiation process. Landsat 5 (TM) and 8 (OLI) satellite images were also used, in a secondary way, to support the proposed mapping.

The properties of the MODIS sensor essentially offer temporal resolution (obtaining images every 1/2 days), an L3 processing level (including radiometric and atmospheric correction), the size of the proposed area (approximately 1200x1200m), and radiometric resolution (12bits) (JUSTICE et al., 2002). The Landsat product has a better spatial resolution (30m) and thus, obtains more detailed surface information, which is decisive when MODIS' properties are unsatisfactory.

Month	Year 2007		Year 2016	
	Date	JD	Date	JD
JAN	Jan-17	17	Jan-1/ Jan-17	1/ 17
FEB	Feb-18	49	Feb-2/ Feb-18	33/ 49
MAR	Mar-06	65	Mar/05	65
APR	Apr-23	113	Apr/22	113
MAY	May-25	145	May/24	145
JUN	Jun-10	161	Jun/09	161
JUL	Jul-12	193	Jul/11	193
AUG	Aug-13	225	Aug/12	225
SEP	Sep-14	257	Sep/13	257
OCT	Oct-16	289	Oct/15	289
NOV	Nov-17	321	Nov-16/ Nov-24	321/ 329
DEC	Dec-19	353	Dec-2/ Dec-18	337/ 353

Table 1 - List of MOD13Q1 Image Package dates obtained for the Study Area tiles

Once the image package had been defined, images were obtained referring to four tiles on the MODIS grid to cover the entire study area: namely, H13V09, H13V10, H14V09, and H14V10. These images were acquired free of charge from the United States Geological Survey - USGS for January to December of 2007 and 2016. The images are listed in Table 1. By obtaining products for each month of the year the intention was to understand the dynamics of the spectral behavior of the targets in the study area.

For the pre-processing steps, image classification, and other spectral and spatial analyses the ArcGIS 10.2.1, ENVI 5.3, and Google Earth 7.1.5 software were used.

The satellite images were pre-processed in the SECOND STAGE, beginning with the composition of bands from the MOD13Q1 products (blue, red, near-infrared – NIR, and medium-infrared - MIR). The resulting mosaic represents the integration of the four tiles for each month and year in the study area, prior to their transformation into a single raster product. Next, the 12 final mosaics were submitted to Reprojection and Resampling. At this point, the mosaics were converted to the WGS 1984 World Mercator Reference System, as they were originally made available in a Sinusoidal Projection (JUSTICE et al., 2002). After the spatial transformation, the data was resampled to standardize the spatial resolution to 250m, a real benefit of the products of the study.

The second stage ended with the cut of the study area, which fully covered the analysis perimeter (mesoregions). This operation was carried out to standardize the number of rows and columns of the images so that they all have the same final image statistics.

The THIRD STEP generated the input products of the classification. At this point, it is important to note the wavelengths and products used to construct the Decision Tree:

1) Winter Mosaic - Red (centered at 645nm) and Near Infrared (centered at 859nm) wavelengths and Summer Mosaic.

2) Normalized Difference Vegetation Index - NDVI (ROUSE et al., 1973) of the Winter Mosaic, Equation 1.

NDVI=(NIR-Red)/(NIR+Red)

3) Soil Adjusted Vegetation Index - SAVI (HUETE, 1988) of the Winter mosaic - Equation 2.

SAVI=[(NIR-Red)/(NIR+Red+L)]*(1+L)

4) Normalized Difference Built-up Index - NDBI (ZHA, GAO, and NI, 2003) of the Winter

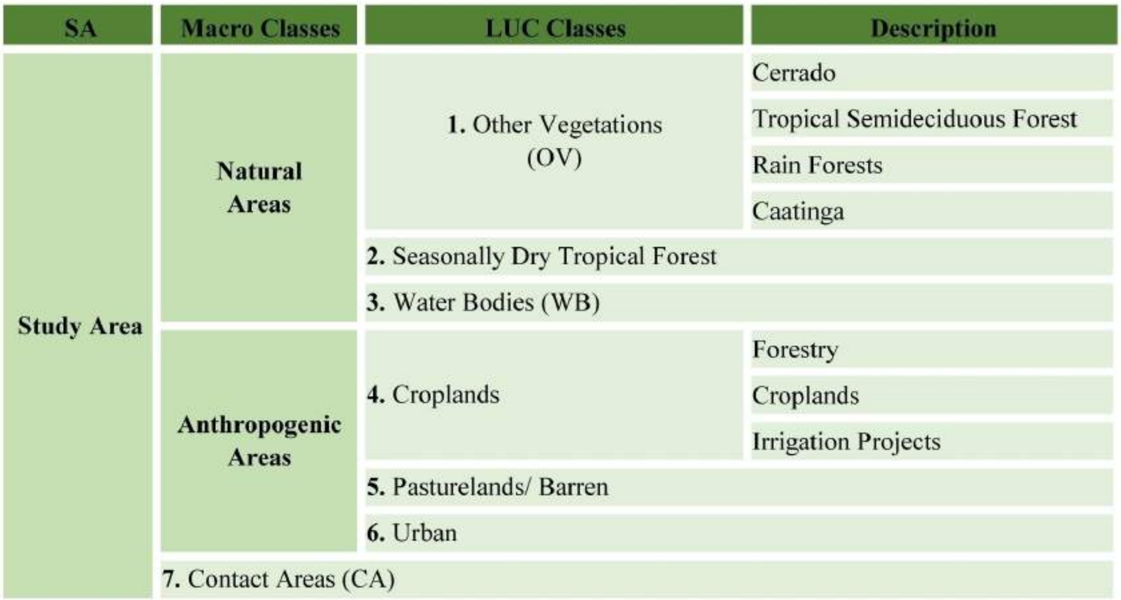
mosaic - Equation 3.

NDBI=(MIR-NIR)/(MIR+NIR)

5) Principal Component Analysis (PCA) of the Winter Mosaic.

The FOURTH STEP defined the classes of Land Use and Coverage using the Photointerpretation technique to read the satellite images from the parameters (tone/color, texture, shape, size, shadow, and pattern) according to Rosa (2009). This technique was undertaken to identify the UCS classes (Table 2); which were defined based on the Coverage and Land Use classes presented by the Technical Manual for Land Use (IBGE, 2006) and the concepts of Land Cover and Use reported by Di Gregorio and Jansen (2005). It is important to note that the Contact Areas - CA was not initially proposed as a LUC class. However, the final mapping revealed problems with the spectral discrimination between the Other Vegetation and/or SDTFs. Therefore, this class was used to represent the areas whose specific class could not be clearly identified.

