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SPACE-TEMPORAL VARIATION OF EVAPOTRANSPIRATION IN CAATINGA AREAS IN SOUTHEAST PIAUIENSE

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Abstract

Caatinga vegetation comprises about 80% of the Northeast region and 11% of the national territory. This biome is predominantly made up of plant species with arboreal and shrub size, which guarantees a complex heterogeneity in the vegetation cover. Understanding the biophysical processes associated with its variation is important for understanding the ecosystem processes. Therefore, the objective of this work was to evaluate the spatio-temporal variation of vegetation index and evapotranspiration in fragments of Caatinga with different phytophysiognomies, located in the municipality of Bom Jesus, Piauí. The images used came from the OLI and TIRS sensors of the Landsat 8 satellite, on the areas that were identified three fragments of the Caatinga. Arboreal Caatinga (CAbo), Arboreal-shrub Caatinga (CAb) and Shrub Caatinga (CAbu). Through the processing of the SEBAL algorithm, the NDVI, SAVI and IAF vegetation indexes and biophysical indices of Surface Temperature (Ts) and Evapotranspiration (ETr) were obtained. It was observed that in relation to the average of vegetation indexes, the fragments had distinct results between vegetation cover and density, being associated with variations of Ts and ETr, in which the occurrence of lower temperatures and higher ETr was noteworthy in areas with higher densities of vegetation. Thus, the relevance of the vegetation cover for the maintenance of the biophysical processes on the terrestrial surface is emphasized.

Keywords: SEBAL; Remote sensing; Native vegetation.

VARIAÇÃO ESPAÇO-TEMPORAL DA EVAPOTRANSPIRAÇÃO EM ÁREAS DE CAATINGA NO SUDOESTE PIAUIENSE

Resumo

A vegetação de Caatinga compreende cerca de 80% da região Nordeste e 11% do território nacional. Este bioma é predominantemente constituído de espécies vegetais de porte arbóreo e arbustivo, o que garante uma complexa heterogeneidade na cobertura vegetal. Entender os processos biofísicos associados à esta variação é de suma importância para compreender os processos ecossistêmicos. Portanto, o objetivo deste trabalho foi avaliar a variação espaço-temporal da evapotranspiração em fragmentos de Caatinga com diferentes fitofisionomias, localizados no município de Bom Jesus, Piauí. As imagens utilizadas foram provenientes dos sensores OLI e TIRS do satélite Landsat 8, para as áreas onde houve a identificação de três fragmentos da Caatinga, Caatinga arbórea (CAbo), Caatinga arbórea-arbustiva (CAb) e Caatinga arbustiva (CAbu). Através do processamento do algoritmo do SEBAL, obteve-se os índices de vegetação NDVI, SAVI e IAF e índices biofísicos de Temperatura da superfície (Ts) e Evapotranspiração (ETr). Observou-se que em relação aos índices de vegetação

médios, os fragmentos apresentaram distinção entre a cobertura e densidade vegetal, estando associados a variações de Ts e ETr, nos quais foi notável a ocorrência de menores temperaturas e maiores ETr em áreas que apresentaram maiores densidades vegetais. Dessa forma, ressalta-se a relevância da cobertura vegetal para a manutenção dos processos biofísicos na superfície terrestre.

Key words: SEBAL; Sensoriamento remoto; Vegetação nativa.

