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Estimation of land surface temperature in caatinga area using Landsat 8 data

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Abstract

The use of remote sensing techniques is of wide application within the various branches of the sciences, among them, to obtain biophysical data of the Earth which can focus to establish relations of temperature between the surface and remote sensors by images. However, the objective of the present work is to estimate the surface temperature in the caatinga area, in semi-arid region during the rainy and dry period, from Landsat 8 OLI / TIRS data. The study was carried out in the Natural Monument Conservation Unit Grota do Angico, located in the semi-arid state of Sergipe, under the domination of hyperxerophilic caatinga vegetation. Images were obtained for the dry and rainy period of the Landsat 8 OLI/TIRS satellite, using its thermal bands, which were processed in ArcGIS 10.2. It was observed a difference between the periods analyzed, both of the NDVI, which was shown with almost no vegetation during the dry season, while in the rainy season it presented forest cover in all analyzed area, regarding to the surface temperature which depends on the values of the vegetation index used, which indicated a difference between the maximum and minimum temperatures of respectively 8.61 and 7.99 °C. The methodology used allowed to estimate the surface temperature in the caatinga area of the semi-arid state of Sergipe, identifying the regions with the temperatures associated to the typology of the vegetation in the different periods analyzed.

Key-words: remote sensing, semi-arid, dry forest.

1. Introduction

The techniques of Remote Sensing have assumed an important role in the detection and monitoring of several meteorological and environmental phenomena (Borges et al., 2016), providing a better understanding of the behavior associated to their responses. climate and biophysical parameters of the earth's surface variables, including the temperature of the surface (Silva et al., 2015).

With the advancement of teledetection and the improvement of algorithms to estimate this type of parameter, which assumes high relevance for the spatial variability of spectral components and results of soil-vegetation-atmosphere interactions, research in the semi-arid region has become increasingly notable, mainly associated to the process of desertification and land reclamation in this region (Cordeiro, et al., 2015), which has a direct link with forest cover mainly through the use of vegetation indexes.

This type of estimation and obtaining of this information through orbital images provides the study of vast areas of the Earth's surface in comparison to the collection of specific data given by climatological stations, mainly due to the low monitoring mainly in regions with scarcity of this type of data, as is the case of the semi-arid portion of the Brazilian Northeast (Silva et al., 2015).

This need for collection is posed as a challenge, since despite the importance of the biome represented by the Caatinga, which covers all the states of the Northeast, there are still few experimental studies in development in order to understand the phenomena associated with heat transfer and in that region, and consequently, among others the surface temperature (Silans and Silva, 2007), which is detected by the sensor based on the brightness of the satellite sensors of the thermal band, and allows the simultaneous analysis of its behavior in areas with soil cover of different dynamics in the same scene (Gomes et al., 2016).

The knowledge of the surface temperature of the Earth has a prominent role in climatological and environmental research, mainly of climatic changes of different scales and also in landscape changes (Gusmão et al., 2013). Changes in land use, physical and biological properties of the surface also alter the energy exchanges between the surface and the Earth's atmosphere, which occur through the components of the radiation balance, and these landscape studies are increasingly being more employees in the research areas due to the monitoring and study of the forest cover (Corrêa et al., 2016), seeking to relate the climatic variables with the vegetation typology in each area.

Therefore, measurements of the energy balance components of a given region are essential for understanding and understanding processes that influence the ecosystem as well as on the local, regional and global hydrological cycle, since such data are also required for modeling studies on climate regime responses and environmental conditions (Batista et al., 2013), specifically when it comes to a region where the water regime is very distinct over the months as in the case of the semi-arid region.

However, the estimation of the surface temperature from the Landsat 8 satellite is still very incipient, going through a growing development and improvement of the algorithms, there are no guiding works in Brazil regarding its use and the algorithms involved including the vegetation in shape of vegetation index as the NDVI (Normalized Difference Vegetation Index), and there are only formulas that use the sensor brightness temperature response. Thus, it is essential to use auxiliary tools, such as mathematical models and other geographic information systems for data processing and generation of information that guide decision making from studies previously developed to plan water as well as environmental actions (Batista et al., 2013).

