Analysis of temporal responses of NDVI to precipitation in Guaratinguetá-SP using Google Earth Engine: a case study in a rice growing area

Jessyca Fernanda dos Santos Duarte[1], Alvaro José Reis Ramos[2]
[1]Instituto Nacional de Pesquisas Espaciais - INPE, São José dos Campos, SP, Brazil;
[2]Embrapa Territorial, Campinas, SP, Brazil.
{duarte.jessyca2; ajr.ramos.pesca}@gmail.com

Abstract: The response of NDVI to precipitation was analyzed using MODIS product acquired over a time period of six growing seasons (2014 to 2019) and rainfall data from 2 weather stations from two cities close to Guaratinguetá. It was possible to identify six cycles with average duration of 5 months. In general, significant correlation was found between average values of rainfall and NDVI range (0.68), so rainfall explains more than 60% of the effects of variation in the vegetation index. However, 2015 was an atypical year, when occurred the lowest average values of NDVI overlapping the peak of precipitation, showing a high correlation (0.79), coinciding with occurrence of phenomenon *El Niño*. In addition to, the year of 2014 stands out for the highest peak of NDVI values in contrast to the lowest peak of rainfall values. The average of the total NDVI was 0.3494 and the global average of the precipitation was 3.8921. The obtained results confirmed that the relationship between precipitation and NDVI is strong and predictable when viewed at the appropriate spatial scale.

Introduction

Rice is one of the most produced and consumed cereals in the world, characterized as the main food for more than half of the world population (FAO, 2004). In Brazil, the estimated production of the grain is 8.3 million tons (USDA/FAS, 2015). O cultivo de arroz em São Paulo tem registros desde o início da colonização do país, em torno das décadas de 1530 e 1540 (CONAB, 2015; CRISTAL, 2020).

According to CONAB (2015), the region of Paraíba Valley went through a transition, with the replacement of sugar cane by coffee, which would dominate the province's economy after the 1850s. During the pre-coffee period, subsistence crops - such as rice - sustained the farms until coffee production was established and reached large volumes until the second half of the 19th century.

In the state of São Paulo, the municipality of Guaratinguetá is among the main producers of irrigated rice in the Paraíba Valley. Irrigation in rice growing in São Paulo is an important and historic activity that began in the early 20th century, and even today it guarantees good rice crops. In Guaratinguetá, irrigation is concentrated in the Piagui Colony, which uses the extensive floodplain area of the homonymous river as the main source of consumption. The Piagui colony presented na increase in rice áreas about 14,2% (PAES JUNIOR; SIMÕES, 2006).

In this context, Remote Sensing represents a reliable approach to effectively monitoring crop growth and production at various scales (BOUMAN, 1995; SHEN et al., 2009). According to Van Niel and McVicar (2004), remote sensing helps in the management of agricultural areas, motivating research aimed at improving the techniques and methods used in the classification of cultivation areas.

According to Quarmby et al. (1992), to map the distribution of rice fields, regional-scale analyses commonly use moderate spatial resolution imagery with larger swath widths such as imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS). Some studies have been applying NDVI information derived from MODIS data to map rice systems (Guan et al., 2015; Gumma et al., 2014; Chen et al., 2012; Kontgis et al., 2015).

Some studies have used NDVI to monitor the response of vegetation to climatic fluctuations in different places in the world and thus, Wang et al. (2010) conclude that temporal variations of NDVI are closely linked with precipitation and there is a strong linear (Malo and Nicholson 1990) or log-linear (Davenport and Nicholson 1993) relationship between NDVI and precipitation in cases where monthly or annual precipitation is within a certain range.

The relationships between NDVI and climatic factors, as precipitation, depend upon location and more detailed analyses are needed for a variety of regions to better understand temporal variation of precipitation and how it influences NDVI. It is known that precipitation influences water balance, and consequently changes soil moisture regime which, in turn, influences plant growth. Besides, precipitation has the primary influence on NDVI, being this relationship strong and predictable when viewed at the appropriate spatial scale, showing a strong influence on agriculture productivity (Wang et al., 2010).

