

INTERRELATIONSHIP BETWEEN RAINFALL AND VEGETATION INDEX BY REMOTE SENSING

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Abstract

Considering the importance of vegetation and influence of climatic factors in development, especially precipitation, the purpose of this study was to find a function that best represents the relationship between rainfall and NDVI in the Paraíba state. We used daily images from the sensor AVHRR / NOAA system with spatial resolution of 4 km and MODIS / Aqua with spatial resolution of 1km product and monthly precipitation data of 250 stations for the years 2007, 2008 and 2009. The method of least squares regression to find the curve that best fitted the dataset was used. The Student t test was applied to the correlation coefficients $\alpha = 0.05$ level of significance. The results indicate relationship that best represents the behavior of NDVI depending on rainfall is a polynomial second degree curve with better correlations during the dry season (June to September). Generally the $NDVI_{AVHRR}$ showed better correlation with rainfall than $NDVI_{MODIS}$. In the rainy season they have been weaker because when vegetation reaches maximum force, the NDVI is practically stable. On average the highest correlations (r) found for the two satellites between 0.69 and 0.86 regardless of the year it was wet or dry. It is noteworthy that these adjustments were a little better for the polynomial model.

Keyword: IVDN, Least Square Method, rainfall.

1. Introduction

The biosphere consists of numerous chemical and physical factors that favor the development of life. In nature, each element plays an important role. However, planet Earth and all its components (atmosphere, continents, oceans, rivers, lakes, ecosystems ...) are in a continuous process of transformation and adaptation, undergoing numerous changes (climatic, geological, biological ...) from its origin. According to Gowdak and Mattos (1991), an ecosystem consists of (not live) biotic factors

(living things) and abiotic interrelated. Changes produced in abiotic factors can directly influence biotic factors and vice versa. For example, the vegetable cover of a locality is related to the type of climate and soil prevailing in this region.

Likewise, the vegetation also influences the local climate, so that their removal may cause significant local or regional changes in climate. The climate in the Paraíba state shows variations due to the geographical position of the state and is influenced relief. Like the climate, the vegetation

also presents variations in its typology throughout the state, where each type is associated with a predominant type of climate and soil in a given region, so it is clear that there is a relationship between vegetation (factor biotic) and climatic factors (abiotic), for example, precipitation.

Anderson et al. (2003) stated that it is necessary to study the Earth as an integrated system, because the relationship between lives, the oceans and the atmosphere are intrinsically linked. According to Huete et al. (1994) the vegetation is a sensitive indicator of the properties of an ecosystem that influence the energy balance, climate, hydrology, and biogeochemical cycles. In the last decades of the last century, techniques of remote sensing and image processing algorithms were developed to characterize the canopy of extensive vegetated areas from vegetation indices (Nascimento, 2012). Nicholson and Farrar (1994) used data from the AVHRR / NOAA to show that in semiarid regions of Africa the variation of NDVI is more related with the storage capacity of the soil water than with the precipitation itself. Srivastava et al. (1997) used the remote sensing to study the relationship between NDVI and seasonal totals of precipitation and transpiration in the Karnataka state (India) data. Gutman and Ignatov (1998) used monthly NDVI data derived from information AVHRR/NOAA data to produce monthly vegetation fraction and incorporate them at the entrance of the overall regional forecasting models (ETA) and medium-term National Center for Environmental Prediction (NCEP) and the National Weather Service (NWS). Preliminary results of incorporating vegetation maps in numerical models of weather forecast (NWS) showed a significant improvement in the

