Revista Geama

Article

Ciências Ambientais

Environmental Sciences

Analysis of Behavior of Vegetation in the Year of 2016 for the Municipality of Remanso- BA

Ismael G. F. Freitas[1], Laurizio E. R. Alves[2], Heliofábio B. Gomes[3], Jeová R. S. Júnior[4], Dimas B. Santiago[5] & Rafael A. Silva[6]

* Corresponding Author: ismael.freitas@icat.ufal.br
Todos autores contribuíram de forma igualitária

Received: June 11, 2017
Accepted: June 21, 2017
Published: July, 2017

ABSTRACT

Droughts are a natural problem in the Northeastern Brazilian region, in addition the rainfall distribution poorly distributed spatially and temporally results in seasonal changes in the surface vegetation. Consequently, the monitoring and evaluation of vegetation in the northeast region of Brazil has become increasingly constant. For this evaluation several techniques are used, but the use of environmental satellites is increasingly applied, such as the Landsat 8 satellite, where the products generated for the calculation of the Normalized Difference Vegetation Index (NDVI) were used. In this circumstance, the objective of this work was to evaluate the vegetation behavior through the NDVI and to analyze the interaction of the same with the occurrence of precipitation in the municipality of Remanso-BA throughout the year 2016. For the calculation and elaboration of the thematic maps of NDVI were respectively, the software Erdas 9.2 and Qgis 2.14.2. In the study, 11 images of the Landsat 8 satellite corresponding to orbit 218 and quadrant 067 were used. The results showed high NDVI values in the rainy season, while in the dry season the values were lower, a significant reduction occurred during the year in the area of body of water in which is the Lago de Sobradinho. It was also evident the decrease of dense vegetation in the first months of the year and the increase of areas devoid of vegetation due to lack of rain. However, the variations of NDVI were due to the occurrence of precipitation over the period studied.

Keywords: Remote sensing, NDVI, Landsat 8

Introduction

In a certain area of the Brazilian Northeast (NEB) the problem of droughts has become more and more frequent with the course of the years, thus, monitoring studies have been carried out to analyze the vegetative behavior and modifications resulting from anthropic action on different surfaces. The NEB has nuclei susceptible to desertification covering the area of 8 states (LOPES et al., 2012), an area known as a drought polygon, and because it is an extensive area, remote sensing data have been fundamental in this type of study area (RIBEIRO et al., 2015).

The use of products obtained through medium resolution satellites, such as Landsat 8-OLI, allows the monitoring of vegetation in great territorial expansion and with a small temporal space. The spectral images captured at the visible and near infrared wavelength resulting from the Operational Land Imager (OLI) sensor can calculate the Normalized Difference Vegetation Index (TUCKER, 1985) and the surface mapping, whether vegetated or devoid of plant cover, as exposed ground, urban area, etc. One of the most used indexes is the NDVI, which according to Tasumi (2003) is an indicator of vegetation density conditions, being calculated by the near infrared reflectance and the red.

The polygon of the droughts presents an irregular rainfall regime at time and space (GONZAGA et al., 2011) with months having a greater intensity of precipitation and others with a scarcity. In addition, NEB presents changes in the rainfall regime due to global scale phenomena such as El Niño (MENDONÇA and DANNI-OLIVEIRA, 2007), resulting in a significant decrease in monthly rainfall totals, which in turn generates a water attenuation in the ground (Freitas et al., 2016).

1,2,3,5,6 Instituto de Ciências Atmosféricas , Universidade Federal de Alagoas, Maceió , Alagoas , Brasill.
4 Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, São Paulo, São Paulo, Brasil.

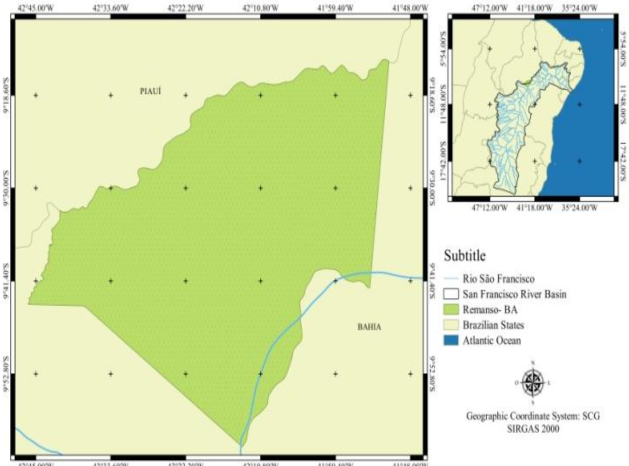
Therefore, the objective of this study was to evaluate the behavior of the Normalized Difference Vegetation Index calculated through spectral data obtained through the Operational Land Imager sensor on the environmental satellite Landsat 8, analyzing the interaction of NDVI and rainfall in Remanso- BA.

