Correlation between precipitation and vegetation indexes under preserved Caatinga condition

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Abstract

The remote sensing techniques have been improved during the last few years, and vegetation indexes have become an increasingly used instrument for the evaluation of landscape units, for instance, the Caatinga's biome. Thus, some indexes such as the Normalized Difference Vegetation Index (NDVI), the Soil Adjusted Vegetation Index (SAVI) and the Leaf Area Index (LAI) are important tools in the study of the vegetation's behavior under the most different climatic conditions, especially in regions of the Brazilian semiarid that have scarce and poorly distributed rains, concentrated in the first half of the year. The objective of this research is to evaluate the influence of precipitation in the behavior of preserved Caatinga's vegetation through vegetation indexes using satellite images. For this, rainfall data of the Aiuaba Experimental Basin (AEB) provided by FUNCEME for the years 2003, 2004 and 2005, were analyzed. In conclusion, there is a strong correlation between rainfall precipitation and the increasing of the vegetation cover in the studied area, showing that the vegetation indexes can be considered as efficient parameters to evaluate the vegetation's behavior under preserved Caatinga condition.

Keywords: Remote sensing; NDVI; SAVI; LAI; semiarid.

1. Introduction

With the advance of the Geographic Information Systems (GIS) during the last years, the use of orbital data for ground cover mapping has been greatly improved, guaranteeing a greater possibility of use of these tools as well as an increase in the reliability of the same ones.

As far as the databases generated by the use of satellites can be considered as a wide source of information on the various phenomena that occurs on the terrestrial surface (Montanher and Fragal, 2013), the use of remote sensing and its techniques have become essential for a good characterization of the globe's vegetation cover, mainly for spatial and temporal analysis of regions where the vegetation undergoes great changes caused by climatic factors.

Nowadays, the great amount and variety of satellites orbiting around the Earth have promoted great advances related to the development of sensors progressively more modern and with more precise spatial and temporal resolutions, increasing this way, its use in studies related to vegetation monitoring both in Brazil and in the world.

The behavior or spectral response of the ground cover is influenced by intrinsic

characteristics of the vegetation, such as height; stem diameter, leaves format and size, as well as by external factors, for example the water availability, presence of fires, agricultural exploration of the land or its preservation. These factors together are responsible for characterizing the vegetative cover of a region and the result of the interaction of them can be captured by satellites whose representation occurs in the form of electromagnetic bands that make possible the analysis of this interaction by means of images with spectral responses.

According to Ponzoni (2001), the use of remote sensing techniques can compose a continuous monitoring of a region, making it possible to identify variable patterns for different analysis, for example, for the vegetation behavior after large rainfall events. These variables can be considered of great importance, mainly in areas of preserved Caatinga, whose characteristics of the vegetation are strongly influenced by the atmospheric factors.

In this context, the area of the Aiuaba Experimental Basin (AEB), which is considered the largest federal conservation unit of the Caatinga biome (Araújo and Piedra, 2009), has been an environment widely used by researchers in order to study and understand the behavior of its vegetation. The Caatinga biome, typically present in the Brazilian northeast region has as main characteristic the deciduous, which is the capacity to lose leaves during drier seasons. It works as an efficient mechanism to avoid the excessive water loss by transpiration when the water availability of the region is reduced by low rainfall rates. Such characteristic directly influences the vegetation cover and the hydrological processes of the watershed basins present in these areas. The rapid response of this vegetation to rainfall leads to a drastic change in the arrangement of the vegetation and a sinuous difference in its appearance during the transition between dry and rainy seasons.

Added to these aspects, the rainfall regime present in this region is considered irregular, concentrating around three to four months during the rainy season that occurs in the first semester of the year (Bezerra et al., 1997). Thusly, vegetation indexes, such as the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Foliar Area Index (LAI) have been increasingly used as parameters to estimate and evaluate the response of the vegetation cover in relation to rainfall presence, especially in watersheds.

In view of the above, this study aims to verify the correlation between rainfall rates and vegetation indexes through satellite image analysis, in order to understand the behavior of the vegetation under preserved Caatinga condition in different rainfall patterns.

2. Materials and methods

2.1 Study area

The Aiuaba Experimental Basin (AEB), with an area of 12 km^2, is located in the municipality of Aiuaba, State of Ceará, Brazil, coordinates 6 ° 42 'S and 40 ° 17'W (Figure 1). Inserted in the Inhamuns micro region, a semiarid portion of the Brazilian semiarid, the AEB is part of an environmental conservation area of the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) and belongs to the Upper Jaguaribe Basin (UJB).

