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Environmental diagnosis by vegetation indices in the Mata da Pimenteira State Park during the rainy and dry seasons

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A B S T R A C T

The objective was to evaluate the Mata da Pimenteira State Park (*Parque Estadual da Mata da Pimenteira - PEMP*) in the rainy and dry periods, based on Sentinel-2 satellite images. The study area belongs to the municipality of Serra Talhada, Pernambuco. The sets of remote sensing techniques and satellite orbital images were used in Google Earth Engine to obtain a composition of the rainy and dry periods; then, in the *QGIS* software version 3.4, the vegetation indices (NDVI and VCI) were determined. With the vegetation indices, it was possible to obtain the descriptive statistics and count the vegetation classes, classified from the *r.recode* tool, in which the map for the analyses and diagnosis of the study area was realized. The spectral response of NDVI in the Caatinga vegetation averaged near 0.7 in the rainy period and 0.3 in the dry period. The severe level of the vegetation condition index predominates for the dry period and is very mild for the rainy period. The PEMP presents, in the rainy period, 75% of the area as a very light drought class of vegetation cover. On the order hand, the dry period presents 90% of the area in the severe drought condition. Finally, remote sensing indices made it possible to identify the evolution in the vegetation co ver of the area, identifying the most critical zones.

Diagnóstico ambiental por índices de vegetação no Parque Estadual Mata da Pimenteira no período chuvoso e seco

R E S U M O

O objetivo era avaliar o Parque Estadual da Mata da Pimenteira (PEMP) nos períodos de chuva e seca, com base em imagens de satélite Sentinel-2. A área de estudo pertence ao município de Serra Talhada, Pernambuco. Os conjuntos de técnicas de detecção remota e imagens orbitais de satélite foram utilizados no Google Earth Engine para obter uma composição dos períodos chuvoso e seco, em seguida, no software *QGIS* versão 3.4, foram determinados os índices de vegetação (NDVI e VCI). Com os índices de vegetação, foi possível obter a estatística descritiva e contar as classes de vegetação, classificadas a partir da ferramenta *r.recode*, na qual o mapa para as análises e diagnóstico da área de estudo foram realizados. A resposta espectral da NDVI na vegetação da Caatinga foi em média perto de 0,7 no período chuvoso e 0,3 no período seco. O nível severo do índice do estado da vegetação predomina para o período seco e é muito suave para o período chuvoso. O PEMP apresenta, no período chuvoso, 75% da área como uma classe de cobertura vegetal muito ligeira no período de seca. Na ordem, o período seco apresenta 90% da área no estado de seca severa. Finalmente, índices de sensoriamento remoto permitiram identificar a evolução na cobertura vegetal da área, identificando as zonas mais críticas.

Palavras-chave: unidade de conservação, geoprocessamento, índices de vegetação, diagnóstico ambiental.

Introduction

According to Fonseca et al. (2010), conservation units are protected areas that play an essential role in maintaining local biodiversity and are essential so that natural resources are not lost. With the growing demand due to the increase in human population and, consequently, not to lose all the benefits derived from them, it becomes increasingly important to reserve spaces for environmental conservation. Therefore, the monitoring/diagnosis of these sites is of utmost importance to effectively manage these environments.

With the help of new technologies that facilitate obtaining and processing geospatial data, such as orbital remote sensing, it is possible to understand different spatial and temporal variability phenomena. Within this context, the land use and land cover analysis can indicate the dynamics of the activities developed in a given space. In this way, remote sensing can provide this information quickly and accurately at a low operational cost.

The remote sensing techniques allow us to obtain images of the land cover in space and time and understand the dynamics of land use and occupation depending on the spectral responses. For this purpose, some indices allow understanding of the cover changes, highlighting the normalized difference vegetation index (NDVI) (Bezerra et al., 2020; Nascimento et al.,2020). These tools seek to analyze the situation of vegetation, and there are specific cases in which the use of only the NDVI cannot be accurate enough to indicate changes, for example, when used to analyze the Caatinga vegetation in dry periods. So, other indices can help to understand the local dynamics, being the vegetation conditions index (VCI), derived from the NDVI itself, a tool to verify the dry conditions of the vegetation over time (Moreira et al., 2015; Jiao et al., 2016).

