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Meteorological Influence on Space-Time Distribution of Tomé-Açu (Eastern Amazon) Vegetation Cover Using MODIS Products

Influência meteorológica na distribuição espaço-temporal da cobertura vegetal de Tomé-Açu (Amazônia Oriental) utilizando produtos MODIS

Matheus Lima Rua[1], Gabriel Siqueira Tavares Fernandes[1], Anderson dos Santos[2], Mateus Augusto de Carvalho Santana[1], Marcos Vinicius Santos Pantoja[1] & Keila Beatriz Silva Teixeira[1]

[1]Universidade Federal Rural da Amazônia, Belém, PA, Brasil
[2]Universidade Federal Rural de Pernambuco, Recife, PE, Brasil

E-mails: matheusrua99@gmail.com, agrogabrielt@gmail.com, agryanderson@gmail.com, mateus.augustosants@gmail.com, marcospantojaagro@gmail.com, keilateixeiraagro@gmail.com
Corresponding author: Matheus Lima Rua; matheusrua99@gmail.com

Abstract

The objective of this study was to analyze the seasonal behavior of vegetation cover and its response to the variation of meteorological elements in the microregion of Tomé-Açu, Eastern Amazon. The study area refers to the microregion of Tomé-Açu, Pará. MODIS sensor images were processed and analyzed on Google Earth Engine and QGIS 3.18.1 software to apply the NDVI, EVI and LAI vegetation indices. Results showed that the vegetation cover of the Microregion of Tomé-Açu has well-defined seasonality, with evident variation in vegetation indices throughout the year. The three indexes showed higher values in the dry season period and lower values in the rainy period of the year. Seasonality of vegetation cover showed a positive correlation with rainfall in the region, with higher values associated with rainfall occurring between 4 and 5 months prior to the observation.

Keywords: Seasonal analysis; Meteorological elements; Ground cover

Resumo

O objetivo deste estudo foi analisar o comportamento sazonal da cobertura vegetal e sua resposta à variação dos elementos meteorológicos na microrregião de Tomé-Açu, Amazônia Oriental. A área de estudo refere-se à microrregião de Tomé-Açu, Pará. As imagens do sensor MODIS foram processadas e analisadas nos softwares Google Earth Engine e QGIS 3.18.1, referentes aos índices de vegetação NDVI, EVI e IAF. Os resultados mostraram que a cobertura vegetal da Microrregião de Tomé-Açu possui sazonalidade bem definida, com evidente variação nos índices de vegetação ao longo do ano. Os três índices apresentaram maiores valores no período menos chuvoso e menores valores no período mais chuvoso do ano. A sazonalidade da cobertura vegetal apresentou correlação positiva com as chuvas na região, com valores mais altos associados às chuvas ocorridas entre 4 e 5 meses anteriores à observação.

Palavras-chave: Análise sazonal; Elementos meteorológicos; Cobertura do solo

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1 Introduction

Currently, the observation of the earth's surface through satellite systems has stood out due to its efficiency and economy in obtaining information on terrestrial natural resources and vegetation conditions (Mallmann et al. 2015). The monitoring of attributes related to green areas, native vegetation and their functions enables the provision of indicators that assist in the environmental planning of municipalities, as a tool that establishes minimum values for vegetation cover, in addition to other indicators correlated with environmental quality (Martins et al. 2021).

In this context, remote sensing stands out amid studies of analysis, detection and monitoring of vegetation cover (Braz et al. 2015). Among the purposes of remote sensing, information on the earth's surface is obtained, based on images obtained through sensors (satellites, radars and/or cameras) (Martins et al. 2021). The results obtained through remote sensing allow the visualization of large territorial extensions, besides allowing the performance of seasonal and space-time analyses, both in the matter of land use and its occupation (Simões et al. 2017). Given this, this method presents itself as an innovative method for mapping areas, deforestation, fire detection, climate studies, and it has a lower cost than the installation, maintenance and retrieval of data from a meteorological station (Souza et al. 2014; Silva Junior et al. 2018; Velasque et al. 2018).

Vegetation cover analyses could be done by remote sensing applying vegetation indices, such as Normalized Difference Vegetation Index (NDVI). This index is widely used and attractive due to its ability to quickly identify vegetation, which is of great importance in studies of land use and vegetation monitoring (Huang et al. 2021).

Another index often used is the Enhanced Vegetation Index (EVI), being more sensitive to structural variations in the canopy, besides minimizing the influence of the atmosphere and soil (Huete et al. 2002). In addition, Leaf Area Index (LAI) collaborates in monitoring the development of vegetation over the years, being defined by the ratio between leaf area of all vegetation per unit of area used by it (Allen et al. 2002). These techniques are of great importance in analyses based on the monitoring of seasonal changes in the development and activity of vegetation (Jensen & Epiphanio 2009).