The results of this step were seven Land Use and Coverage classes, shown below:



SA	Macro Classes	LUC Classes	Description
Study Area	**Natural Areas**	**1.** Other Vegetations (OV)	Cerrado
			Tropical Semideciduous Forest
			Rain Forests
			Caatinga
		2. Seasonally Dry Tropical Forest	
		3. Water Bodies (WB)	
	Anthropogenic Areas	**4.** Croplands	Forestry
			Croplands
			Irrigation Projects
		5. Pasturelands/ Barren	
		6. Urban	
	7. Contact Areas (CA)		

Table 2 - Definition of Land Use and Coverage Classes (LUC)

Given the relative extension of the study area and the spectral differences for the same LUC, 11 homogeneous regions were defined (Figure 2) to facilitate the classification process, differentiated based on spectral and/or topographic characteristics. There are similar cutouts in homogeneous regions in the Mapping and Inventory of native flora and reforestations in Minas Gerais by Carvalho et al. (2006).

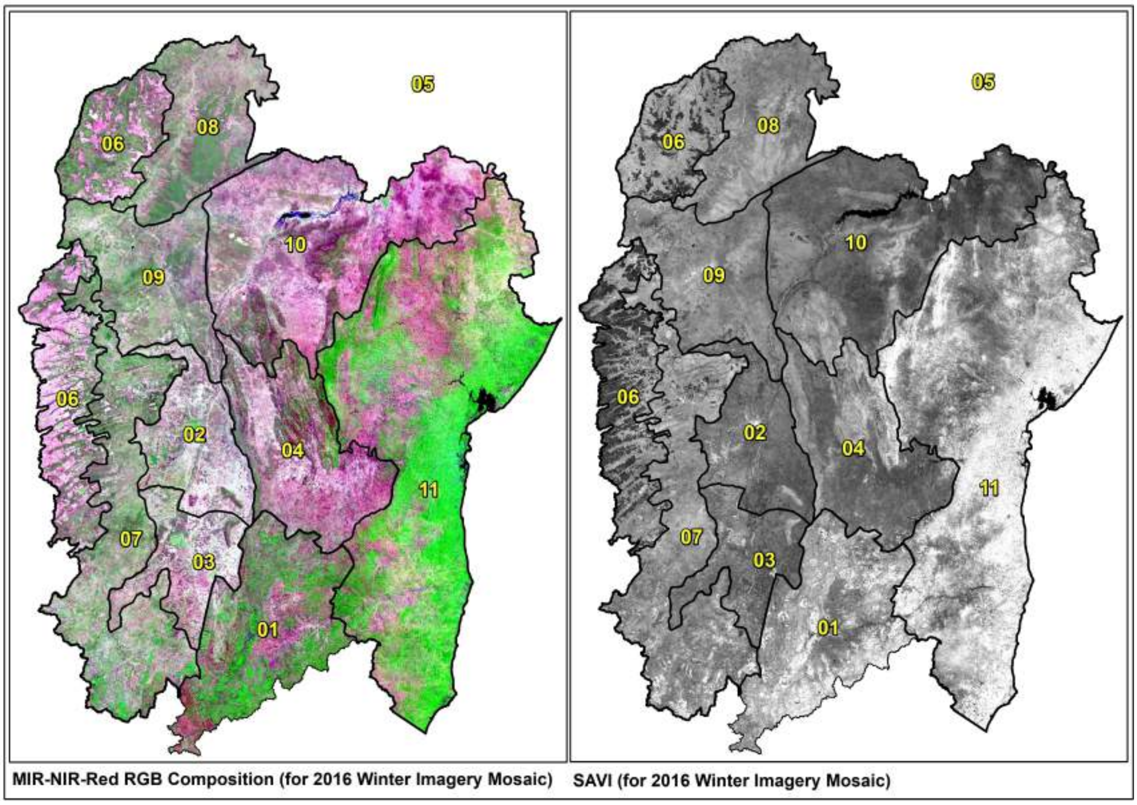


Figure 2 - The fragmentation of the Study Area into 11 regions, according to spectral and topographic characteristics.

In addition to the above, it is noteworthy that establishing homogeneous regions was justified by the relative size of the study perimeter. In this way, for the classification, the control carried out using the Decision Tree was undertaken through each homogeneous region, thus enabling a particular and specific assessment of the various areas that make up the study perimeter.

The FIFTH STEP involved the construction and execution of the Supervised Decision Tree Classifier. Otukei and Blaschke (2010) highlight this classifier, as well as artificial neural networks, as an advanced classification algorithm. The decision tree is a multistage classifier, which allows the user to concretely determine the most appropriate class for each pixel in the image, based on a series of binary decisions (ENVI, 2004). Therefore, to allow the spectral discrimination of the LUC classes, all the images, by-products, and masks produced were used, since the evaluation of the spectral behavior in Steps 3 and 5 was fundamental to define the products be used in the binary decisions.