Analysis of big data from a long time interval requires high computational resources for processing geospatial data. In this context, Google Earth Engine has been widely used for the analysis of large time series, as it allows the user to develop algorithms and create a fast cycle of tests and improvements for large data processing (GORELICK et al., 2017).

The present study used the information library of the Google Earth Engine platform to obtain time series and analyze the response of vegetation to precipitation for a rice-growing area, during the period of 6 years (2014-2019), in Guaratinguetá, São Paulo, Brazil.

Material and methods

Study area

The study area (Figure 1) is a rice-growing area located in 45°13’23.45”W longitude and 22°43’36.61”S latitude, in the municipality of Guaratinguetá, state of São Paulo and southeast region of Brazil. The total area has an extension of 778.7399 ha. This region borders the Piagui River and it is close to the Presidente Dutra highway (BR-116), which links the states of São Paulo and Rio de Janeiro, presenting a strategic location for the economy, as it enables a greater access and transportation of products and goods. In relation to climatic data, Lima e Silva et al. (2016) show an average annual rainfall of 1388.1 mm and an average annual temperature of 22.5 º C for the municipality.

Guaratinguetá is inserted in an old occupation area, the Paraíba Valley, and stands out in the rice production. Irrigation activity in the region guarantees good rice crops planted in the floodplains of the Paraíba do Sul River and some of its main affluent, as Piagui River. In addition to, irrigation consumes about 51% of the surface water resources (SÃO PAULO, 2002; PAES JUNIOR.; SIMÕES, 2006).

