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Spatial-temporal dynamics of biome Cerrado using different vegetation indexes

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Abstract

The Cerrado ranks among the major biomes in Brazil and its vegetation can now be monitored through remote sensing, although environmental factors can affect the use of this technique. Thus, the possibility of conducting a study in a region with negligible anthropogenic intrusion may become a potential reference work in controlling the spatio-temporal alterations occurring in the Cerrado biome. This study aimed at assessing the spatio-temporal dynamics of the Brazilian Cerrado biome at different seasons of the year (wet and dry), employing various vegetation indices (NDVI, SAVI, EVI and LAI) drawn from the LANDSAT satellite images 8. The study itself was conducted in the Tadarimana Indigenous reserve situated in the State of Mato Grosso, Brazil. Extending across an area of 9952 hectares, the predominant vegetation cover in this reserve include the Savanna-Seasonal Contact (84.78%) and Savanna (15.22%). The data was analyzed using descriptive statistics and the best characterization of the vegetation was identified in the regions where higher variability was observed in the responses of the vegetation indices. The LAI revealed the best performance when the spatio-temporal dynamics of the Brazilian Cerrado biome was assessed. The wet season displayed the highest values among the different vegetation indices, despite the variances.

Keywords: Geotechnology; landsat; leaf area index; satellite imagery; vegetation cover.

Abbreviations: NDVI_ Normalized Difference Vegetation Index, SAVI_ Soil Adjusted Vegetation Index, EVI_Enhanced Vegetation Index, LAI_Leaf Area Index, INMET_National Institute of Meteorology, MT_Mato Grosso, USGS_United States Geological Survey, OLI_Operational Land Imager, GIS_Geographic Information Systems, UTM_Universal Transversade Mercator.

Introduction

Central Brazil is the home of the Cerrado biome which encompasses a vast area of roughly 200 million hectares. Ranked the second largest Brazilian biome, the Cerrado hosts a wealth of flora, some of which are endemic. In fact it is the most abundant savannah in the world in terms of biodiversity. The Cerrado biome also forms one of the most extensive agricultural frontiers in Brazil and because of its vast expanse, the Cerrado, depending on its location, exhibits changes in its ecosystem. In this case, the ecosystems present in the Cerrado can be classified as the Cerradão, Campo Cerrado and Cerrado de Matas, among others (Klink and Machado, 2005; Rada, 2013).

For decades the processes of change in the land cover and land use for this biome have featured in many global environmental discussions. Suitable environmental planning is necessary, based on the understanding of the activities present here, to minimize their impacts. These impacts on the terrain can be decreased by carefully monitoring the spatio-temporal data (Cunha et al., 2012; Coelho et al., 2014).

Environmental planning, however, hinges on substantial and expensive fieldwork, in addition to locations in the restricted regions (Freitas et al., 2005). Remote sensing has made a huge difference, and the vegetation cover can now be monitored across extensive expanses, employing digital satellite image processing methods, which facilitate the identification of the spatial and temporal changes in the vegetation (Parise and Vettorazzi, 2005; Pavanelli and Guimarães, 2014).

One of these methods involves vegetation indices, which are evaluated by the relationships existing among the red, blue and infrared bands adjoining the satellite images. This enables identifying the regions with greater or lesser vegetation cover. The vegetation indices, however, may be influenced by environmental variables like soil class, rainfall, and spatial and temporal resolutions of the sensors and platforms, which may hinder the analysis of the vegetation cover (Schnur et al., 2010; Liu et al., 2012).

Many vegetation indices were introduced like, Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI) and Leaf Area Index (LAI). The NDVI helps in the identification and evaluation of changes in the vegetative cover layout, appearance and location (Aquino and Oliveira, 2012). SAVI is applied as an adjustment criterion to minimize the influence of soil presence in the vegetation while, Santiago et al. (2009) continue to hold that the LAI is best used to categorize the vegetative cycle via remote sensing. The EVI shows higher sensitivity to enable dense vegetation to be identified, over time (Danelichen et al., 2016).