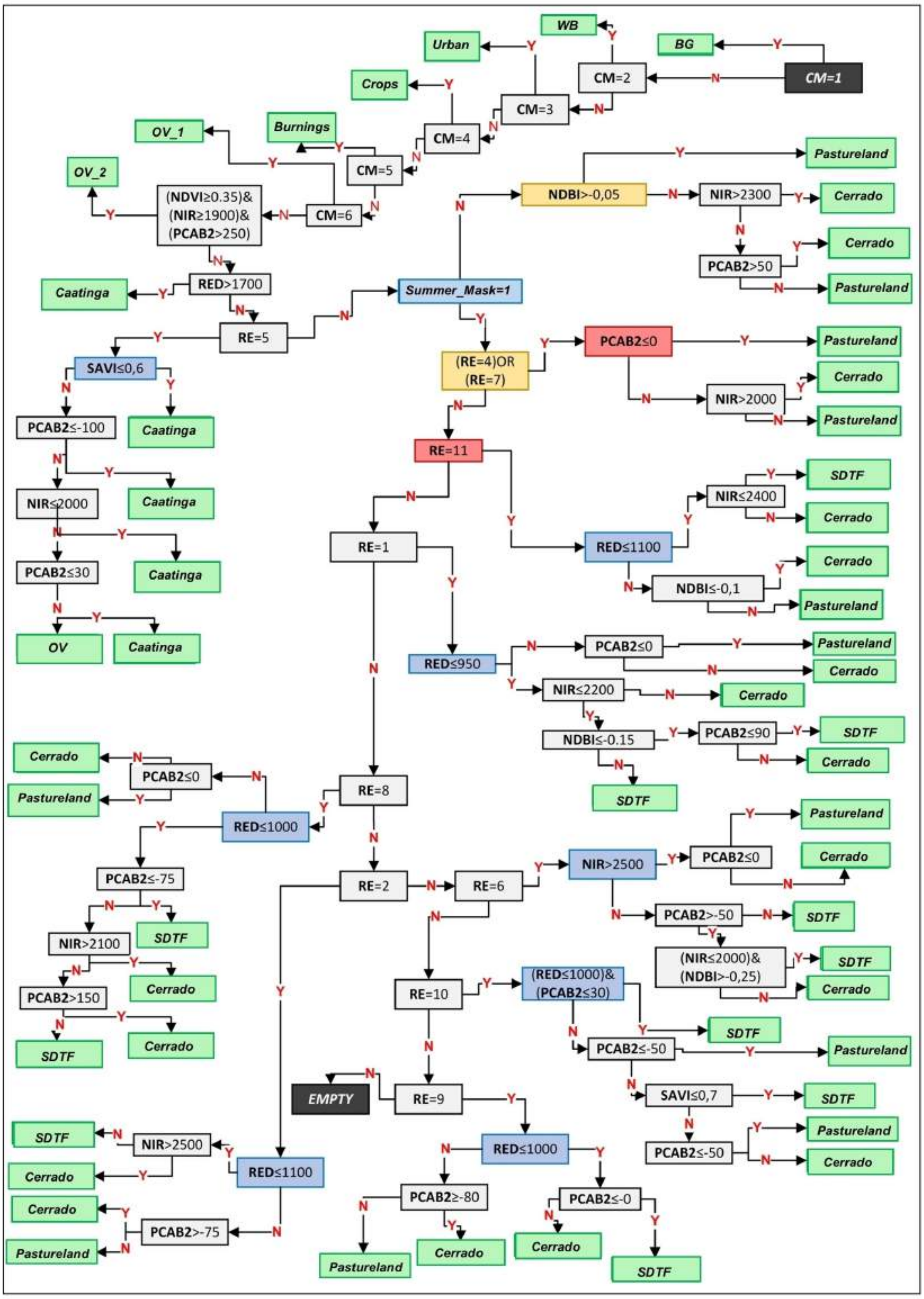


Figure 3 - Decision Tree for 2016 MODIS Classification

Figure 3 schematically represents the final structure of the decision tree used to identify the LUC classes. At this point, it is pertinent to observe the dynamics of the binary decisions mentioned above, which show that the decision tree is made up of nodes, each of which is a dialog box where the conditioning expressions are computed. As a result, a binary decision is made at each node, which may be true (yes) or false (no). For continuity, the classification process continues calculating the expressions until all the image's relevant pixels are correctly classified.

The post-classification stage took place in the SIXTH STEP, which initially corresponded to field visits in those parts of the Study Area that were unclear, making the spectral discrimination of targets impossible.

Figure 4 shows the route (highways) traveled in the field, which were selected based on the ambiguous areas closest to roads (accessibility criterion). Therefore, the most distant points were not considered, and in these cases, questions were resolved using Google Earth software images.

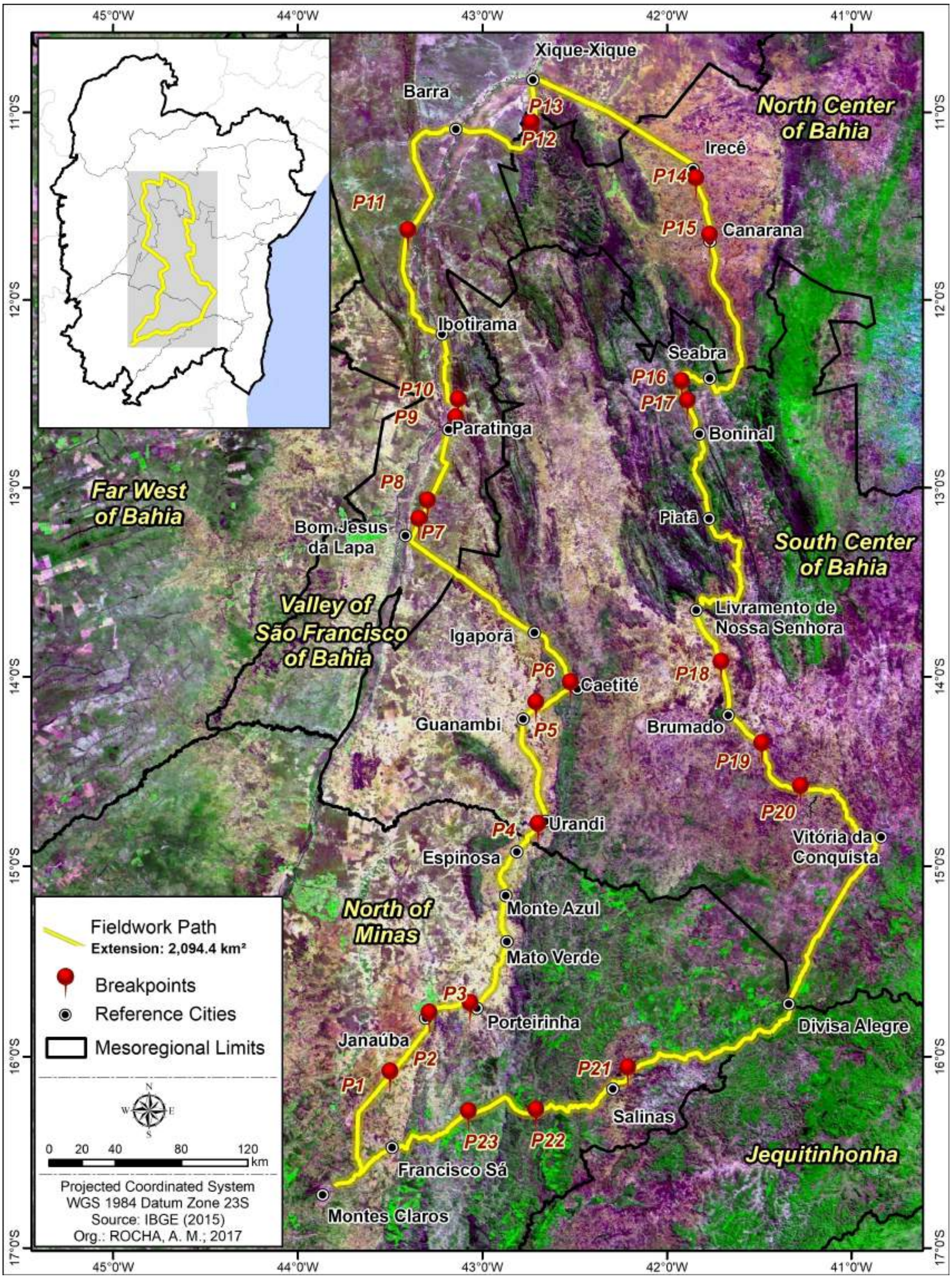


Figure 4 - Determination of the route taken in the fieldwork.