Thus, the aim of this study was to analyze the seasonal behavior of vegetation cover and its response to the variation of meteorological elements in the microregion of Tomé-Açu, Eastern Amazon, using vegetation indices NDVI, EVI and LAI.

2 Material and Methods

Area under study refers to the microregion of Tomé-Açu, located in northeastern Pará, which includes the municipalities of Acará, Concordia do Pará, Moju, Thailand and Tomé-Açu and has a territorial area of approximately 23,714,951 km² (IBGE 2020) (Figure 1).

According to Koppen's classification, the Microregion of Tomé-Açu has two climatic types: Af - Tropical without dry season and Am - Tropical monsoon. Af type has an average annual temperature greater than 26 °C and annual rainfall of approximately 2,500 mm, while Am type is characterized by average annual temperatures of approximately 26.5 °C and annual rainfall above 2,000 mm (Alvares et al. 2013).

The region under study presents predominance of three types of vegetation: 1) Dense anthropophilous forest of the lowlands; 2) Dense alluvial obiphilous forest; and 3) Secondary vegetation. In addition to agriculture and pasture areas (BDIA 2021). The dense ombrophilous forest vegetations of the lowlands are defined as a generally occupying formation of coastal plains, capeed by pliopleistocene plains of the Barreiras Group. While the vegetation of the dense alluvial obiphilous forest type is conceptualized as a riverside formation or "ciliary forest" of occurrence along the watercourses. Secondary vegetation is present in areas where there has been human intervention for land use (mining, agriculture or livestock), mischaracterizing primary vegetation. Thus, after the abandonment of these areas, this vegetation reacts differently according to the time and form of land use (IBGE 2012).

Rainfall and air temperature data refer to the years 2009 to 2020 and were obtained through the automatic weather station of the National Institute of Meteorology (INMET) (-2.59°S, -48.36°W) of the municipality of Tomé-Açu (Figure 1).

Twenty images were elaborated, referring to each month of the year, representing the monthly averages between the years 2010 to 2020, to analyze the seasonality and spatial distribution of vegetation. For the seasonal analysis of vegetation cover in the Microregion of Tomé-Açu, MODIS sensor products were used. Products are located in the Terra and Aqua satellites. Products used were *Leaf Area Index*/FPAR (MODIS/006/MCD15A3H) to obtain Leaf Area Index (LAI) with 500 m of spatial resolution and 4 days of temporal resolution. Product *Terra Vegetation Indices* (MODIS/006/MOD13A1) were applied to obtain the NDVI and EVI indices with 500 m of spatial resolution and 16 days of temporal resolution.

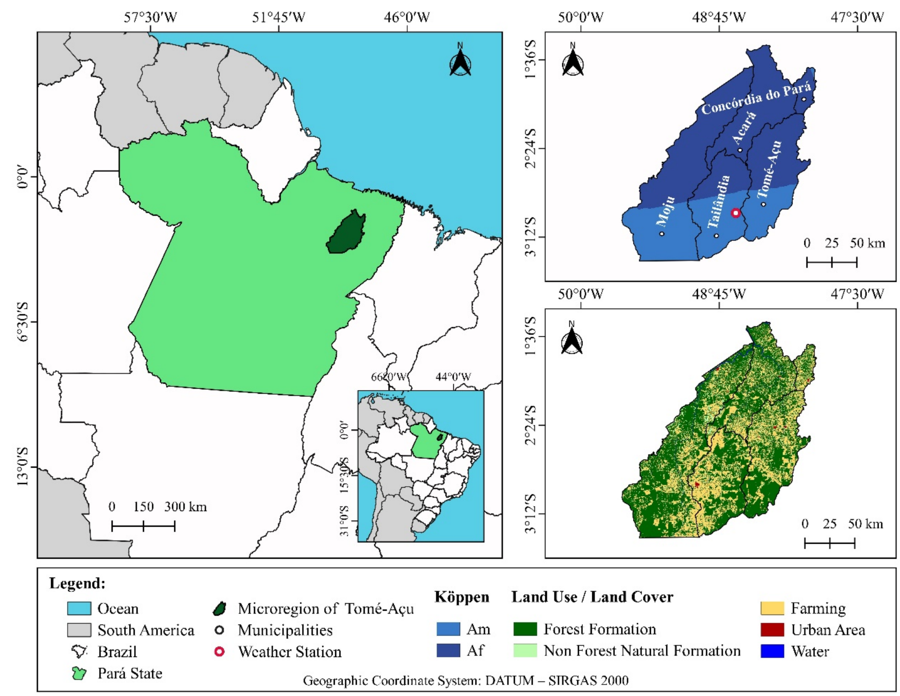

Figure 1 Location of the Tomé-Açu microregion, northeast of Pará.

