An assessment of water stress conditions in Ceará state based on TVDI using MODIS data

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Abstract. *Droughts are complex phenomena that directly impact on water supply, frequently occurring in the northeast region of Brazil. Temperature-Vegetation Dryness Index (TVDI) is an approach for a remotely-sensed based drought monitoring, based on surface temperature and NDVI. In order to assess the potential of TVDI in Ceará, this study evaluates the correlation between TVDI and accumulated rainfall in May/2019 and September/2018. The linear regression analysis indicated a strong relationship for the 90 days accumulated rainfall drier period. This assessment can be applied in future works involving time series analysis, detection of trends and investigation of relationships between TVDI and in situ soil moisture data in this region*

1. Introduction

Droughts are complex phenomena which directly impact water supply on regional and global scales. On northeastern Brazilian region, droughts tend to occur more frequently and severely in the face of climate change [Barbieri et al. 2010]. This can not only lead to land degradation but also hinder social-economic development, considering the effects on agricultural production.

Meteorological and hydrological measurements for drought assessments are conventionally performed with in situ data collected by probes and sensors. Despite being the most accurate methods, it can be costly and poorly spatially placed. On the other hand, remote sensing techniques allows continuous measurements of terrestrial conditions on a regular image acquisition time-span.

A wide range of remotely-sensed based indexes has been proposed to assess the vegetation conditions, such as Normalized Difference Vegetation Index - NDVI, Vegetation Health Index (VHI), Crop Water Stress Index (CWSI), and soil moisture, as an example of the Temperature Vegetation Dryness Index (TVDI) proposed by Sandholt et al. (2002). By a combination of Surface Temperature (T_S), visible and near-infrared information, the TVDI method has shown ability to capture information about surface water content and energy availability. Nonetheless, a drawback of this method is that the region must be large enough to represent the entire range of surface moisture content.

Considerable efforts have been made to investigate the potential of TVDI on semi-arid regions across the globe [Patel et al. 2007; Rahimzadeh-Bajgiran et al. 2012;

Du et al. 2017]. Yet, its applications on the Brazilian semi-arid region still remains to be explored.

To assess the potential of TVDI in capturing hydric stress conditions, this work aims to evaluate the TVDI model with in situ precipitation data in Ceará through linear regression analysis for a dry and wet period, each one comprised by 16 days. In this context, this paper was organized in the acquisition of NDVI and temperature MODIS products to calculate the TVDI and further comparison with in situ rainfall data. The obtained results were discussed based on correlation analysis.

2. Materials and Methods

2.1 Study site and precipitation data

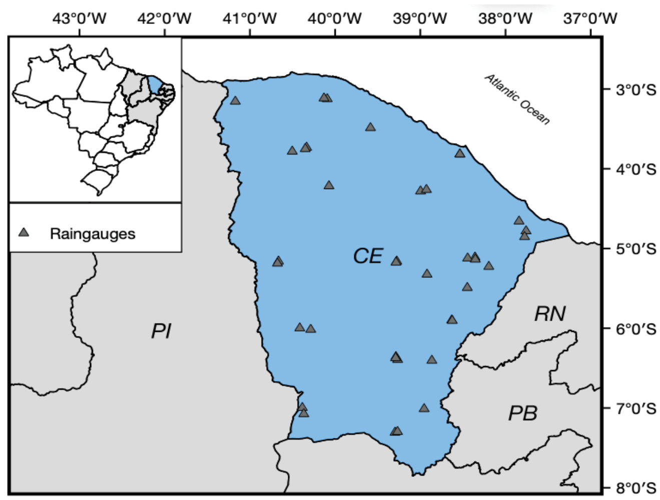

Figure 1. Location map of the state of Ceará and the spatial distribution of selected rain gauges.

The state of Ceará is located in the north-eastern part of Brazil (Figure 1), comprising a total population of approximately 8.5 million and a total area of around 146000 km². Most of the area is located on a semi-arid region, classified as BSh according to Köppen's climate classification [Alvares et al. 2013]. Its rainfall is irregularly distributed, represented by a short wet period (Feb-Mar-Apr-May) and a dry period (Aug-Sep-Oct-Nov) comprised of a large number of zero-rainfall days. Geologically, most of the region presents shallow and rocky soils, which gives a low capacity to store water and makes difficult agricultural mechanization [Alvalá et al 2017].