In the semi-arid region of Pernambuco, the State Government of Pernambuco created the Mata da Pimenteira State Park (*Parque Estadual da Mata da Pimenteira - PEMP*) in 2012. Since its creation, this conservation unit has kept the vegetation intact and allows it to be a viable object of study of the Caatinga biome. In this sense, some studies have analyzed the vegetation cover by remote sensing products in PEMP, such as Bilar et al. (2018). The authors analyzed the conditions of the vegetation cover of the Park in three different years (2007, 2013, and 2016) with NDVI and other vegetation indices. Sousa and Santos (2020) observed the changes in land use and land cover over ten years, before and after the creation of the Park. However, this study performed an unsupervised classification based on an RGB mosaic.

These studies used the Landsat products with a spatial resolution of 30 meters and a temporal resolution of 16 days. Moreover, the evaluation consisted of scenes obtained on specific and close dates, making the analysis more susceptible to biases. Since the Caatinga tends to recover quickly in the face of rainfall events furthermore, they did not identify the difference in behavior in the rainy and dry seasons. Thus, the proposed study presents a different use of the Sentinel-2 product, with better spatial (10 m) and temporal (5 days) resolution. In addition, digital cloud processing was used through the Google Earth Engine Platform (Gorelick et al., 2017) to generate a reduced image in the wet and dry seasons.

This study started from the premise that digital cloud processing of an image collection allows characterizing the differences in the spectral response of the vegetation cover in the Caatinga biome in a semi-arid region. Thus, the objective of this work was to analyze the NDVI and VCI from 2016 to 2020 in the rainy and dry period, with the use of geoprocessing and remote sensing in the Mata da Pimenteira State Park located in Serra Talhada -PE.

Material and Methods

Study area

The Mapa da Pimenteira State Park (*Parque Estadual da Mata da Pimenteira - PEMP*) is located in the central Pernambuco hinterland, microregion of Pajeú, more precisely in the Saco Farm, rural area of Serra Talhada, Pernambuco state, Brazil (Figure 1), at the geographical coordinates 7°56'10'' S and 38°17'55'' W with an altitude of 613 m. It has an area of 887.24 hectares with soft-rounded relief and typical vegetation being the hyperxerophilic Caatinga. It has an average annual temperature of around 37 °C and precipitation in the range of 400 to 800 mm annually (PERNAMBUCO, 2013).

Data Base

Precipitation data for the study area comes from the Pernambuco Agency of Water and Climate (APAC) from 1987 to 2020 from the weather station located in Serra Talhada. The data are available as monthly accumulated, determining the monthly average for the period.

The image layers were generated on the Google Earth Engine platform using Sentinel-2 satellite image collection. For this, obtained ten reduced scenes were obtained for 2016, 2017, 2018, 2019, and 2020 in two periods of each year: rainy and dry. The rainy period was considered from January to April and the dry period from August to November.

A cloud mask was applied with maximum coverage of 10%, to the scenes to obtain better images in each evaluation period through the digital processing script. In addition, the pixel average as an image reduction criterion in each period.