The images were transmitted and processed on the Google Earth Engine platform and after the acquisition of the images, a monthly average of each index was performed, in which an average of eight images were performed for LAI and for NDVI and EVI two images per month.

These average images were taken for a period of one year, that is, generating one image per month, later a general spatial media was performed, considering the 20 years of data. After obtaining the 20-year parallel average images, they were exported and directed to the software QGIS 3.18.1 (QGIS Development Team 2021), where the maps were drawn up.

In order to evaluate the impact of changes in soil use and cover caused in biophysical variables in the microregion of Tomé-Açu, descriptive statistical parameters (i.e., minimum, maximum, mean, median and standard deviation) were extracted from indices (NDVI, EVI and LAI) in each class of land use and cover from the maps available on the collection 6 of the MapBiomas Brasil platform (MapBiomas Brasil 2022), using the QGIS software3.18.1 (QGIS Development Team 2021). This collection is highly reliable, includes annual land use and land cover data for the period 1985 to 2021, and prioritizes the following classes: (1) forest formation, (2) non-forest natural formation, (3) agriculture, (4) urbanized area, and (8) water bodies with spatial resolution of 30 meters (Pérez-Hoyos et al. 2017; Fendrich et al. 2020).

The meteorological and vegetation index data obtained were submitted to hierarchical cluster analysis based on the Euclidean distance measure and the agglomeration criterion proposed by Ward (1963), seeking to generate groups (clusters) that had a high internal homogeneity. The techniques were implemented with the software R 3.6.1 (R Core Team 2019).

The data obtained for vegetation indices (VI's) were correlated via correlation matrix through Past software (PAST 2022), with weather data and precipitation, considering current precipitation (PP - current month of observation) and the precipitation occurred 1, 2, 3, 4, 5 and 6 months prior to the month of observation.

3 Results and Discussion

Regarding the meteorological variables analyzed from 2009 to 2020, the air temperature (Tar) had an average of 26.28 °C (± 0.54), average maximum of 27.16 °C and average minimum of 25.55 °C. The average annual rainfall (PP) was 2,227.80 mm, with April characterized as the rainiest month with an average of 380.53 mm, and August the least rainy month with an average of 36.42 mm (Figure 2).

Monthly precipitation reaches values above 150 mm during the period between December and May, characterizing a rainiest season that represents about 82% of the annual precipitation, and decreases between the months of June and November, which marks the dry season (Figure 2).

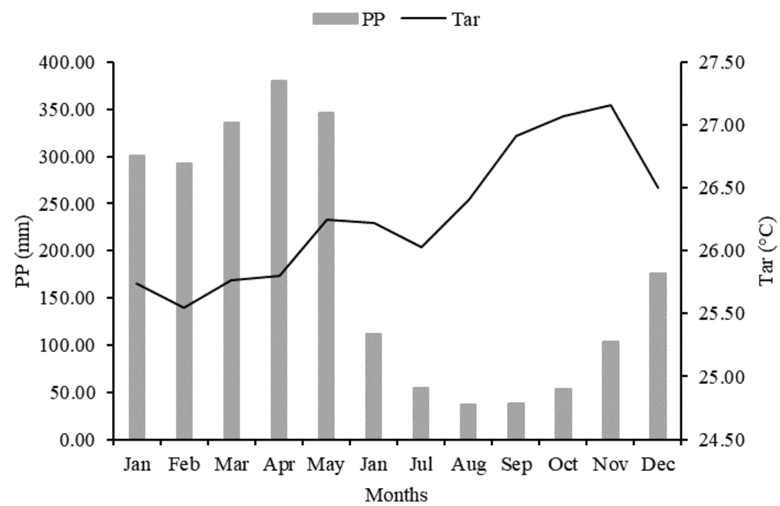

Figure 2 Average values of Rainfall (PP) and average Air Temperature (Tar), from the Tomé-Açu meteorological station, between 2009 and 2020.

The temporal variability of the meteorological elements of air temperature and precipitation over the years studied can be observed in Figure 3. It is noted that there is a well-defined seasonal pattern even with the interannual variation, evidencing the pattern obtained in Figure 2, where there are higher rainfall totals and lower air temperatures between December and May (rainy period).

To study the temporal and spatial characteristics of the changes that occurred in the terrestrial surface vegetation of the Tomé-Açu microregion, in response to the variability of rainfall and air temperature, the monthly averages of vegetation indexes NDVI, EVI and LAI were estimated for the period from 2009 to 2020.

