

Space-temporal evaluation of biophysical parameters in the High Ipanema watershed by remote sensing

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Abstract

The High Ipanema watershed is located in a semiarid region and because of this, becomes more vulnerable and susceptible to the effects of environmental changes and the degradation process, it has serious economic and socio-environmental implications. In recent years with the advancement of remote sensing based on satellite imagery or other platforms, it has become possible to monitor different and large areas of the various biomes in the world. The objective of this study was to identify changes in the vegetation cover conditions in the Alto Ipanema watershed, using spectral analyzes of Landsat-8 OLI / TIRS satellite images, using remote sensing techniques. Landsat-8 OLI / TIRS satellite images were obtained from the United States Geological Survey – USGS, on 10/12/2013, 14/01/2015 and 12/08/2016, where they were processed from ERDAS IMAGINE[®] software, version 9.1. The thematic maps of biophysical parameters were processed by ArcGis[®] 10.2.2 software. With the biophysical parameters analyzed, it was found that the northwest portion of the watershed presents a considerable area of exposed soils with indication of a high degree of susceptibility to degradation and that the biophysical parameters evaluated by the SEBAL algorithm are efficient in understanding the dynamics of spatial and temporal areas of semiarid environments.

Key words: degradation, vegetation index, semiarid, surface temperature, agrometeorology.

1. Introduction

The semiarid regions of northeastern Brazil in recent years show environmental changes and a delicate water aspect, a fact of great concern to the population, especially those who practice agricultural activities. This problem is associated with several factors, such as irregularities and low rainfall rates, which are characteristic for these regions. In addition, it is also important noting the long periods of drought that can cause irreversible damages in the various sectors of the semiarid (Hastenrath, 2012; Rodriguez et al., 2016).

However, the anthropological actions also stand out against the diverse uses and occupations of

the soil in the semiarid, the forms of action in the majority of the sectors bring constant negative impacts. The Aspects like deforestation, forest fires and inadequate management of irrigated agriculture are adverse factors that contribute to the worsening of the environmental degradation of these regions, increasing areas of exposed soil, susceptibility to erosion and desertification (Dantas et al., 2010; Ribeiro et al., 2016).

The Caatinga is a biome exclusively characteristic of semiarid regions, this way the study of vegetal cover and its main characteristics becomes relevant. Observing the space-temporal distribution of vegetation is important for the efficient management of water resources, exceptionally in the planning of

watershed management. Therefore, due to the frequent environmental changes in the semiarid region, we are looking for techniques that allow rapid and low-cost monitoring, aiming to mitigate the degradation and consequent desertification of the Caatinga, but the use of remote sensing from orbital images, which make possible large-scale studies at the regional and even global level, studies with this tool are quite observed in the regions of the Brazilian Northeast (Oliveira et al., 2012; Bezerra et al., 2014; Ferraz et al., 2014; Ribeiro et al., 2016; Lins et al., 2017).

With the use of remote sensing, it is possible to classify phenomena such as city growth, changes in land and occupation, changes in vegetation indexes, population statistics, and others things (Gallo and Xian, 2014).

So, the remote sensing has the capacity to identify diverse information at the surface and atmosphere interface, such as the investigation of biophysical parameters such as Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), Leaf Area Index (LAI) and Surface Temperature (Ts), which are important in the detection of climatic changes, since the vegetation indexes have become a very useful alternative, exceptionally used in the characterization of cultivated areas and native vegetation (Gusmão et al., 2013; Bezerra et al., 2014).

In this context, the objective was to identify changes in the vegetation cover in the High Ipanema watershed, by means of remote sensing techniques, associated to the methodology of biophysical parameters calculations for the characterization of the vegetation of the region.

2. Materials and methods

The High Ipanema watershed is located in the Pernambuco's state. It covers part of the municipalities of Arcoverde and Pesqueira, located between the coordinates: 8 ° 34 '17 "and 8 ° 18' 11" south latitude, and 37 ° 1 '35 "and 36 ° 47' 20" west longitude. It has an area of 187.55 km², with a perimeter of 90.25 km. The north it limits with the Ipojuca river and to the west, with the Moxotó river (Silva Junior et al., 2011).

