

Spatiotemporal variation of the vegetation index by normalized difference in the hydrographic basin of Pernambuco semiarid, Brazil

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Received 28 September 2021; accepted 30 December 2021

Abstract

Remote sensing is an important mechanism for spatiotemporal monitoring of vegetation. Vegetation indexes have been widely used in monitoring vegetated areas, to determine and estimate the index of leaf area, biomass, and photosynthetically active radiation, among others. In these indexes, the Normalized Difference Index Vegetation (NDVI) stands out, which indicates the health status of a vegetative canopy. Considering the proven applicability of this index, in addition to the relevant importance of the Caatinga biome, related to the need for monitoring at the expense of desertification processes, the article aimed to analyze temporal variations of the NDVI in a hydrographic basin of the Brazilian semiarid region, in the municipality of Itacuruba/PE, Brazil. The study area covers a hydrographic basin belonging to the São Francisco river. Remote sensing techniques were used to estimate the NDVI in four orbital images provided by NASA/USGS in the year 2020, with less than 10% clouds. Then, the data were subjected to descriptive statistical analysis to obtain minimum, maximum, mean, standard deviation, and coefficient of variation values. The results showed that the NDVI presented values ranging from -0.30 to 0.57. The means found ranged from 0.16 to 0.23 for the months studied, as well as in the standard deviation values, values between 0.06 and 0.09 were found, corroborating other correlated studies in the region. The coefficient of variation data showed average variability, according to the Warrick and Nielsen classification criteria. It is noteworthy that, in addition to the dry climate of the region, the shrubby vegetation presents physiological defense characteristics such as the fall of foliage. It was concluded that the use of remote sensing was effective in evaluating the spatiotemporal dynamics of the vegetation index in the watershed, managing to measure environmental variations at the expense of climate change.

Keywords: caatinga, vegetation index, remote sensing, semiarid, watershed.

1. Introduction

Monitoring with orbital images allows detecting, analyzing, and inferring changes in the Earth's surface caused by natural or artificial processes (Leite et al., 2020). The use of remote orbital sensors has been highlighted in the scientific community for providing a synoptic, fast, and accurate assessment of the environment (Foody, 2010; Nassur et al., 2015; Zhu; Liu, 2015).

The Earth's natural resources and their characteristics benefit from Remote Sensing to obtain information about their spatial detection, description, quantification, and monitoring (Kimm et al., 2020; Arekhi et al., 2019). Remote Sensing systems provide periodic and consistent data from the Earth's surface, being a fundamental tool in global monitoring and one of the main tools used to understand the dynamic processes inherent in different ecosystem forms and their responses to climate change (Mercier et al., 2020; Gholizadeh et al., 2018; Testa et al., 2018).

Among the image processing techniques obtained by Remote Sensing are the vegetation

indexes (VIs), aiming to explore the spectral properties of the vegetation, from the behavior of its reflectance in the visible and near-infrared regions, with applications for the monitoring regions such as the semiarid and planning these spaces (Zhang et al., 2019; Yang et al., 2018; Beck et al., 2006). Among them, the NDVI (Normalized Difference Vegetation) stands out, which is indicative of photosynthetically active vegetation (Zhou; Zhong, 2020; Ali et al., 2019).

The usefulness of NDVI has already been presented in different fields, such as precision agriculture, the study of vegetation phenology, in spectral classifications, and primary yield assessments, according to related studies (Bezerra et al., 2018; Nhongo et al., 2017; Zanzarini et al., 2013). The Normalized Difference Vegetation Index (NDVI) is one of the parameters widely used in the assessment of desertification and land degradation (Cunha et al., 2015; Ferreira et al., 2017; Mariano et al., 2018; Tomasella et al., 2018). Applying NDVI time-series analyses, the research by Ferreira et al. (2017), Militino et al. (2017) and Wang et al. (2017).

Some studies show the correlation of environmental variables with vegetation indexes obtained through remote sensing (Delgado et al., 2012; Araújo et al., 2018; Santos et al., 2020). Solar radiation and rain are among the main factors influencing tree growth and, consequently, natural regeneration. According to Ataíde et al. (2011) and Menezes et al. (2011), these factors fit into one of the groups considered most important, that of climate factors.