prediction of fluxes at the surface. According Huete et al. (2002) vegetation indices are intended to indicate the properties of the vegetation and allow reliable spatial temporal terrestrial photosynthetic activity and variations in canopy structure and comparisons, and allow monitoring of seasonal variation, interannual phenological and biophysical parameters of vegetation long term. Braga et al. (2003) used the NDVI time series to determine the time response of vegetation to rainfall. Araújo et al. (2009) use images of TM / Landsat 5 for 1987 and 2008 with the aim of evaluating the environmental impact of vegetation in the Chapada Araribe / Ceará and Pernambuco and showed that in some areas there was a process of degradation and showed other signs of recovery. Silva et al. (2008), with the objective of analyzing the vegetation cover in the Brejo da Madre de Deus city, used images from the CCD sensor of the CBERS-2 satellite. The authors concluded that NDVI values associated with altitude enables the quantification of the percentage of vegetated with vigor and density influenced by terrain area. Almeida (1997) found that in the Brazilian cerrado the response of NDVI to precipitation occurs with a time lag between the moments the rain and the time needed for absorption of water available to vegetation, thereby increasing photosynthetic activity due to high values of NDVI. Souza et al. (2011) used monthly NDVI data from the AVHRR/NOAA and rainfall in the Paraíba state in the year 2010 to find correlations between two variables. Souza et al. (2011) and Sousa and Braga (2012) used data from the AVHRR/NOAA to monitor the monthly variability of vegetation in the years 2011 and 2012, in Paraíba and Pernambuco states.

Galvncio and Silva (2012) used images from the Landsat TM sensor 5 to analyze the behavior of vegetation in different periods. The authors suggest that SAVI is more suitable for determination of vegetation indices when compared with NDVI in areas of caatinga. Recently, Dantas et al. (2013) used data from AVHRR/NOAA to assess vegetation dynamics in the last decade in the Paraba state. The result showed that even in years of below average rainfall did not occur significant fluctuations in the Forest and Coastal Zone.

Considering the importance of vegetation as well as the influence of climatic factors in its

development, especially precipitation, this study aims to find functional relationships between NDVI and rainfall incidence in the Paraba state for years with different characteristics.

Material and Methods

Study area

The study area comprises the Paraba state located in the eastern sector of the Brazilian Northeast, occupying a land area of 56,469,466 km² (IBGE 2012). Is limited to the north by the Rio Grande do Norte, Cear to the west, south with the Pernambuco state and on the east by the Atlantic Ocean (Figure 1).



Figure 1- Localization of the Paraba state. Source: Wikipdia adapted, 2012.

Data

Daily images from the AVHRR sensor system, covering the whole study area, were obtained directly from the NOAA site, with a spatial resolution of 4 km. The images were calibrated and georeferenced with the aid of ENVI software. NDVI was calculated for each day of the month, obtaining a data matrix and then we

selected the highest monthly value of NDVI for each grid point. Thus, we generated a new file corresponding to the days of the month with the highest NDVI. This procedure aims to minimize atmospheric effects such as contamination by clouds, water vapor, aerosols that reduce the contrast between the spectral reflectance in the

visible band and near infrared (GUTTMAN, 1991).

The MODIS products were obtained without charge from the NASA website. They are purchased in HDF (Hierarchical Data Format), and were converted in IMG format. Such products are arranged in mosaics so-called "tiles". The Paraíba state is located in tile v9 and h_14. All MODIS products already come calibrated and atmospherically corrected before being transferred to the distribution centers. The MOD13A1 and MYD13A1 products represent compositions of monthly NDVI and were corrected by multiplying the image by the correction factor 0.0001. Then, the images were turned into spreadsheets with latitude, longitude and NDVI in order to enable the application of statistical techniques.

We also used data from the monthly total precipitation of 250 stations monitored by the Executive Agency of Water Management in the Paraíba state for the period studied (AESAs, 2012).

Normalized Difference Vegetation Index

The NDVI measures the degree of development of vegetation, is a very important index for searches related to the environment. The basic proposition of these indexes is the antagonistic behavior of the spectral reflectance of vegetation in regions of the visible and near infrared due to their pigmentation, the green color of healthy vegetation reflects more in the near infrared and less visible channel, which leads to high values NDVI (HUETE and JACKSON, 1991). When the foliage begins to dry it loses its green pigmentation, increasing its reflectance in the visible and near infrared decreasing, producing lower NDVI values, allowing

distinguishing vegetation and dry the surface of the remaining targets (PARKINSON, 1997).