In general, the vegetation cover showed a notable variation of the vegetation cover throughout the year. These indices showed seasonal peaks in June and July, months that integrate the transition from the rainiest to the least rainy period. While February integrates the rainiest season of the year and has the lowest average values of NDVI, EVI and LAI (Figures 2 and 4). It is also observed that the average monthly VI's indicate a cycle of growth and development of vegetation throughout the year with two well-defined seasons. The first station shows that the increase in the spectral response of vegetation starts from April and reaches its maximum in June (NDVI) and July (EVI and LAI). On the other hand, the second season indicates a trend of reduction in vegetation cover, which starts from August and extends until March (Figure 4). This shows that the seasonality of NDVI, EVI and LAI in the Tomé-Açu micro-region follows a similar pattern.

Regarding the two dry season and rainy seasons, the mean and respective standard deviations for the variables analyzed in Table 1 can be observed. It is noted that the dry season period presented higher vegetation rates, indicating higher vegetation cover at this time. On the other hand, minors VI's are found in the rainy season of the year.

The monthly average of NDVI for the period 2010 to 2020 are presented in Figure 5. In the present study, NDVI presented average annual value and standard deviation of (0.711 ± 0.052), reaching minimum values of ~ 0.22 and maximum of 0.90. Therefore, the months from May to July stood out as the period of largest vegetation coverage in much of the Tomé-Açu microregion, reaching the highest average NDVI values ranging from (0.772± 0.041 to 0.828 ± 0.043). Similarly, from January to March presented the minors values with NDVI varying predominantly between (0.476 ± 0.059 to 0.503 ± 0.065) (Figure 4).

Certainly, native vegetation areas showed greater resistance, recovery and resilience to seasonal variations of precipitation that occurred throughout the study period, being responsible for the highest NDVI values, which ranged from 0.584 ± 0.054 in February to 0.858 ± 0.016 in June. On the other hand, areas with agricultural activity (pasture and agriculture) were more susceptible to seasonal variations in precipitation, a fact observed by the greater fluctuation and lower NDVI values, which ranged from 0.565 ± 0.064 in February to 0.764 ± 0.058 in June.

Figure 6 shows the variability of the average monthly EVI in the period from 2010 to 2020 for the Tomé-Açu micro-region. Range of EVI values is comparatively smaller than the NDVI values over the period. Such differences between these indices may be related to the intrinsic characteristics of each one of them. Although NDVI has greater sensitivity to chlorophyll and other pigments that are also responsible for the absorption of solar radiation in the red band, this index is more saturated at higher biomass levels due to leaf canopy variations. While EVI minimizes this error, as it improves the estimate of the biomass level under saturation conditions, presenting greater sensitivity to canopy variation, plant physiognomy and LAI (Gao et al. 2000; Huete et al. 2002; Gu et al. 2008). In addition, the EVI range is more extensive and dynamic and allows the capture of more variations than the NDVI, as it includes the resistance coefficient terms that correct for the influence of aerossol (Hu et al. 2021).

At first, the average EVI within the microregion was 0.486 ± 0.038, reaching minimum values of ~0.17 and maximum of ~0.70. Therefore, the EVI showed similar seasonality of the spectral response of the vegetation cover compared to the NDVI, differing only in terms of the month with the highest spectral responses of the vegetation, reaching values of ~0.534. Meanwhile, the months from January to March showed a variation in the mean values of EVI from 0.435 ± 0.044 to 0.443 ± 0.047.

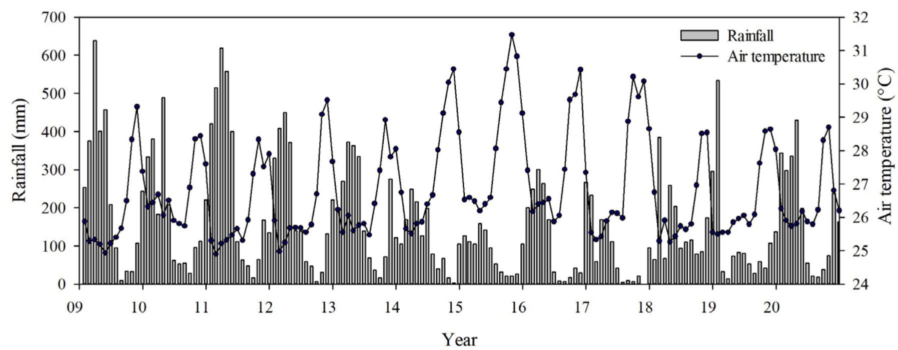

Figure 3 Temporal variability of meteorological elements of rainfall and air temperature for the microregion of Tomé-Açu. Eastern Amazon.