Remote sensing has been essential in the environmental monitoring of watersheds through spatiotemporal analysis of the various biophysical parameters, which allow the assessment of the impacts and degradations resulting from land use and occupation in the environment (Ribeiro et al., 2015). According to Sousa (2016), due to the exacerbated and uncontrolled use of the areas located around the hydrographic basins in the past, they are where the main degraded areas are currently located, framed as desertification cores. Hence the importance of studies aimed at the problem of degradation/desertification based on methodologies that make it possible to diagnose and qualify the elements and processes that form these environmental systems to better understand their natural dynamics and their changes in the face of human interventions to which they are subjected (Sousa, 2016; Lourenço et al., 2017).

In Brazil, the existence of desertification zones is concentrated in the Northeast, as this region is located in the semi-arid climatic range, constituting an area susceptible to erosion and soil degradation processes that lead to desertification (Lopes and Candeias, 2005). The vulnerability of semiarid regions to climate change in Brazil is the object of study by several researchers (Huang et al., 2016; Marengo et al., 2017; Marengo et al., 2018; Dubreuil et al., 2019). Most research highlights the importance of studying meteorological variables such as air temperature and accumulated rainfall. Such variables can significantly affect society, causing impacts on water resources management, agriculture, and the degradation of areas with greater environmental vulnerability.

Allied to climatic conditions, water resources are essential for the survival of biomes and of human society itself. Its availability on the Earth's surface cannot be separated from the actions of the climate system. Linked to this, the reduction in water recharge capacity can also be reduced by changing the vegetation cover through human intervention. In some environments, especially semi-arid ones, there is a greater tendency to this factor, due to rainfall occurring with great intensity, that is, large amounts in a short time (Silva and Galvêncio, 2013).

Regarding the impacts of climate variability in hydrographic basins in the northeast region, Magalhães (2016) explains that several models

indicate a reduction in water flow in important basins, such as the São Francisco. "With more droughts, less humidity, less water, the impacts could be greater on agriculture, on the economy, on living conditions." In this context, deforestation in the caatinga, soil fragility, and climate change are important parameters for the environmental management of watersheds, to plan prevention actions in areas susceptible to desertification, as well as in the restoration and rehabilitation of areas degraded and desertified.

In the State of Pernambuco, the desertification nucleus comprises the municipalities: Belém de São Francisco, Cabrobó, Carnaubeira da Penha, Floresta and Itacuruba. And, 135 municipalities are located in areas susceptible to desertification, where, according to the results of the 2000 demographic census, live around 2,622,519 million inhabitants, with a demographic density of 35.34 inhabit./km² (PERNAMBUCO, 2009, 2011).

A study carried out by Nobre (2011), on the assessment of the impacts of climate change on Brazilian biomes, reveals that, in Brazil, the biome most vulnerable to environmental degradation, in the context of increasing global temperatures, is the Caatinga biome. For the researcher, the semiarid region of northeastern Brazil is in a state of alert, as the vulnerability of the Caatinga biome to the effects of climate change represents a pressure factor for desertification in the region. Studies carried out by Freire (2020) show the vulnerability of this biome, even in areas of environmental protection the author warns that the Caatinga is at risk. In this sense, the chosen study area was the São Francisco river basin, located within the municipality of Itacuruba, inserted in areas susceptible to desertification.

The São Francisco river basin, in the semiarid region of Pernambuco, is a fundamental unit to support planning and decision-making on water and natural resources, the use of biophysical parameters by remote sensing techniques, as an important tool in the detection of possible environmental changes (Sousa, 2014). Studies presented on the Caatinga biome are relevant and are justified as this region is little studied and has the inevitability of conservation, given the maintenance of its high degree of understanding and abundance of species from the only typically Brazilian biome (Fernandes et al., 2021; Silva et al., 2021). So, the relevance of the Caatinga biome, related to the primordality of monitoring and the operability that methods with remote sensing allow.

Considering the proven applicability of this vegetation index, in addition to the relevant importance of the Caatinga biome associated with the need for monitoring at the expense of desertification processes, this study aimed to analyze spatiotemporal

variations of the Normalized Difference Vegetation Index (NDVI) and the rainfall in the Caatinga vegetation, in a hydrographic basin of the São Francisco river, inserted in the Municipality of Itacuruba, Pernambuco, Brazil.