According to Rouse et al. (1973) NDVI is a representative of the vegetation indices most used in the world and is given by the following expression:

$$NDVI = (NIR - VIS) / (NIR + VIS)$$

where NIR is the reflectance in the near infrared spectral band, and VIS is the reflectance in the visible spectral band.

Interpolation methods

As the pixels that constitute the MODIS and AVHRR images are not presented exactly the same points of latitude and longitude, since the spatial resolution of the products from each sensor are different, there was an interpolation in the processing of the images to match the grid points of the two sensors. There is several interpolation methods, among them opted for the Kriging method, because it has good reliability with the original data (LANDIN, 2000). Thus, it was possible to compare the $IVDN_{MODIS}$ and $IVDN_{AVHRR}$ with rainfall in a single grid point. From there we generated new worksheets with the aim of studying the functional relationship between precipitation and NDVI obtained by the two satellites.

Statistical Analysis

The NDVI and rainfall data were fitted to a straight line and at a second-degree polynomial by least squares method. Let $Y = \alpha + \beta X$ and the linear model $Y = \alpha + \beta X + \gamma X^2$ the second degree polynomial model chosen to fit the points (X_i, Y_i) of the sample. Will be designated by "a", "b" and "c" values estimated from α , β and γ

respectively. The estimate of Y composing the fitted model "a" and "b" of the linear equation, and "a", " b" and " c" of the parabolic equation, are given respectively by:

$$Y = a + bX \quad (2)$$

$$Y = a + bX + cX^2 \quad (3)$$

The correlation coefficient r measures the degree of fit data which is used for both linear and nonlinear relationships Therefore; the correlation coefficient r is given by the following expression:

$$r = \pm \sqrt{\frac{\text{Variação explicada}}{\text{Variação total}}} \\ = \pm \sqrt{\frac{\sum(Y_{\text{estimado}} - \bar{Y})^2}{\sum(Y_{\text{observado}} - \bar{Y})^2}} \quad (4)$$

where r is a dimensionless quantity ranging between $-1 \leq r \leq 1$.

The test of significance of the r sample used was the bilateral Student test. Whereas "ρ" as the correlation coefficient of a theoretical population calculated from the sample correlation coefficient for $\rho = 0$ (null hypothesis) denoted by:

$$t = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}} \quad (5)$$

In the case of the null hypothesis is rejected at a given level of significance, is to say that the sample or is in the area of acceptance, ie, there is a correlation between populations, otherwise the null hypothesis is accepted, the correlation between populations is zero standing in the area of rejection, (Spiegel, 1978).

Results and discussion

Tables 1-4 show the correlations between rainfall and vegetation index normalized difference of AVHRR / NOAA (NDVI_{AVHRR}) and MODIS / Aqua (NDVI_{MODIS}) sensor for the years 2007, 2008 and 2009. Tables 1 and 2 contain the correlations between precipitation and NDVI_{AVHRR}, Tables 3 and 4, the correlations between precipitation and NDVI_{MODIS}. The indices under written in the correlations of 1-4 tables match the response time of vegetation in relation to rainfall, ie written under 1 indicates that the response of vegetation to rainfall has been a month, 2 indicates that the response the plant occurred in two months, and so forth.

The largest linear correlations between rainfall and NDVI_{AVHRR} were between $0.69 < r < 0.84$, and the highest correlations polynomial of the second degree between $0.69 < r < 0.86$ for $\alpha = 0.05$ significance level, and occurred in the months of January and February, prerainy season and the beginning and end of winter. Although one can see that on average the highest correlations occurred with a lag of up to three months after the occurrence of rainfall (Tables 1, 2, 3 and 4).

The monthly spatial variability of NDVI AVHRR / MODIS and precipitation from June to October for the year 2007 are shown in Figure 2. It can be observed that from June rains cease in the Sertao and Cariri region, where the predominant vegetation these regions is the savanna, begins to dry quickly. However, in regions of the rugged coastline to the rains continue to fall in smaller quantities, so that these regions NDVI presents higher because of the type of vegetation, which mostly is large and not

completely lose their foliage as the amount of rain is reduced. In 2007, the highest correlations between rainfall and $NDVI_{AVHRR}$ and $NDVI_{MODIS}$, are found in the drier months. This is explained due to the fact that the reduction in rainfall in the

state of Paraíba causes a gradual decrease in $NDVI$ gradually increasing the correlation between the two variables.