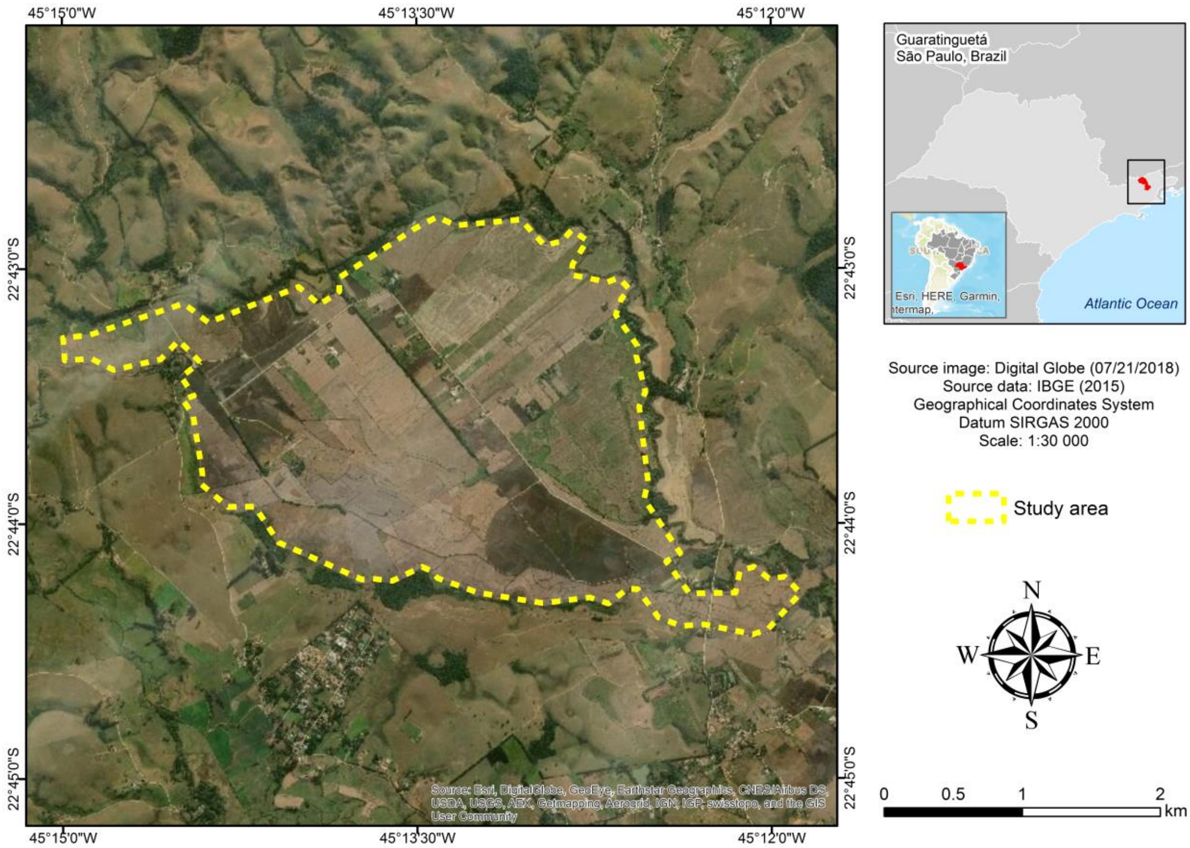

Figure 1 – Study area location map.
Source: Authors (2020).

Normalized Difference Vegetation Index (NDVI)

The NDVI (ROUSE at al., 1973) is a vegetation index used to measure vegetation vigor and other vegetation conditions. The premise of this index is that the vegetation with greater leaf vigor presents a greater absorption of the red wavelength energy and a greater reflectance in the near infrared energy (PONZONI, 2012). NDVI is calculated according to equation 1. NDVI considers the reflectance values from spectral bands of red (0.6 µm) and near infrared (0.8 µm) wavelengths. The data of NDVI were obtained from the product MODIS Terra Daily NDVI (MOD09GA_006).

$$(NIR - R) / (NIR + R) \qquad \text{Equation (1)}$$

NIR and R refer to the regions of Near Infrared and Red (visible light) from electromagnetic spectrum, respectively.

Moderate Resolution Imaging Spectroradiometer (MODIS)

The collect of data from MODIS sensor started in the year of 2000 on board the *Terra* satellite and then went into orbit with the *Aqua* satellite in 2002 (JUSTICE et al., 2002; RUDORFF et al., 2007). In this study, a variation of the daily product MOD09GA was used, which provides an estimate of the surface spectral reflectance of MODIS Bands 1 through 7, corrected for atmospheric conditions such as gases, aerosols, and Rayleigh scattering. Provided along with the 500 meters (m) surface reflectance, observation, and quality bands are a set of ten 1 kilometer (km) observation bands and geolocation flags (USGS, 2020). The variation from this product is named as *MODIS Terra Daily NDVI* and it is found on the GEE platform as "MOD09GA_006_NDVI". The NDVI is generated from the NIR and Red bands of each scene, and ranges in value from -1.0 to 1.0.

Rainfall data

The automatic stations integrate the observed rainfall values from minute to minute and make them available daily. The precipitation historical series was obtained in .txt format on the website of the National Meteorological Institute (INMET), available at: http://www.inmet.gov.br/portal/index.php?r=estacoes/estacoesAutomaticas.

The time series covered the period from 01/01/2014 to 12/31/2019, corresponding to the period of the NDVI time series. The stations used were Campos do Jordão (A706) and Taubaté (A728), which are closer to Guaratinguetá, the specifications are in Figures 2.A and 2.B.

(A)

Nome: TAUBATÉ	
Código: A728	
WSI: 0-76-0-3554102000000162	
Coordenadas/Altitude	**Data/Hora**
Latitude: -23.041668	Fundação: 19/12/2006
Longitude: -45.520841	Medição: 07/05/2020
Altitude: 582.26 m	Última Medição: 00 UTC
Dados	**Temperatura**
Umidade: %	Instantânea: °C
Pressão: hPa	Máxima: °C
Precipitação: mm	Mínima: °C

(B)

Nome: CAMPOS DO JORDÃO	
Código: A706	
WSI: 0-76-0-3509700000000019	
Coordenadas/Altitude	**Data/Hora**
Latitude: -22.750231	Fundação: 12/03/2002
Longitude: -45.603836	Medição: 07/05/2020
Altitude: 1662.95 m	Última Medição: 00 UTC
Dados	**Temperatura**
Umidade: %	Instantânea: 12.7°C
Pressão: 835.4 hPa	Máxima: 13.3°C
Precipitação: 0 mm	Mínima: 12.7°C

Figure 2 - General specifications of stations: A) Taubaté; B) Campos do Jordão.
Source: INMET (2020).