Therefore, the objective of the present study is to estimate the surface temperature in the fragment of the caatinga vegetation in the Natural Monument Conservation Unit of the Angico Grotto, in the semi-arid region of the State of Sergipe, during the rainy and dry season using Landsat 8 OLI/ TIRS data.

2. Materials and methods

2.1 Study area

The study was carried out on the hyperxerophilic caatinga fragment, characteristic for the climate of the region, and it can be defined as aesthetical Savana (Veloso et al., 1991), in the semi-arid region of the State of Sergipe, precisely in the State Conservation Unit Grota Natural Monument of Angico, which covers the municipalities of Canindé de São Francisco and Poço Redondo, located between the coordinates in UTM X/Y meters: 637270.59/8935547.258 and 649298.966/8925786.101 (Figure 1).

The climate of the region is characterized, according to Köeppen, as type Bssh', considered a very hot, semi-arid, steppe-type climate with a rainy season concentrated in autumn and winter, with 7 to 8 months considered drier. It has a mean annual precipitation of 483.9 mm, with a maximum of 918.6 mm and a minimum of 203.0 mm (Souza et al., 2014). The predominant soils in the area are classified as Non-Calcic Bruno and Litholic Neosols, which, in turn, are identified along the São Francisco River (Sergipe, 2012).

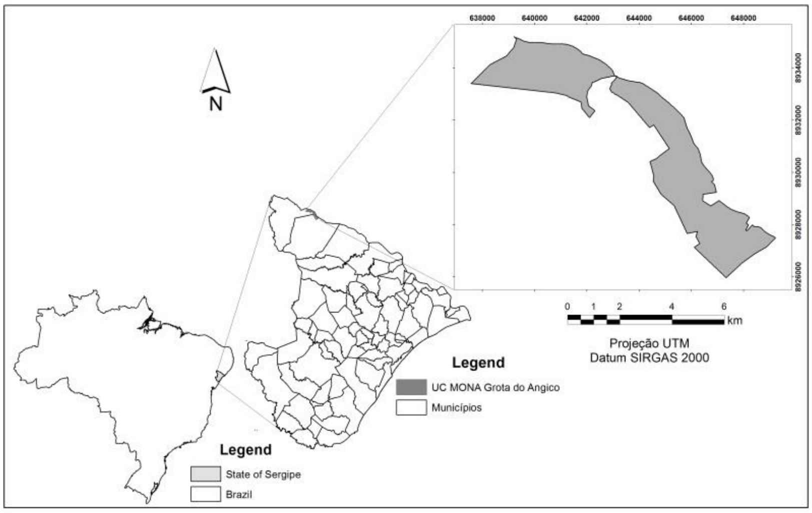

Figure 1 - Location of the Conservation Unit Natural Monument of the Angico Grotto.

2.2 Surface temperature estimation

To obtain the estimation of the Earth surface temperature (LST), images were obtained from the Landsat-8 satellite OLI/TIRS sensor in the rainy season (July 23, 2014) and the dry season (January 14, 2015), to estimate the soil surface temperature (LST). Of the US Geological Survey (USGS), where they were worked on in ArcGIS 10.2.2 and the result of the average of the bands 10 and 11 obtained by means of equation 1:

$$LST= T/1+W*(T/p)*In(e)) \qquad (1)$$

Where:
T= At satellite temperature;
W=Wavelength of emitted radiance (11.5μm);
p = h*C/S ($1.438*10^{-2}$mk);
h = planck's Constant ($6.626*10^{-34}$Js);
s = Boltzmann Constant ($1.38*10^{-23}$J/K);
C = Velocity of light ($2.998 *10^{8}$ m/s);
p = 14380;