Table 1 - Linear correlations between rainfall and $NDVI_{AVHRR}$.

| Rainfall/NDVI | 2007 | 2008 | 2009 |
|---------------|---------------------|---------------------|---------------------|
| Jan | 0.73 | 0.73 ⁽¹⁾ | 0.67 |
| Feb | 0.69 | 0.75 ⁽¹⁾ | 0.35 |
| Mar | 0.55 ⁽¹⁾ | 0.70 | 0.27 |
| Apr | 0.41 ⁽²⁾ | 0.22 | 0.28 |
| May | 0.43 ⁽³⁾ | -0.17 | -0.37 |
| Jun | 0.75 ⁽³⁾ | 0.69 ⁽³⁾ | 0.68 ⁽³⁾ |
| Jul | 0.79 ⁽³⁾ | 0.76 ⁽³⁾ | 0.44 ⁽²⁾ |
| Ago | 0.79 ⁽³⁾ | 0.77 ⁽³⁾ | 0.69 ⁽²⁾ |
| Sep | 0.84 | 0.77 ⁽³⁾ | 0.66 ⁽¹⁾ |
| Oct | 0.71 ⁽¹⁾ | 0.67 ⁽¹⁾ | 0.38 ⁽¹⁾ |
| Nov | 0.72 ⁽¹⁾ | 0.40 | 0.45 ⁽¹⁾ |
| Dec | 0.51 | 0.46 | 0.19 |

(1) (2) (3) correspond to the response time of 1 month, 2 months and 3 months, respectively.

Table 2 - Second degree polynomial correlations between rainfall and $NDVI_{AVHRR}$.

| Rainfall/NDVI | 2007 | 2008 | 2009 |
|---------------|---------------------|---------------------|---------------------|
| Jan | 0.75 | 0.79 ⁽¹⁾ | 0.68 |
| Feb | 0.69 | 0.78 ⁽¹⁾ | 0.42 |
| Mar | 0.60 ⁽¹⁾ | 0.70 | 0.34 |
| Apr | 0.47 ⁽²⁾ | 0.23 | 0.32 |
| May | 0.57 ⁽¹⁾ | 0.30 | 0.39 |
| Jun | 0.86 ⁽³⁾ | 0.65 ⁽³⁾ | 0.48 ⁽²⁾ |
| Jul | 0.84 ⁽¹⁾ | 0.76 ⁽³⁾ | 0.72 ⁽³⁾ |
| Ago | 0.84 ⁽¹⁾ | 0.78 ⁽²⁾ | 0.71 ⁽²⁾ |
| Sep | 0.86 | 0.77 ⁽¹⁾ | 0.69 ⁽¹⁾ |
| Oct | 0.75 ⁽¹⁾ | 0.71 | 0.43 ⁽²⁾ |
| Nov | 0.72 ⁽¹⁾ | 0.50 | 0.46 |
| Dec | 0.54 ⁽¹⁾ | 0.47 | 0.20 |

(1) (2) (3) correspond to the response time of 1 month, 2 months and 3 months, respectively.

Table 3 – Linear correlations between rainfall and $NDVI_{MODIS}$.

| Rainfall/NDVI | 2007 | 2008 | 2009 |
|---------------|---------------------|------|---------------------|
| Jan | 0.39 ⁽²⁾ | 0.59 | 0.45 ⁽²⁾ |
| Feb | 0.49 | 0.42 | 0.28 |
| Mar | 0.50 | 0.24 | 0.32 |

| | | | |
|------------|---------------------|---------------------|---------------------|
| Apr | 0.43 ⁽³⁾ | 0.04 | 0.13 |
| May | 0.46 ⁽³⁾ | -0.08 | -0.11 |
| Jun | 0.77 ⁽²⁾ | 0.71 ⁽³⁾ | 0.66 ⁽³⁾ |
| Jul | 0.81 ⁽¹⁾ | 0.77 ⁽²⁾ | 0.67 ⁽²⁾ |
| Ago | 0.75 | 0.77 ⁽¹⁾ | 0.68 ⁽²⁾ |
| Sep | 0.79 | 0.76 | 0.64 ⁽¹⁾ |
| Oct | 0.65 | 0.67 | 0.31 ⁽¹⁾ |
| Nov | 0.65 | 0.23 | 0.18 |
| Dec | 0.32 | 0.09 | 0.43 |