Material and Methods

Study Area

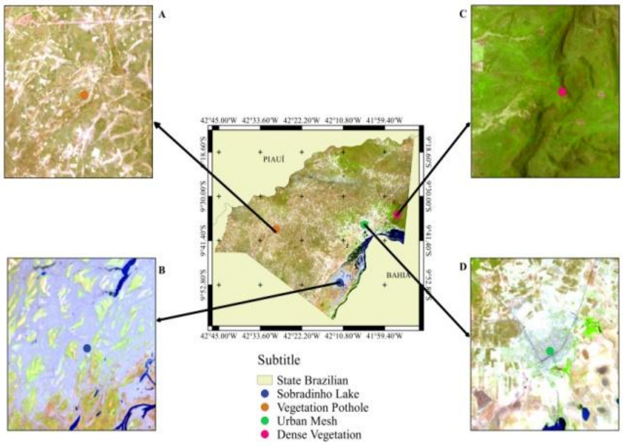
The studied area comprises the municipality of Remanso in the state of Bahia (Figure 1), being partially inserted within the São Francisco River Basin, where, to the south the municipality makes a bank with the bed of the river, and makes a border to the north with state of Piauí, totaling an area of 4,693,505 Km², which corresponds to 0.82% of the state of Bahia, with elevation of topography varying up to 398 m of altitude with respect to the average level of the sea, having the following coordinates: Latitude 09 ° 37' 19" S and Longitude 42 ° 04' 51" W. Due to it's coordinates, the municipality is located within the region where the native vegetation of Caatinga and Cerrado (OLIVEIRA, 2003) predominates, with a degree of soil degradation. Regarding the economic point of view, Remanso-BA is the largest sheep farmer, so it has large pasture areas for livestock (SANTANA, 2007).

Figure 1 - Map of the location of Remanso-BA municipality in the São Francisco River Basin.



For the spatial analysis of the vegetation index in the municipality, regions were identified in the RGB composition (band 5 - Red, band 4 - Green, band 3 - Blue), in which they represent different types of land use and cover, in order to observe the changes covered by thematic maps. Figure 2B Sobradinho Lake, which due to the Sobradinho Dam spillway, shows a variation in the soil cover, passing from the area with Corpo D'água to silting, Figure 2C Dense Vegetation with the presence of native tree species and urban 3D Figure occupied by houses, buildings, etc.

Figure 2. Identification of points with different soil cover: (A) Underground vegetation, (B) Sobradinho Lake, (C) Dense Vegetation and (D) Urban Meshes.



For the elaboration of this work 11 images captured by the Sensor Operational Land (OLI) were used on board the Landsat 8 satellite, where the sensor presents spectral resolution improvements compared to the predecessor sensors. The products generated with the OLI sensor represent nine multispectral bands with spatial resolution of 30 meters (bands 1 to 7 and 9) and 15 meters (band 8) the part of thermal sensor TIRS (Thermal Infringed Sensor), has two spectral sides 10 and 11). In the present study, bands 5 and 4, respectively, the Near Infrared (0.85 - 0.88 µm) and Red (0.64 - 0.67 µm) channels of the OLI sensor were used to calculate the vegetation index. The images analyzed correspond to the satellite passages in the 067 quadrant and the orbit 218 on the following dates: February 23, 26 March, April 27, May 13, June 14, July 16, August 17, September 18, October 4, November 5, and December 23, all of the year 2016. All images were downloaded through the Site Earth Explored by the US Geological Survey (USGS, 2017).

In order to perform the satellite image processing, Erdas 9.2 software was used in the Model Maker function and for the elaboration of the Normalized Difference Vegetation Index (NDVI) thematic maps the free software QGis 2.14.2 in the Laboratory of Remote Sensing and Applied Geoprocessing (SENSORGEO). The steps performed to calculate the NDVI are described in the following flowchart (Figure 3).

Figure 3- Flowchart of the steps of the procedure for the calculation of the NDVI and interpretation of the results.

Calculation of Monochromatic Reflectance ($\rho_{\lambda,b}$)

The initial step was to compute the Monochromatic Reflectance (ρλ, b) of side 5 and 4 of the sensor used in this research, according to Allen et al. (2002a) is defined as the ratio between the reflected radiation and the incident radiation, in which the fluxes characterize the reflectance at the top of the Earth's atmosphere, calculating with the information present in each pixel of the spectral sides of the images. In this way the sides (5 and 4), as suggested by Chander & Markham (2003), were calculated:

$$\rho_{\lambda,b} = \frac{Add_{ref,b} + Mult_{ref,b} ND_b}{Cos\theta \cdot dr} \quad \text{(Eq. 01)}$$

Where Addref, be Multref, b symbolize the terms Additives and Multiplicatives of relectance, respectively for each satellite side used in this calculation. The values of both terms (Addref, be Multref, b) are arranged through the metadata files, where Even accompanies the satellite images after the download. Values have constant values, -0, 1000 for Addref, and 2 * 10^-5 for Multref, b.