SPACIO-TEMPORAL VARIACIÓN OF THE INDICES OF VEGETACIÓN AND EVAPOTRANSPIRACIÓN IN THE CAATINGA AREAS

Resumen

La vegetación de Caatinga comprende alrededor del 80% de la región Nordeste y el 11% del territorio nacional. Este bioma está formado predominantemente por especies vegetales de tamaño arbóreo y arbustivo, lo que garantiza una compleja heterogeneidad en la cobertura vegetal. Comprender los procesos biofísicos asociados con esta variación es de suma importancia para comprender los procesos de los ecosistemas. Por tanto, el objetivo de este estudio fue evaluar la variación espacio-temporal de índices vegetativos y evapotranspiración en fragmentos de Caatinga con diferentes fitofisiognomías, ubicados en el municipio de Bom Jesus, Piauí. Las imágenes utilizadas provienen de los sensores OLI y TIRS del satélite Landsat 8, para las áreas donde se identificaron tres fragmentos de Caatinga, Caatinga árbol (CAbo), Caatinga árbol-arbusto (CAb) y Caatinga arbusto (CAbu) . Mediante el procesamiento del algoritmo SEBAL se obtuvieron los índices de vegetación NDVI, SAVI e IAF y los índices biofísicos de Temperatura de Superficie (Ts) y Evapotranspiración (ETr). Se observó que en relación con los índices de vegetación promedio, los fragmentos mostraron una distinción entre cobertura vegetal y densidad, asociándose con variaciones de Ts y ETr, en las que se destacó la ocurrencia de temperaturas más bajas y ETr más altas en áreas que presentaron densidades de vegetación más altas. Así, se enfatiza la relevancia de la cobertura vegetal para el mantenimiento de los procesos biofísicos en la superficie terrestre.

Palabras-clave: SEBAL; Percepción remota; Vegetación nativa..

1. INTRODUCTION

Caatinga vegetation enbraces the Brazilian semiarid region and covers about 80% of the Northeast region and 11% of the brazilian territory (SANTOS et al., 2012). This biome aggregates 5344 species of plants, 318 of which are endemic and, in their majority, are characteristic of tree and shrub forests, with deciduous or xerophytic behavior (LOIOLA et al., 2012). Its climate is seasonal, with rainy months, from January to April, and a long period without rain, from May to December (SOUZA et al., 2015).

This biome is characterized by having plant species of arboreal and shrub size, high incidence of sunlight, high temperatures and high evapotranspiration, factors that reflect on the fragility of this ecosystem (MDR, 2018). The Caatinga, presents a high heterogeneity in its phytophysiognomy due to its diversity of species (VASCONCELOS et al., 2017), which causes a high variation in the vegetation density and distribution.

Forests play a determining role in climate maintenance through various factors, including evapotranspiration (DAVIDSON et al., 2012). Evapotranspiration is one of the main components of the hydrological cycle and can be defined as the amount of water that a surface with some degree of vegetation evaporates and transpires during a certain period, which includes the evaporation of water from the soil, from the water deposited by irrigation, rain or dew on the surface of the leaves and plant transpiration, that is, the evapotranspiration process is a function of the meteorological elements, the soil and the plant (BEZERRA, 2013).

The evapotranspiration process has variability in space and time. In space, due to the volatility of precipitation, the hydraulic characteristics of the soil, types and density of vegetation, and its variability in time is due to the climate seasonality (ALLEN et al., 2002). Through remote sensing it is possible to analyze this variable, as an effective and economical alternative for monitoring the Earth's surface, allowing the determination of spatial and temporal changes in real evapotranspiration.

Therefore, the objective of this work was to evaluate the spatio-temporal variation of vegetation index and evapotranspiration in Caatinga fragments with different phytophysiognomies, located in the municipality of Bom Jesus, Piauí.

2. METHODOLOGY

The study was carried out in three different areas in the municipality of Bom Jesus located at 09º04'28"S and 44º21'31"W with an average altitude of 277 m, located in the southwestern mesoregion of the state of Piauí (Figure 1), which is part of the states semi-arid region, with a hot and humid climate. It has an average temperature of 27.7ºC and precipitation of 986.7 mm.year-1 (INMET, 2019) and is classified by Köppen as Aw, rainy tropical with dry season in winter and average temperature of the hottest month above 22 °C (ALVARES et al., 2013).

Figure 1 - Municipality of Bom Jesus, Piauí and fragments of the Caatinga biome analyzed, arboreal Caatinga (CAbo), shrub Caatinga (CAbu) and arboreal-shrub Caatinga (CAb). Source: Adapted from Google Earth, 2019.