Google Earth Engine

The GEE platform was designed with main objective of studying high-impact social problems such as drought, diseases, food security, water management, monitoring climate, environmental protection, among others. This platform is widely used for geospatial analysis on a global scale, as GEE uses high-performance computational resources for image analysis and the computational operations performed on the system take place in the cloud, facilitating saving and simplifying information processing. The GEE represents a catalog of information associated with an API (Application Programming Interface) and accessible, through internet, to an interactive development environment (IDE) for generating and visualizing geospatial results on a global scale (CHEN et al., 2017; GORELICK et al., 2017). The data collection can be accessed in: https://earthengine.google.com. In addition to, it can be also found the user guide, terms of use and tutorials for beginners in *JavaScript* language. Due to the large volume of necessary data to obtain the time series, it was decided to use this platform for steps related to the calculation of NDVI and generation of charts. The steps of the process performed are shown in Figure 3, where the steps performed on the GEE platform are presented.

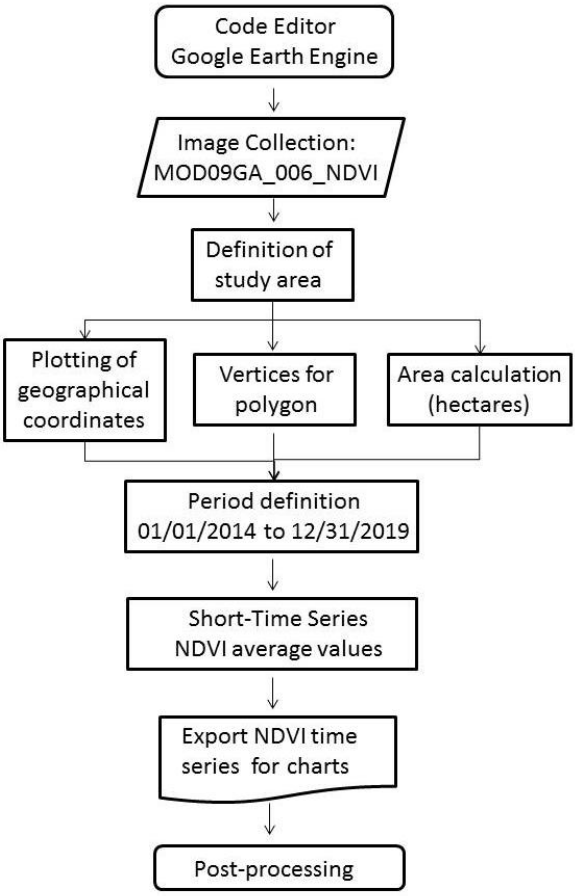

Figure 3 - Flowchart for obtaining NDVI time series in GEE.
Source: Authors (2020).

Post-processing

The rainfall and NDVI time series were post-processed on the free software *Octave*, a powerful tool for mathematical computation and solution for numeric problems and is available in: https://www.gnu.org/software/octave/. First, the NDVI time series was exported in .csv format from GEE platform to *Octave*, where it was possible to smooth the curve of time series using the Moving Average Filter, which is a simple digital filter using in programming for eliminate the unwanted noises. The same moving average filtering process was also applied to rain data. Finally, graphs were generated for each type of data, as well as a double-axis graph for comparison purposes.

Fieldwork

The fieldwork was carried out in September 2018 to obtain the ground truth, where the points to validation (Table 1) were collected with the aid of using GPS of navigation. The coordinates helped to locate and to delimit the area of interest in GEE platform. The access sketch of the study area is presented in Figure 4.

ID	**X**	**Y**
1	45°13’00.912”W	22°43’23.257”S
2	45°12’47.534”W	22°44’06.112”S
3	45°13’17.951”W	22°43’15.348”S

Table 1 - Geographic coordinates collected in the fieldwork.