The term NDb represents the intensity of variation of the side pixels in grayscale, where for Landsat-8, NDb varies between 0 and 65365; The Cosθ is the zenital angle pertinent to the earth-sun vector, which is also obtained in the metadata file of the images; While dr corresponds to the inverse of the square of the distance earth sun calculated through Equation 02.

$$dr = 1 + 0{,}033 \cdot \cos\left(\frac{DJ \cdot 2\pi}{365}\right) \quad \text{(Eq. 02)}$$

Where the angle of the equation is calculated in radians as a function of the Julian Day (JD) of the year.

Calculation of the Normalized Difference Vegetation Index (NDVI)

Proposed by Tucker (1979) the Normalized Difference Vegetation Index makes it possible to observe the density of the vegetation cover of a given area through different enhancements (ALVES et al 2015, FREITAS et al. 2016). The calculation of the IVDN was done using the Monochromatic Reflectance computing results. The INDV according to Allen et al. (2002a) corresponds to the ratio between the near infrared monochromatic reflectance (band 5 ρλ, IVP) and red (band 4 ρλ, V) of Landsat 8 - OLI, as presented in equation 03.

$$NDVI = \frac{\rho_{\lambda,IVP} - \rho_{\lambda,V}}{\rho_{\lambda,IVP} + \rho_{\lambda,V}} \quad \text{(Eq.03)}$$

Pluviometric Data

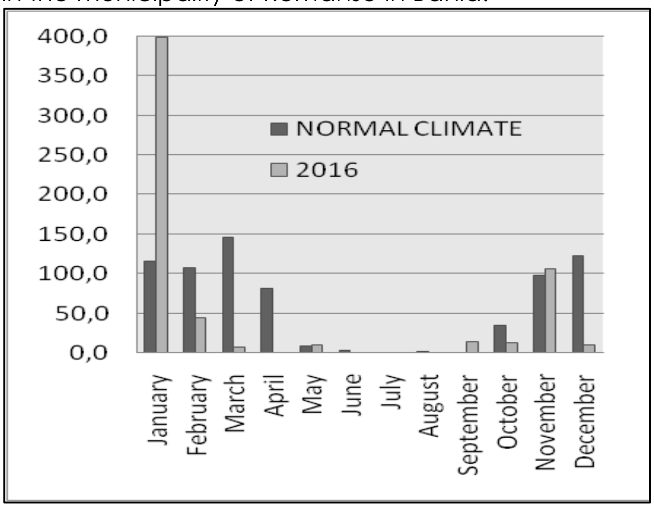
The pluviometric regime is a preponderant factor in the dynamics and variability of the vegetative behavior of a region, the monthly rainfall for 2016 and the climatological normal of the region in the period from 1961 to 1990 according to the data of the meteorological station Remanso-A423 , were obtained through the website of the National Institute of Meteorology (INMET, 2017). Monthly and daily precipitation data were used to analyze the occurrence of precipitation antecedent to the passage of the satellite. The information on these rainfall values was related to the NDVI values, since the rainfall volume can significantly result in the vegetative behavior of an área, in other words, the higher the rainfall intensity the greater the vegetation vigor, and the lower the rainfall intensity, the lower the vigor of the vegetation, due to the water requirement.

Results and Discussion

Climatology of the Region

Figure 3 shows that the month of January 2016 presented greater rainfall accumulation, above the climatological normal with 398.5 mm, it was also verified that in the months of September and November the monthly accumulation was higher than expected, 13.5 Mm and 105.9 mm, respectively. In the other months the volume of monthly precipitation observed a significant negative anomaly, as in the months of February, March, April, October and December, where these anomalies can be explained due to the El Niño phenomenon in strong intensity during these periods with Niño oceanic Index of 1,6 (GGWEATHER, 2017), so the pluviometric pattern was changed. In many cases, the link between El Niño and dry matter in the Brazilian Northeast (NEB) is observed in episodes of strong El Niño, significantly influencing the northern region of Bahia (ARAGÃO, 1990) as the case of Remanso-BA municipality that is inserted in this area.

Figure 3 - Monthly pluviometric variation in 2016 and climatological norm made in the period 1961-1990, in the municipality of Remanso in Bahia.



According to the monthly pluviometric volume of 2016, the municipality of Remanso-BA had a pluviometric regime divided into two periods, rainy in January, February and November, and dry for the other months.