The study area comprises a private property that has 480 hectares, whose vegetation has different phytophysiognomies and was characterized and classified by Leite et al. (2019). According to these authors, the vegetation plots (Figure 1) vary in size, florist composition, altitude and depending on the distance from the

Gurguéia Riverbed and, in addition, the plant biomass in the area varies from 15.4 to 121, 9 Mg ha-1, being higher in CAbo, followed by CAb and CAbu. For this work, samples with areas of 16471.5 m² for CAbo, 16719.6 m² for CAbu and 18646.7 m² for CAb were considered.

The Arboreal Caatinga (CAbo) area has a predominance of the tree species Bauhinia ungulata L. and Lonchocarpus sericeus (Poir.) DC., Which have closed canopy and can reach up to 12 and 20 m in height, respectively; The Shrub Caatinga (CAbu) has a majority of shrubs (below 6 m in height), where there is a predominance of Mimosa verrucosa Benth species. and Piptadenia moniliformis Benth e; in the Arboreal-shrub Caatinga fragment (CAb), the superiority of medium-sized plants with species of Annona leptopetala (R.E.Fr.) H. Raine and Piptadenia moniliformis Benth (LEITE et al., 2019) is configured.

The images used for the analysis of evapotranspiration in each areas come from the sensors that are on board the Landsat 8, OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor), which have a spatial resolution of 30 m for the bands reflective 1 to 7 and 100 m in the thermal bands 10 and 11, and the panchromatic band 8 with a resolution of 15 m (NASA, 2019).

The meteorological data used for the processing of the images were obtained at the meteorological station of the Brazilian National Institute of Meteorology (INMET), of the station that is located at the Federal University of Piauí (UFPI / CPCE).

The images were obtained from the United States Geological Survey (USGS, 2019) and selected with cloud cover less than 10% and considering the seasons of the year. In this way the images of the days 01/09/2018, 01/05/2018, 07/07/2018 and 09/22/2018 were selected, which were re-projected with the aid of the QGIS 3.8.3 software (QGIS Development Team, 2019), assuming the UTM Projection (Universal Transverse Mercator), Datum SIRGAS 2000 and Fuso 23S.

The images were processed in the GRASS GIS 7.4.0 program (GRASS Development Team, 2018), using a script in the python programming language (WOLFF, 2016) until the calculation of the soil Heat Flow (G), proceeding with the calculation of the SEBAL steps in the QGIS 3.8.3 software (QGIS Development Team, 2019), until obtaining the real evapotranspiration (mm.dia-1). At the end of the processing, the images were limited to fragments of Caatinga in the municipality of Bom Jesus using the clipping tool.

In order to verify the relationship between the fractions of vegetation (NDVI) and evapotranspiration, polynomial regression was performed between the variables using the Software R version 3.6.1 (R CORE TEAM, 2019)

3. RESULTS AND DISCUSSION

It was found difference between the vegetation indexes (NDVI, SAVI and IAF), surface temperature and evapotranspiration at the dates and areas evaluated (Table 1). At the January month, the arboreal-shrub Caatinga (CAb) has the highest values of NDVI (0.76), IAF (1.11) and SAVI (0.47), followed by the arboreal Caatinga (Cabo) and the shrub Caatinga (CAbu).

Table 1 - Average vegetation and biophysical indices in different Caatinga fragments on the days, 01/09/2018, 05/01/2018, 05/01/2018 and 09/22/2018 in the region of Bom Jesus, Piauí. Source: Own (2020).