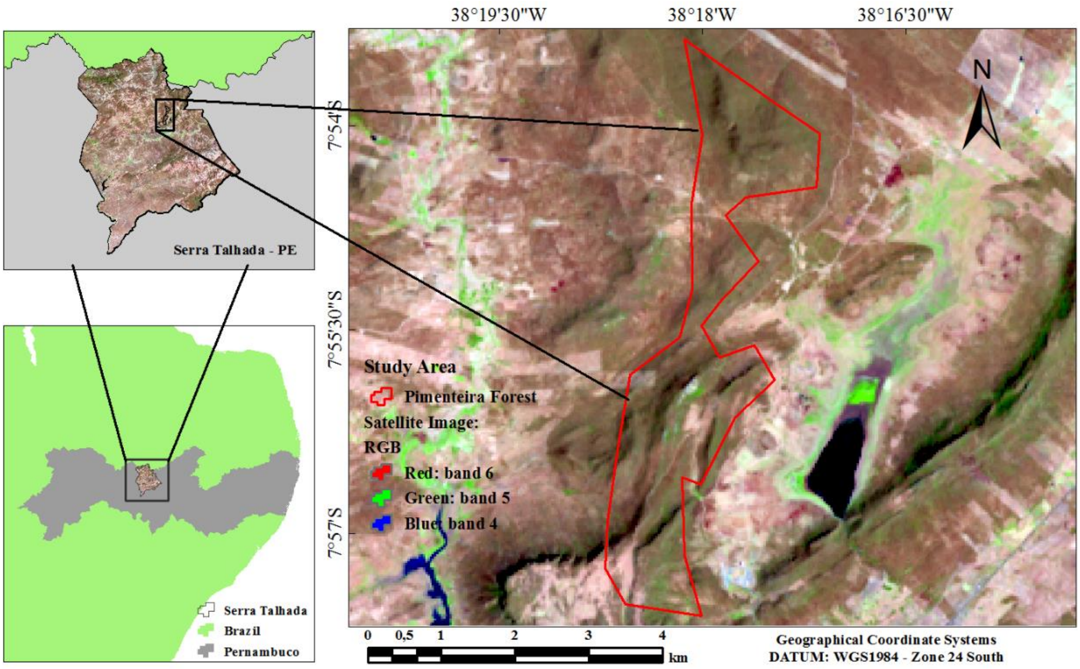

Figure 1. Spatial geographic location of the study area, Mata da Pimenteira, Serra Talhada, Pernambuco, Brazil.

Digital Processing of the Images

For the digital processing of the data, the free access software Qgis version 3.4 (wood) was used, selecting the multispectral bands 8 (near-infrared) and 4 (red) for the calculation of the NDVI. A descriptive statistical analysis of the 20 images considered in this study was performed: 10 NDVI images (dry and rainy) and 10 VCI images (dry and rainy). The raster calculator was used to obtain the layers with the application of the methodology used by Bezerra (2019):

$$NDVI = \frac{RbIV - RBV}{RbIV + RBV}$$

NDVI: Normalized Difference Vegetation Index; RbIV: Near-Infrared band reflectance; RBV: Red band reflectance.

The NDVI values vary from -1 to 1 and its classes were divided into five ranges: class 1: water body (-1 to 0); class 2: exposed soil/buildings (0 to 0.1); class 3: low vegetation density (0.1 to 0.3); class 4: medium vegetation density (0.3 to 0.5); class 5: high vegetation density (0.5 to 1).

From the generated NDVI images was also generated the VCI vegetation index, which uses statistics from the image itself previously generated, where we adopted the formula used by Moreira et al. (2015):

$$VCI = \left(\frac{NDVI - NDVImin}{NDVImax - NDVImin}\right) * 100$$

NDVI: NDVI value of the pixel; NDVImin: lowest NDVI value; NDVImax: highest NDVI value.

The VCI values range from 0 to 100 and are represented in percentage, indicating the vegetation cover level of dryness from the control of local differences in vegetation (Jiao et al., 2016). To this end, we performed a classification of the drought level into the following classes: class 1 - extreme (0 to 20%); class 2 - Severe (20 to 40%); class 3 - Moderate (40 to 60%); class 4 - Light (60 to 80%); class 5 - Very light (80 to 100%) (Villalta; Navas; Pérez, 2019). Finally, we classified the images according to the previously-mentioned classes, and we generated the thematic maps were. Then, we performed the counting of the classes with the r.recode tool of Qgis to follow the quantification of the cover classes.

Results and Discussion

Rainfall

From the graph of accumulated monthly precipitation (Figure 2), it can be noted that the highest values for the summer/autumn in March 2020. The spring presented lower values, with accumulated near zero, as can also be seen in works done with a similar period, performed by Marengo (2011); Silva (2017; Medeiros (2019).