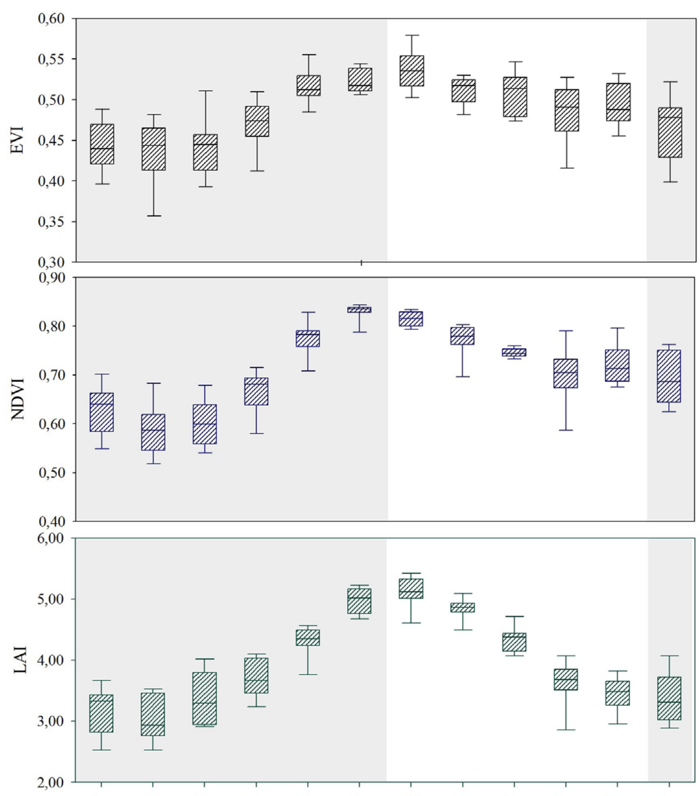

Figure 4 Average values, in the rainy season (dark area) and dry season (light area), in the Tomé-Açu micro-region of: A. NDVI; B. EVI; C. LAI.

Table 1 Mean and standard deviation of the rainiest and dry seasons for NDVI, EVI, LAI, Rainfall (PP) and Air Temperature (Tar).

Variable	Season	
	Rainy	Dry
NDVI	0.66 ± 0.07	0.76 ± 0.05
EVI	0.46 ± 0.03	0.51 ± 0.02
LAI	3.5 ± 0.46	4.39 ± 0.71
PP	1830.8 ± 70.9	397 ± 33.3
Tar	25.93 ± 0.36	26.63 ± 0.47

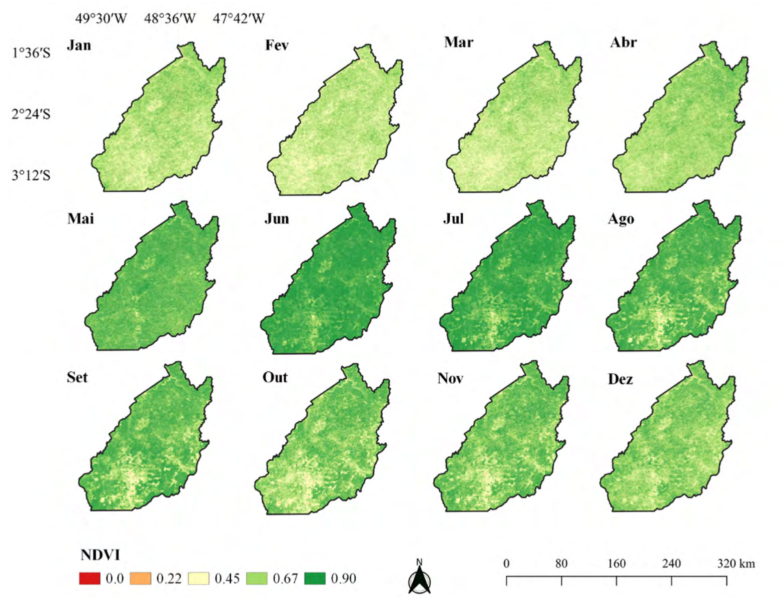

Figure 5 Spatio-temporal distribution of the average monthly NDVI from 2010 to 2020 for the microregion of Tomé-Açu, northeast of Pará.