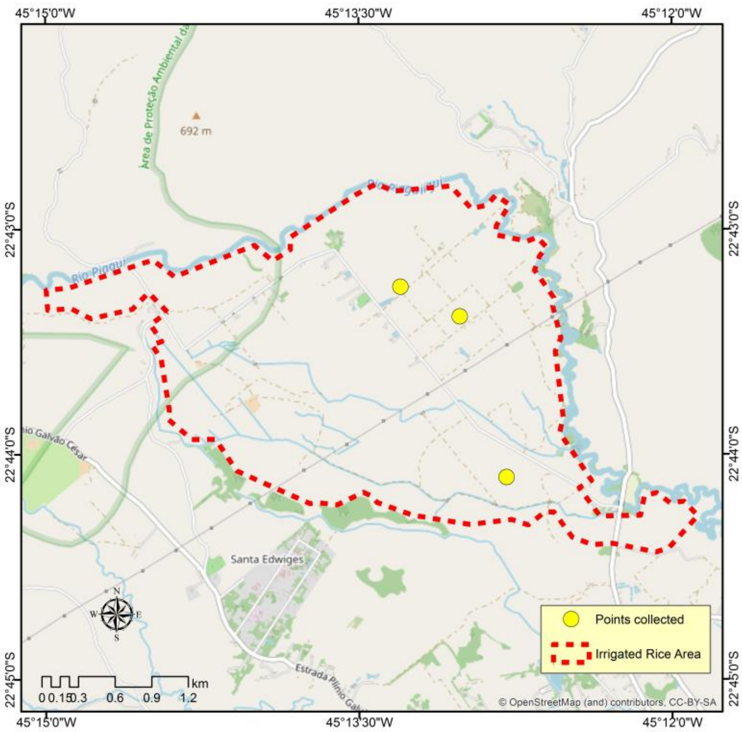

Figure 4 - Sketch of access to the study area.
Source: Authors (2020).

Results and Discussion

The Figure 5 and 6 show the time series of NDVI and rainfall data, first presenting without filtering (black lines) and then, the data post-processing (colored lines). The minimum and maximum values of NDVI were -0.02 and 0.85, while for precipitation it was 0.1 and 123 mm, respectively. The negative NDVI values occurred mainly between the months of September and December, coinciding with the low precipitation rates for the region. Among the 2189 data analyzed, 38 presented negative NDVI values very far from the average, and after filtering these values were excluded.

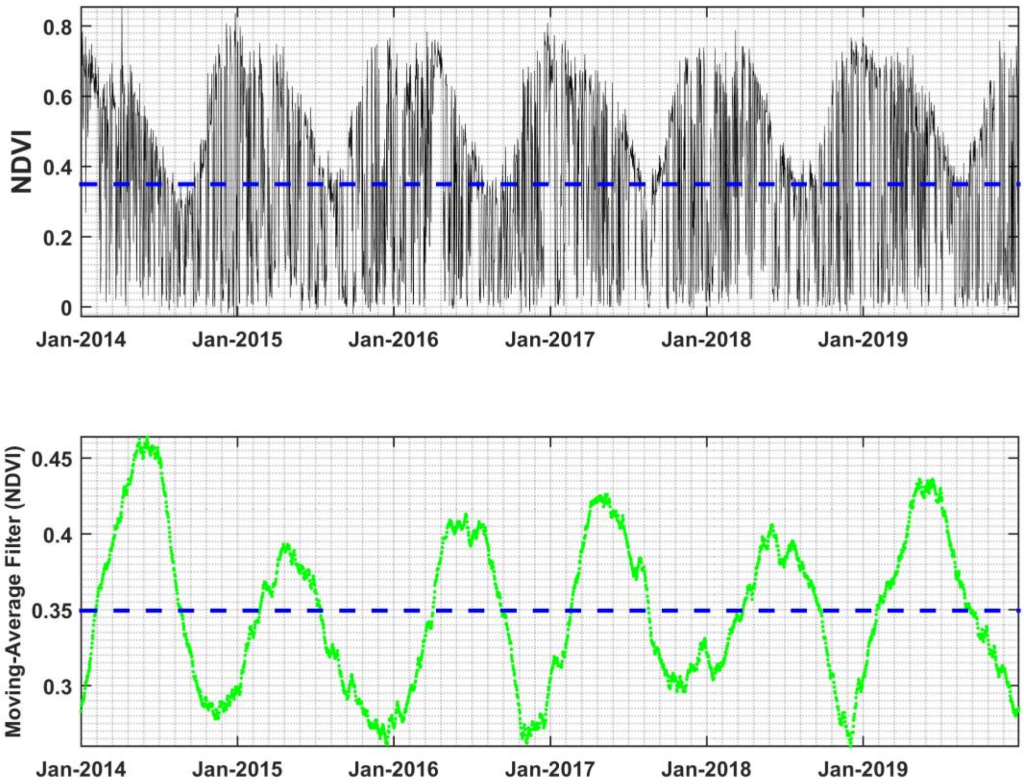

Figure 5 - NDVI values (Y axis) in a rice plantation during the period from 01/2014 to 12/2019 (X axis). Black lines: time series without moving average filter; Green line Moving-Average Filter applied.
Source: Authors (2020).