Many authors refer to the efficiency of employing vegetation indices in studying its spatio-temporal dynamics in different biomes and across the world (Ferreira and Huete, 2004; Schnur et al., 2010; Liu et al., 2012; Danelichen et al., 2016). However, a study conducted in a particular region with the least possible anthropogenic interference may prove to be a potential reference work in controlling the spatio-temporal alterations occurring in the Cerrado biome.

In light of these facts, the aim was to assess the spatiotemporal dynamics of the Brazilian Cerrado biome during different times of the year (wet and dry seasons) through the use of different vegetation indices (NDVI, SAVI, EVI and LAI) utilizing the LANDSAT satellite 8 images.

Results and discussion

Water-climatological balance

From the findings of the monthly water balance for the five years of study (2013 to 2017) it is evident (from Fig 1) that water surplus was present in three months of 2013, viz., January (174.8 mm), February (9.1 mm) and December (96.8 mm). Barring April and the months of water surplus, the other eight months of the year experienced water deficiency.

Meanwhile, in 2014, the three months of January (7.1 mm), November (18.7 mm) and December (103.8 mm) experienced water surplus, whereas in 2015 the water surplus was confirmed for February (76.0 mm) and March (160.5 mm). However, while the 2016 data revealed water surplus in January (10.5 mm) alone, the records for 2017 revealed water recovery, with water surpluses in January (18.3 mm), February (16.9 mm), November (44.1 mm) and December (167.5 mm).

From the water balance it is clear that the water deficit could occur even during the rainy season, for instance in January and December 2015, where the poor water levels designated it as summer, implying the monthly inconsistency of the precipitation in the area under investigation. Critical values of the annual water deficiency are evident during September, barring in August 2015.

Souza et al. (2013) investigated the climatological water balance and categorization of climate for 13 conventional meteorological stations (from 1995 to 2010), using data taken from the station network of the National Institute of Meteorology (INMET), in the State of Mato Grosso (MT). In Rondonópolis the rainfall recorded was 1416.07 mm from May to September, with the monthly precipitation average falling below 36 mm. It was also confirmed that from October to March the average monthly precipitation always exceeded 113 mm, with January recording the highest monthly rainfall, of around 280 mm.

Seasonal and interannual dynamics of vegetation indices

In terms of the descriptive statistics (mean, standard deviation and variance) of the vegetation indices recorded between the wet and dry periods every year (seasonal differences), the highest values of variance and standard deviation of the LAI were observed for the years 2014, 2015 and 2016. In the meantime, the EVI showed the highest values of variance and standard deviation for 2013. The other indices (NDVI and SAVI), showed that the values remained similar for the years of the study. Thus, the LAI appeared to be a reliable indicator of the biomass of each pixel of the images analyzed. Therefore, it is a very significant biophysical index for the management, characterization and use of soil and occupation (Table 1).

From the descriptive statistics (mean, standard deviation and variance) of the vegetation indices from 2013 to 2017 (interannual differences) during the wet period, it is clear that the greatest values of variance and standard deviation were evident in the LAI and EVI indices. The LAI showed variance of 0.32 and standard deviation of 0.57, while the EVI revealed variance and standard deviation of 0.003 and 0.05, respectively. Therefore, these two vegetation indices are considered to exert the greatest effectiveness in discriminating among the targets (Cerrado vegetation) during the humid period.

The NDVI and SAVI recorded the least values of the statistical indices, showing variance of 0.002 and standard deviation of 0.04 for both, and are therefore not approved for the determination of the vegetation cover in biomes like the Brazilian Cerrado.

However, Ferreira and Huete (2004) in their studies on soil cover changes assessed the seasonal vegetation dynamics of the Brazilian Cerrado via vegetation indices which confirmed that the EVI is most reliable. Goltz et al. (2007) using MODIS vegetation spectral indices, also concurred that the EVI is the most recommended vegetation index to determine the areas vulnerable to flooding in the Paiaguás and Nhecolândia (Pantanal South MT) regions.