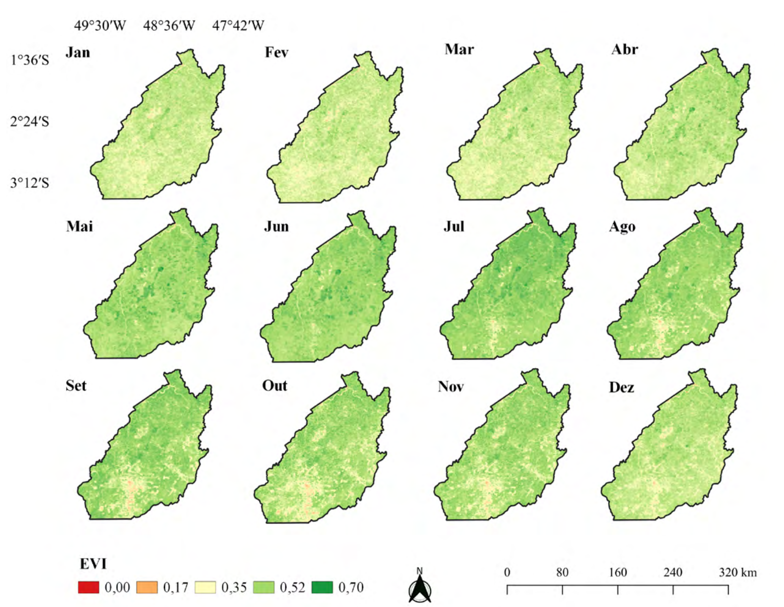

Figure 6 Spatio-temporal distribution of the average monthly EVI from 2010 to 2020 for the microregion of Tomé-Açu, northeast of Pará.

It is worth noting that the smallest standard deviations of the VI's metrics were obtained from the average monthly data of the EVI, suggesting less sensitivity to the leaf canopy context and atmospheric effects of the index. According to Buides et al. (2022), the EVI can provide indications on green and vegetation cover (leaf area) over time in response to the energy available for photosynthesis and water supply, being suitable for areas with dense vegetation and high biomass compared to other indices, such as NDVI.

Spatially, the lowest EVI values were found in urban areas (0.358 ± 0.066) and with agricultural activity (0.440 ± 0.050). The agricultural activity presents rainfeed cultivation practices, areas in the soil preparation phase for cultivation, intense grazing activity and high degree of degradation of pastures, factors that reduce the percentage of soil cover and vegetation density, often resulting in exposed soil. In addition, this heterogeneity of areas impacts spatio-temporal dynamics and causes sudden variations in VI's (Marengo et al. 2018; Ferreira et al. 2020; Jardim et al. 2022). On the other hand, the highest EVI values occurred in areas with forest formation (0.492), which were more homogeneous as indicated by the lowest standard deviation (± 0.040). The native arboreal vegetation of the Amazon biome is less susceptible to climatic variations in relation to the vegetation cultivated in agricultural areas, making seasonal variations in VI's values less drastic.

In the period studied, the mean annual LAI was (3.95 ± 0.733.02 $m^2 m^{-2}$), with a maximum mean value of $m^2 m^{-2}$and a mean minimum of $m^2 m^{-2}$. Due to seasonal variation, from October to April, the occurrence of the lowest leaf area index values is observed, with sequential increase from May onwards, remaining mostly between 4.97 and 6.50 $m^2 m^{-2}$ until September, characterizing this period as the one with the highest LAI (Figure 7).

Based on land use and occupation data, the lowest average annual LAI was measured for urban areas (1,230 ± 0,519 $m^2 m^{-2}$) and areas with agricultural activity (1,928 ± 0,380 $m^2 m^{-2}$). In relation to agriculture, the lowest values were verified in pasture areas. On the other hand, the highest values of average annual LAI were observed in areas with forest formation (4.475 ± 0.169 $m^2 m^{-2}$).

While in agricultural areas the highest average value of LAI was observed in the month of June (2.878 ± 0.721 $m^2 m^{-2}$), in areas of native vegetation the highest average value of LAI was observed in the month of August (5.602 ± 0.219 $m^2 m^{-2}$).

According to the hierarchical cluster analysis (Figure 8), two homogeneous clusters were identified, considering both meteorological and vegetation quantification variables. The first cluster (Group 1) considers the rainy period (December to March) and the months of June and November, which present precipitation above 100 mm, lower temperatures and lower values of vegetation indices. Second cluster (Group 2) refers to the dry period and is associated with lower rainfall rate, higher temperatures and vegetation indices values.