The elevation in the basin ranges from 530 to 670 meters above the sea level, with the highest altitudes in the south and southwest. In these areas predominate the flat relief with slopes lower than 3%. The vegetation present in the area is the Caatinga, showing tree exuberance in the rainy season and total loss of the leaves of most plants as an adaptive form to the dry season, characteristic of the semiarid region.

In regard to the soil aspects, three distinct soil orders can be found in the area: Red-Yellow Ultisol, Hypochromic Alfisol, and Lithic-Leptosol (Costa, 2012) and its geology is composed of crystalline complex and sedimentary formation (Araújo and Piedra, 2009). In relation to the soil use and occupation, it can be considered a dry forest preserved according to studies done by Creutzfeldt (2006).
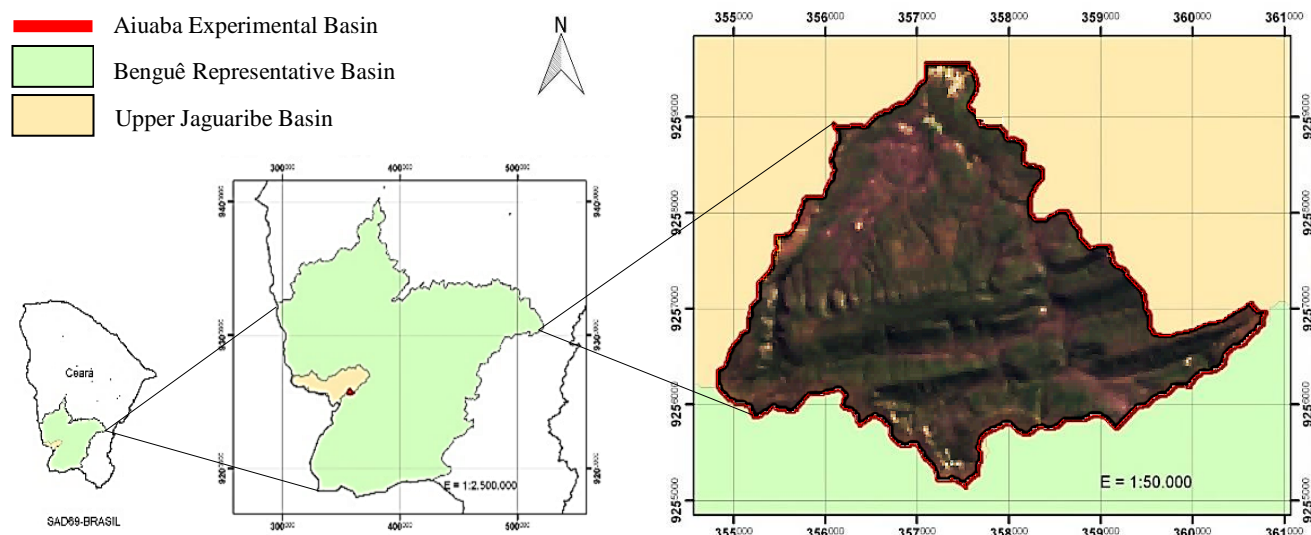
Figure 1 - Location of the study area. Source: Costa (2012), adapted.

2.2 Rainfall data

According to Köppen's classification system, the climate in the study area is considered 'Bs', with average precipitation of 560mm/year, Class A Tank evaporation of 2500 mm/year, and runoff coefficient lower than 1% (Figueiredo, 2011). The Caatinga domain presents a strong climatic irregularity, presenting the most extreme meteorological rates of the country: the strongest sunshine; the lowest cloudiness; the highest thermal averages between 25 ° and 30 ° C; the highest evaporation rates and the lowest rainfall rates, with great spatial and temporal variability throughout the year (Reddy, 1983; Sampaio, 2003), which contributes to higher transpiration rates by plants and, consequently, higher evapotranspiration rates in the area.

The rainfall data was obtained from rainfall stations of the Cearense Foundation of Meteorology and Water Resources (FUNCEME) installed at the Aiuaba Experimental Basin area. It was observed that the annual average for 2004 was quite high (1019.1mm), even surpassing the historical average of the last 30 years (climatological normal) for this region. This amount of rainfall was also much higher than the previous year, 2003 and the subsequent year, 2005 (Table 1).