Precipitation Background

The vegetation cover in areas of Caatinga is strongly related to the rainfall volume, so the occurrence of precipitation before the passage of the satellite sensor may alter the vegetative vigor, resulting in higher values of IVDN. Figure 4 shows the occurrence of precipitation antecedent (10 days) the passage of the satellite, therefore, making it possible to analyze the rainfall interference in the IVDN values, in which was verified seasonal vegetative behavior. In Figure 4 it is possible to observe between March and September no precipitation value was registered that would interfere with the analysis, this period is considered a dry period for Remanso-BA with precipitations below 12 mm monthly. In the month of February were observed two days with precipitation that also corresponded all monthly accumulation of February with 45 mm. In the month of October the accumulated antecedent of precipitation to the passage was of 13,5 mm and December 9,8 mm. Regarding the previous precipitation the image of the day November 5 also did not record accumulated pluviometric.

Figure 4 - Accumulated antecedent precipitation (mm) to the dates of the Landsat-8 - OLI satellite passages.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31
FEV	0	0	0	0	0	0	0	0	0	0	0	0	29,2	0	15,8	0	0	0	0	0	0	0	0	0	0	0	0	0			
MAR	0	0	0	0	0	7,3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ABR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
MAI	0	0	0	0,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9,8	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
JUL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12,9	0,6	0	0	
OUT	0	0	0	0	0	4,2	6,4	0	1,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOV	0	0	0	0	0	0	0	0	0	0	0	0	8,2	4,6	22,4	4,4	13,2	0	0	4	0	0	0	0	0	0	0	0	0	0	
DEZ	0	0	0	0	0	0	0	0	0	0	0	0	1,6	7,8	0,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FEV MAR ABR MAI JUN JUL AGO SET OUT NOV DEZ

Vegetation Index of Normalized Difference

Table 1, shows the vegetation index ranges, classified according to the analysis between the IVDN values found in the calculation and the RGB Composition of the images used in this work.

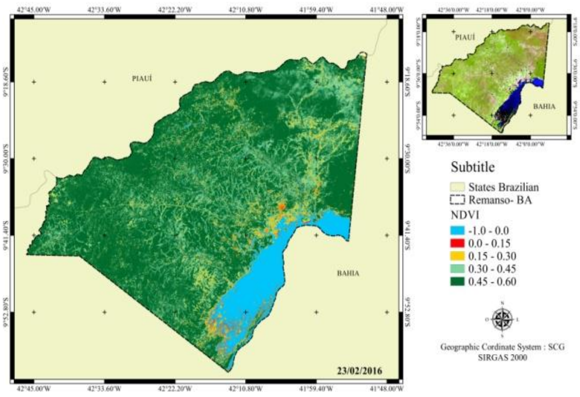
Table 1 - Relation between the values of Vegetation Index of the Normalized Difference and the type of cover of the ground.

Type of coverage	NDVI
Sobradinho Lake (water body)	-1.0 - 0.0
Urban Mesh	0.0 - 0.15
Sedimentation/ Exposed Ground	0.15 - 0.30
Pothole Vegetation/ Scare	0.30 - 0.45
Dense Vegetation	0.45 - 0.60

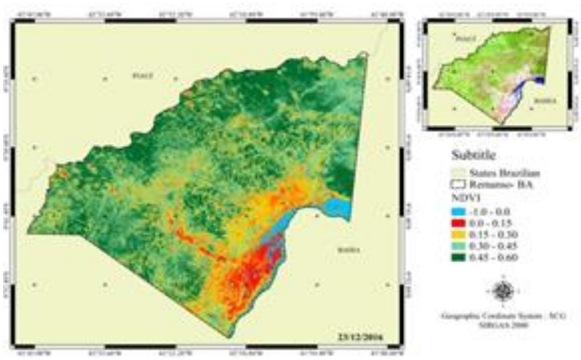
Figure 5 presents the results generated with the IVDN values spatially distributed to the Municipality, during the dates referring to the passage of the satellite on February 23 and December 25, 2016, respectively corresponding to the rainy season; which had higher cumulative values of previous precipitation, as well as higher vegetation indexes. The values of IVDN in the green color representing dense vegetation were higher observed on February 23, 2016 with a large spatial distribution, ranging from 0.45 - 0.60, in addition to areas with light green undergrowth with values between 0 , 30 - 0.45, while in the IVDN urban mesh area between 0.0 - 0.15 in red color. The negative values presented areas of water bodies, blue color in thematic maps, much of this hue is seen in the Sobradinho Lake, being remarkable that the same in Figure 5A is occupying an extensive area of the margins of the municipality. As it was a scene captured on February 23, the region before the satellite had a cumulative total of 443.5 mm that resulted in high IVDN values. This association of precipitation with IVDN corroborates with Barbieri et al. (2009), which according to the author, regions that predominate the Caatinga type vegetation, the high results of IVDN are directly associated with the occurrence of rainfall. In the scene taken on December 25, 2016 (Figure 5B) a significant reduction in the area where water bodies were present resulted in an extensive silting region with IVDN between 0.0 - 0.15 similar to the area value Urban, still on the Sobradinho lake is seen in the margins the yellow color that presents result of IVDN between 0,15 - 0,30, indicating region of exposed soil, Freitas et al. (2016) in an area study with Caatinga biome in the municipality of Cabrobó - PE, found an index for exposed soil varying between 0.14 - 0.15, which corroborates with the present study. Differently from Figure 5A, the predominance in green color was reduced more evident at the following coordinates 9° 18.60 'S / 42° 10.80' W and 9° 30.0 'S / 41° 59.40' W, with high density of IVDN values represented in green color, due to the presence of shrub Caatinga. In the other areas, the predominant variation was 0.30 - 0.45. Due to the precipitation intensity (114 mm) the IVDN values were reduced spatially.