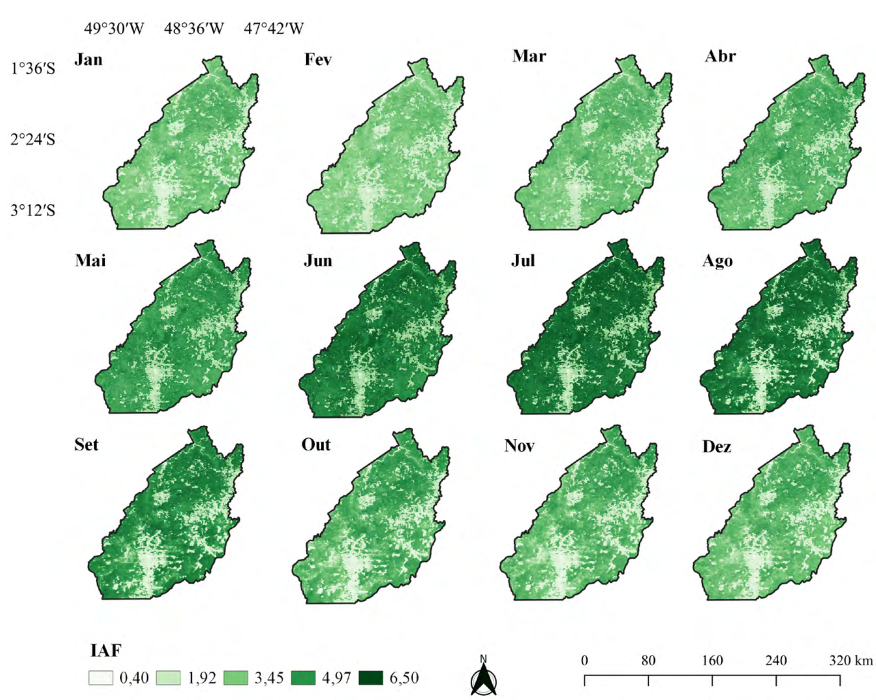

Figure 7 Spatio-temporal distribution of the average monthly LAI from 2010 to 2020 for the Tomé-Açu microregion, northeast of Pará.

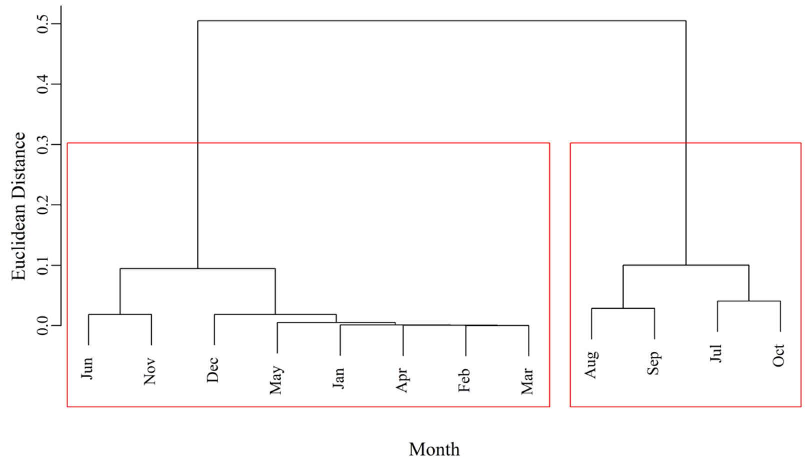

Figure 8 Cluster analysis for the variables LAI, NDVI, EVI, rainfall and air temperature.

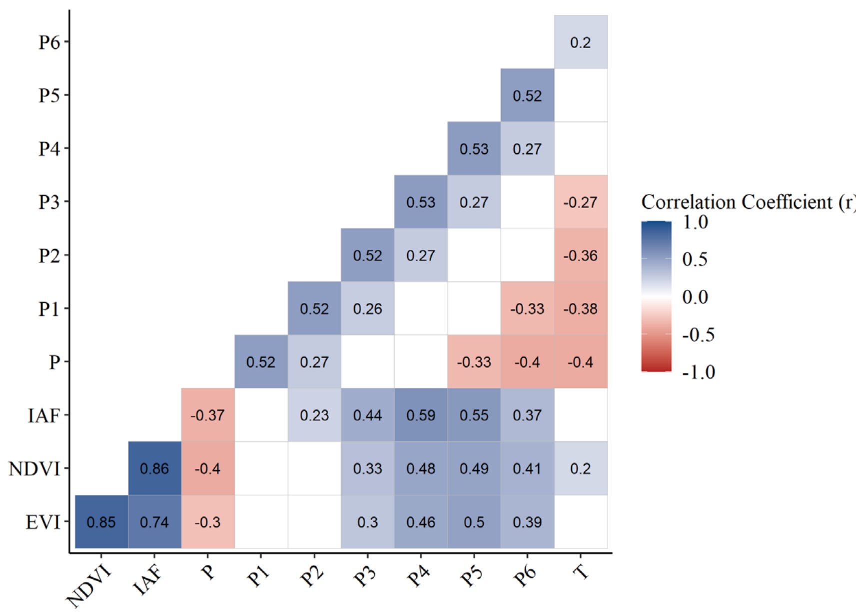

Figure 9 Correlation between vegetation indices and meteorological variables of air temperature and current precipitation (P - current month of observation) and precipitation that occurred 1, 2, 3, 4, 5 and 6 months prior to the month of observation.