Still in the sixth stage, the Error Matrix was created to analyze the degree of accuracy of the 2016 classification, using sample reference points as a parameter. Table 3 below presents the structuring of the Error Matrix and its results. Congalton and Green (2008) define the Error Matrix as a quadratic matrix, in which the association between the categories of reference data (columns) and mapping x (lines) are established to allow an assessment of the level of accuracy between them, and which is supposedly more correct. To perform this individual and global assessment of the mapping x categories, the Error Matrix represented in Table 3 shows three groups of parametric values: 1. Omission and Commission Errors; 2. User and Producer Accuracy, and 3. Kappa coefficient and Overall Accuracy.

	Reference Pixels Data Classes								
LUC Classes	**WB**	**Croplands**	**SDTF**	**OV**	**Pasturelands**	**Urban**	**Total**	***Commission Error***	***User's Accuracy***
WB	***131***	*0*	*0*	3	6	*0*	140	6.4%	93.6%
Croplands	*0*	***370***	*0*	*0*	15	*0*	385	3.9%	96.1%
SDTF	*0*	*0*	***199***	15	20	*0*	234	15.0%	85.0%
OV	*0*	*0*	31	***524***	17	*0*	572	8.4%	91.6%
Pasturelands	3	12	42	33	***234***	1	325	28.0%	72.0%
Urban	4	*0*	*0*	*0*	*0*	***245***	249	1.6%	98.4%
Total	138	382	272	575	292	246	**1.905**		
Omission Error	5.07%	3.14%	26.84%	8.87%	19.86%	0.41%			
Producer's Accuracy	94.93%	96.86%	73.16%	91.13%	80.14%	99.59%			
Kappa Coefficient: 86,79% e **Overall Accuracy:** 89,40%									

Table 3 - Error Matrix for Classification of Land Cover Use 2016

Thus, with the reference points collected in the field and via Google Earth, the Error Matrix of the 2016 classification indicated an Overall Accuracy of 89.40% and a Kappa Coefficient of 86.79%, meaning a high correspondence of the 2016 mapping categories with the reference sample points. These statistics are also justified by the individual averages of the User's and Producer's accuracies, which were 89.45% and 89.30%, respectively, and the average of the Omission and Commission errors, at 10.7% and 10.5%. These groups of values were considered positive, as the User's and Producer's Accuracy were high, and the Omission and Commission Errors were low.

Despite the positive results of the sample analysis it is important to note that several spectral confusions between the Land Use and Coverage classes were identified during the classification process. This is especially the case in the interpretation key, in which it was possible to observe the proximity between the spectral responses of the SDTF, Caatinga, and Pasture areas, among others. Consequently, it is concluded that although the sample statistics were favorable, the problems associated with spectral differentiation of the targets should not be disregarded, given that it is a fundamental step in the process of mapping Land Use and Coverage.

RESULTS AND DISCUSSION

Following the objectives established at the beginning of this work, the results discussed below aim to evaluate the dynamics of Land Use and Coverage for the Study Area for 2007 and 2016, with the main goal of focusing on the deforestation and regeneration processes of Seasonally Dry Tropical Forest areas to understand the drivers of these changes.

Given the above, Figure 5 below shows the distribution of the Land Use and Coverage classes in the study area, with the totals of the areas (km2 and hectares) and the percentages of each LUC for 2007 and 2016. The 2007 mapping showed the dominance, by size, of three specific classes: Other Vegetation (561,944.81km²), Pasturelands (200,193.19km²), and Seasonally Dry Tropical Forests (76,693.25km²) corresponding to 61.2%, 21.8%, and 8.4%, respectively, which together account for 91.4% of the area in question. In a complementary way, the remaining 8.6% of the analyzed area is composed of Croplands (32,969.56km²), Contact Areas (30,231.75km²), Burnings (8,104.9km²), Water Bodies (5,881.75km²), and Urban Areas (1,749.63km²), with the respective proportions of 3.6%, 3.3%, 0.9%, 0.6%, and 0.3%.

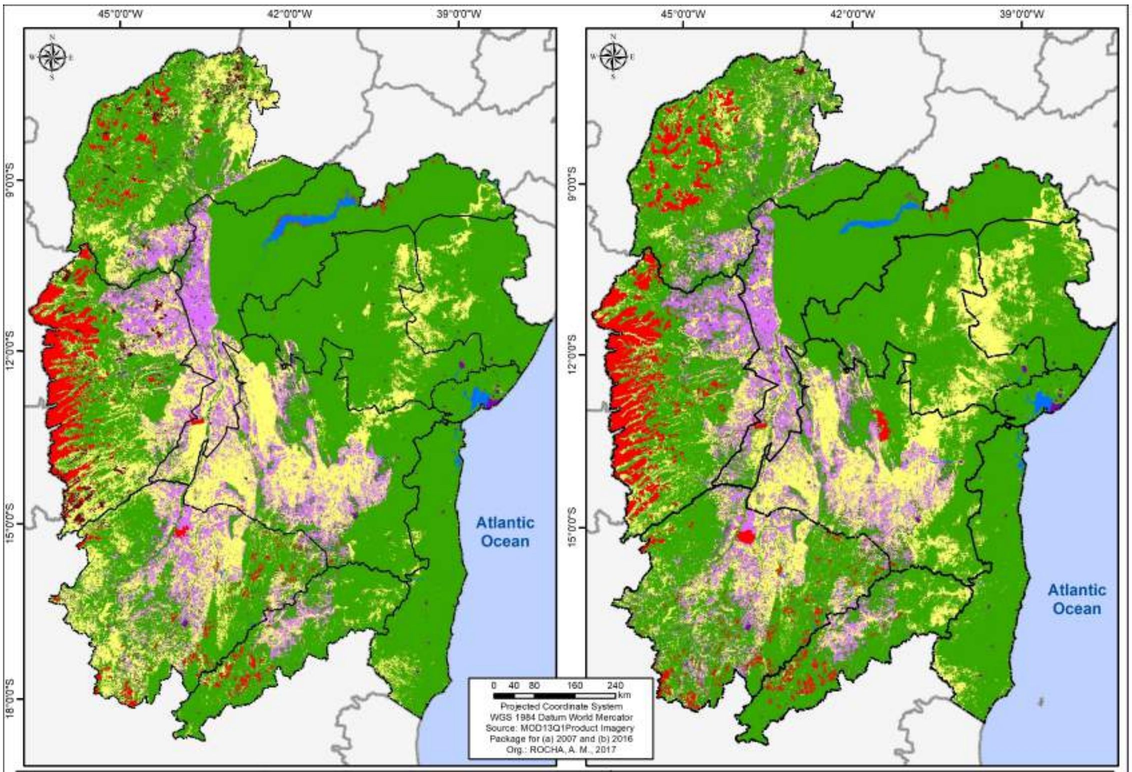
The 2016 mapping recorded a relatively similar proportion of Land Use and Coverage in the study area to those seen in the 2007 mapping. Thus, the classes Other Vegetation (571,086.50km²), Pasturelands (181,593.0km²), and Seasonally Dry Tropical Forests (80,964.31km²) together accounted for 90.8% of the areas in the analysis perimeter, accounting for 62.2%, 19.8%, and 8.8%, respectively. The other areas, in turn, accounted for 9.2%, represented by the classes Croplands (47.417,13km²), Contact Areas (30,231.75km²), Water Bodies (4,518.94km²), Urban Areas (1,731.44km²) and Burnings (212.69km²), thus responding in the order described by 5.2%, 3.3%, 0.5%, 0.2% and 0.02%.