Figure 5 - Thematic map of vegetation index of the normalized difference on 02/23/2016 (A) and 12/25/2016 (B)

(A)



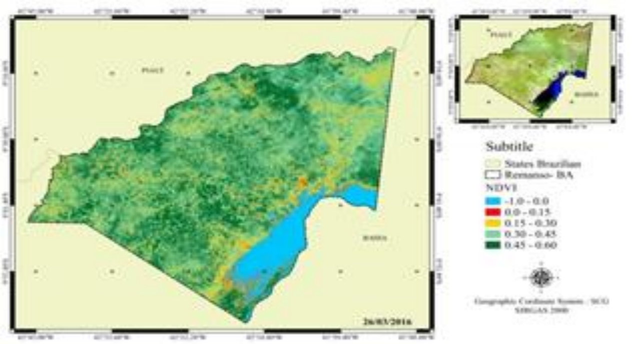
(B)



In the next figure are arranged the images referring to the beginning of the dry period, which begins in the month of March and extends until the month of October. In Figure 6A, which has the IVDN values computed for March 26, 2016, it also showed intense greenness in all areas with variation greater than 0.30 - 0.45 and 0.45 - 0.60 in several points, however There are areas with lower values such as IVD water body margins between 0.15 - 0.30. Despite the fact that March did not have high rainfall values, the vegetative vigor observed was due to the water availability in the ground, due to the large volume of precipitation in the previous months. In Figure 6B, for the date April 27, 2016, a spatial reduction of the index is observed, in which values for exposed ground (0.15 - 0.30) to the west of the map predominate and the margins of Sobradinho Lake with greater Density in yellow color; And undergrowth (0.30 - 0.45), while the greener-colored surfaces of arboreal vegetation (dense vegetation) prevailed.

Figure 6 - Thematic map of vegetation index of the normalized difference on 03/26/2016 (A) and 04/27/2016 (B)

(A)



(B)

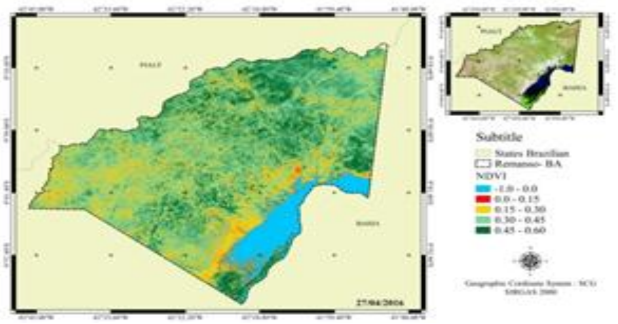
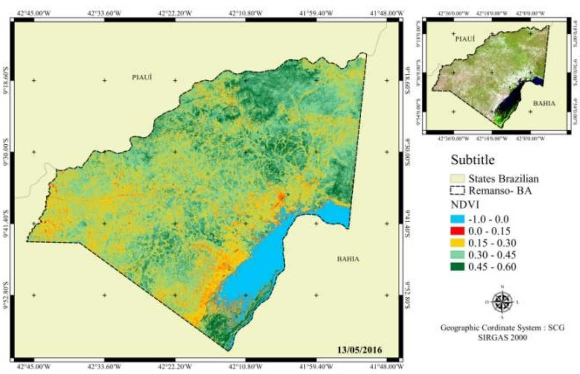