Área	**09/01/2018**				
	NDVI	**IAF ($m^2.m^{-2}$)**	**SAVI**	**T (°C)**	**ETr ($mm.dia^{-1}$)**
CAbo	0,70	1,02	0,45	26,88	5,33
CAbu	0,70	0,91	0,43	27,19	5,28
CAb	0,76	1,11	0,47	26,84	5,41
Área	**01/05/2018**				
CAbo	0,75	1,04	0,46	25,76	3,64
CAbu	0,73	0,91	0,31	26,12	4,08
CAb	0,73	0,89	0,27	26,39	4,05
Área	**04/07/2018**				
CAbo	0,70	0,88	0,42	28,55	4,19
CAbu	0,57	0,49	0,42	29,14	3,54
CAb	0,49	0,38	0,42	30,23	3,31
Área	**22/09/2018**				
CAbo	0,65	0,89	0,42	35,57	4,64
CAbu	0,41	0,32	0,25	37,87	4,11
CAb	0,39	0,29	0,24	37,52	4,14

In May, July and September, was noted that the CAbo fragment has the highest values in the vegetation indexes, with a variation from 0.65 to 0.75 for NDVI, 0.89 to 1.02 m².m-2 for the IAF and from 0.42 to 0.46 for the SAVI, while the CAb area presents lower values of these variables, with variation between 0.39 and 0.76, 0.29 and 1.11 m².m-2 and 0.24 and 0.47, for the NDVI, IAF and SAVI, respectively. It is observed that the CAbu area has intermediary values in relation to CAbo and Cab.

Higher values of NDVI, SAVI and IAF indicate the presence of green vegetation denser in the area. Thus, it is noted that CAbo showed a higher density and, consequently, a greater vegetation coverage during the year, being surpassed, however, in January by CAb. This behavior may be associated with the fact that CAbo is closer to the river (Figure 1), which would provide a greater amount of soil moisture in this region, allowing the maintenance of green cover.

The spatial variability of the vegetation cover is also related to the large heterogeneity of the native vegetation of the region, which presents different species with their respective sizes and leaf architecture (LEITE et al., 2019), which results in differences in density and distribution of the vegetation cover (VASCONCELOS et al., 2017).

The Caatinga region is highly heterogeneous in terms of density and size of its vegetation. Natural environmental factors are responsible for this heterogeneity, such as, for example, the water deficit that makes the plants smaller, or regions with higher humidity that present taller vegetation (AMORIM et al. 2005).

In Caatinga vegetation classified as arboreal-shrub, in the municipality of Petrolina, Brito et al. (2017) found NDVI values ranging predominantly between 0.4 and 0.6. Results similar to those presented in this study.

The behavior of meteorological elements is directly related to the seasonal variation of vegetation density, especially in regard to precipitation. Thus, higher rainfall values are associated with higher values of vegetation indexes (LIU et al., 1991). As can be seen in Figure 2, the highest rainfall values were recorded in January (276.4 mm), in which month that the highest values were obtained for the variables NDVI, IAF and SAVI (Table 1).

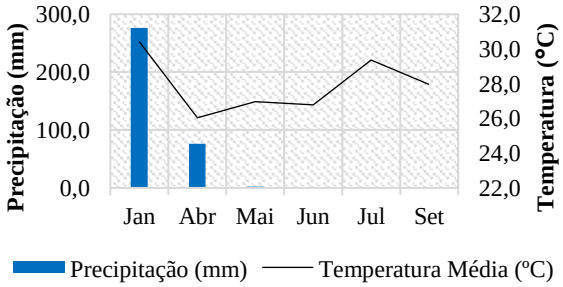

Figure 2 - Variation of accumulated monthly rainfall and average air temperature in the municipality of Bom Jesus, Piauí. Source: Own (2019).

Associated with the variation of vegetation are the biophysical indices of surface temperature (Ts) and real evapotranspiration (ETr) (Table 1). Concerning Ts, it is noted that there was a variation from 25.75 to 35.57 ° C; 26.12 to 37.87 ° C and from 26.39 to 37.52 ° C; in the areas of CAbo, CAbu and CAb, respectively (Table 1).

It is worth mentioning that a relationship between this variable and the vegetation indices is noticeable, in which higher temperatures are related to areas of lower vegetation cover.