(1) (2) (3) correspondem ao tempo de resposta de 1 mês, 2 meses e 3 meses respectivamente.

Table 4 - Second degree polynomial correlations between rainfall and NDVI_{MODIS}.

| Rainfall/NDVI | 2007 | 2008 | 2009 |
|----------------------|---------------------|---------------------|---------------------|
| Jan | 0.41 ⁽²⁾ | 0.64 | 0.45 ⁽²⁾ |
| Feb | 0.52 | 0.42 | 0.33 |
| Mar | 0.53 | 0.25 | 0.34 |
| Apr | 0.42 | 0.27 ⁽³⁾ | 0.23 |
| May | 0.48 | 0.16 ⁽³⁾ | 0.26 |
| Jun | 0.84 ⁽²⁾ | 0.73 ⁽³⁾ | 0.67 ⁽³⁾ |
| Jul | 0.84 | 0.77 ⁽²⁾ | 0.71 ⁽²⁾ |
| Ago | 0.84 | 0.78 ⁽¹⁾ | 0.69 ⁽¹⁾ |
| Sep | 0.8 | 0.76 | 0.67 |
| Oct | 0.69 | 0.71 | 0.38 ⁽¹⁾ |
| Nov | 0.65 | 0.31 | 0.19 |
| Dec | 0.34 | 0.09 | 0.44 |

(1) (2) (3) correspond to the response time of 1 month, 2 months and 3 months, respectively.

It is observed that in 2008 the monthly correlations for AVHRR (Table 1 and 2) were higher than for MODIS (Table 3 and 4). The rains this year were above average from January to June with more significant correlations ranging from 0.7 to 0.75 in the pre - rainy season and from 0.65 to 0.78 June to October for AVHRR and MODIS were lower in the rainy season and similarly in the period from June to October (Table 1-4). This shows that the spectral response of vegetation for both MODIS and for the AVHRR were better in the dry than wet years for all analyzed time period. This can be associated with spatial resolution of the sensors, and the time of the satellite overpass.

For the rainy year 2009, average, correlations between rainfall and vegetation index were lower than the correlations observed in 2007

for the two sensors. For the AVHRR, the largest linear correlations ranged from 0.67 in January, 0.68 in June, 0.69 in August and 0.66 in September. The largest second-degree polynomial correlations ranged from 0.68 in January, 0.72 and 0.71 in June and August and 0.69 in September. For the MODIS correlations have the same order of magnitude of AVHRR with the exception of January. This may be associated with high soil moisture due to excessive rain this year. Accordingly vegetation remained longer in full force thus NDVI remained stable for both AVHRR as MODIS (Tables 1 to 4). The Figure 3 shows the spatial variability of rainfall and NDVI_{AVHRR} and NDVI_{MODIS} for the months from June to October 2009. Rains this year extended to July, decreasing from August in the Sertao and Cariri regions, to a lesser extent in the sector east

(harsh, marsh and coastal area) as can be seen in Figure 3 showing that both the $NDVI_{MODIS}$ as $NDVI_{AVHRR}$ exhibit good spectral response of vegetation in the dry season. Overall the relationship between the scores obtained by the two sensors and the rains showed better correlations (r) during dry months (Table 1-4). On average, the response time of vegetation incidence of rainfall was up to 3 months (Tables 1-4), for the two sensors, however, the rains of June have strong correlation with the NDVI September, indicating that the measure which reduces rainfall in the eastern sector of the state correlations tend to increase. We note that the polynomial correlations were high and better especially in the dry season months.