Therefore, for this study were chosen years with different rates of precipitation, in order to evaluate how the vegetation in the area responds to rainfall above and below the average. From these data and the strong influence that the Caatinga vegetation has in relation to rainfall, it is expected that the vegetation indexes estimated for the year 2004 differ positively from those calculated for the years 2003 and 2005.

Table 1 - Rainfall data

Year	2003	2004	2005	Climatological normal
Average (mm)	435,6	1019,1	512,9	561,6

Source: FUNCEME (2016)

2.3 Image processing

The satellite images were downloaded from the website of the National Institute of Spatial Research of Brazil (INPE). Such images undergo for a previous treatment in order to correct atmospheric errors on the scenes. The images utilized were captured by the American satellite Landsat 5, which orbited the Earth's surface from 1984 to mid-2013 and has a temporal resolution or revisit cycle of 16 days.

For the present study, were used images of the months of July, August and September for the year 2003; July, October and November for 2004 and July, September and November for 2005, as

shown in Table 2. The criteria used for choosing the images was the minimal presence of clouds on the scene so the vegetation indexes values could be calculated with minimum interference.

Therefore, only images of the second semester were used, reflecting the vegetation arrangement during the dry season.

Table 2 – Image data used detailed information

Year	Date	Orbit/point	Spatial resolution	Projection
2003	6th July 23rd August 8th September	217-65	30 m	UTM / WGS84
2004	24th July 12nd October 13rd November	217-65	30 m	UTM / WGS84
2005	11th July 20th September 16th November	217-65	30 m	UTM / WGS84

For the image processing, was used the software QGIS and the bands used to calculate the indexes values were the bands 3 and 4, corresponding to red and near infrared bands, respectively.

The estimation of the vegetation indexes was based in of part of the procedures of the semi-empirical model Surface Energy Balance Algorithm for Land (SEBAL), proposed by Bastiaanssen et al. (1998) which is outlined in the Figure 2. The SEBAL algorithm uses satellite images that provide information of the electromagnetic radiation in the visible region, near-infrared and infrared regions (Bastiaanssen et al., 1998; Allen et al., 2002).

Initially, it was done the radiometric calibration, also known as spectral radiance (Lλ), which is the conversion of the Digital Number (DN) of each pixel into monochromatic spectral radiance, calculated by the equation 1:

$$L\lambda i = LMIN + \left(\frac{LMAX - LMIN}{255} \right) * ND \qquad (1)$$

where Lλi is the radiometric calibration or spectral radiance; LMIN and LMAX are the minimum and maximum radiance and ND is the digital number.

Afterwards, the reflectance was calculated, which is the ratio between the flux of reflected radiation and the flux of radiation incident on the top of the atmosphere (Allen et al., 2002). The parameters for this calculation can be found in equation 2:

$$P\lambda i = \frac{\pi * L\lambda i}{K\lambda i * cosZ * Dr} \qquad (2)$$

whose Pλi is the reflectance; Lλi is the radiometric calibration or spectral radiance for each band; Kλi is the monochromatic solar constant or solar irradiance on the top of the atmosphere or the mean exoatmospheric solar irradiance for each band (W.m^{-2}.μm-1); Dr and Z are the inverse of the square of the distance earth-sun and the zenithal angle of the sun, respectively.
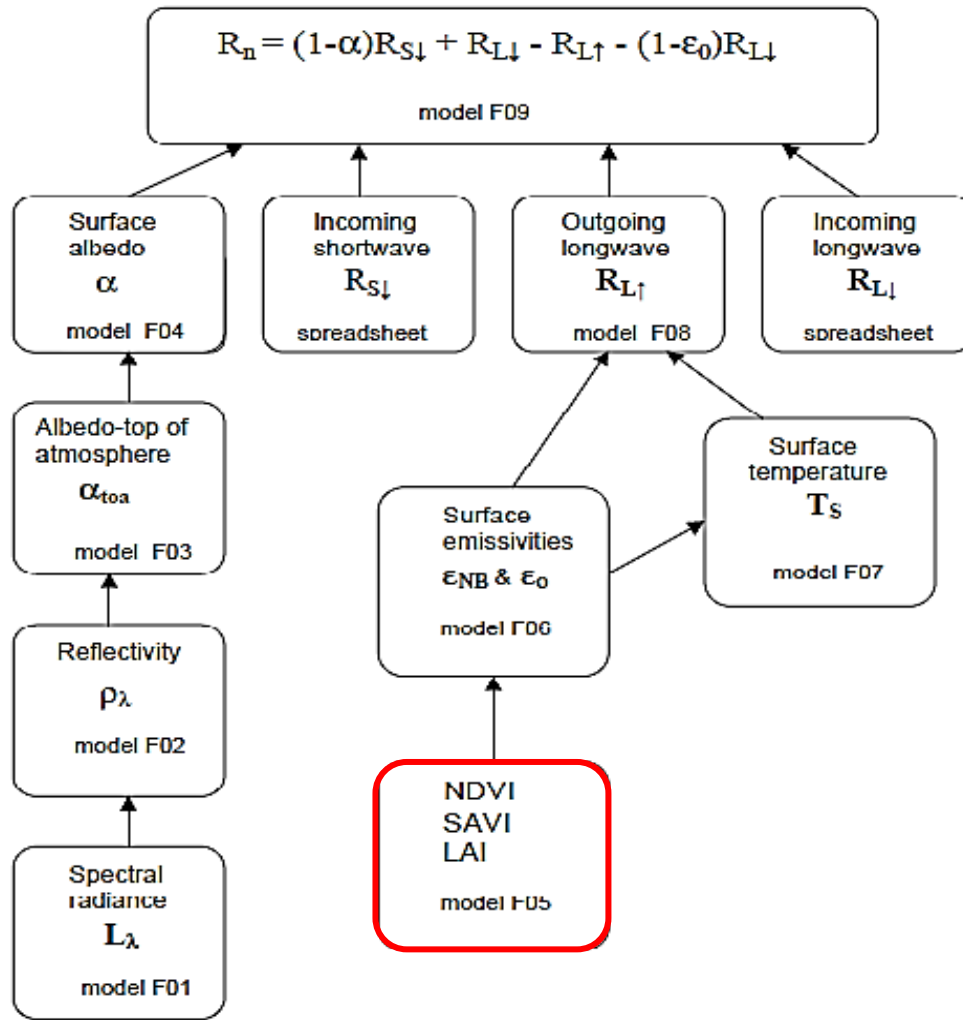
Figure 2 - Flow chart of the net surface radiation computation. Source: Allen et al. (2002).

From the reflectance calculated for each band, it is possible to estimate vegetation indexes. The Normalized Difference Vegetation Index (NDVI), which is an indicative of the conditions, density and size of the vegetation, was obtained by the ratio between the reflectance difference of the near infrared (band 4) and red (band 3) and the sum of them according to equation 3:

$$NDVI = \frac{\beta IV - \beta III}{\beta IV + \beta III} \qquad (3)$$

where βIV and βIII are the reflectance of band 4 (near infrared) and reflectance of band 3 (red)

For the estimation of the Soil Adjusted Vegetation Index (SAVI), which aims to soften the effects that NDVI suffers in relation to the soil, reducing the impacts of soil moisture effects, the

equation 4 is used:

$$SAVI = \frac{(1+Ls)(\beta IV - \beta III)}{(Ls + \beta IV + \beta III)} \qquad (4)$$

in which Ls is the constant of the adjustment factor of the SAVI index; and βIV and βIII are the reflectance of band 4 (near infrared) and reflectance of band 3 (red), respectively.

Ls values range from 0.25 to 1 depending on the soil cover. According to Huete (1988), a value for Ls of 0.25 is indicated for dense vegetation and 0.5 for vegetation with intermediate density, when the vegetation presents low density the recommended value of Ls is 1. For preserved Caatinga, condition of this study, the Ls value used was 0.5.

To calculate the Leaf Area Index (LAI), which is an indicator of the biomass and resistance of the tree canopy, it is utilized the equation 5 bellow. The LAI represents the ratio of the total area of leaves inserted in the pixel, by the pixel area (Allen et al., 2002).

$$IAF = \frac{-\ln\left(\frac{0.69 - SAVI}{0.59}\right)}{0.91} \quad (5)$$

whose SAVI represents the SAVI of the area of interest, calculated previously.

The results obtained for the respective indexes (NDVI, SAVI and LAI) were grouped and submitted to the analyzes of the values of minimum and maximum. Also, the average was obtained.