According to the work of Biudes et al. (2015) the energy exchange patterns for the tropical ecosystems in the various climatic types in the State of Mato Grosso (MT), viz., the low vapor pressure, air temperature, solar radiation and net radiation exerted a direct influence on the seasonal amplitude of the EVI vegetation index. It was concluded that the EVI drawn from suitable satellites can identify the vegetation patterns of this region.

On analyzing the spatial variability (relative distribution) of the vegetation indices by classes (between 2013 and 2017) during the rainy and dry periods (Fig 2), a drop in the values of the vegetation indices was noted as seen in Table 1. Table 1 reveals the correlation coefficients between the soil water storage and vegetation index.

In their work, Adami et al. (2008) examined the spatialtemporal dynamics of the Pantanal biome using the MODIS images. They confirmed temporal and spatial dependence of the spectral response of the vegetation to precipitation, establishing the hypothesis that the spectral response of the

Table 1. Mean, standard deviation and variance of the vegetation indexes used in the study of the spatial-temporal dynamics of the cerrado biome between the wet and dry periods (seasonal) and between the years 2013 and 2017 (interannual).

Seasonal difference					
Wet-	NDVI	SAVI	EVI	LAI	
Dry	Mean ± standard deviation (variance)				
2013	0.21±0.09 (0.008)	0.16±0.06 (0.004)	0.18±0.70 (0.50)	0.86±0.37 (0.14)	
2014	0.07±0.12 (0.014)	0.09±0.10 (0.01)	0.13±0.10 (0.01)	0.65±0.63 (0.40)	
2015	0.20±0.08 (0.006)	0.21±0.07 (0.005)	0.27±0.07 (0.005)	1.77±0.81 (0.65)	
2016	0.58±0.05 (0.003)	0.21±0.06 (0.004)	0.24±0.07 (0.005)	1.60±0.64 (0.41)	
2017	0.35±0.15 (0.022)	0.31±0.12 (0.014)	0.33±0.12 (0.014)	1.93±0.73 (0.53)	
Interannual difference					
2013-	NDVI	SAVI	EVI	LAI	
2017	Mean ± standard deviation (variance)				
Wet	-0.02±0.04 (0.002)	-0.07±0.04 (0.002)	-0.12±0.05 (0.003)	-0.83±0.57 (0.32)	
Dry	0.12±0.14 (0.02)	0.07±0.11 (0.01)	0.03±0.10 (0.01)	0.24±0.34 (0.12)	

NDVI = Normalized Difference Vegetation Index, SAVI = Soil Adjusted Vegetation Index, EVI = Enhanced Vegetation Index, LAI = Leaf Area Index.



Monthly

Fig 1. Monthly water-climatological balance from the years 2013 to 2017 and period of passage of the Landsat 8 satellite in the study area.

Vegetation indexes	Number of the equation	Equation
NDVI	1	$NDVI = \frac{(B_{Infra Red} - B_{Red})}{(B_{Infra Red} + B_{Red})}$
SAVI	2	$SAVI = \frac{(1+L_S) (B_{infra Red} - B_{Red})}{(L_S + B_{infra Red} + B_{Red})}$
EVI	3	$EVI=2.5 \frac{(B_{infra Red} - B_{Red})}{(B_{infra Red} + C_1 B_{Red} - C_2 B_{Rive} + 1)}$
LAI	4	LAI=- $\frac{\ln\left(\frac{0.69-SAVI}{0.59}\right)}{0.01}$

NDVI = Normalized Difference Vegetation Index, SAVI = Soil Adjusted Vegetation Index, EVI = Enhanced Vegetation Index, LAI = Leaf Area Index, B_{Red} = reflectance in the band 4; $B_{Infra Red}$ = reflectance in the band 5; B_{Blue} = reflectance in the band 2, L_s = soil factor (L_s = 0.25), C1 e C2 = coefficients for removal of the vegetation signal (C1 = 6; C2 = 7.5).