On the other hand, denser vegetation areas have a lower surface temperature on all evaluated dates (Table 1). The Ts variation, in this case, is related to the distribution of solar radiation in the vegetation, since areas that have greater coverage and plant density intercept greater amounts of radiation, preventing this energy from being available in greater quantities on the surface to heat it (ANDRADE et al., 2014).

In studies carried out on the same Caatinga fragments evaluated in the present study, Fernandes et al. (2019), seeking to characterize the energy balance, have found greater fractions of the radiation balance being directed to sensitive heat in areas of thinner vegetation (CAbu) and smaller ones in areas of higher density (CAbo), indicating greater heating of the surface in less dense areas, thus emphasizing the importance of the presence of vegetation in maintaining the surface temperature.

As for ETR, there were a variation between 3.64 and 5.33 mm.day-1; 3.54 and 5.28 mm.day-1 and from 3.31 to 5.41 mm.day-1; in the areas of CAbo, CAbu and CAb, respectively (Table 1). It is evident that the occurrence of greater quantities of this variable is associated with areas of denser vegetation, except for the image obtained in the month of May, in which the area with the highest density (CAbo) did not obtain a greater amount of water loss through evapotranspiration. This position was occupied by CAbu, which obtained 4.08 mm.day-1 of ETr.

Evapotranspiration is a biophysical process that directly depends on the leaf amount present in the vegetation, which are the biggest contributors to the transpiration process (PEREIRA et al., 2002) therefore, the characterization of denser vegetation that presents a greater IAF, in a given area, implies a greater amount of water lost in the evapotranspiration process.

In order to obtain a more concrete characterization of the space-temporal variation of ETR, this variable was spatialized (Figure 3), where values between 0 and 6.81 mm.day-1 were obtained in the region.

Considering the seasonal variation of the ETr images (Figure 3), it is noted that higher values of ETr spatially distributed can be observed in the image obtained in January. On the other hand, the image of July obtained lower values for this index.