In relation to the vegetal condition, the hypoxerophilic Caatinga prevails, characterized by a great variation in its foliar regime during the year. According to Montenegro et al. (2002) the upper part of the watershed is partially covered by dense caatinga forest, where shallow soils predominate, with a thickness of less than 2 m on the slopes.

Figure 1 shows the study area with natural color image of RGB - 432 composition of Landsat 8 OLI satellite on August 12, 2016.

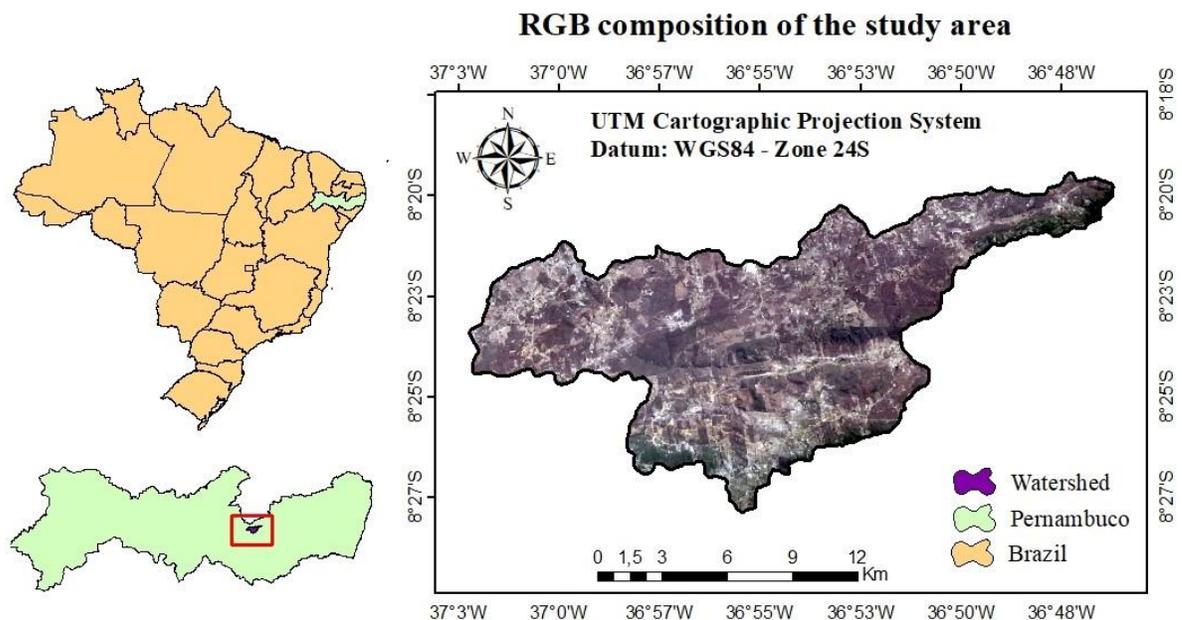


Figure 1 - Location map of High Ipanema watershed.

At first, the pre-processing of the images was done with: stacking of the bands, georeferencing of the images, and thus, the images were stacked using

ERDAS IMAGINE[®] 9.1 tools. After preprocessing, radiance, reflectance, vegetation indexes and surface temperature were generated with the SEBAL

algorithm, conforme Bastiaanssen et al., (1998). The thematic maps of these parameters were all processed by ArcGis® 10.2.2 Software.

Spectral radiance ($L_{b \text{ Land } 8}$) was determined based on the additive and multiplicative terms. Radiometric radiometric coefficients were used, available in the metadata files of the images used in the research. To determine the spectral radiance in each band was used Equation 1 (Chander & Markham, 2003; Silva et al., 2016).

$$L_{b \text{ Land } 8} = \text{Add}_{\text{rad } b} + \text{Mult}_{\text{rad } b} \cdot \text{ND}_b \quad (1)$$

Where, $\text{Add}_{\text{rad } b}$ is the additive term and $\text{Mult}_{\text{rad } b}$ the multiplicative, relative to radiance, these were extracted from the metadata of each OLI image and ND_b is the intensity of each pixel and band (value between 0 and 65365), which were also observed from the images under study. It was also necessary to convert the quantized and calibrated values of the gray level of each band of the OLI to the reflectance.