3. Results and discussion

For the NDVI estimation, the averages of the maximum and minimum values obtained for the years 2003, 2004 and 2005 were, respectively, 0.105570; 0.132359 and 0.116837 (Table 3). It was observed an increase of the NDVI for the year of higher rainfall rates (2004), which can indicate that the great precipitation amount occurred in that year contributed to the increasing of the vegetation density present in the studied area. In relation to the other two indexes (SAVI and IAF), they demonstrated a behavior similar to NDVI. For SAVI, the averages for the years 2003, 2004 and 2005 were, respectively, 0.105582; 0.129157 and 0.125455 (Table 4). The annual results for the IAF were 0.062455; 0.168261 and 0.099454 for the same three years (2003, 2004 and 2005, respectively) as shown in Table 5.

This trend can also be perceived by analyzing the averages of the maximum and minimum values calculated for the observed months (Figure 3). It is noted that the NDVI, SAVI and IAF values found for 2004 were higher than those found for the previous and subsequent years for this area under preserved caatinga condition, making clear the effects of an intense rain in that region.

Table 3 - Minimum and maximum NDVI values for the analyzed months and annual average for the years 2003, 2004 and 2005 for the AEB.

NDVI			
Date	Monthly		Annual Average
	Min	Max	
Jul/2003	0.07190	0.15511	
Aug/2003	0.07968	0.12100	0.1324
Sep/2003	0.08476	0.12093	
Jul/2004	0.08151	0.21834	
Oct/2004	0.07141	0.16595	0.18316
Nov/2004	0.09174	0.16518	
Jul/2005	0.07125	0.16418	
Sep/2005	0.08382	0.14735	0.15098
Nov/2005	0.09300	0.14141	

Table 4 - Minimum and maximum SAVI values for the analyzed months and annual average for the years 2003, 2004 and 2005 for the AEB.

SAVI			
Date	Monthly		Annual Average
	Min	Max	
Jul/2003	0.07190	0.15518	
Aug/2003	0.07968	0.12100	0.13237
Sep/2003	0.08476	0.12093	
Jul/2004	0.08570	0.22259	
Oct/2004	0.06425	0.16198	0.18328
Nov/2004	0.07513	0.16526	
Jul/2005	0.10372	0.18497	
Sep/2005	0.08863	0.14705	0.15614
Nov/2005	0.09195	0.13638	

Table 5 - Minimum and maximum LAI values for the analyzed months and annual average for the years 2003, 2004 and 2005 for the AEB.

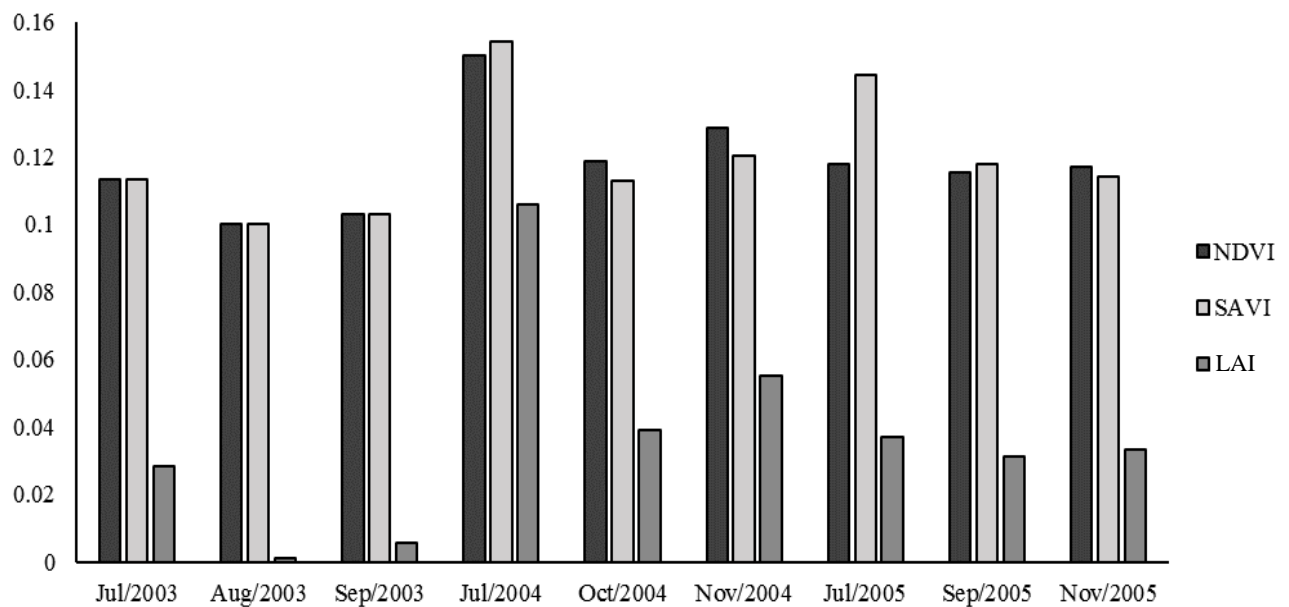| LAI			
Date	Monthly		Annual Average
	Min	Max	
Jul/2003	-0.0511	0.1079	
Aug/2003	-0.0372	0.0398	0.0118
Sep/2003	-0.0281	0.0397	
Jul/2004	-0.0339	0.2460	
Oct/2004	-0.0520	0.1302	0.0553
Nov/2004	-0.0180	0.1286	
Jul/2005	-0.0521	0.1264	
Sep/2005	-0.0298	0.0919	0.0339
Nov/2005	-0.0130	0.0800	