2. Material and methods

The focus area of this study comprises the hydrographic basin of the São Francisco river in the municipality of Itacuruba, Pernambuco. The municipality of Itacuruba is located in the Macroregion of Sertão de Pernambuco and in the Mesoregion of São Francisco Pernambucano (Figure 1). The municipal area occupies 436.7 km² and has the geographic coordinates 8°50'02" of latitude and 38°42'14.0" of longitude. According to Beltrão et al. (2005), the municipality is inserted in the geoenvironmental unit of the Sertaneja Depression, with predominantly smooth-wavy relief. The vegetation is composed of hyperxerophilic Caatinga.

The climate is Tropical Semi-arid, with summer rains. The rainy season starts in November and ends in April. From a climatic point of view, the study area is characterized by the great irregularity of rainfall and presents as the main rainy period from January to April. The rains that occur in the Sertão de Pernambuco have their origin in the cold fronts, in the upper air cyclonic vortices (VCAS), and the intertropical convergence zone (ITCZ).

The onset of rains in the Sertão de Pernambuco occurs in December (far west) and is associated with the instabilities of cold fronts and VCAS. From February or March, depending on the year, ZCIT starts operating throughout the Sertão, which is already in its main rainy season. The average annual rainfall in the municipality is 431.8 mm (CPRM, 2005).

As for the soils: there are Planosols, poorly drained, average natural fertility and salt problems; Luvisols, shallow and high natural fertility; drained Ultisols and average natural fertility, and shallow, stony Neosols and average natural fertility. Itacuruba is in the domains of the macro hydrographic basin of the São Francisco river, the hydrographic basin of the Rio Pajeú, and the Small Interior Rivers Basin Group (Beltrão et al., 2005).

The municipality of Itacuruba is part of the desertification nucleus of the state of Pernambuco. This nucleus is located in the central hinterland of the state, between the geographic coordinates 08° 43' 47.5" S and 08° 48' 07.8" S and 38° 40' 54.3" W and 38° 43' 38.1" W with an area of 175,066 km². The municipality of Itacuruba is part of the desertification nucleus of the state of Pernambuco. This nucleus is located in the central hinterland of the state, between the geographic coordinates 08° 43' 47.5" S and 08° 48' 07.8" S and 38° 40' 54.3" W and 38° 43' 38.1" W with an area of 175,066 km² (Sousa, 2014).