Thus, the radiometric coefficients related to the reflectance, made available in the metadata of the images (Chander & Markham, 2003; Silva et al., 2016) were used. The reflectance was determined by Equation 2.

$$r_{b \text{ Land } 8} = \frac{(\text{Add}_{\text{ref } b} + \text{Mult}_{\text{ref } b} \cdot \text{ND}_b)}{\cos \theta \cdot d_r} \quad (2)$$

Where, $r_{b \text{ Land } 8}$ ($\text{W m}^{-2} \text{sr}^{-1} \mu\text{m}^{-1}$) is the monochromatic reflectance of each pixel in each band; $\text{Add}_{\text{ref } b}$ is the term additive and $\text{Mult}_{\text{ref } b}$ the multiplicative, relating to the reflectance. These were extracted from the metadata of each image used and d_r obtained according to Equation 3 (Iqbal, 1983).

$$d_r = 1 + 0,033 \cdot \cos\left(\frac{\text{SDY} \cdot 2 \cdot \pi}{365}\right) \quad (3)$$

Where, SDY is the sequential day of the year and the argument of the \cos function is in radians. The mean annual value of d_r is equal to 1.00, ranging from about 0.97 to about 1.03. The cosine of the solar zenith angle (θ , dimensionless) is obtained from the angle of elevation of the sun (E , degrees), available in the metadata of the images, according to Equation 4.

$$\cos \theta = \cos\left(\frac{\pi}{2} - E\right) = \text{sen}(E) \quad (4)$$

The NDVI was proposed by Tucker (1979),

and it is an indicative of the conditions, the density and size of the vegetation, being obtained by the ratio between the difference of the reflected bands of the near infrared and of red, and the sum of the same bands, according to Equation 5 (Allen et al., 2002).

$$\text{NDVI} = \frac{r_{b \text{ IR}} - r_{b \text{ R}}}{r_{b \text{ IR}} + r_{b \text{ R}}} \quad (5)$$

Where, $r_{b \text{ IR}}$ and $r_{b \text{ R}}$ correspond respectively to the reflective bands 4 and 5 to Landsat 8 OLI.

The index of vegetation adjusted to soil conditions (SAVI), is an index that seeks to soften the antecedent effects of the soil, according to Equation 6 (Huete, 1988).

$$\text{SAVI} = \frac{(1 + L) \cdot (r_{b \text{ IR}} - r_{b \text{ R}})}{(L + r_{b \text{ IR}} + r_{b \text{ R}})} \quad (6)$$

Where, L is the soil adjustment constant, which depends on the soil type. For this research 0.1 was used due to the more recent studies, as proposed by (Allen et al., 2007; Silva et al., 2011).

With SAVI's data, it was possible to obtain the Leaf Area Index (LAI), defined by the ratio between the leaf area of all vegetation per unit area used by this vegetation. It is an indicator of the biomass of each pixel in the image. It was calculated according to (Allen et al., 2007), described by Equation 7, as follows:

$$\text{LAI} = - \frac{\ln\left(\frac{0.69 - \text{SAVI}}{0.59}\right)}{0.91} \quad (7)$$

The inverted Planck equation, valid for a blackbody, was used to obtain the surface temperature. Since each pixel does not emit electromagnetic radiation as a blackbody, there is a need to introduce the emissivity of each pixel in the spectral domain of the thermal band ε_{NB} (10.4 - 12.5 μm). In turn, when emitting the long wave radiation emitted by each pixel, the emissivity in the broadband domain ε_0 (5 - 100 μm) must be considered.

According to Allen et al. (2002), the emissivity of each pixel (ε_{NB}) and a (ε_0) can be obtained and validated, for $\text{NDVI} > 0$ and $\text{LAI} < 3$, according to Equations 8 and 9, as follows:

$$\varepsilon_{\text{NB}} = 0.97 + 0.0033 \cdot \text{LAI} \quad (8)$$

$$\varepsilon_0 = 0.95 + 0.01 \cdot \text{LAI} \quad (9)$$

The following conditions were followed for pixels with LAI values ≥ 3 , $\epsilon_{NB} = \epsilon_0 = 0.98$. For NDVI < 0 , $\epsilon_{NB} = 0.99$ and $\epsilon_0 = 0.985$ (Allen et al., 2002).