Fig 2. Representativeness of different classes of vegetation indexes Enhanced Vegetation Index (EVI) (A), Leaf Area Index (LAI) (B), Normalized Difference Vegetation Index (NDVI) (C) and in different periods (wet and dry) and Soil Adjusted Vegetation Index (SAVI) (D) in different years (2013 to 2017).



Fig 3. Spatial distribution maps of vegetation indexes Enhanced Vegetation Index (EVI) (A and E), Leaf Area Index (LAI) (B and F), Normalized Difference Vegetation Index (NDVI) (C and G) and Soil Adjusted Vegetation Index (SAVI) (D and H) in different periods (wet and dry) and in different years (2013 to 2017).



Fig 4. Location of the study area (Tadarimana indian reserve), predominant elevation classes and location of the meteorological station used in the work.

samples reveal a periodic pattern and are affected by rainfall. Santos et al. (2017) after investigating natural regeneration in the anthropic regions of the Uberaba-MG Cerrado verified that the precipitation variable induced the greatest variations in the vegetation flourishing in this Brazilian biome. They also concurred that the climatic phenomenon El Niño exerted a negative influence on natural regeneration. During the 2013 and 2015 drought seasons, the classes showed similarity for all the indices, but less than the values of 2014. The EVI, LAI and SAVI in 2016 revealed a class of an almost insignificant non-vegetated area in comparison to the NDVI which showed the greatest rise in the non-vegetated area during the dry period when compared with the other years. In 2017, the EVI, NDVI and SAVI demonstrated a striking rise in the values of the nonvegetated class, while the LAI was limited to the classes showing variations of between 0.50 and 3.00.

On analyzing the seasonal dynamics and spectral separability of a few vegetation indices of the cerrado with those of the Modis / Terra and Aqua sensors, Liesenberg et al. (2007) indicated that among the vegetation classes the NDVI revealed higher variability than the EVI only during the dry season. However, the distinction between the phytophysiognomies showed improvement from the rainy to the dry season and the NDVI showed greater efficiency than the EVI in discriminating among the vegetation classes during the dry season, with the reverse phenomenon being seen during the rainy season.

When the seasonal dynamics in all the years were examined, the best values appeared in the vegetation classes during the rainy season than in the dry period (Fig 2), using the LAI as the reference index.

Junges et al. (2016) in their investigation of the temporal vegetation index profiles (NDVI and EVI) to characterize the Pampa biome vegetation confirmed that the lowest NDVI and EVI values were found during the winter (dry period) because of the decrease in the available solar radiation and air temperature. This reduction lowers the impact on plant

growth and biomass accumulation, validating the hypothesis that soil moisture affects the responses of the vegetation indices. During all the wet seasons, all the indices examined revealed a surge in the vegetation cover, as anticipated. For the years 2015, 2016 and 2017, growth was evident in all the classes, with all the indices studied showing higher values, indicative of the recovery of the denser vegetation. The analysis of the inter-annual dry season revealed a drop in the vegetation index from 99.94% to 96.49% and in turn the intensification of the non-vegetated area from 0.06% to 3.51%. This occurred because the replenishment and water surplus in 2017 were less than the withdrawal and water deficit (Fig 1), which indicated a higher percentage of scarce vegetation. For the NDVI, as well as the other indices, the indigenous reservation was affected by the drought which influenced the vegetation, and which was reported to hover between 0.50 and 0.75 and 0.25 to -1.0, for the dense and non-vegetated vegetation, respectively.

It was noted that when the NDVI was used as the reference for the denser class of 0.75 to 1.00, the general observation was a drop in the levels of vegetal protection in the area under investigation, for the years of study. This means that the protection in 2013 which was 96.03% went down to 95.04% in 2017 during the rainy season. During the dry period, however, these values declined from 9.64% to 0.56%, respectively (Fig 2).