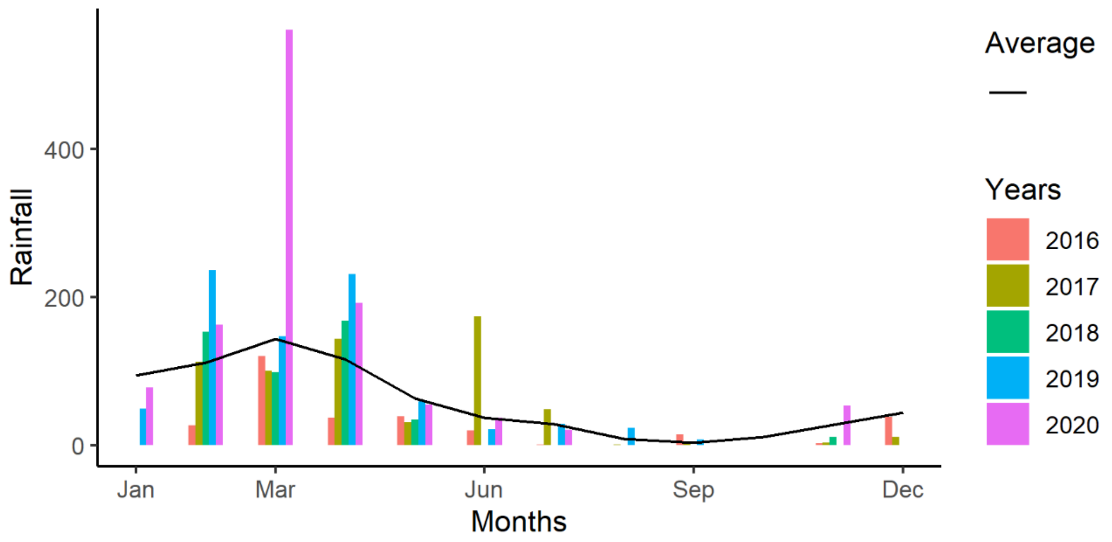

Figure 2. Accumulated monthly precipitation between 2016 and 2020 for Serra Talhada-PE, and the black line corresponds to the monthly average from 1987 to 2020.

Temporal variability of NDVI and VCI

The rainy season presented NDVI results near 0.7, from 2016 to 2020, similar to Bezerra et al. (2014), who obtained higher values in the range of 0.7 to 0.8 and Lourenço et al. (2017) with an average of 0.619. For the dry period, the average observed was 0.30, approaching the data found by Bezerra et al. (2014) with the lowest values in the range 0 to 2 and those of Lourenço et al. (2017) with 0.463, Bilar et al. (2018) found values lower than 0.4 in the spatio-temporal analysis and Silva et al. (2019) found similar averages (Figure 3A).

Figure 3. Rainy and dry season average values between 2016 and 2020: (A) NDVI; (B) VCI.

However, the rainy period presented in 2018 has a lower result than others, and the dry period presented the year 2020 above the others (Figure 3A). While the results of the VCI (Figure 3B) present a similar behavior, in which the dry period of 2020 presented a higher average concerning previous years and the rainy period of 2018 the lowest in relation to the others. The year 2018 presented a lower average in the rainy season due to the cloud cover criterion used in the choice of images; in this case, the maximum cloud cover of 10. Thus, the collection images were concentrated at the beginning of the rainy season, with little cloud cover, a time when the vegetation had not yet responded with maximum vigor.

In turn, the year 2020 showed a more significant response in the dry period due to precipitation events at the end of the rainy season - especially March and April - above the historical average for the period (Figure 2). With this, soil moisture was maintained longer in the PEMP, which allowed vegetation vigor to be maintained longer in the dry season.

Spatial variability of NDVI and VCI

In the rainy season, Figure 4 presents the NDVI maps which shows a high vegetation density class, but in 2018 showed a large medium and low-density vegetation, as discussed previously.