In order to use the final TST equation, it is necessary to obtain the other parameters which are acquired from the following equations, where it is necessary to estimate the satellite brightness temperature by means of equation 2:

$$T = K2/In\,(K1/ L\lambda+1) – 273.15 \qquad (2)$$

Where
T= At – Satellite brightness temperature in Kelvin (K);
Lλ = TOA spectral radiance (watts/(m^2*ster* μm));
K1 = Band_Specific thermal conversion from the metadata (K1 – Constant_Band_X, where X is the band number, 10 or 11);
K2 = Band_Specific thermal conversion from the metadata (K2 – Constant_Band_X, where X is the band number, 10 or 11);
- 273.15 = Conversion of Kelvin to degrees Celsius;

However, to calculate T, it is necessary to perform the conversion of the digital number values of each pixel to spectral radiance, which is given by equation 3:

$$L\lambda = ML*Qcal + AL \qquad (3)$$

Where:
Lλ = TOA spectral radiance (watts/(m^2*ster*μm));
ML = Band Specific multiplicative rescaling factor from the meta (RADIANCE _MULT_BAND_X, Where X is the band number 10 or 11);
AL = Band specific additive rescaling factor from the metadata (RADIANCE _ADD_BAND_X, Where X is the band number 10 or 11);
Qcal = Quantized and calibrated standard product pixel values (DN);

Finally, to find the value "e" (the last component of the TST equation), which refers to the emissivity of the land surface cover, the equation 4 used in the study by Das (2015) and Suresh et al. (2016) and proposed initially by Sobrino et al. (2004):

e = 0.004*Pv + 0.986 (4)

Where:
e = land surface emissivity from NDVI;
Pv = Proportion of vegetation, obtained by the following equation:

Pv = (NDVI - NDVI min / NDVI max - NDVI min)^2 (5)

Where:
Pv = Proportion of vegetation
NDVI = Normalised Difference Vegetation Index, obtained by equation 6;
NDVI min = minimum value do NDVI;
NDVI max = maximum value do NDVI;
Being:

NDVI = NIR – R/ NIR + R (6)

Where:
NIR= near infrared wavelength (0.85-0.88 micrometers), referring to the spectral band 5;
R= wavelength of red (0.64-0.67 micrometers), referring to the spectral band 4;

3. Results and discussion

The study area is composed of caatinga vegetation, and as it is characteristic of this forest typology, a great variation of the presence of leaves in relation to the periods of study is observed, resulting from the own adaptive condition of the species that promote the deciduous process, which is clearly visible in Figure 2. In this study, it can be observed that during the rainy season the NDVI response is larger and the vegetation covers practically the entire study area. In the dry period, the vegetation loses its leaves, and the index is much lower, having only a few points of higher values that are associated with the forest along the watercourse. This condition was observed by Albuquerque et al. (2014), who in their study verified the differences obtained in the caatinga vegetation under different pluviometric regimes through the NDVI, proving to be efficient to analyze the spectral response of this type of vegetation covering which is framed in the semi-arid region of the Northeast of Brazil.