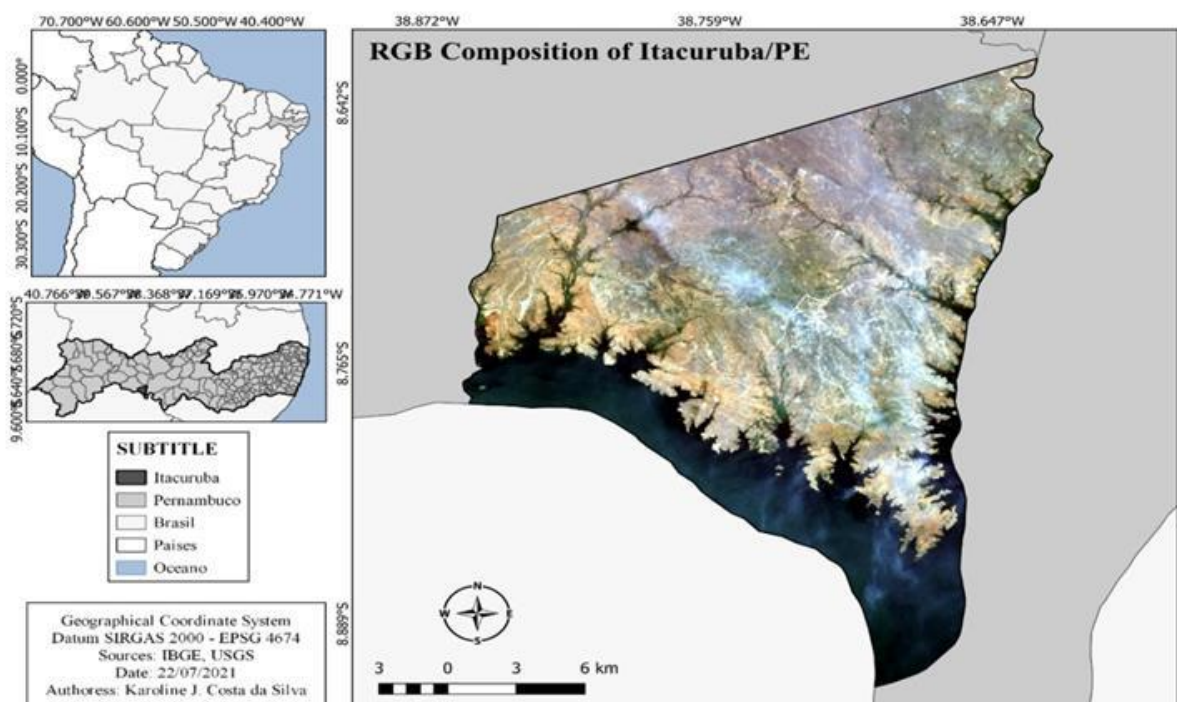


Figure 1- Geographical location map of the municipality of Itacuruba, Pernambuco, Brazil.

Rainfall data were acquired through monitoring stations of the Pernambuco Agency for

Water and Climate (APAC) for the period from January 1, 2020, to December 31, 2020. The

multispectral bands were acquired from the Landsat-8 OLI/TIRS sensor, with dates of 04/08/2020 and 12/20/2020, free of charge from the American space database of the National Aeronautics and Space Administration/United States Geological Survey (NASA/USGS) available at <https://earthexplorer.usgs.gov/>.

The scenes that cover the study area were chosen in the condition of clear sky with the least possible presence of clouds (<10%) and belonging to the rainy year (04/08/2020) and dry year (20/12/2020), passing over the site approximately between 9:00 am and 10:00 am (local time). They are composed of 11 bands, with a spatial resolution of 30 meters in bands 1, 2, 3, 4, 5, 6, and 7 and 100 meters in bands 10 and 11. All bands were redesigned for the SIRGAS 2000 projection system. EPSG 4674, Zone 24 South. Image processing and obtaining the vegetation index used in the study were performed using the free Qgis® software (version 3.16 Hannover).

The NDVI, initially proposed by Rouse et al. (1973), significantly indicates the quantity and condition of vegetation in the areas under study. Despite being an index developed in the 70s, it is still widely used today and explored in agricultural, forestry, and climate analysis (Ponzoni and Shimabukuro, 2010). The NDVI is the result of the relationship between the reflectance of the near-infrared (NIR) and red bands (ROUSE et al. 1973) is calculated from the Equation:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where the NIR and RED are the reflectance values of bands B5 and B4, respectively, of Landsat 8 OLI/TIRS.

Then, the data were submitted to descriptive statistical analysis to obtain minimum, maximum, mean, standard deviation, and coefficient of variation (CV) values. CV (%) was also evaluated as its variability, according to the classification criteria of Warrick and Nielsen (1980), where CV <12% (low variability), CV between 12 and 60% (mean variability) and CV > 60% (high variability).

3. Results and discussion

The determination of biophysical variables has been used in spatial and temporal studies to detect environmental changes since the main interest is to understand the changes that occurred in the landscape over time. However, the analysis of vegetation cover is complex due to the high degree of intra-annual variability of rainfall, which can lead to changes in the environment, not being directly related to the effects of land use and occupation. Precipitation and temperature are key variables in understanding NDVI variations, especially in semiarid climate areas (Brito et al., 2017; Brito et al., 2020).

According to the climatology of the studied year, the rainy season presented monthly precipitation that exceeded 23 mm in April, with February registering the highest value, 367 mm. Temperatures during the rainy season ranged between 22 and 37 °C, and during the dry period, they ranged between 17 and 38 °C (Figure 2 and Figure 3). In Figure 3, rainfall fluctuation in the region was observed, indicating low rainfall and poor rainfall distribution during the year 2020. Similar behaviors have been observed in previous years by Ferreira et al. (2012), Jardim et al. (2021) and Ferreira et al. (2017).