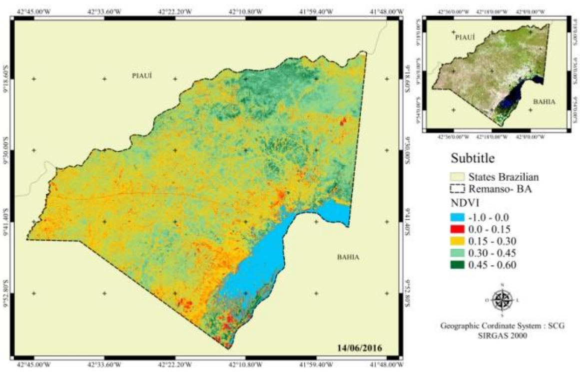
Figure 7 presents IVDN values on May 13 (Figure 7A) and June 14, 2016 (Figure 7B), these values obtained within the dry period. Figure 7A shows that the results of IVDN with variation between -1.0 - 0.0 continued to reduce spatially, which indicates the decrease of the water body, as well as the coverage of the surface that underwent greater ground influence resulting in values of IVDN for exposed ground (0.15 - 0.30) both to the west of the map and to the east. In places of dense vegetation the green color shade also reduced, being seen only in some isolated spots. In Figure 7B, due to the rainfall deficiency in the previous dates, the values of IVDN were lower, resulting in a predominance in yellow color with IVDN between 0.15 - 0.30; In the areas where dense vegetation was previously, the values decreased to 0.30 - 0.45 and with the presence of silting points in Sobradinho Lake, represented in red color, corresponding values were between 0.0 - 0.15

Figure 7 - Thematic map of vegetation index of the normalized difference on 05/13/2016 (A) and 06/14/2016 (B).

(A)



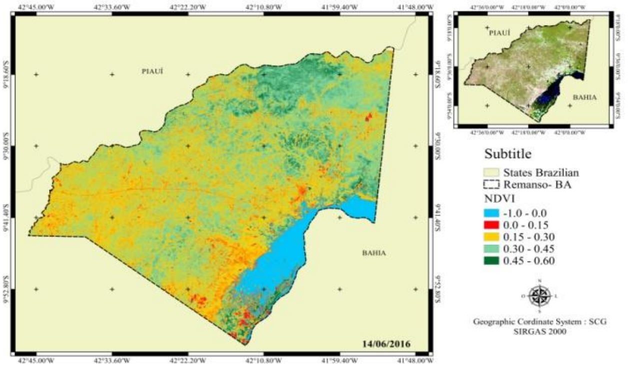
(B)



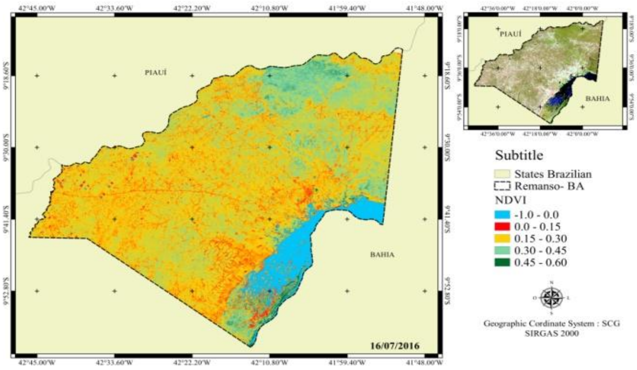
In Figure 8, it is possible to analyze visually the progress in changing scenarios, with decreasing IVDN values in the spatial coverage of the area, with shades of yellow (IVDN = 0.15 - 0.30) and red color with lower density (IVDN = 0.00 - 0.15) as of July 16, 2016 (Figure 8A), while in Figure 8B the density of pixel for IVDN values between 0.0 - 0.15 was much more prominent.

Figure 8 - Thematic map of vegetation index of the normalized difference on 07/16/2016 (A) and 08/17/2016 (B).

(A)



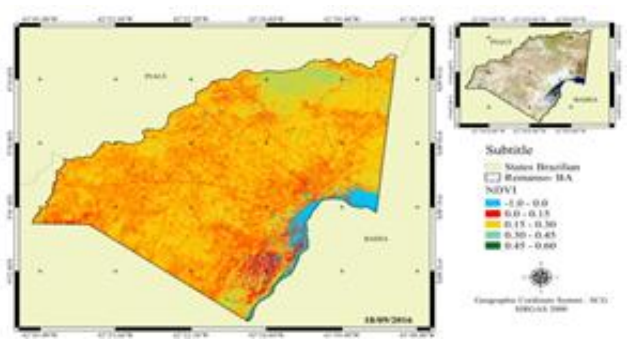
(B)