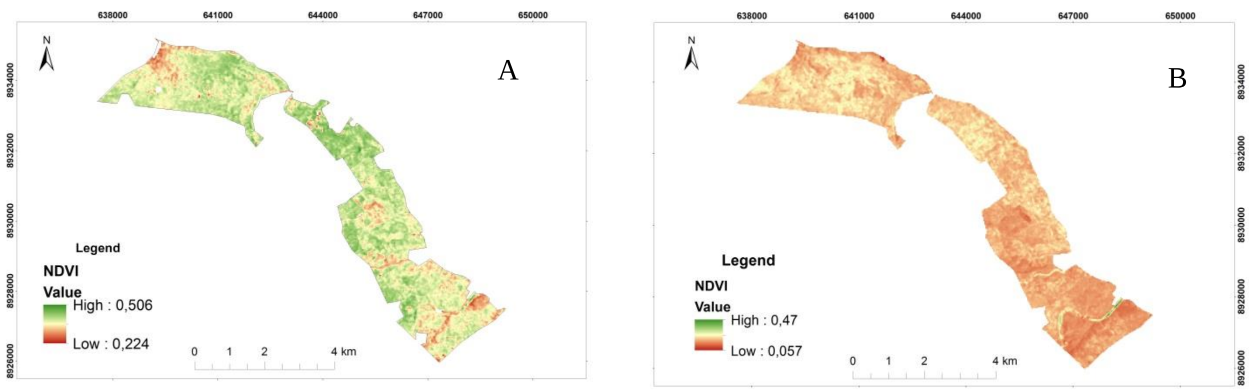

Figure 2 - NDVI of the caatinga vegetation for rainy season A, and dry season B.

The variation of the surface temperature as a function of the different responses of the vegetation index is clearly seen according to Figure 3, where it is observed that in the vegetation regions there are temperatures of lower values, as Borges et al. (2016) verified the relationship between the NDVI and the surface temperature in caatinga area, indicating that by reducing the vegetation index value, therefore, the temperature in the associated pixel is increased.

In the present study area in Canindé de São Francisco, there was variation along the study area in both periods of analysis, where the temperature during the rainy season was milder when compared to the dry period, and that in the great majority of the area obtained lower temperatures, with higher values in places of low vegetation. In the dry period, the surface temperature was spatially with a much higher expansion of the highs, and with a standard at the estimated temperature, where in the upper portion of the study area are the lower values and in the lower region the higher temperatures. Comparing the periods, it is observed that the spatial variation coincides, since areas with higher temperatures in the rainy season are reflected in the same areas during the dry period, but with a lower magnitude of the temperatures and to a lesser extent.

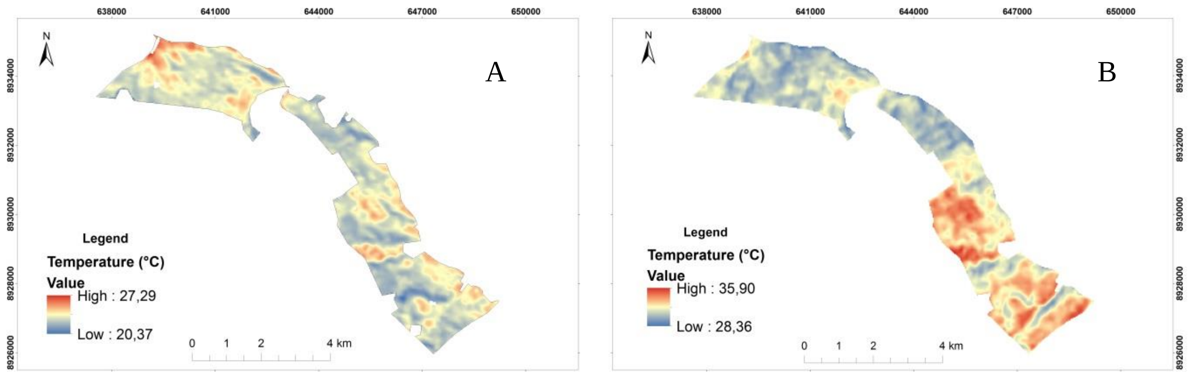

Figure 3 - Surface temperature (° C) for rainy season A, and dry season B.

This spatial variation of both the NVDI and consecutively surface temperature is common in the studies already produced, also seen by Cordeiro et al. (2015) when analyzing three different years of the city of Mossoró, which also has the caatinga biome as characteristic vegetation, as well as: Corrêa et al. (2016) when studying the Hydrographic Basin of the Mojuí-PA, also with variation in the study area; Gusmão et al. (2013) that detected large changes in deforested sites in relation to sites with native vegetation, with the finding that in the lower values of the NVDI the surface temperature increases; Silva et al. (2015) using the SEBAL algorithm verified a variation between 17.46 °C and 42.32 °C, showing that there is a great thermal variation between the different uses of the soil in Experimental of São João do Cariri, with sites of the basin presenting lower values of temperature and higher radiation balance, because they present areas with more vigorous vegetation which is characterized by the vegetation of caatinga; Silva et al. (2014), analyzing the space-time variation of the surface temperature in the semi-arid region of Pernambuco, with maximum values between 32.5 and 46.1ºC (higher values than the present study).