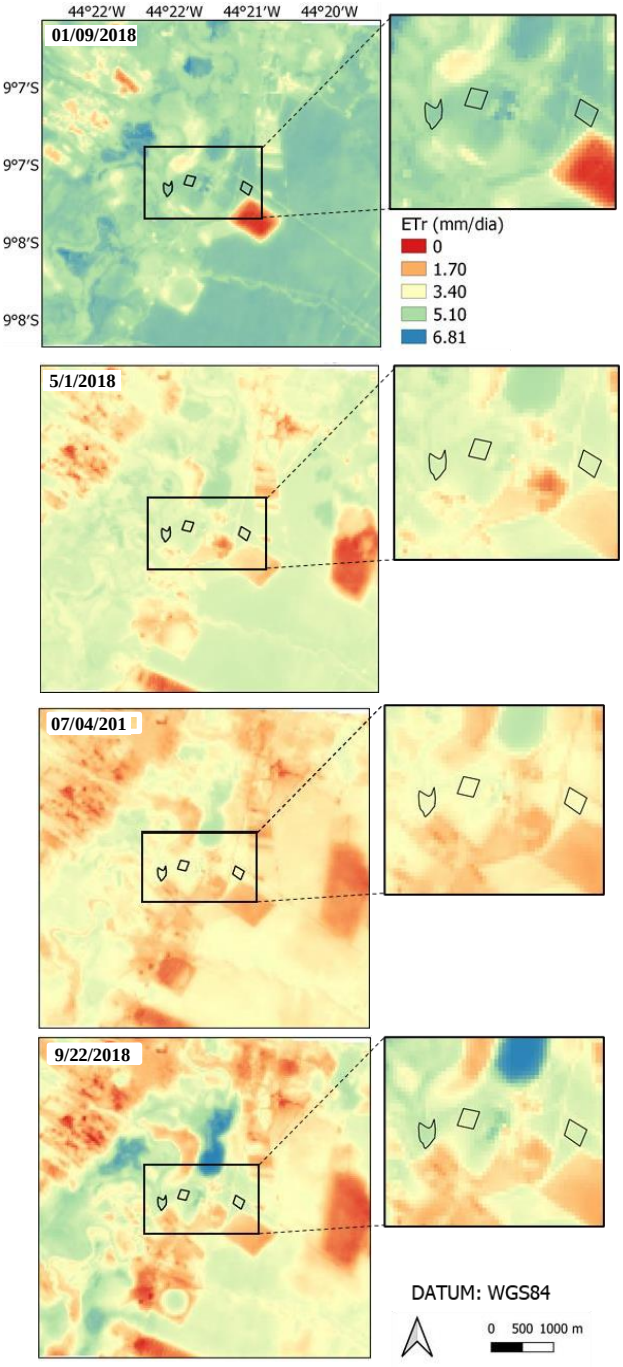

Figure 3 - Spatial and temporal variation of actual daily evapotranspiration (mm.day-1) in fragments of Caatinga located in the municipality of Bom Jesus, Piauí. Source: Own (2019).

In January, is predominant evapotranspiration between 5.10 and 6.81 mm.day-1, with a similar distribution between the areas of Caatinga, which presented ETR around 5.10 mm.day-1 (Figure 3). Higher values of ETr relative to this date may be associated with greater water availability in the region, during this period (Figure 2).

In May, there is a distribution of ETr values mostly between 1.70 and 5.10 mm.day-1, with the areas of the Caatinga fragments varying from 3.40 to 5.10 mm.day -1. Among the images, the one obtained in July showed lower ETr values, which are predominantly between 0 and 3.40 mm.day-1.

Values between 0 and 3.40 mm.day-1 prevail in the September image however, the areas of Caatinga evaluated obtained ETr between 3.40 and 5.10 mm.day-1. It is worth mentioning that the lowest values of evapotranspiration in May, July and September are related to the lowest total rainfall in their respective seasons (Figure 2).

Due to the low variation between the areas (CAbo, CAbu and CAb) for this variable, it is not possible to notice a trend in the influence of the size and vegetation cover characteristic of each fragment in the ETR, in the spatialized image (Figure 3). On the other hand, this relationship is evident when observing the average ETR (Table 1), as mentioned above.

Analyzing the energy balance in the same fragments, Fernandes et al. (2019), found a greater part of the available solar radiation being directed to the latent heat in the CAbo area, when compared to the others, emphasizing the relevance of the greater coverage and plant density in this area and its impact on evapotranspiration.

Caatinga areas on semiarid of Pernambuco that have herbaceous, shrubby and arboreal phytophysiognomy, analyzed by Lima et al. (2018) obtained evapotranspiration ranging from 0.2 to 4.9 mm.day-1 and a mean of 2.3 mm.day-1.

4. FINAL CONSIDERATIONS

The heterogeneous behavior in the Caatinga vegetation in the southwest of Piauí causes differences in the size and distribution of vegetation, which promotes spatial variation in vegetation indices. In the assessed areas, the arboreal Caatinga (CAbo) maintained a greater vegetation cover for most of the year.

The temporal variation of the NDVI, SAVI and IAF are related to the occurrence of precipitation in the region, higher values of these indices were found in the month in which there was an accumulation of precipitation (January).

The surface temperature is associated with the vegetation density, higher values in the vegetative indexes configure areas with lower surface temperature, showing the importance of the vegetation cover in the thermal maintenance of the surface.

The average evapotranspiration in the region is associated with the density of vegetation, areas with higher vegetative indexes are subject to losing a greater amount of water through the evapotranspiration process. Thus, evapotranspiration was higher in the CAbo fragment, for most of the year.

According to the data displayed, it is evident that the present work brings relevant results to the region and emphasizes the need for studies that aim to evaluate the importance of the presence and maintenance of natural vegetation in the biophysical processes that act on the terrestrial surface, as well as the impacts of removing and/or replacing these areas on these components.

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