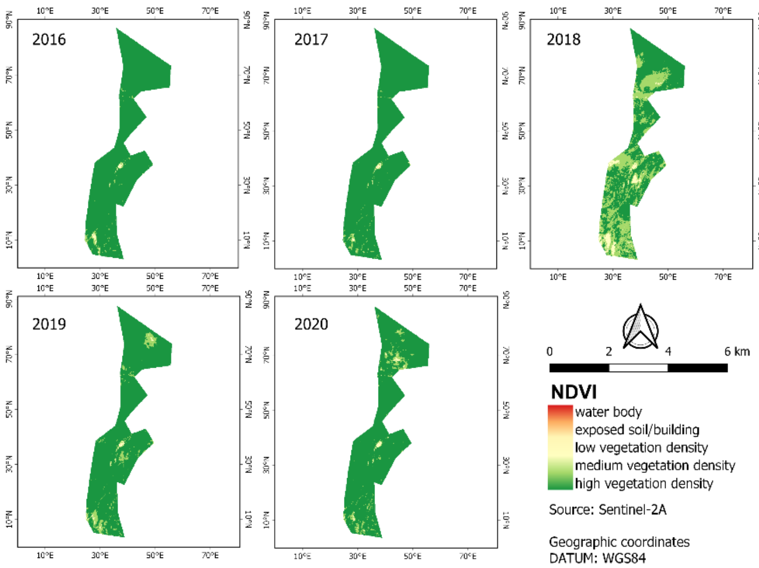

Figure 4. Rainy season NDVI – Classified images in PEMP for 2016 to 2020.

While in the dry season, 2020 presents a different condition (Figure 5) and a predominance of the medium density of vegetation. Overall, for the other years, predominate areas with low vegetation density since the vegetation becomes sparse, this is because, in the dry period, most of the species of the Caatinga vegetation lose their leaves (MOURA et al., 2016) and decreases considerably the photosynthetic activity, which reduces the response of the vegetation indices. The results diverged from the study conducted by Sousa and Santos (2020), who used the unsupervised method on Landsat RGB products and found a predominance of denser vegetation. This difference in the type of cover is probably due to the methodologies used and the application of vegetation indices (NDVI and VCI) and other classification ranges.

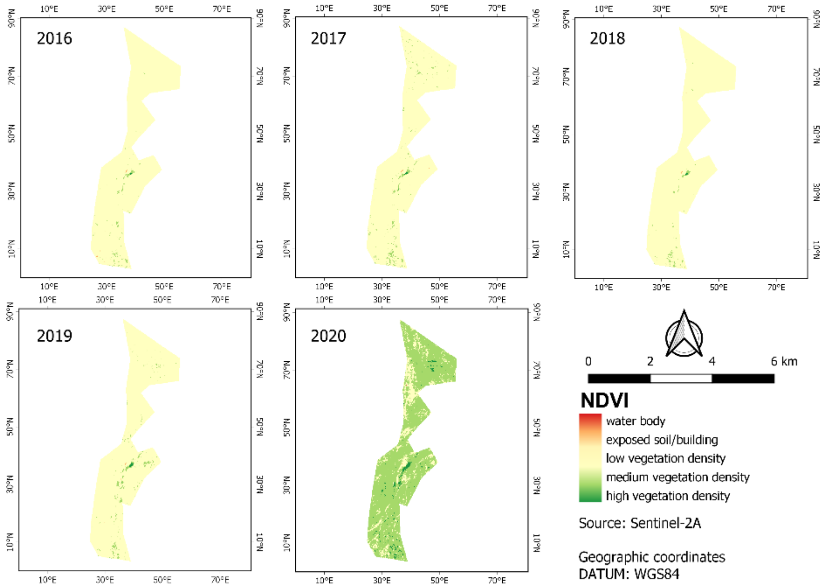

Figure 5. Dry season NDVI - Classified images in PEMP for 2016 to 2020

The VCI used NDVI images (Figures 6 and 7), and one can notice a more significant difference for the rainy period in 2018 (Figure 6), as seen previously. However, it is possible to notice some regions with a more critical condition, emphasizing the southern sector of the PEMP. For the other years, the predominant class remains exceptionally light.