Based on the results above, especially the Net Balance column of the synthesis table in Figure 5, the combined evaluation of the mappings had a positive net balance for three classes in particular, Croplands, Other Vegetation, and Seasonally Dry Tropical Forests, with gains of +14,447.6 km², +9,141.7 km² and +4,271.1 km², respectively.

However, it is relevant that the significant increases in these classes do not imply the absence of losses. Actually, they reflect the fact that for the years in question, the areas gained were greater than those lost. On the other hand, except for the Contact Areas that had the same total area for both years, the remaining four classes, namely: Pasturelands, Burnings, Water Bodies, and Urban Areas registered a negative net balance for the period 2007-2016, with losses of -18,600.2km², -7,829.3km², -1,362.8km² and -18.3km², respectively. Following the reasoning above, these results also mean that the net balance for the classes is not only an indication of losses; they describe a scenario in which the gains in area were lower than the losses.

Furthermore, although clear changes have occurred in the classes of Other Vegetation, SDTFs, and Pasturelands, these changes did not really stand out, as they represent final changes of less than ±10% of the initial areas identified in 2007, mainly due to the expressiveness of these classes in the study area. On the other hand, it was found that the classes Burning, Croplands, and Water Bodies were the classes with the greatest proportion of change compared to the initial year of analysis, representing net changes of 97.4%, 43.8%, and 23.2 %.

Taken individually, it is important to note that in 2007, Burnings were identified exclusively in three particular mesoregions, the Far West of Bahia (55.4%), the Southwestern Piauí (42.9%), and the North of Minas Gerais (1.7%). It was possible to identify that the fires had only occurred in 2007, considering that in 2016, less than 3% of the burnt areas observed in the initial year of analysis had persisted. As a result, this was the class with the greatest change in its area. Also, in both years, the cultivated areas predominated more than 90% in three particular mesoregions: Far West of Bahia, Southeastern Piauí, and North of Minas Gerais, with a net increase of approximately 14,000 km², thus decisively corroborating a net change of 43.8% compared to 2007.



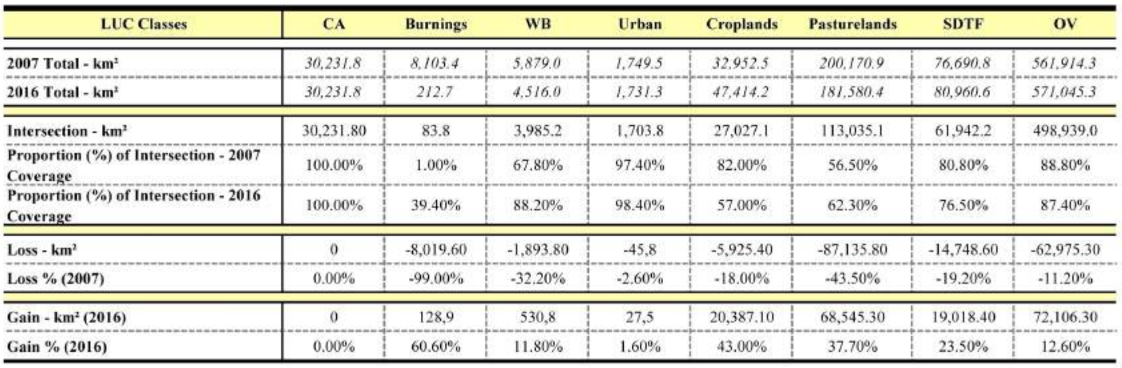
Land Use and Coverage (LUC) Classes	(A) MODIS Mapping 2007 Year			(B) MODIS Mapping 2016 Year			NET BALANCE
	km²	ha (millions)	%	km²	ha (millions)	%	km²
⬛ CA	30,231.75	3.02	3.29%	30,231.75	3.02	3.29%	-
🟦 Water Bodies	5,881.75	0.59	0.64%	4,518.94	0.45	0.49%	- 1,362.8
🟪 Urban	1,749.63	0.17	0.19%	1,731.44	0.17	0.19%	- 18.2
🟫 Burnings	8,104.94	0.81	0.88%	212.69	0.02	0.02%	- 7,892.3
🟥 Cropland	32,969.56	3.30	3.59%	47,417.13	4.74	5.17%	+ 14,447.6
🟨 Pastureland	200,193.19	20.02	21.81%	181,593.00	18.16	19.79%	- 18,600.2
◼ SDTF	76,693.25	7.67	8.36%	80,964.31	8.10	8.82%	+ 4,271.1
🟩 Other Vegetations	561,944.81	56.19	61.23%	571,086.50	57.11	62.23%	+ 9,141.7

Figure 5 - Distribution of Land Use and Coverage Classes and associated Statistics for the Years 2007 (A) and 2016 (B)

The class of Water Bodies is noteworthy as the computed drop of 1,362 km² was a net loss of 23.2% of the initial area ascertained in 2007. This loss was notably concrete and visible in the areas of the Irapé, Gorutuba, and Sobradinho reservoirs, which stood out for their reduced water blade.

Table 4 summarizes the totals of the areas identified for each LUC, with a breakdown of the values related to losses, gains, and intersection areas (Common Areas). Therefore, based on the explanation above, the first aspect refers to the Common Areas between the mappings, which accounted for 80.3% or 736,947.8 km² of the total study area. Thus, it was observed that four-fifths of the analysis perimeter remained unchanged, without LUC conversions. The remaining 19.7% (180,744.3 km²), on the other hand, were the areas that showed conversions between LUC. In specific terms, for the period 2007-2016, the classes Urban, Other Vegetation and Seasonally Dry Tropical Forests had the highest percentage of unchanged or maintained areas compared to those identified in 2007, presenting unconverted plots of 97.4%, (498,939.0 km²), 88,8% (61,942.2 km²), and 80.8% (1,703.8 km²), respectively.

It is also important to consider that in the areas for the same classes identified in 2016, values of over 75% without change can be observed, so although the changes (losses/gains) of the OV and SDTF classes are significant in terms of area (km²), both the losses (11.2% and 19.2%) and gains (12.6% and 23.5%) have low percentages in relation to the totals identified in 2007 and 2016.