In summary, the correlations between rainfall and NDVI from AVHRR and MODIS sensors in 2007 were higher than the correlations obtained in 2008 and 2009, when the regime of rainfall this year was below average in several regions of the Paraíba state. In 2008, the rains were above average from January to June, with low correlations with one-month lag in January February and March for the MODIS sensor. However, in the same year, the correlations between the $NDVI_{AVHRR}$ were higher than 0.7 in the rainy months (January-March), this indicates that the spectral response of the AVHRR is better than the MODIS during the rainy season (Tables 1 2 , 3 and 4). April and May can be seen that with continued rains, wet soil and vegetation recovered, NDVI becomes practically stable lowering the correlations. As of July begins the period of drought in almost every state, drier vegetation, high NDVI, high correlations in the following months (Table 1, 2, 3 and 4). In 2009

the correlations were low since there have been considerable rainfall volumes every month contributing to a lower variability of NDVI, which has led to lower correlations between rainfall and NDVI that year. In general in the April and May, the correlations were lower, with linear polynomial relationships presenting similar results in all years.

The best correlation (r) found ranged from 0.69 to 0.86 for the two satellites, regardless of whether the year was wet or dry. It is noteworthy that these adjustments are a little better for the polynomial model, ie, r ranged from 0.69, $r = 0.86$ to $r = 0.69$ and $r = 0.84$ for the linear model.

The results of this study partly corroborate the Jacobsen et al. (2004) who linked the growth and development of vegetation cover and its temporal evolution in the Rio Grande do Sul state with El Niño and La Nina where the authors found that positive precipitation anomalies attributed to El niño entailed positive anomalies in NDVI and exactly the reverse occurred in La Niña events. According to Nicholson and Farrar (1994), there are numerous studies that suggest a linear relationship between NDVI and rainfall in semiarid Africa, but analyzing the semiarid Botswana (Africa) the authors found that this linearity between these two parameters occur only in the range of 25 to 200 mm (monthly) and 200 to 1200 mm (annual) .

Araújo et al. (2011) found excellent correlations between rainfall and NDVI of soybean reaching values of 0.99 during the early development of the soybean cycle. Sousa et al. (2011) and Sousa and Braga (2012) used data from the AVHRR NDVI obtained to make

monthly monitoring of vegetation in the Paraíba state. The authors showed that the NDVI is good indicator of rainfall in the state.

Francis et al. (2012), with the objective of mapping areas of caatinga vegetation, several satellite images used to determine quantitatively and qualitatively vegetation indices. The authors concluded that the index that best correlates with vegetation NDVI was to scrub the dry period, and that the methodology used was efficient for

characterization, classification and separation from 9 classes. Also, Ferreira et al. (2012) studied the dynamics of vegetation in the region of Petrolina -PE using the NDVI and the Normalized Difference Water Index (NDWI) indices. The authors concluded that the analyzes of vegetation indices showed better results obtained in the rainy period for the NDWI and NDVI for the dry period.