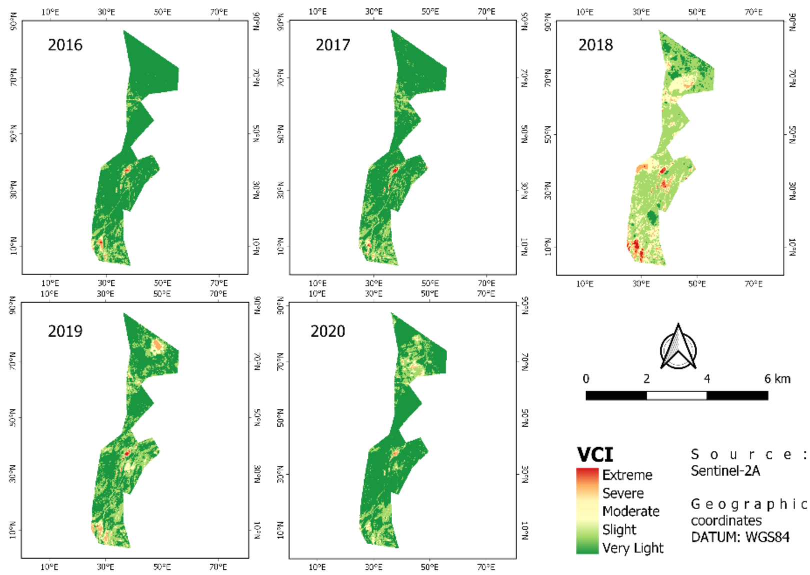

Figure 6. Rainy Season VCI- Classified images in PEMP for 2016 to 2020.

Observing the VCI maps for the dry period (Figure 7), the year 2020 differs from the others and presents a domain of areas with a moderate index, with some areas with a light class of VCI. In 2016, a considerable portion of regions with extreme class, indicating stress and worse values in vegetation condition occurs. This condition can be justified by the dry season from 2012 to 2017 (Lins et al., 2017; Bezerra et al., 2021).

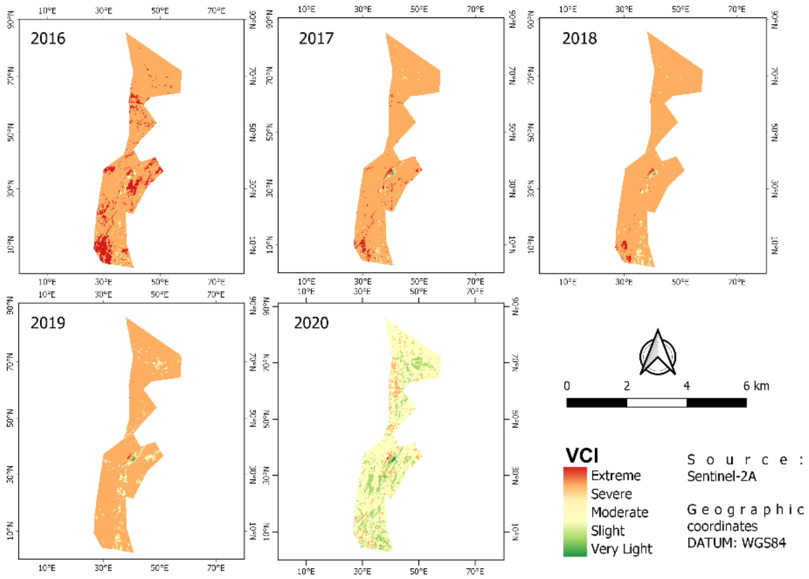

Figure 7. Dry Season VCI- Classified images in PEMP for 2016 to 2020

Quantification of class areas

Figure 8 presents the graphs with the area counts of the NDVI and VCI classes for the rainy (Figure 8A and 8C) and dry seasons (Figure 8B and 8D). In the rainy season, the NDVI presents a significant area with high vegetation density for the entire study period, with an average of 95% of the total area for the four years, except 2018, which presented fewer areas, about 62%. The dry season proves to be much higher than class 3 (low vegetation density) in almost all years with an average of 98%; only 2020 presented a different condition, which presents a higher NDVI value and higher count for level 4 (medium vegetation density), approximately 82%, it explains a higher density of vegetations distributed in the Conservation Unit.