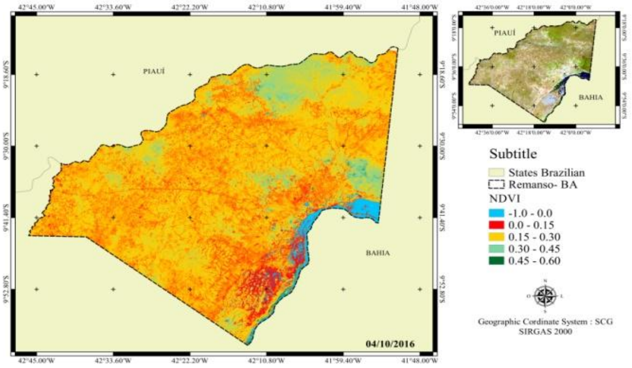
In the image for September 18, 2016 (Figure 9A), it is still seen the range of the index 0.0 - 0.15 and 0.15 - 0.30, but it is notable to observe that the sites that had dense vegetation at water requirement resulted in IVDN values between 0.30 - 0.45 with little light green density. Already in the image for October 4, 2016 (Figure 9B) it is possible to observe light green color tones in larger coverage, as well as the spatial reduction of areas with IVDN between 0.0 - 0.15, this change was due to the occurrence of precipitation preceding the passage of the satellite, accumulating 13.5 mm.

Figure 9 - Thematic map of vegetation index of the normalized difference on 09/18/2016 (A) and 10/04/2016 (B).

(A)

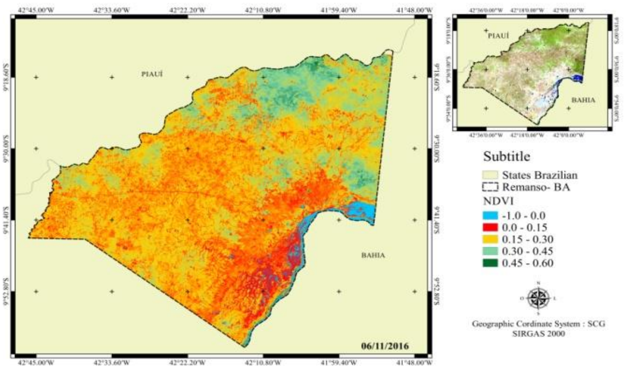


(B)



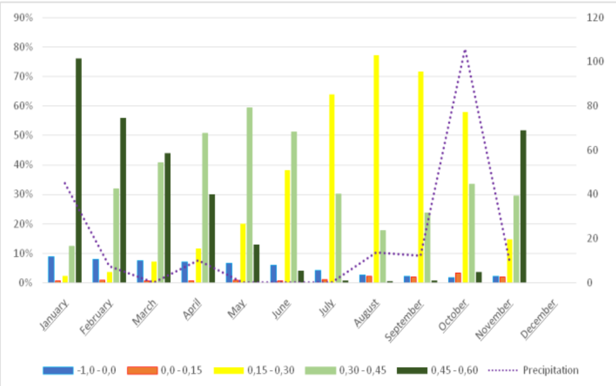
The IVDN result for November 06, 2016 (Figure 10) resulted in a larger spatial distribution of IVDN between 0.0 - 0.15 along Lake Sobradinho, being considered the month with the highest sediment among all the images used In the analysis, besides the maximum reduction of the negative values of IVDN that represent body of water. Still, in the picture it is possible to see higher values and higher density (IVDN = 0.45 - 0.60) , showing the development of dense vegetation after the need of the dry period studied.

Figure 10- Thematic map of vegetation index of the normalized difference on 11/06/2016.



In the next Figure the histogram of relative frequency of the classes determined in the study is arranged, where each month represents each image used. Figure 11 shows that the class representing water bodies over the area of the municipality of Remanso-BA had a decrease during the year, where in February it occupied 9% of the total area of the municipality, started to occupy value Minimum of 2% in the month of December. On the other hand, the IVDN class between 0.0 - 0.15 the maximum frequency found was at the end of the dry season with 3% in November due to the great reduction of the water body of the area. In the class of 0.15 - 0.30 the frequency increased during the year, from minor values (12% in February) from rainy season to higher values in the dry period (77% in September), observed although this same class increased its frequency according to the pluviometric deficiency, where in November with the rainfall volume of 105.9 mm resulted in a decrease of the class frequency in the month of December. The frequency of the class between 0.30 - 0.45 showed a growth until the month of May with 59%, decreasing and returning to have higher values of frequency after the occurrence of precipitation, as seen in the month of September. The fifth and last class of IVDN between 0.45 - 0.60 presented higher frequency within the rainy season with 76% in the month of February and 52% in the month of December, it is still verified that the class in the color seen is inversely proportional to the class in light green during the period between February and June, indicating that the vegetation with greater vigor passed to less dense vegetation.

Figure 11 - Frequency of IVDN classes and rainfall volume for the year 2016.



Conclusions

The use of remote sensing techniques and data from the OLI - Landsat 8 sensor, it was possible to analyze the seasonal vegetative behavior through the Normalized Difference Vegetation Index (IVDN) with favorable values on ground cover in Remanso - BA municipality.