Precipitation daily data (mm) were obtained from Fundação Cearense de Recursos Hídricos e Meteorologia (FUNCEME), which comprises rain gauges network from Agência Nacional de Águas (ANA) and Instituto Nacional de Meteorologia (INMET), which includes manual and automated stations. A total of 38 stations were selected for the studied area and period after a data availability check.

2.2 Temperature Vegetation Dryness Index - TVDI

The TVDI is based on the relationship between NDVI and T_S. These variables may have a triangular or trapezoidal format in a scatterplot. The superior and inferior limits of this space are known as the dry and wet edge. The index has a range of 0 to 1. It is assumed that the pixels with a higher temperature are in hydric stress (TVDI=1) and those with a lower temperature are in a more humid condition (TVDI=0), as shown in Figure 2. The wet and dry edges were obtained from a scatter plot of NDVI versus T_S delimiting the evaporative triangle.

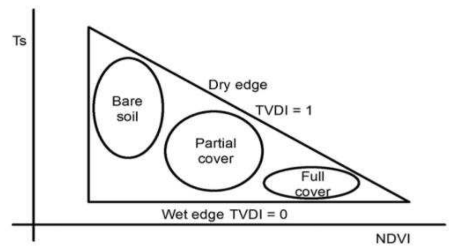

Figure 2. Schematic representation of the Evaporative Triangle, given by the relationship between surface temperature (TS) and normalized difference vegetation index (NDVI); Source: Shirmbeck et al. (2018).

The pixels between the edges receive a value depending on how far the pixel is from the wet edge, according to Equation 1:

$$TVDI = \frac{T_s - (a + b * NDVI)}{(c + d * NDVI) - (a + b * NDVI)} \quad (1)$$

where a+b*NDVI corresponds to the wet line function and c+d*NDVI to the dry line function.

In order to identify these edges, T_S values were extracted corresponding to the 99% most drier and wetter pixels of the image, as a way to remove outlier values. This approach has an advantage compared to Sandhold et al. (2002) method, since the authors used pixels with higher and lower temperatures, being highly sensitive to extreme values. To facilitate this method reproducibility, the project code is available on a public repository[1].

The index was calculated for a 16 days composite, utilizing NDVI (MOD13A2 version 6) and T_S (MOD11A2 version 6) products from Terra platform. The dates selected represent the dry (14/Sep/2018 - 30/Sep/2018) and wet season (01/May/2019 - 17/May/2019) in Ceará state.

Further, to validate and compare results, a linear regression analysis based on the correlation coefficient (R) was carried out between the TVDI data and accumulated

[1] https://github.com/dxbezerra/TVDI

rainfall (mm) data. Several accumulated rainfall time lags were calculated, including the 16 days period MODIS composite, and 7, 15, 30, 60 and 90 days prior to the MODIS composition date.

3. Results and Discussion

The T_S/NDVI scatterplot and the dry and wet edges for each period are represented in Figure 3. It is important to note that for the 2018 September image (dry season) the dry line was more inclined (higher angular coefficient) when compared to the May 2019 image (wet season). That was expected, as the probability of finding truly dry pixels tends to be lower in the rainy season. Due to the decrease of the temperature variation in humid conditions, the dry line inclination reduced. That result was also found by Schirmbeck et al. (2018), which hat applied the TVDI in a wetter south Brazilian region.

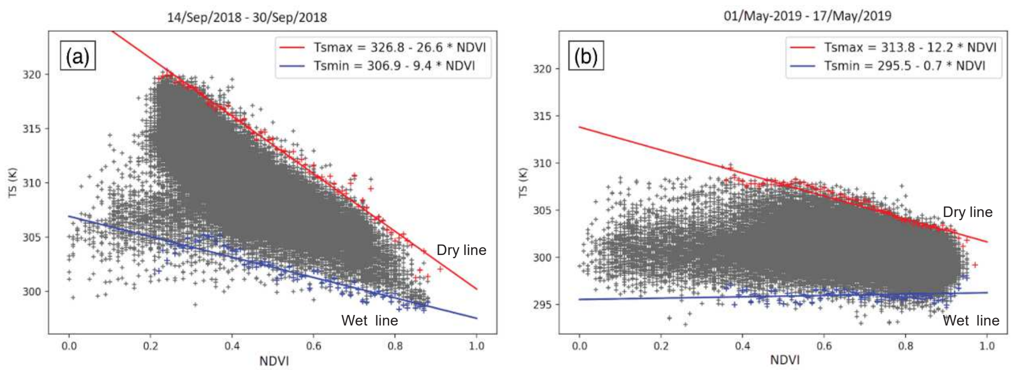

Figure 3. Superficial Temperature/NDVI scatterplot with the (a) dry and (b) wet periods.