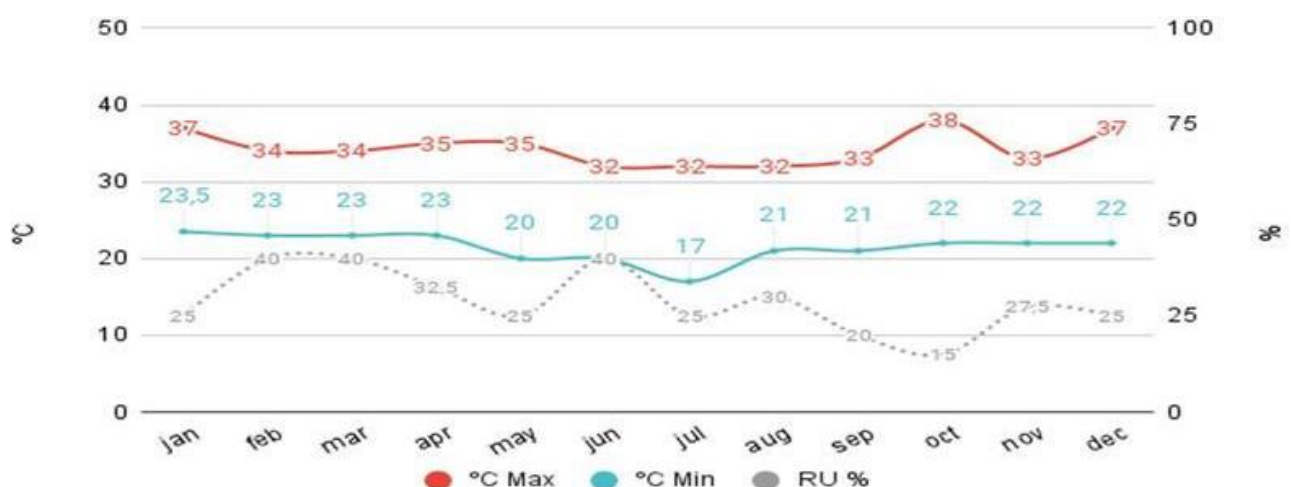


Figure 2- Monthly temperature (°C) and relative air humidity (%) in 2020 in the municipality of Itacuruba-PE.

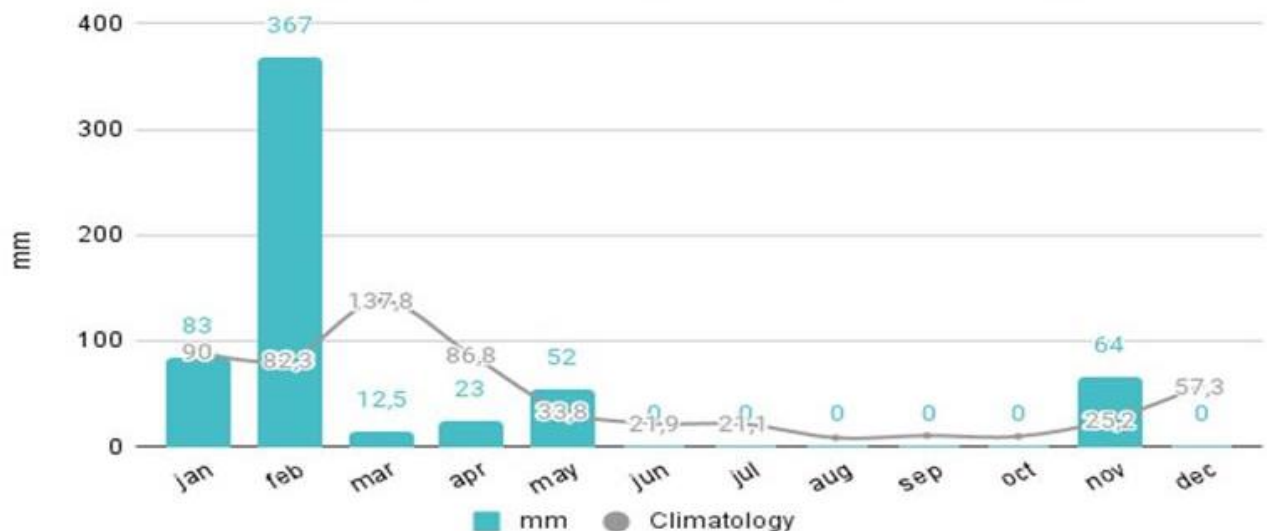


Figure 3- Monthly rainfall (mm) in 2020 in the municipality of Itacuruba-PE.