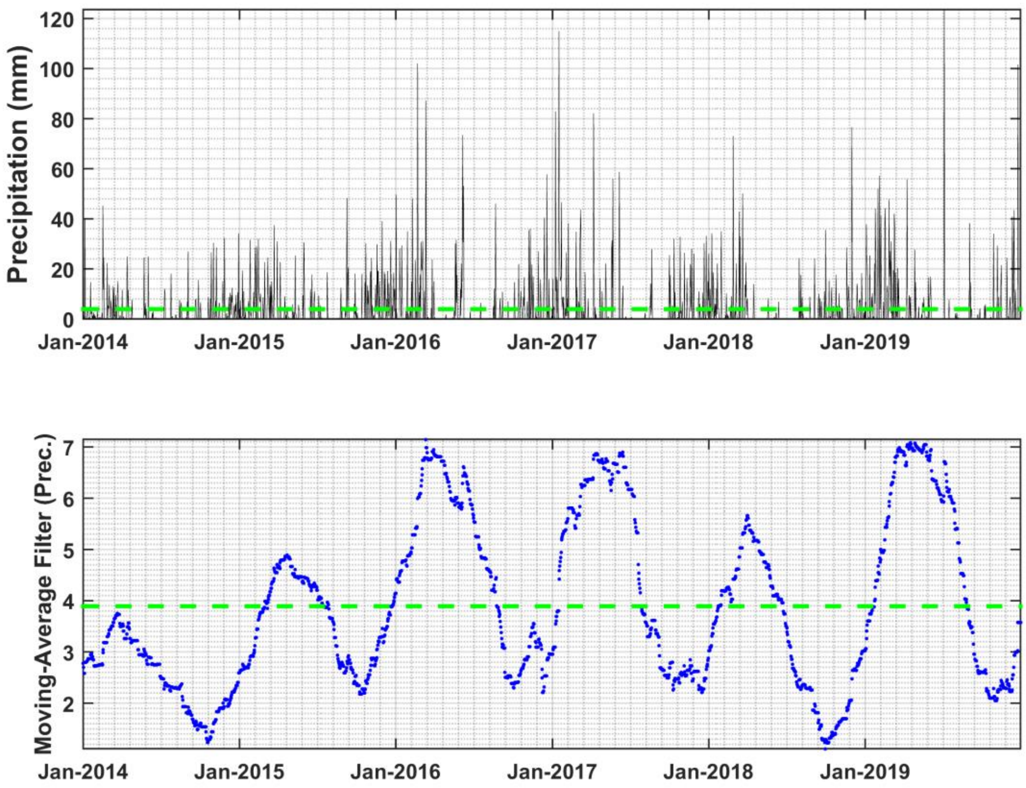

Figure 6 – Precipitation values during the period from 01/2014 to 12/2019 (10^2 mm). Black lines: time series without moving average filter; Blue line Moving-Average Filter applied.
Source: Authors (2020).

For the analyzed period, the drops in NDVI values occurred in the second half of 2014 (July to December), happening again between May 2015 until January 2016, May 2016 to January 2017, May 2017 to January 2018, July 2018 to February 2019. The average period of 7 to 8 months with negative NDVI values means the duration of the absence of rice cultivation in the field, due to its withdrawn or fallow land.

The NDVI time series can indicate changes in the cultivation cycle, such as reform or replacement of the crop, weed growth, cultural methods, among others. In this study, the results show the repetition of the rice cycle in the analyzed period, with duration between 4 and 5 months, coinciding with the common cycle for rice crops, which can range from 100 to 140 days according to EMBRAPA (2007).