The differences in the results between the values of the NVDI and the surface temperature in the two study periods can be verified according to Table 1, which depicts the dispersion parameters of the statistic. The NVDI presented a wide amplitude in the values for the dry period, indicating areas with little vegetation and others with significant presence for the time, since it had a minimum value of 0.057 and a maximum value of 0.469, values lower than the rainy season that was shown with the indexes of 0.224 and 0.506, respectively, and therefore having a higher average (which was already expected due to the forest typology), as well as a standard deviation, which shows the expansion of values in this period.

Regarding the surface temperature, it was observed that during the dry period there was a greater amplitude in the result (7.54 °C), with the minimum and maximum values above during the rainy season, as well as of the other measures. In addition, comparing the temperature range for the maximum and minimum measurements between the periods, a variation of 8.61 and 7.99 °C, respectively, is observed.

The variation and distribution of the estimated values of the surface temperature can be visualized in Figure 3, illustrating the normal curve for each studied period, where in each one a trend pattern of symmetry is observed in each one. During the rainy season, it is clear that the maximum value does not reach the minimum of the dry season, which actually indicates the difference in the estimated temperature response between the analyzed moments.

Table 1 - Values of NDVI dispersion measurements and estimated surface temperature for the rainy and dry period in the caatinga area.

Measures of dispersion	NVDI		Surface tempeture (°C)	
	rainy	dry	rainy	dry
Average	0.386	0.204	23.25	31.83
Minimum	0.224	0.057	20.37	28.36
Maximum	0.506	0.469	27.29	35.90
Extent	0.282	0.412	6.92	7.54
Standard deviation	0.035	0.030	0.88	1.37
Variance	0.001	0.001	0.77	1.88
Coefficient of variation (%)	9.05	14.83	3.77	4.31

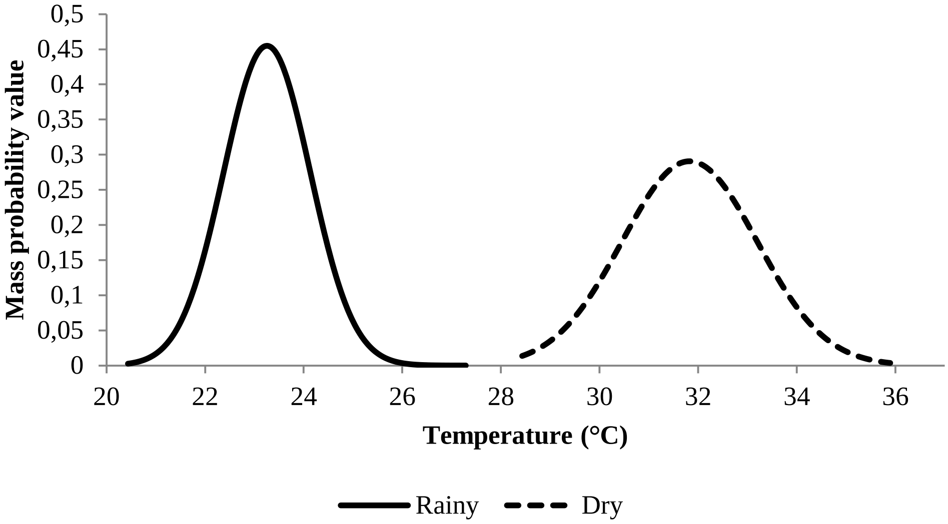

Figure 3 - Curves of the normal distribution of the estimated surface temperature.