Table 1 shows the statistical analysis of the NDVI, which according to the classification criteria of Warrick and Nielsen (1980) showed a behavior of average variability (CV ranged from 56.04% to 56.08%).

The minimum and average values of NDVI showed significant variation within the rainy season (April) and dry season (December), differing from

the maximum values. The NDVI variation range for the studied area, regardless of the time of year, is high, with values ranging from -0.19 to 0.57.

The standard deviation values of the mean for the NDVI of the analyzed images are less than 0.09 and the coefficient of variation values vary 56%. In general, we obtained mean, maximum and minimum values of 0.19, 0.57, and -0.30, respectively.

Table 1 - Temporal variation of the NDVI for the São Francisco river basin in the municipality of Itacuruba-PE.

Period analyzed (month/year)	Min	Max	Med	Σ	CV (%)
Rainy season (April 2020)	-0.30	0.57	0.23	0.09	56.08
Dry period (December 2020)	-0.19	0.55	0.16	0.06	56.04

The influence of rainfall on the spatial variability of the NDVI and consequently on the seasonality of the vegetation present in the São Francisco river basin can be seen in Figure 4 for the days 08/04/2020 (A) and 12/20/2020 (B). It is possible to observe that the reddish and orange tones for lower NDVI values are related to soil areas with little or no vegetation, the yellow color indicates intermediate values related to Caatinga areas with less vigorous vegetation, with green and dark green tones, are the areas with the densest vegetation.

In the rainy season (Figure 4A) we found higher NDVI values when compared to dry period images (Figure 4B). Thus, it is observed that precipitation exerts a strong influence on vegetation characteristics, expressed by the NDVI values found. Furthermore, the analysis of these images allows us to identify the typical behavior of the Caatinga vegetation, the deciduous one.

In Figure 4A corresponding to the rainy season, the vegetation is in full photosynthetic

activity and with expressive leaf biomass, which is represented by the highest NDVI values. In the dry period image (Figure 4B), there is a predominance of lower NDVI values that are associated with a decline in photosynthetic activity and consequent loss of leaf biomass.

The differences between the two images can be explained by the behavior of precipitation in the rainy season. In the three months preceding the image of 08/04/2020, 462.5 mm of accumulated rain were recorded, according to data from APAC. On the other hand, in the same period that preceded the image obtained on 12/20/2020, there was accumulated precipitation of only 64 mm. In a study by Silva et al. (2019) in Petrolina, it was found that the rains accumulated in the months before the imaging dates used in the research contributed to the accumulation of moisture in the soil before the passage of the satellite, influencing the maintenance of herbaceous extracts and the presence of leaves in the crown of vegetation, favoring the elevation of the NDVI.