Figure 3 - Temporal distribution of the vegetation indexes NDVI, SAVI and LAI for the Aiuaba Experimental Basin (AEB), for the years 2003, 2004 and 2005.

It was also observed that, for the three vegetation indexes analyzed, there was an increase in the values obtained for the year after the one with rains above the average (2005) when compared to the values of the year prior to great precipitation event (2003). This increase can demonstrate the ability of the vegetation characteristic of this biome to respond to intense rains for longer periods, conserving the vegetal cover acquired for a longer time.

The influence of rain on the vegetation behavior of the Aiuaba Experimental Basin can also be observed spatially in Figure 4, where the green shades show a higher vegetation density, orange and red shades express medium and low vegetation presence. In this way, it can be seen that the intense rains that occurred in 2004 contributed to the increasing of vegetation density in the dry season which means that there was an intensification of the presence of vegetation cover in the region, as well as to the increase of NDVI, SAVI and LAI values.
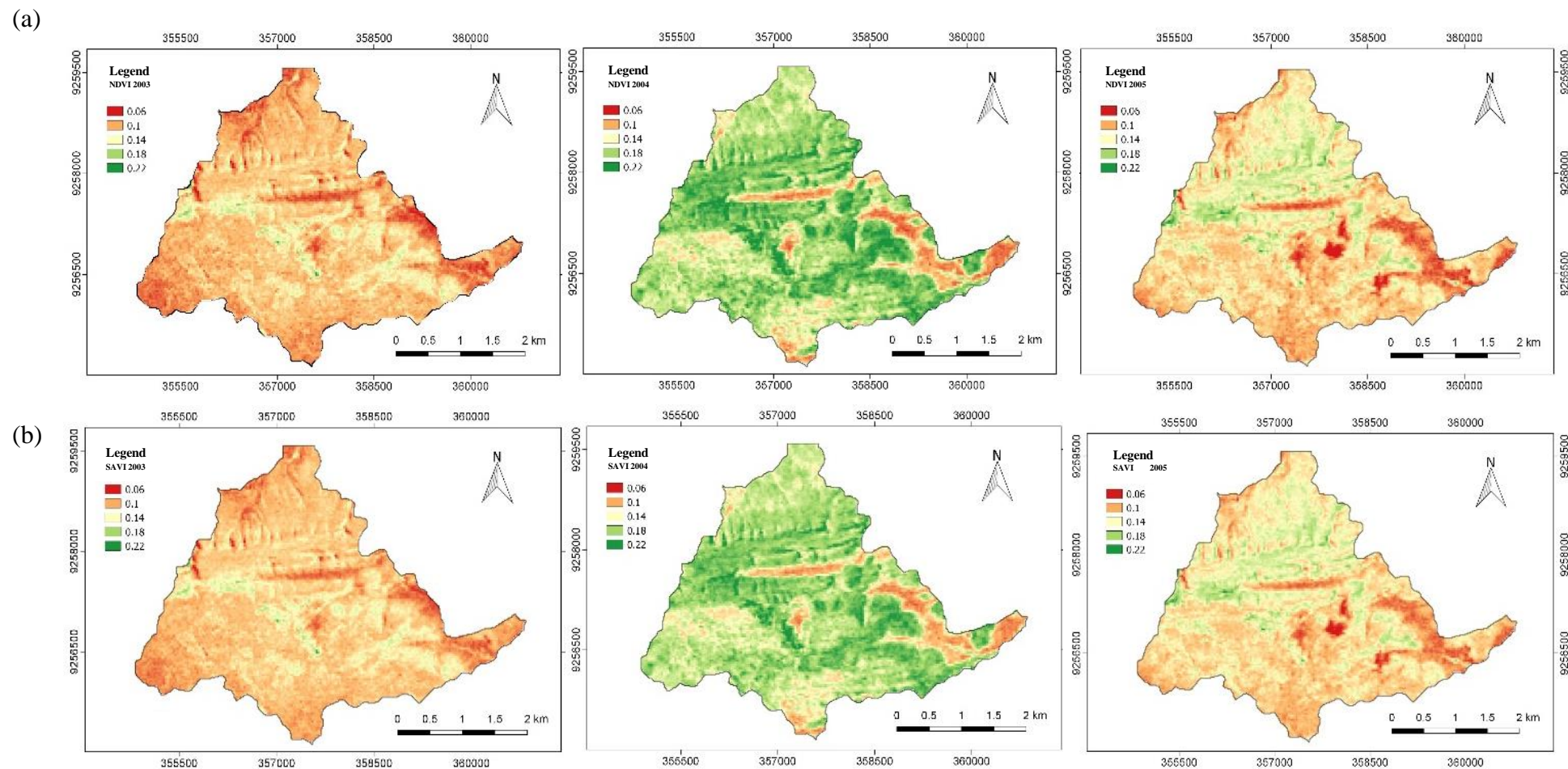
(a)