The Figure 7 shows the response of daily NDVI to precipitation. The results showed that the average NDVI values showed a positive correlation (0.68) with the precipitation values. The NDVI peaks are highly influenced by the increase in precipitation, but without immediate effect, as occurs in nature. Rainfall explains more than 60% of the effects of variation in the vegetation index, while the remaining 40% are explained by other variables. Analyzing the period it is noticeable that 2015 was an atypical year, with the lowest average values of NDVI overlapping the peak of precipitation in the year, showing a high correlation between these variables (0.79). In contrast, in the same year the climatic phenomenon called *El Niño* occurred, which according to Berlato and Fontana (2003), the main effects in Brazil are the abnormal increase in temperatures and rains in the South and Southeast and severe droughts in the Northeast. In addition to, the year of 2014 stands out for the highest peak of NDVI values in contrast to the lowest peak of rainfall values. A greater understanding of anomalies in the response of NDVI due to rainfall requires more detailed research considering other edaphoclimatic variables.

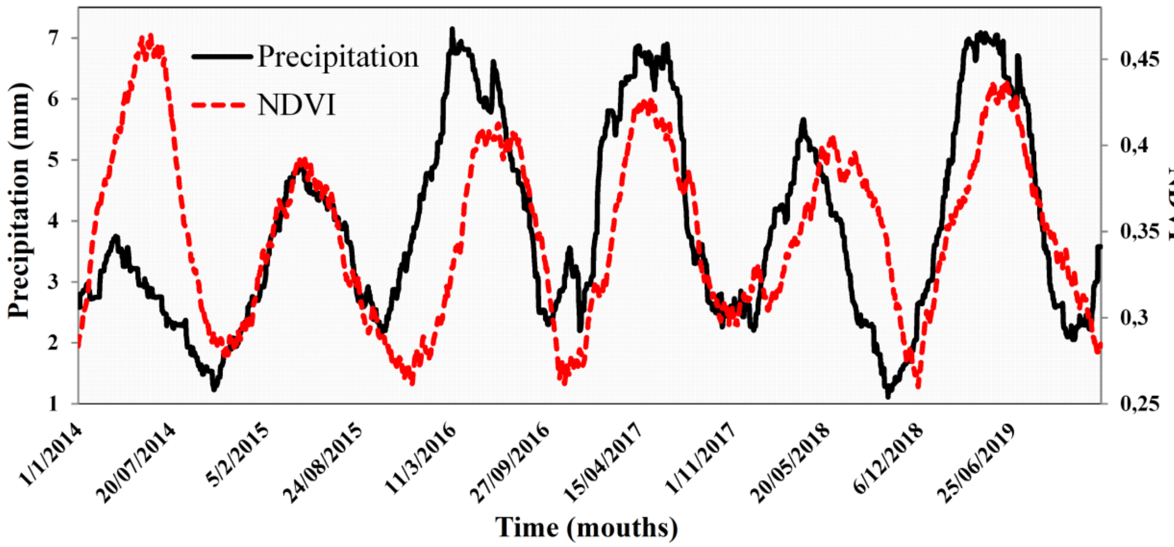

Figure 7 – Response of daily NDVI to precipitation (mm x 10^2).
Source: Authors (2020).

The Figure 8 shows the average annual of NDVI and rainfall. The average of the total NDVI is 0.3494 and the global average of the precipitation is 3.8921. The highest average for NDVI occurred in the year 2014, while the lowest average occurred in 2017, same year when *El Niño* occurred (CPTEC/INPE, 2020). In relation to precipitation, the highest and lowest average occurred in the years of 2019 and 2014, respectively.