From 2013 to 2017 (interannual dynamics), the NDVI during the wet season registered a very slight difference, from 96.03% to 95.05% for the very dense vegetation class; however, in the dense vegetation class an increase was reported from 3.72 % to 4.72%, while in the classes of sparse vegetation and non-vegetated areas variations of 0.25% to 0.23% were recorded.

The spatial distribution maps of the vegetation indices in the area under investigation used the average of the years analyzed for two distinct periods, the dry period and wet one (Fig 3). It was evident, as anticipated, that the class boundaries of the different vegetation indices showed lower

values during the dry period in comparison to those during the wet period.

Regarding the variations occurring during the wet period to the EVI indices (Fig 3A), LAI (Fig 3B), NDVI (Fig 3C) and SAVI (Fig 3D), they were from 0.44 to 0.63, 1.93 to 3.74, 71 to 0.86 and 0.50 to 0.65, respectively. The dry period revealed variations in the EVI indices (Fig 3E), LAI (Fig 3F), NDVI (Fig 3G) and SAVI (Fig 3H) to be from 0.23 to 0.43, 1.05 to 1.89, 0.41 to 0.68 and 0.30 to 0.50, respectively.

Müller et al. (2015) who identified the different vegetation types in a heterogeneous landscape of the Brazilian Cerrado in the State of Mato Grosso confirmed that good spatial consistency and accurate classification of the vegetation types (land use and cover) cannot be done using spectral information alone. This emphasizes the great importance of the temporal information for such a study, thus reiterating the concept of utilizing the average spectral data of several years in various studies done of the spatial dynamics of the various vegetation indices.

Materials and methods

Characterization of the study area

The Tadarimana Indian Reservation extending into the Rondonópolis and Pedra Preta municipalities in the State of Mato Grosso, Brazil was selected for the study. The reserve sprawls across 9952 hectares and is situated in the quadrant constituted by the coordinates, 54.578 W / 16.575 S and 54.431 W / 16. 480 S, at 200-300 m altitude (Fig 4). The area has two types of natural vegetation cover viz., Contact Savannah-Seasonal Forest (84.78%) and Savanna (15.22%), also recognized as the Cerradão and Cerrado, respectively. The Red-Yellow Dystrophic Latossolos and Eutrophic Red Argisols are the predominant soil types, with around 49% of the territory showing flat topography, 30% with smooth undulating relief, 15% having corrugated relief and 6% of strongly undulating terrain. The reserve is fed by the River Tadarimana, River Jurigue and River Vermelho, all of which join the São Lourenço River and the Mato Grosso Pantanal (ISA, 2018, EMBRAPA, 2013). The indigenous reserve supports three distinct villages: the central Tadarimana, Praião and Jurigue village. From the data of 2014, the residents of this reserve belong to the Bororo ethnic group, and have increased by around 200% since 1994 - from a mere 202 members in 1994 to 604 inhabitants in 2014 (ISA, 2018). The Aw type of climate is prevalent (Alvares et al., 2013), with average temperatures and annual rainfall of 24.8 °C and 1527 mm, respectively. July is the time of greatest drought with only 9 mm average rainfall and 21.7 °C average temperature. January tops the chart with the highest precipitation registering an average of 271 mm and an average temperature of 26.2 °C. May to September is the annual dry season while December to March is the rainy season.

The water-climatological balance

The monthly climatological water balance (Thornthwaite and Mather, 1955) was used over the five years of this study, employing the comprehensive climatological variables (mean air temperature and monthly precipitation) and Excel spreadsheets of Rolim et al. (1998). The meteorological data employed were taken from an automatic meteorological station of the National Institute of Meteorology (INMET) located in Rondonópolis-MT. It included a data logger unit connected to several different sensors of the meteorological parameters (atmospheric pressure, temperature and relative humidity, precipitation, solar radiation, direction and wind speed, etc.), which integrated the values perceived every minute and automatically supplying this information every hour.