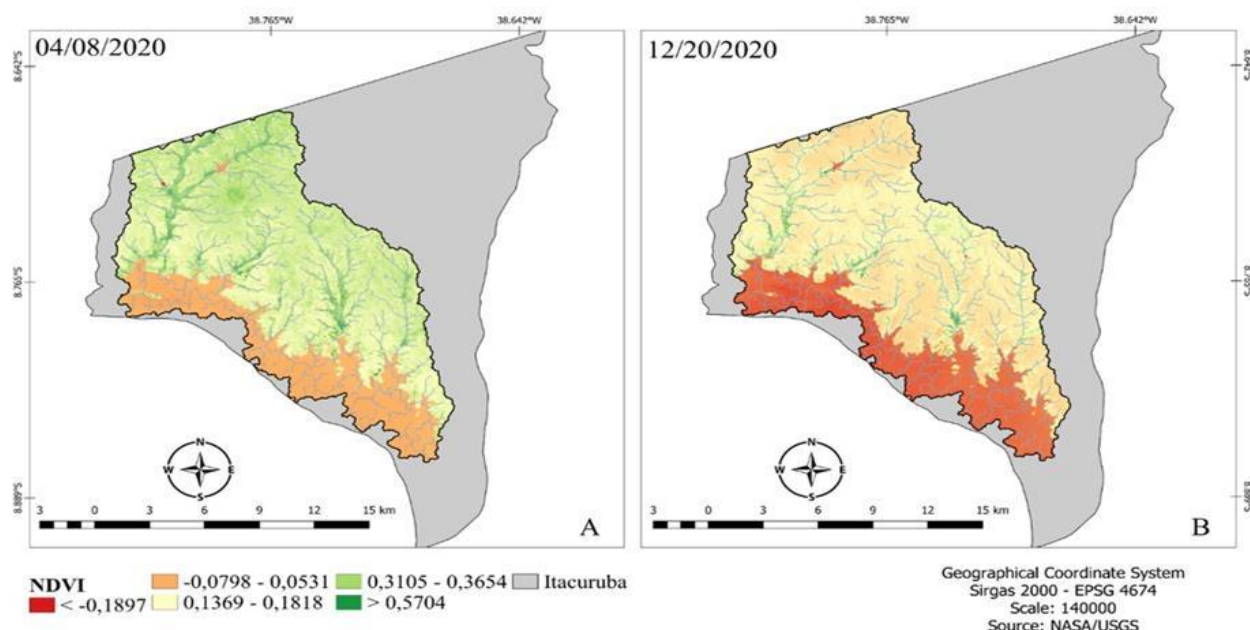


Figure 4 - Spatial distribution of the NDVI (Normalized Difference Vegetation Index) for the São Francisco river basin in the municipality of Itacuruba-PE on 04/08/2020 and 12/20/2020).

The temporal distribution of rainfall has a strong influence on the water balance of the Caatinga biome and, consequently, on the soil moisture, directly influencing the NDVI (Arraes et al., 2012). The reduction of humidity and the reduction of the vegetative canopy result in an increase in the incidence of radiation on the surface, corroborating Bezerra et al. (2021a, 2021b) for the semiarid region of the state of Pernambuco, Northeast of Brazil.

The results obtained in this study corroborate other studies carried out in the semiarid region (Leite et al., 2019; Bezerra et al., 2014; Santos et al., 2014). Albuquerque et al. (2014) analyzed the behavior of NDVI and NDWI in periods with different rainfall intensities in the municipality of Souza, Paraíba. In the period of low precipitation, the NDVI presented an average of 0.23, due to the loss of vegetation cover, and in the rainy period, the average was 0.34. In the Trussu river basin, in the semiarid region of Ceará in 2000 and 2001, Rodrigues et al. (2009) found NDVI values from 0.003 to 0.20 in the dry season; in the period of occurrence of precipitation, it ranged from 0.003 to 0.76, with a predominance of values in the class from 0.20 to 0.39.

Differences in NDVI values in the same period can be attributed to variations in precipitation in the same year in different areas of the basin (Pinheiro et al., 2016). Despite the significant reduction in NDVI values from the wet to the dry season, the maximum values are approximate. mainly in the month of the dry period (December) due to the variability of species losing their leaves, indicating low photosynthetic activity, a phenological characteristic of the caatinga biome (Oliveira et al.,

2021; Oliveira and Costa, 2020). Associated with this, the spatial heterogeneity of NDVI found in the hydrographic basin, both in the dry and rainy seasons, is due to the great diversity of native botanical families in the Caatinga, which present different growth behavior and sizes (Rodrigues et al., 2020; Silva et al., 2019; Bezerra et al., 2014).

Thus, it was found that precipitation is related as the main factor of alteration of the NDVI in the studied area, where the vegetation index values are higher after the passage of rains. The Caatinga biome has a great power of resilience, as its power to respond to precipitation and its restoration of vegetation occurs quickly with the arrival of the first seasonal rains

4. Conclusion

It was concluded that the use of remote sensing was effective in evaluating the spatial-temporal dynamics of the vegetation index in the São Francisco river basin, managing to measure environmental variations at the expense of climate change. The NDVI values varied according to the precipitation index in the watershed, indicating that the vegetation index is strongly correlated with the humidity and precipitation.

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