LUC Classes	CA	Burnings	WB	Urban	Croplands	Pasturelands	SDTF	OV
2007 Total - km²	*30,231.8*	*8,103.4*	*5,879.0*	*1,749.5*	*32,952.5*	*200,170.9*	*76,690.8*	*561,914.3*
2016 Total - km²	*30,231.8*	*212.7*	*4,516.0*	*1,731.3*	*47,414.2*	*181,580.4*	*80,960.6*	*571,045.3*
Intersection - km²	30,231.80	83.8	3,985.2	1,703.8	27,027.1	113,035.1	61,942.2	498,939.0
Proportion (%) of Intersection - 2007 Coverage	100.00%	1.00%	67.80%	97.40%	82.00%	56.50%	80.80%	88.80%
Proportion (%) of Intersection - 2016 Coverage	100.00%	39.40%	88.20%	98.40%	57.00%	62.30%	76.50%	87.40%
Loss - km²	0	-8,019.60	-1,893.80	-45,8	-5,925.40	-87,135.80	-14,748.60	-62,975.30
Loss % (2007)	0.00%	-99.00%	-32.20%	-2.60%	-18.00%	-43.50%	-19.20%	-11.20%
Gain - km² (2016)	0	128,9	530,8	27,5	20,387.10	68,545.30	19,018.40	72,106.30
Gain % (2016)	0.00%	60.60%	11.80%	1.60%	43.00%	37.70%	23.50%	12.60%

Table 4- Statistical Synthesis, with a description of the Totals mapped in 2007 and 2016 by LUC classes and discrimination of Intersections (Common Areas), Losses and Gains

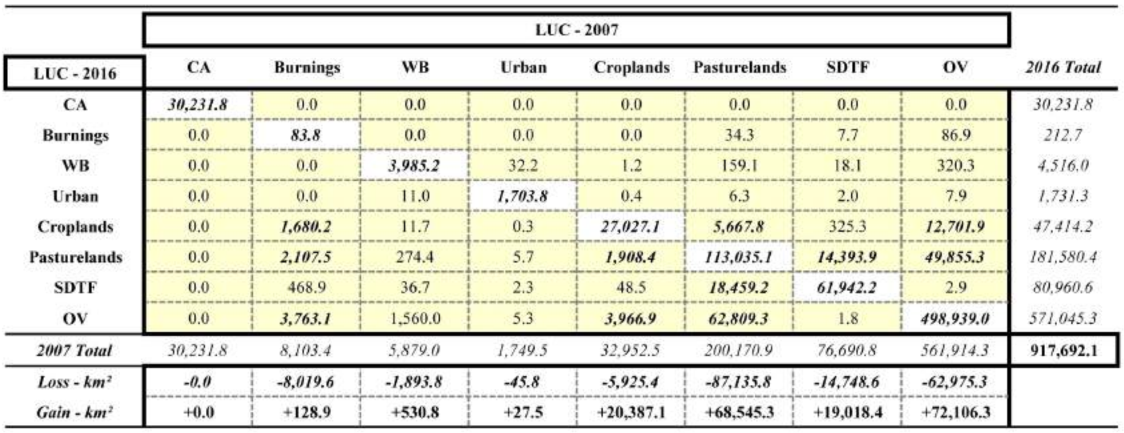
Unlike the above scenario, the Burnings and Pasturelands classes recorded for the two periods have the lowest proportions of common or unaltered areas, indicating high spatial mobility. In these terms, Burnings only registered 83.8 km² of common areas, which represents 1% and 39.4% of the burnt areas identified in 2007 and 2016, respectively. Consequently, it is apparent that 99% of the areas indicated in the initial mapping have disappeared, being converted into other LUCs. On the other hand, 60.6% of the areas in 2016 represent direct gains. These values point to the dominance of losses (-8,019.6 km²) over gains (+128.9 km²) and naturally justify the previously observed negative net balance of the Burnings class.

The Pasturelands class had similar characteristics to the Burnings, although less aggressively. Indeed, 113,035.1 km² of Pasture area were identified in both years, representing 56.5% and 62.3% in the ranking of the initial and final years. It was found that the remaining 43.5% (87,135.8 km²) and 37.7% (68,545.3 km²) were the losses and gains of area compared to those identified in 2007 and 2016, signaling the evident variation in Pasture areas.

On the other hand, the classes of Croplands and Water Bodies did not have fixed patterns similar to those observed above, with high percentages of unalterable areas or high spatial mutability. Table 4 shows that these two classes had a mixture of the characteristics of the two scenarios mentioned. The Croplands class initially recorded 27,027.1 km² of equally identified spatial areas in both years, thus constituting common areas between 2007 and 2016. However, there were two situations, the first is the fact that the extension describes 82.0% of the areas identified in 2007, which translates into a high retention of the areas initially identified since the loss was only -18.0%. However, the 2016 analysis pointed to an inversion of this scenario, as it estimated that the proportion of areas in 2016 that were also identified in 2007 was only 57.0%. Following this line of thought, it appears that the remaining 43% of the areas identified in 2016 are a net increment in crops areas. Hence, the positive net balance of over 14,000 km² observed for the Cultivated areas results from the retention of the existing areas plus the systematic increase in new areas.

The Water Bodies class, in turn, behaved inversely to the situation of the Cultivation areas. Considering the total of 3,985.2 km² of common areas identified between the 2007 and 2016 mappings, this value corresponds to only 67.8% of the total areas mapped in 2007, with the remaining -32.2% (-1,893.8km²) being the portion related to net losses of water bodies. Therefore, taking into account the percentage of new water bodies identified in 2016, which correspond to + 11.8% (+ 530.8 km²) of the mapped area, the negative net balance ascertained for the Water Bodies class is explained.

Table 5 (conversion matrix) below enables the assessment of the change dynamics of the LUC classes. For evaluation purposes, the matrix of the 2007 LUCs with its conversion to 2016 is shown in the matrix columns. The lines, in turn, show the 2016 LUCs distribution compared to the classes they belonged to in 2007. The diagonals resulting from this structure show the common areas between the two mappings, that is, unchanged areas. As a result, any value outside the diagonals represents converted areas, thus gains (rows) or losses (columns). Given the purpose of this research, the evaluations focus particularly on the areas of Other Vegetation and, more importantly, on the Seasonally Dry Tropical Forests.