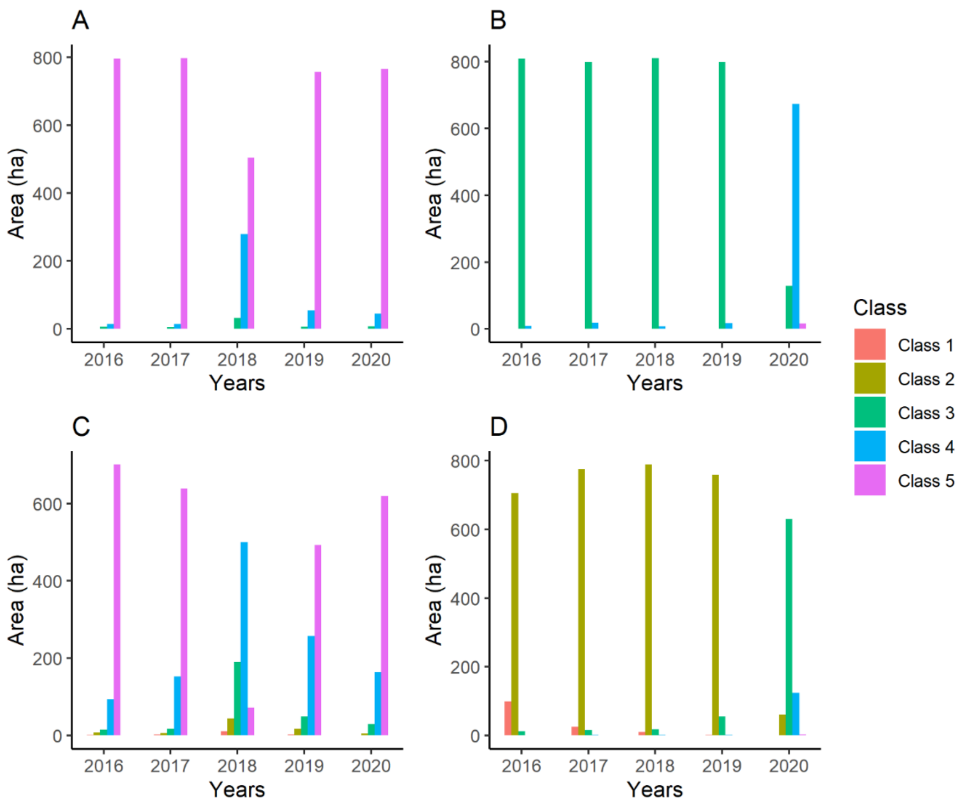

Figure 8. Areas of vegetation index classes in hectares: NDVI-rainy (A); NDVI-dry (B); VCI-rainy (C); VCI-dry (D)

The VCI in the rainy season predominates class 5 (Very Light), approximately 75% of the PEMP's area. In 2018, the exception, presents 9, 61, and 23% for class 5 (Very Light), 4 (Light), and 3 (Moderate).

For the dry season, the vegetation condition indices were lower, with most of the area in class 2 (Severe) comprising 93% of the area. In 2020, about 77% of the area comprised class 3 (Moderate) and 15% class 4 (Light).

These areas present drought conditions are at risk of fires due to low humidity; fires can occur accidentally, such as rupture of power lines or caused by human action (Mauger, 2009).

The vegetation indices analysis shows that the most critical points, areas of extreme levels, and more significant stress concentrate in the State Park's southern region. Therefore, greater attention in case of adverse events, mainly meteorological, should be done to avoid damage to the ecosystem of the PEMP.

Conclusions

The application of NDVI and VCI in the studied period made it possible to analyze the evolution of the vegetation cover of the Mata da Pimenteira, identifying the significant changes and making a diagnosis and possible solutions to the problems found.

The NDVI spectral response of the Caatinga was 0.7 in the rainy period and 0.3 in the dry period. Severe vegetation condition index level is predominant for the dry period and very mild for the rainy period. The PEMP presents, in the rainy period, 75% of the area as a very light drought class of vegetation cover, while the dry period presents 90% of the area in the severe drought condition.

Finally, to mitigate possible damage to the ecosystem of the conservation unit, it is important to have discussions to sensitize nearby residents to avoid any eventualities. Future studies should compare the evolution of the vegetation cover and the effects of implementing the Mata da Pimenteira State Park (PEMP).

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