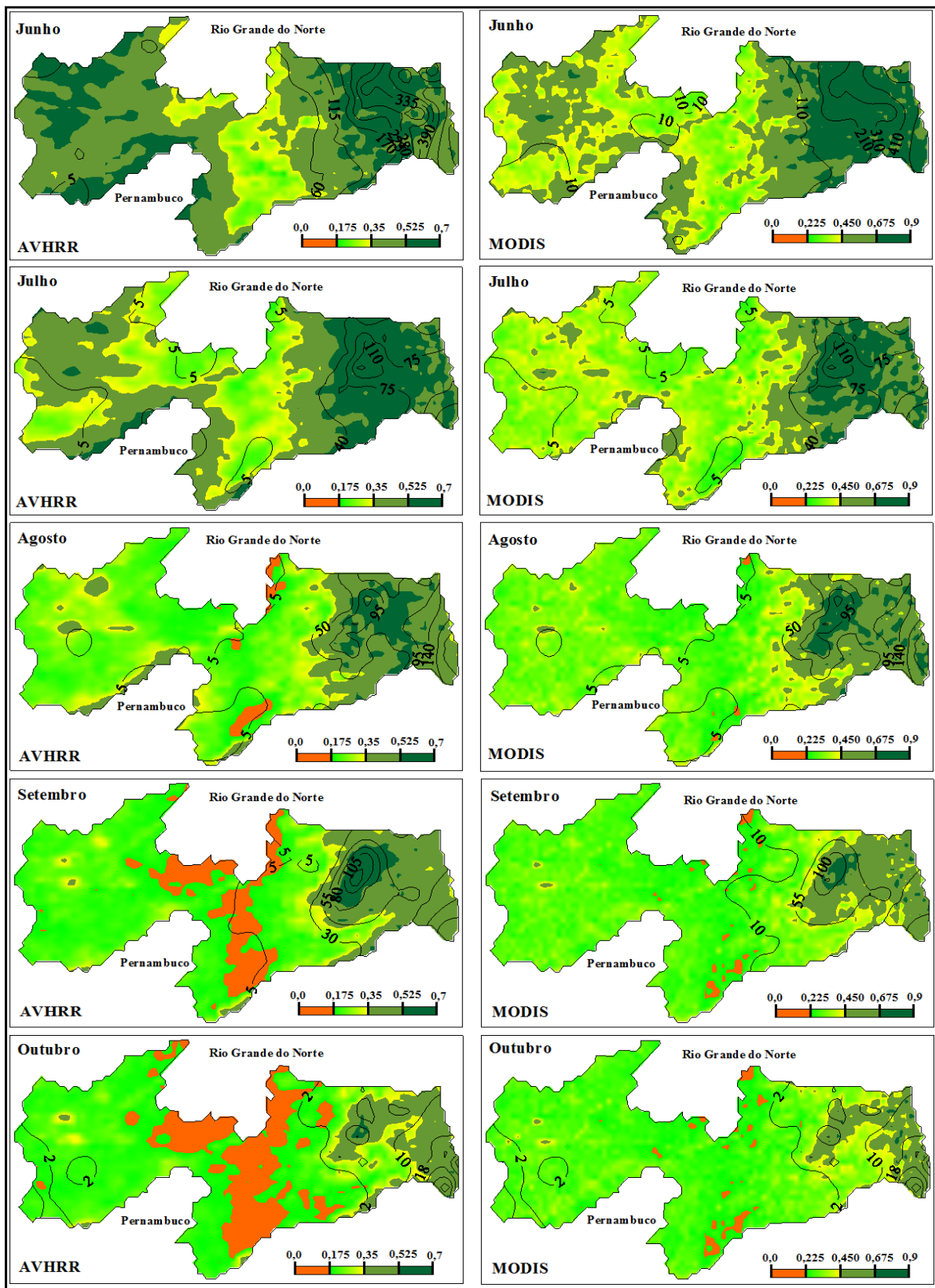


Figure 2 – Spatial distribution of vegetation index with isolines of rainfall to 2007 year.