	LUC - 2007								
LUC - 2016	**CA**	**Burnings**	**WB**	**Urban**	**Croplands**	**Pasturelands**	**SDTF**	**OV**	***2016 Total***
CA	***30,231.8***	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*30,231.8*
Burnings	0.0	***83.8***	0.0	0.0	0.0	34.3	7.7	86.9	*212.7*
WB	0.0	0.0	***3,985.2***	32.2	1.2	159.1	18.1	320.3	*4,516.0*
Urban	0.0	0.0	11.0	***1,703.8***	0.4	6.3	2.0	7.9	*1,731.3*
Croplands	0.0	***1,680.2***	11.7	0.3	***27,027.1***	***5,667.8***	325.3	***12,701.9***	*47,414.2*
Pasturelands	0.0	***2,107.5***	274.4	5.7	***1,908.4***	***113,035.1***	***14,393.9***	***49,855.3***	*181,580.4*
SDTF	0.0	468.9	36.7	2.3	48.5	***18,459.2***	***61,942.2***	2.9	*80,960.6*
OV	0.0	***3,763.1***	1,560.0	5.3	***3,966.9***	***62,809.3***	1.8	***498,939.0***	*571,045.3*
2007 Total	*30,231.8*	*8,103.4*	*5,879.0*	*1,749.5*	*32,952.5*	*200,170.9*	*76,690.8*	*561,914.3*	**917,692.1**
Loss - km²	***-0.0***	***-8,019.6***	***-1,893.8***	***-45.8***	***-5,925.4***	***-87,135.8***	***-14,748.6***	***-62,975.3***	
Gain - km²	**+0.0**	**+128.9**	**+530.8**	**+27.5**	**+20,387.1**	**+68,545.3**	**+19,018.4**	**+72,106.3**	

Table 5- Conversion Matrix of Land Use and Cover, between 2007 and 2016, in area units (km²)

As mentioned, the Other Vegetation class registered a positive net balance, indicating an increase of +9,141.7 km², thus constituting an area expansion from 561,944.81 km² (2007) to 571,086.50 km² (2016). As noted in table 5, the positive balance is directly due to the preeminence of gains (regeneration) over losses (deforestation), which totaled +72,106.3km² and -62,975.3km², respectively. Of these values, the analysis showed that in the case of deforestation, of the total -62,975.3 km² lost, 79.2% were explained exclusively by the Pasture areas (49,855.3 km²), and secondly, by the Cultivated areas, which accounted for 20.2% (12,701.9 km²). Although there are certainly other LUCs that influenced the loss of area of Other Vegetation, it is evident that about 99% of the loss observed is due to the Pasture and Crop areas. Equally, it is significant that over 60% of the gains in the Burnings, Pastures, and Cultivation classes were processed over the areas of Other Vegetation. This is an important fact, as these circumstances were not repeated in the SDTFs, being specific to this class.

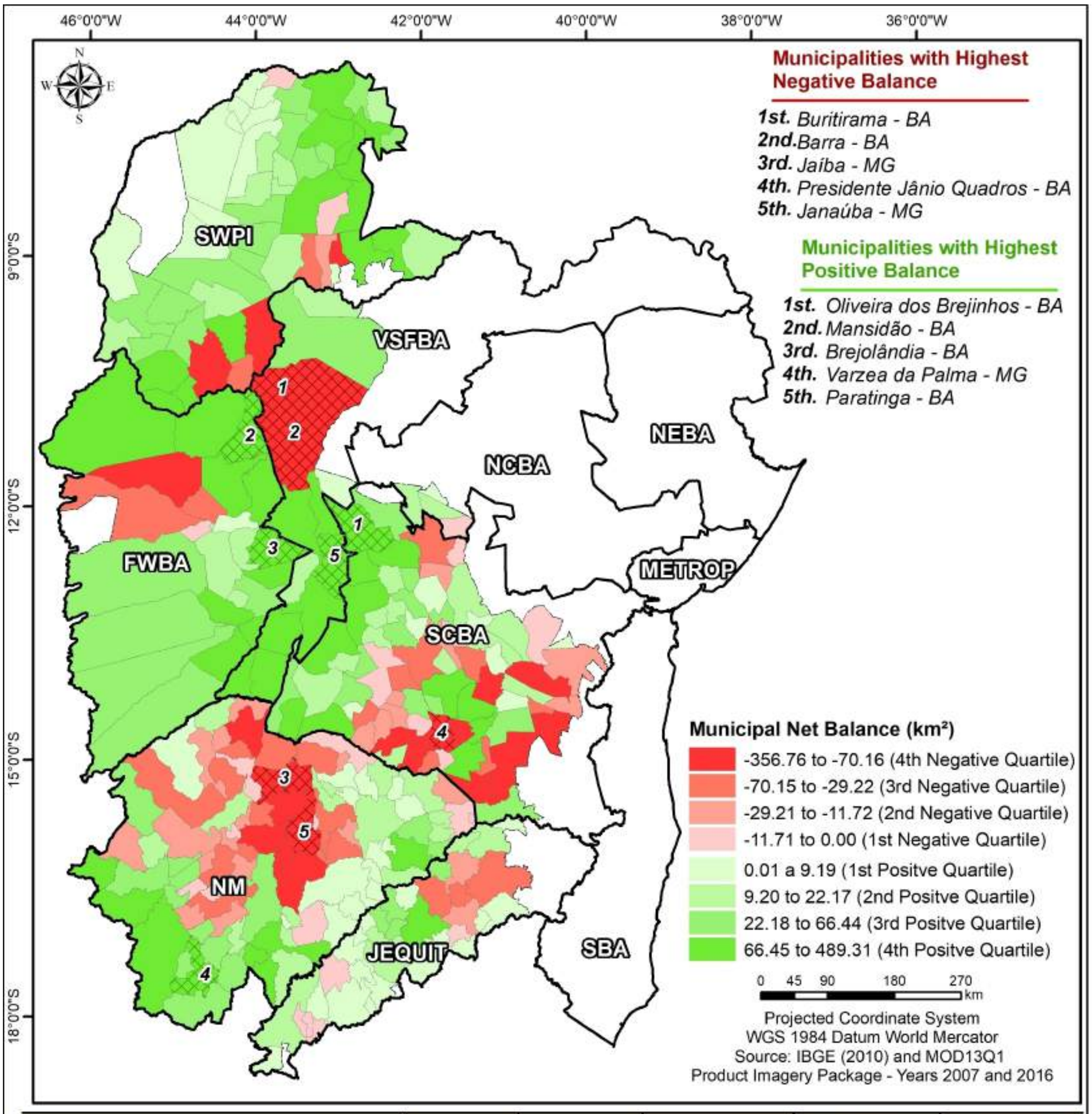
Concerning the areas of regeneration in the Other Vegetation class, Table 5 shows that from the total +72,106.3 km² gained, three particular classes of regeneration took place, in order of importance, the Pasture, Cultivation, and Burnings classes, which accounted for 87.1% (62,809.3 km²), 5.5% (3,966.9 km²), and 5.3% (3,763.1 km²), respectively, over 95% of the area gained.