Paiva and Jesus (2016) emphasize that the Amazonian vegetation, in relation to the seasonality of the NDVI, has higher values after the rainy season and lower values occurring after the dry season. The same authors state that this vegetation responds to water excess in the temporal period of one to four months and from one month to water deficit. In contrast, Xie et al. (2022), studying the entire Amazon region, show that the pattern of increase in vegetation cover in the dry season period occurs in most of the biome, with the EVI and LAI indices reaching their maximum between the end of the rainy season and the beginning of the dry season, corroborating the present study (Figure 4). Huete et al. (2006) and Saleska et al. (2016) previously documented similar behavior for the dynamics of vegetation cover in the Amazon.

Based on the correlation analysis between vegetation indices and air temperature and rainfall data (Figure 9), it was observed that the seasonal variation of vegetation cover based on NDVI, EVI and LAI showed a negative correlation (-0.39, -0.30 and -0.37, respectively) that was significant (p <0.05), with rainfall values collected in the same month (P).

The highest positive correlations obtained occurred between vegetation indices and rainfall four and five months in advance (P4 and P5) of the month of observation, reaching 0.48, 0.46 and 0.59 for NDVI, EVI and LAI, respectively, considering P4 and; 0.49, 0.50 and 0.55, for the same sequence of indices, in relation to P5. Being classified as a median correlation (Christmann 1978). In this sense, it can be attributed that the vegetation cover of this region will only respond effectively, in relation to its development, to the monthly water supply in the period of 4 to 5 months. As for the correlation between vegetation indices and air temperature, a low correlation was observed between these variables.

The IV's are directly proportional to the amount of rainfall in the region, but with a delay in vegetation feedback, as also observed by Dantas et al. (2016) in the Caatinga and Atlantic Forest. So, seasonality of the vegetation cover presents a behavior consistent with the amount of rain, indicating that the response of the vegetation, with regard to the production of biomass, by the water supply, occurs with a certain delay in time.

Physiologically, after the sprouting of the leaves, which in turn is stimulated by photosynthesis, being conditioned by the supply of water, the leaves need about a month to carry out their maturation process. Subsequently, the new mature leaves reach the peak of photosynthesis, resulting in a delay in the increase in the production of photoassimilates and, consequently, in an increase in biomass (Restrepo-Coupe et al. 2013; Taiz & Zeiger 2013). Jones et al. (2012) elucidate that aboveground biomass requires time to grow and develop. Thus, the delay in the response of vegetation through IV's to meteorological stimuli may be related to the intrinsic characteristics of plants.

Therefore, studies of this nature, which aim to identify and characterize the seasonality of vegetation, as well as its response to environmental stimuli, are of total relevance to the understanding of ecosystem processes in the Amazon, fostering an understanding of the dynamics between vegetation and atmosphere. Thus, the importance of further studies in the biome is reiterated, aiming at its conservation and the perpetuation of species, considering the already occurring climate changes.

Additionally, it is worth mentioning the relevance of monitoring the vegetation of Brazilian biomes with a focus on detecting changes and deforestation, in view of the expansion of anthropic activities, especially in monoculture areas, as emphasized by Moura Neto et al. (2022), which quantify the impacts of monoculture in the Caatinga Biome and highlight the importance of preserving native vegetation in mitigating climate change. In this sense, it is suggested that more work be carried out in the region with the intention of understanding the changes in the surface and their possible environmental impacts.

4 Conclusion

Vegetation cover of the Tomé-Açu micro-region has a well-defined seasonality, with evident variation in vegetation indices.

The vegetation indices NDVI, EVI and LAI showed similar results regarding the seasonality of vegetation cover over the analyzed period, showing higher values in the dry period and lower values in the rainy period of the year.

Seasonality of the vegetation cover was related to the rainfall in the region, with a response between four and five months after the record of the volume of rain, evidencing a response of the indexes after the rainy season, resulting in greater vegetation cover during the dry period of the year.

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Author contributions

Matheus Lima Rua: conceptualization; formal analysis; methodology; writing-original draft; writing - review and editing; visualization. Gabriel Siqueira Tavares Fernandes: conceptualization; formal analysis; methodology; writing-original draft; writing - review and editing; supervision; visualization. Anderson dos Santos: formal analysis; writing-original draft; writing – review and editing; visualization. Mateus Augusto de Carvalho Santana: writing-original draft; visualization. Marcos Vinicius Santos Pantoja: conceptualization; writing-original draft; visualization. Keila Beatriz Silva Teixeira: conceptualization; writing-original draft; visualization.

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