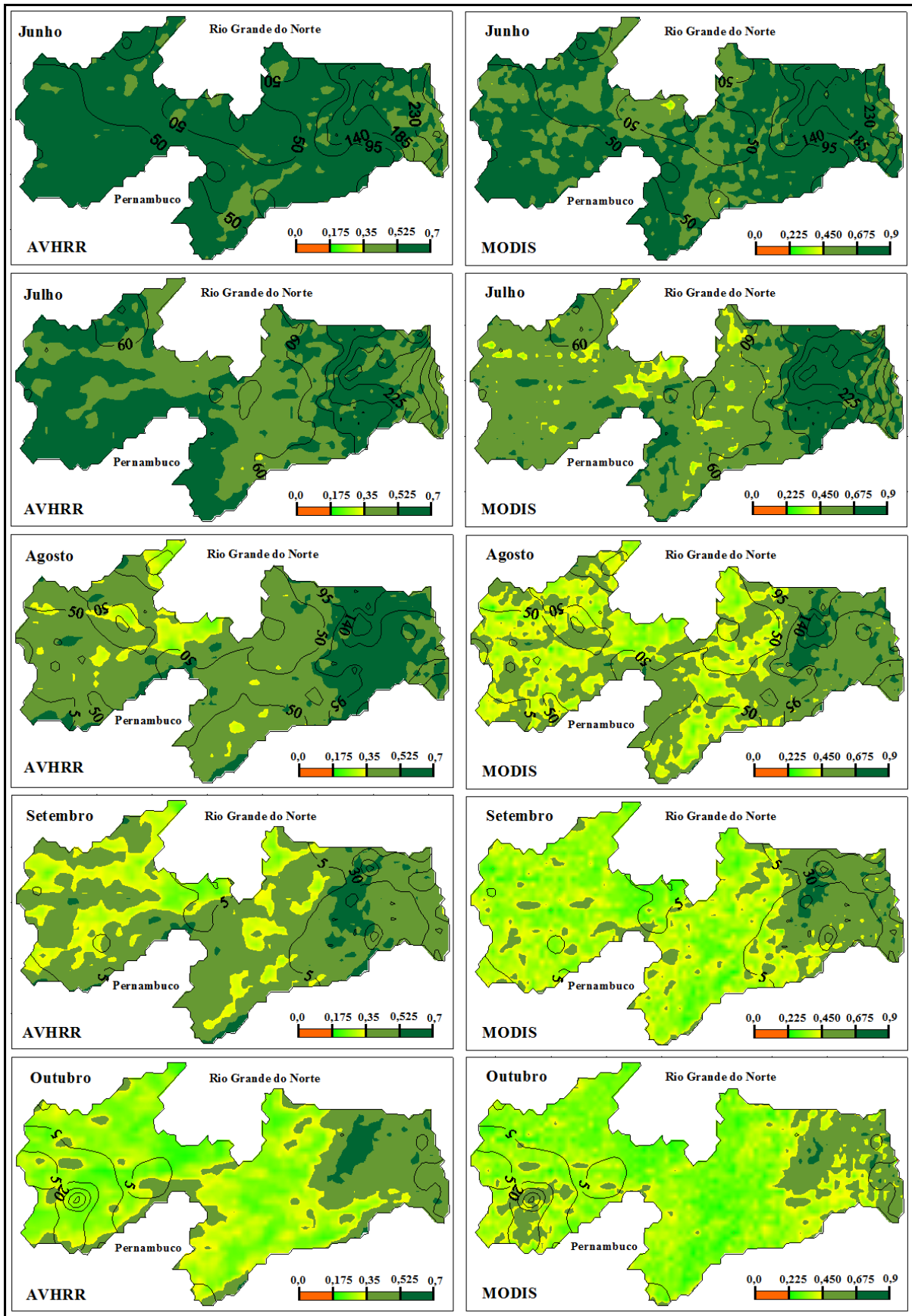


Figure 3- Spatial distribution of vegetation index with isolines of rainfall to 2009 year.

Conclusion

Considering the analysis made from the vegetation response to the incidence of rainfall in the Paraíba state for years with different rainfall characteristics, we can conclude:

The correlations between precipitation and NDVI were higher in 2007 due to the occurrence of rainfall below normal.

In 2009 the correlations were low since there have been considerable rainfall volumes every month contributing to a lower variability of NDVI, because the spectral response is lower due to high soil moisture.

In general in the March, April and May, correlations were lower, with linear and polynomial relationships presenting similar results in all years, in agreement with previous observation.

The NDVI_{AVHRR} in all years showed better correlations with rainfall in the early rainy season (January, February and March) than those obtained by NDVI_{MODIS} sensor.

The best correlation (r) found between precipitation and NDVI obtained by the two satellites ranged from 0.69 to 0.86, regardless of the year it was wet or dry, however the polynomial models showed to better.

The relationship between precipitation and NDVI is best observed in the months of reduced rainfall (July, August, September and October).

The NDVI can be estimated from data of precipitation mainly during the dry season, because the models are more representative and vice versa.

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