(b)

Figure 4 - Spatial distribution of the vegetation indexes NDVI (a), SAVI- (b) and LAI (c) for the Aiuaba Experimental Basin (AEB), for the years 2003, 2004 and 2005. Projection System UTM / Datum WGS84 - Zone 24S. (Continued…)
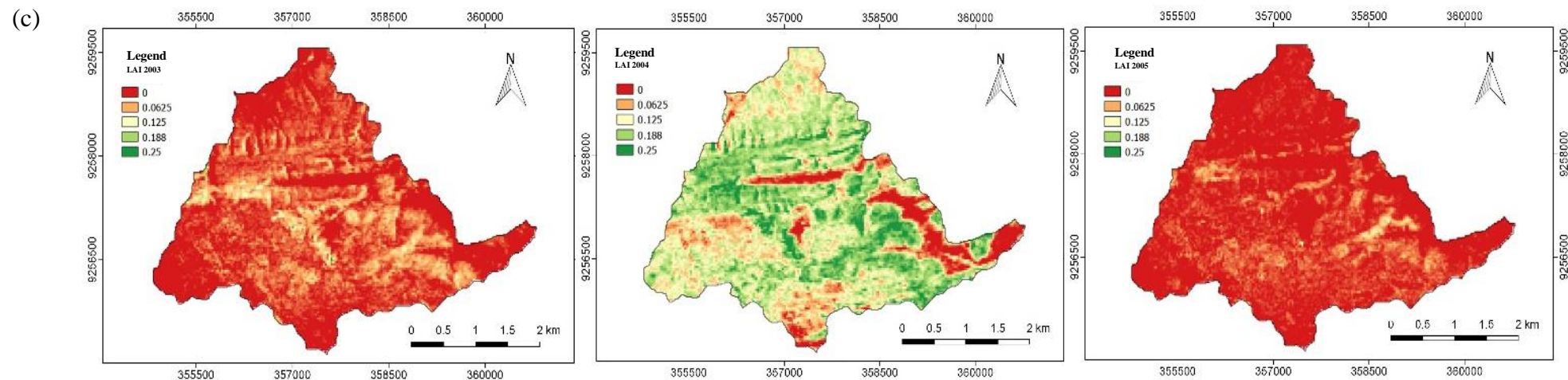
(c)

Figure 4 - Spatial distribution of the vegetation indexes NDVI-2003, 2004 e 2005 (a), SAVI- (b) and LAI (c) for the Aiuaba Experimental Basin (AEB), for the years 2003, 2004 and 2005. (Conclusion)

4. Conclusions

From the results of NDVI, SAVI and IAF obtained for the Aiuaba Experimental Basin area, it can be concluded that there is a strong correlation between the occurrence of rainfall events and the increase of the vegetation cover of the studied area. This way, the vegetation indexes can be considered as efficient parameters to evaluate the vegetation behavior under preserved caatinga condition.

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