Analyzing separately. the rainy season has a greater significance of its values between the temperature of 22 and 24.5 °C, whereas in the dry season the observed data are between 30 and 33.6 °C. It is also noted that the difference between the peaks of the curves, where in the rainy season it is higher, indicating that the frequency of the values is mostly in the central classes, the opposite of the dry period that denotes a greater proximity of the frequency distribution of the temperatures in the series obtained. This temperature difference between the analyzed epochs may be associated with the air temperature (Galvíncio et al., 2014) as well as the vegetation cover (Alves et al., 2017).

The surface temperature values for each study date are arranged differently within their own estimated series, which is characterized by Figure 4 which indicates the range, medians and quartiles of the data and which is expressed in a similar way In both periods, with values of the lower and upper limits at a similar distance from the central value, as well as the intervals of the internal quartiles.

The values for the rainy season show that the median of the whole series is 23.18 °C, which means, half of the values are below and the other half above this value, the same happens for the rainy season that has its median in 31.69 °C. The interquartile ranges are 1.17 and 2.07 °C, respectively, in the rainy and dry period, and the difference between the first and third quartiles in relation to the median is similar, showing little variation in these data and indicating the trend of symmetry of the Observed data.

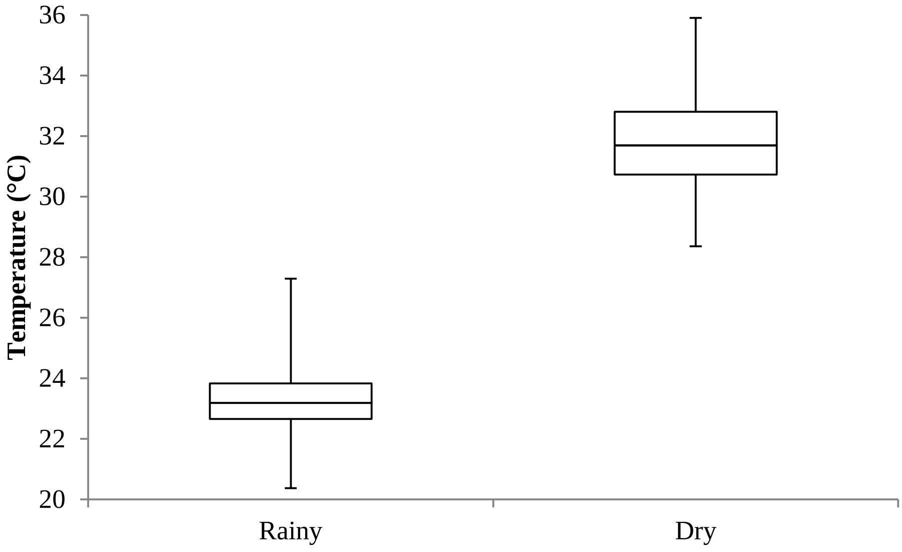

Figure 4 - Boxplot of the estimated surface temperatures for the rainy and dry period.

Although studies involving the estimation of surface temperature using remote sensing serve as a promising tool in climate studies (Gomes et al., 2016), these studies should be continuous, aiming at monitoring and observing both patterns and changes in the relationship between the target and sensor, as well as to improve the estimation through better algorithms and analysis processes, especially in study areas with great environmental variation such as native caatinga areas. In addition. the importance of maintaining this type of vegetation is mitigated in order to reduce surface temperatures, which also mitigates variations in the microclimate of the biome, as well as reducing the increasing degree of risk posed by pressure on environmental resources. Which over time. may lead to a state of advanced degradation in the Basin and difficult to reverse (Lopes et al., 2009).

4. Conclusion

The methodology allowed to estimate the surface temperature in the semi-arid area of the State of Sergipe, identifying regions with temperatures associated with the caatinga vegetation influence in the different periods analyzed, as well as to verify the spatial distribution and differences in surface temperature values in the two analyzed periods.

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