The changes in the values of IVDN in the region of Remanso-BA were strong and related to the intensity of the pluviometric volume, in which the months with the highest volume of precipitation resulted in higher indices, whereas in the dry months the indices were lower, with regard to the water needed to maintain the greenness of the native vegetation. The changes in the values of IVDN in the region of Remanso-BA were strong and related to the intensity of the pluviometric volume, in which the months with the highest volume of precipitation resulted in higher indices, whereas in the dry months the indices were lower, result of the water need to maintain the greenness of the native vegetation..

Acknowledgement

The authors thank the Laboratory of Remote Sensing and Applied Geoprocessing (SENSORGEO) of the Institute of Atmospheric Sciences (ICAT / UFAL) for the support to this study.

References

ALLEN, R.; TASUMI, M.; TREZZA, R. SEBAL (Surface Energy Balance Algorithms for Land) – Advanced Training and Users Manual – Idaho Implementation, version 1.0, 2002a.

ARAGÃO, J. A. R. Fatos sobre o fenômeno de El Niño e sua relação com as secas no NEB. Boletim da Sociedade Brasileira de Meteorologia – SBMET. V. 14, n 1, 1990.

BARBIERI, L.F.P.; CÉLIA, C. C.; SOUSA, L. F. Monitoramento da Vegetação do Estado da Paraíba nos Anos 2008 e 2009. In:Congresso de Iniciação Científica da Universidade Federal de Campina Grande, Anais. Campina Grande, 2009.

COELHO-JUNIOR, J. M.; NOBREGA, R. S. Influência de líquens no cultivo do morangueiro. *Revista Geama*, Recife, v. 24, n. 2, 2017.

CHANDER, G.; MARKHAM, B. Revised Landsat-5 TM Radiometric Calibration Procedures and Postcalibration Dynamic Ranges. IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING. v. 41. n. 11. 2003.

FREITAS, I. G. F.; GOMES, H. B. ; MOURA, M. A. L. ; ALVES, L. E. R. ; SILVA JUNIOR, J. R. ; SANTOS, M. N. . Estudo dos índices de vegetação e temperatura em anos de El Niño para o município de Cabrobró-PE com uso de imagens de Satélite. In: Lucas Barbosa Cavalcante. (Org.). 4° Geoalagoas. 4ed.Maceió: SECRETARIA DE ESTADO DO PLANEJAMENTO GESTÃO E PATRIMÔNIO, 2016, v. 1, p. 328-339.

GGWEATHER- El Niño and La Niña Years and Intensities. Acesso em: 05 /03/ 2017. Disponível em: < http://ggweather.com/enso/oni.htm>.

GONZAGA, E. P.; SANTOS, V. V. ; NICACIO, R. M. . Análise do comportamento do NDVI e NDWI em períodos de diferentes intensidades pluviométricas no Sertão alagoano. In: XV Simpósio Brasileiro de Sensoriamento Remoto - SBSR, 2011, Curitiba - PR. Análise Florestal e Vegetação, 2011. p. 1736-1743.

LOPES, L.; SANTOS, R. W. P.; MIGUEL FILHO, M. A. Núcleo de desertificação de Gilbués (PI): causas e intervenções. GEOGRAFIA (Londrina), v. 20, n. 2, p. 53-66, 2012.

MENDONÇA, F.; DANNI-OLIVEIRA, I.M. Climatologia: noções básicas e climas do Brasil. São Paulo: Oficina de textos, 2007.

OLIVEIRA, J.A., GONÇALVES, P.R. & BONVICINO, C.R. Mamíferos da Caatinga. In Ecologia e conservação da caatinga. Universidade Federal de Pernambuco, Recife, 2003.

RIBEIRO, G. N.; SILVA, J. R. S. ; ROCHA, R. N. R. ; Megna Francisco, P.R. . Análise da utilização do IVDN em estudos ambientais na Paraíba na última década (2004-2014). In: Simpósio Brasileiro de Sensoriamento Remoto, 2015, João Pessoa. XVII Simpósio Brasileiro de Sensoriamento Remoto - SBSR. SãoJosé dos Campos: MCT/INPE, 2015. v. 1. p. 4589-4595.

SANTANA, M. O. Atlas das áreas susceptíveis à desertificação do Brasil. Brasília: MMA/SRH/UFPB, 2007.

TASUMI, M. Progress in operational estimation of regional evapotranspiration using satellite imagery. PhD thesis, Dept. Biological and Agricultural Engineering, University of Idaho. Idaho, 2003.

TUCKER, C. J. TOWNSHEND, J. R. G., GOFF, T. E. African land cover classification using satellite data. Science. V.227, 369-375, 1985.

USGS, 2017. Earth Explorer. Acesso em: 03/02/2017. Disponível em: < https://earthexplorer.usgs.gov/ >.