Determination of vegetation indices

The vegetation indices were calculated using the images of the OLI sensor of the LANDSAT 8 satellite, over a 5-year period of (2013 - 2017), by selecting an image representative of the dry period of the year and another to indicate the wet period. The representative dates for both these periods were chosen based on the climatological water balance of each year analyzed. The images were taken from the location of the US Geological Survey (USGS). Selection was carefully done, choosing images with no cloud cover, for a better assessment of the vegetation indices.

These images were reprojected to the Universal Transversade Mercator (UTM), Zona 21 Sul and Datum Sirgas 2000 coordinate systems using the EPSG code 31981. These images were also converted from digital numbers to reflectance values at the top of the atmosphere and employing the DOS 1 method, the atmospheric values were corrected. These procedures were implemented in the Semiautomatic classification plugin, in bands 2 (Blue), 4 (Red) and 5 (Infrared - near), for automation of the preprocessing procedure. Later the images were cut to represent the area occupied by the Tadarimana indigenous reserve. The GIS (Geographic Information Systems) QGIS 2.18.7 (QGIS Development Team, 2017) software was used for this action. Once the images were pre-processed, the following vegetation indices were assessed using Reflectance Data: Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI) and Leaf Area Index (LAI). From Table 2 it is clear that the NDVI was drawn from the normalized difference between the near infrared and red bands (bands 4 and 5 of LANDSAT 8). The SAVI, which involves incorporating a soil coefficient (LS = 0.25) to remove the NDVI dependence on the brightness of the material below the vegetative canopy was calculated prior, based on equation 2 (Table 2). The EVI, an advanced version of the NDVI, which includes an additional group of coefficients to circumvent the vegetation signal with saturation issues, was calculated using equation 3 (Table 2). The LAI, determined from the SAVI data and constants proposed for the assessment (Braz et al., 2015), was calculated according to equation 4 (Table 2). All calculations for the vegetation indices were done using the QGIS 2.18.7 program environment (QGIS Development Team, 2017) with the Raster Calculator tool.

Data analysis

The data were analyzed using descriptive statistics, and the averages, standard deviations and variances of the various vegetation indices were assessed. The best representativeness of the Cerrado biome vegetation was noted, where the highest variability in the vegetation index response was observed. Galvanin et al. (2014) declared that the vegetation index which revealed the greatest variability among the statistical variables was the one which demonstrated the most effectiveness in distinguishing between the targets.

Variability in the vegetation indices was investigated under the two conditions of seasonal and interannual dynamics. Seasonal dynamics were calculated via the differences between the wet and dry periods over one year, whereas the interannual dynamics were assessed by the differences between the years of study, for the same wet and dry periods.

While examining the spatial variability of the vegetation cover, the vegetation index values were distributed under different classes and, thus, the percentages of the areas these different classes occupied were determined. For the NDVI, the classification was done from the values of 1.00 and -1.00, in which 1.00 to 0.75 indicated very dense vegetation, 0.75 to 0.50 implied dense vegetation, 0.50 to 0.25 suggested sparse vegetation and 0.25 to -1.00 included the areas lacking vegetation, such as exposed soil or water bodies.

Besides, in this exploration of the spatial dynamics of the Cerrado biome, distribution maps were drawn up of the vegetation indices in the region of study, and the averages of the years analyzed for the two distinct situations, the dry and wet periods were considered.

Conclusion

The conclusion drawn from studies involving the space-time dynamics of the Brazilian Cerrado biome was that from among all the vegetation indices investigated, the leaf area index (LAI), demonstrated the best performance to depict this phytophysiognomy. The vegetation indices (NDVI, SAVI, EVI and LAI) drawn from the LANDSAT 8 satellite images and analyzed in this study, exhibited higher values during the wet period when compared to the dry one, even when it was summer. Generally, a decline in the levels of plant protection was noted in the study area for the duration of this study.

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