With special regard to the Seasonally Dry Tropical Forests areas, the analysis of the 2007-2016 mappings certainly shows a positive net balance for the study period, with a net increase of +4,272.2 km², similarly to the case for Other Vegetation. As verified, this result is a clear expansion of the SDTF areas of 76,693.25 km² in 2007 to 80,960.6 km² in the year 2016. Also, the positive net balance was derived from the prevalence of gains (+19,018.4km²) of regeneration, over the losses (-14,748.6 km²) due to deforestation.

Regarding these values, the analysis in Table 5 also indicated that more than 95% of the deforestation and regeneration in the SDTFs areas were explained by the Pasture class. Indeed, it was clear that 97.6% (14,393.9 km²) of the SDTF loss is due to this class, and was secondarily affected by the Cultivation class, which although less influential, had a 2.2% slice (325.3 km²), so that these two classes account for over 99% of the deforestation of the SDTF areas. As for regeneration, the Pasture class accounted for 97.1% (18,459.2 km²), followed by the Burnings class, with a 2.5% share (468.9 km²).

Figure 6 shows the spatial distribution of the net balance (loss/gain) for each municipality in the study area, and it is notable that in the mappings, SDTF areas were identified in 294 of the total 619 municipalities. Of these, 98 and 196 municipalities registered negative and positive net balances, in 2007 and 2016, respectively, once again demonstrating the prevalence of gains over losses. It is important to highlight, however, that despite the dominance of the gains, the positive net balance was not verified in the seven mesoregions with identified SDTFs. Of the mesoregions listed, the North of Minas mesoregion (MG) registered the only negative balance.

In addition to the above, from the spatial point of view, the South Central of Bahia (SCBA), North of Minas (NM), and Valley of São Francisco of Bahia (VSFBA) mesoregions had the largest areas (km²) of SDTF in both mappings, with portions over 65% of the total SDTF values identified. This especially denotes a clear locational pattern for the seasonally dry tropical forest areas, which are predominantly distributed in a longitudinal direction, in the surroundings of the São Francisco valley.



Mesoregions	2007 TDF	2016 TDF	Net Balance (in km²)	Loss (in km²)	Gain (in km²)
Southwestern Piaui **(SWPI)**	7.9%	9.5%	**+1,655.7**	-1,702.80	**3,358.50**
Far West of Bahia **(FWBA)**	17.0%	17.8%	**+1,390.3**	-1,826.10	3,216.40
Valley of São Francisco of Bahia **(VSFBA)**	***19.7%***	***19.4%***	**+636.2**	**-2,038.50**	2,674.60
South Center of Bahia **(SCBA)**	***27.3%***	***26.6%***	**+599.9**	**-4,514.50**	**5,114.40**
Jequitinhonha **(JEQUIT)**	5.0%	5.0%	**+191.3**	-628.4	819.8
North Center of Bahia **(NCBA)**	0.3%	0.3%	**+24.3**	-29.9	54.2
North of Minas **(NM)**	***22.8%***	***21.3%***	**-229.4**	**-4,010.10**	**3,780.70**
Southern Bahia **(SBA)**	*0.0%*	*0.0%*	-	-	-
Metropolitan Area of Salvador **(METROP)**	*0.0%*	*0.0%*	-	-	-
Northeastern Bahia **(NEBA)**	*0.0%*	*0.0%*	-	-	-

Figure 6- Municipal Distribution of the Net Balance (Loss and Gain) of Seasonally Dry Tropical Forest and statistical summary (% Distribution SDTF, Net Balance, Gain and Loss) of the Mesoregions of the Study Area.

The assessment of these location dynamics is very relevant, given that these areas are the intersection limit between the Caatinga and Cerrado biomes, and as the biophysical characteristics between the Caatinga and SDTFs are closely related, this helps illustrate some of the problems of discrimination observed in the methodological steps.

Given the information presented above, it is evident that classes of the Mappings of Land Use and Coverage for 2007 and 2016 showed a tendency for gains to dominate over losses, resulting in positive balances. Also, the classes of Pasture, Burnings, and Cultivation, which are the most significant anthropic actions in the study area, played an extremely important role in the losses and gains identified.

In the particular case of the Other Vegetation class, it was noted that despite the dominance of Pastures over losses and gains, Burnings and Cultivation accounted for part of the phenomenon. This particular fact was not found in the areas of Seasonally Dry Tropical Forests. As has been well observed, Burnings and Cultivation had very restricted location dynamics in the northern regions of Minas, Far West of Bahia, and Southeastern Piauí. These spatial dynamics corroborated the results, indicating the greater influence these classes have on the Other Vegetation class. The Seasonally Dry Tropical Forests recorded distinct location dynamics from the other two classes and for this reason, Pastures were the most influential driver of losses and gains.

Given our research proposals and the final results achieved, the most important point is that the analyzes of the Brazilian Seasonally Dry Tropical Forest were justified due to the characteristic context of this type of vegetation. In fact, SDTFs are one of the least significant forest formations in the Brazilian territory, as their distribution is in the form of disjunctions that are differentially located in predominantly non-forested biomes (Caatinga and Cerrado). This circumstance decisively hinders its concrete identification, considering that some of their structural and climatic-edaphic characteristics are similar to other types of formations. Therefore, the mapping of Land Use and Coverage developed for the years 2007 and 2016 intended to contribute to the effective identification of tropical dry forest areas, and therefore serve as an indirect subsidy for any conservation policies.

CONCLUSION

The methodological aspects of this study particularly underline the importance of the MODIS sensor image package (TERRA satellite) used, given its temporal properties and processing level, which contributed significantly to the study. This is relevant because the dimensions of the study area are relatively extensive and the use of other orbital products, such as the Landsat series, would lengthen the processing time and make certain operational procedures unworkable. It is also noteworthy that, given the biophysical and consequently spectral characteristics of the land uses identified, the isolated use of red, near, and medium infrared wavelengths were particularly useful in the process of spectral discrimination of soil-vegetation matrices.

Finally, in terms of land use and cover change in the combined analysis for 2007-2016, there was a clear trend of the predominance of gains over losses in the vegetation areas, which justified the positive net balance sheets in the Other Vegetation and SDTFs classes. However, considering the particular characteristics of Seasonally Dry Tropical Forests and the methodological limitations observed, the authors wish to stimulate future research, particularly to overcome the challenges posed herein, which will certainly have a positive influence on the concrete identification of dry forest areas and consequently contribute towards their eventual conservation.

ACKNOWLEDGEMENTS

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NOTE

1- The work of Murphy and Lugo (1995), Prado (2000), Miles et al. (2006) and Portiollo-Quintero and Sánchez-Azofeifa (2010) refer to these studies and, therefore, are sources of information.

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