On the other hand, if the dry line is more representative of a drought condition in a rainless period, the wet line is better estimated in a rainy season image. This corroborates with Sandholt et al. (2002) study, which considered the wet edge as a constant line, as seen in the wet period scatterplot (low angular coefficient). Thus, it endorses the importance of applying TVDI in sufficiently large areas that includes extreme soil moisture conditions.

Figure 4 shows the TVDI spatial distribution for dry and wet periods. The index was able to identify dry areas situated in northeast semiarid region, represented as high TVDI values. To some extent, these areas were identified as regions of intense desertification process by Oliveira et al. (2017).

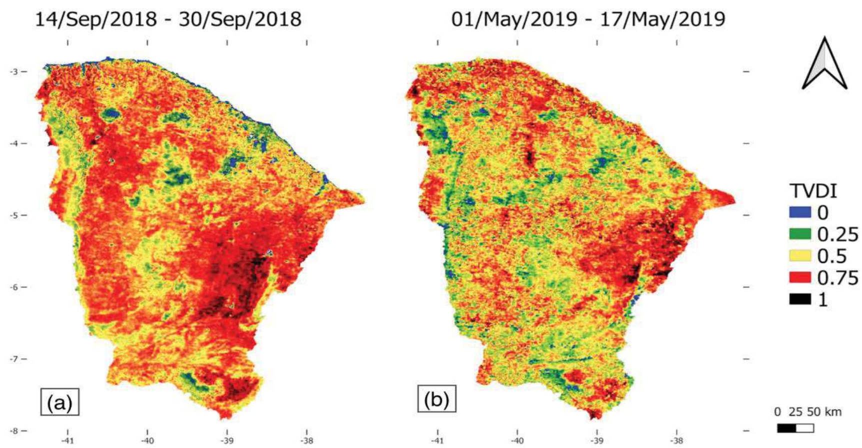

Figure 4. TVDI spatial distribution for (a) dry and (b) wet periods.

The correlation coefficient (R) between the TVDI values for both periods and accumulated rainfall for different time lags is presented in Table 1. The negative R values point out that places with higher TVDI are associated with lower accumulated rainfall.

Table 1. Correlation coefficients between TVDI values and accumulated rainfalls for different time lags.

	CP(0)	CP (-7)	CP (-15)	CP (-30)	CP (-60)	CP (-90)
Wet TVDI (May)	**-0.66**	-0.54	-0.45	-0.51	-0.52	**-0.65**
Dry TVDI (Sep)	-0.2	-0.25	-0.3	-0.28	-0.34	-0.4
CP = Composition period (-days)						

It is observed that the 90 days total rainfall (CP-90) performed better when compared to the other time lags, for both periods. This means that the 3 months accumulated rainfall is better represented by the TVDI. This result is unique, considering that authors normally use short rainfall time lags to validate the TVDI, such as 16 days total rainfall [Shirmbeck et al., 2018], or the monthly SPI (Standard Precipitation Index), which uses historical rainfall information to calculate the SPI index [Jun et al., 2017; Zormand and Jafari. 2017].

The correlation analysis also shows that the wet period (May) performed better when compared to the dry period (September). That is also unique, considering that Sandholt et al. (2002) and Cao et al. (2017) informed that the TVDI performance is better in drier environments.

4. Conclusions and Future work

The considerable correlation between TVDI and the rainfall data indicated the potential of TVDI as a method to remotely assess water stress. As far as we know, this is the first attempt to apply TVDI on the northeast Brazilian semiarid.

For future work it is strongly recommended that the assessment of the relationship between TVDI and in situ soil moisture data on this region. Also, time series analysis for this index in Ceará state could be a useful tool to detect trends of desertification and land degradation processes to improve drought monitoring.

5. References

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