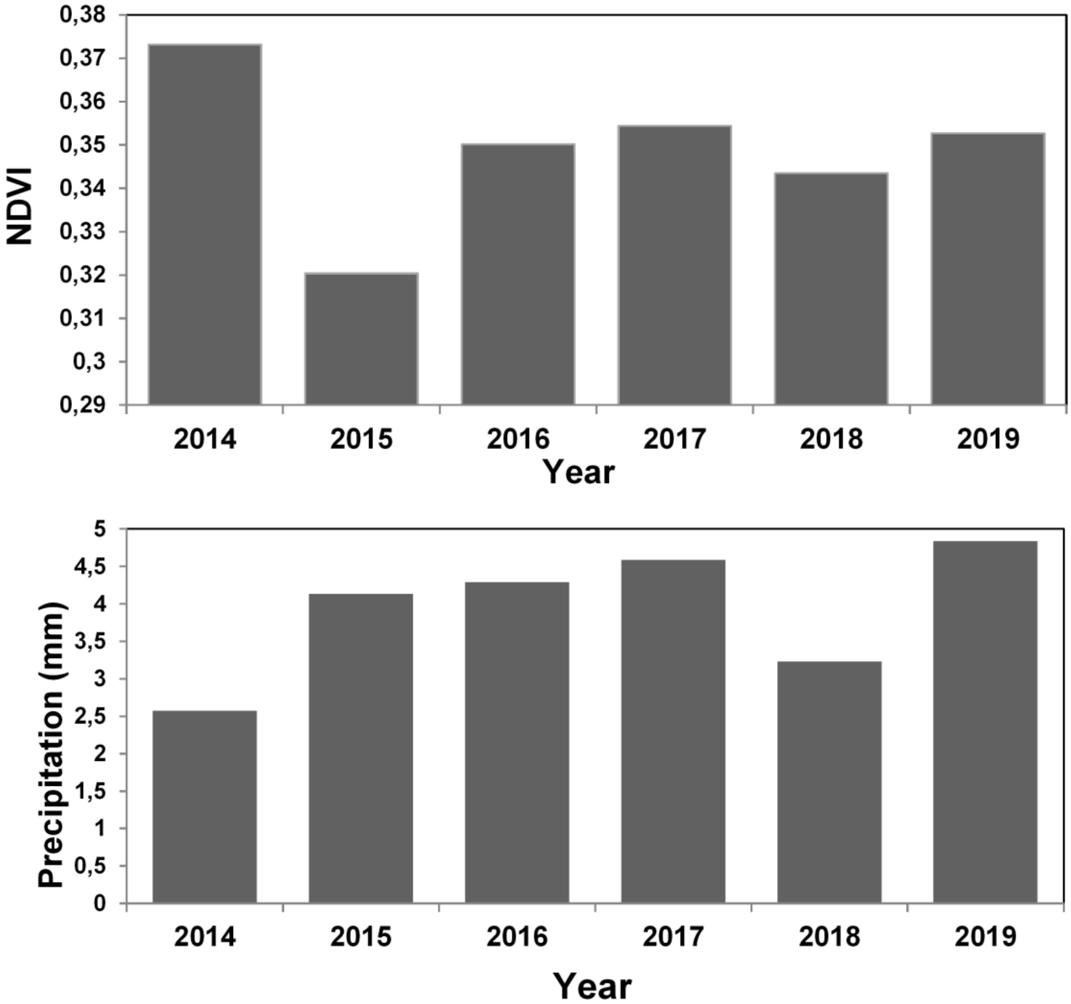

Figure 8 - Annual averages of NDVI and rainfall.

During the visit in the study area, the Piagui polder was identified, with several rice trays and the concrete water conduction channels, well organized and with good structure. It was also possible to identify crops other than rice, in smaller lots. The main source for irrigation is the Piagui River. The surroundings of the study area are composed of large urban plots, pasture areas and drainage networks. According to Paes Jr and Simões (2006), the region is an area of old occupation that stands out for rice production, and their results showed a positive evolution for the expansion of these areas between the years 1988 and 2003.

Conclusions

The script used in this study was previously tested in another region and a different culture, and as expected, the performance was very satisfactory in both studies, confirming that this computational routine can be applied to other crops in different regions. The daily NDVI values were essential to generate a time series consistent with reality.

Only 1 cycle per year was identified, with 2014 and 2015 being the most atypical years in the series. In general, precipitation was positively correlated with NDVI early and late in the growing crop, and there was a high negative correlation in the year of 2014.

The cloud processing allowed to process and to optimize the extraction of refined information from a large volume of data in an agile way and with less demand for computational resources. As a suggestion for future studies, it is to integrate more variables into the analysis, such as temperature and relief.

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