To obtain the surface temperature (T_s) was obtained using the spectral radiance of the thermal band (L_{b6}) of the satellite Landsat 5 of sensor TM and the thermal (L_{b10}) of the Landsat 8 of TIRS sensor and the emissivity (ϵ_{NB}) obtained in step previous. In this way, the surface temperature (K) was obtained by the following Equation 10.

$$T_{sup} = \frac{K_2}{\left(\frac{\epsilon_{NB} \cdot K_1}{L_b} + 1\right)} \quad (10)$$

Where, K_1 and K_2 ($W m^{-2} sr^{-1} \mu m^{-1}$) are calibration constants of the Landsat 5 TM (thermal band 6, L_{b6} , K_1

$= 607.76$ and $K_2 = 1260.56 W m^{-1}$) and Landsat 8 TIRS (thermal band 10, L_{b10} , $K_1 = 774.89$ and $K_2 = 1321.08 W m^{-2} sr^{-1} \mu m^{-1}$), extracted from the metadata of the processed images.

The estimated biophysical parameters (NDVI, SAVI, LAI and temperature) were statistically analyzed through measures of central tendency and dispersion, calculated through the ERDAS Software.

3. Results and discussion

Figure 2 illustrates the map of the processed images for the NDVI calculations for the periods studied, where it was divided into six classes: < 0 (Water); 0 - 0.2 (Exposed soil); 0.2-0.35 (Rala Vegetation); 0.35 - 0.5 (sparse vegetation); 0.5 - 0.65 (Transition Vegetation); > 0.65 (Dense Vegetation).

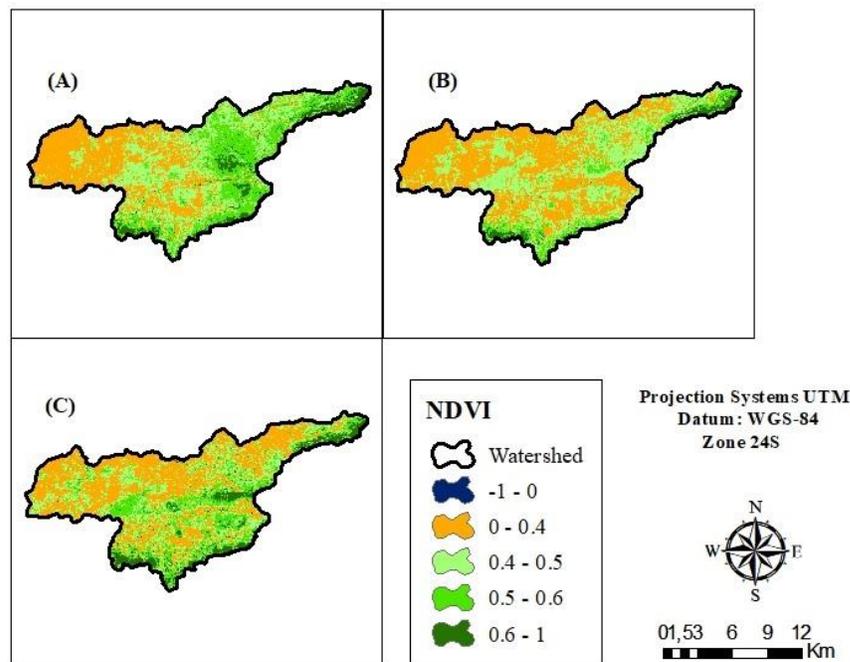


Figure 2 - Thematic map of the spatial and temporal distribution of the NDVI on the dates: 10/12/2013 (A), 14/11/2015 (B), 12/08/2016 (C).

It was contacted that in 2013 there was a smaller amount of soil exposed in the municipality in relation to the other years, and that the year 2016 was where the largest amount of exposed soil occurred and consequently the least amount of vegetation in the watershed. It was also evident that in the north-western portion the areas with a lot of exposed soil were identified and that they are very propitious to the process of environmental degradation.

NDVI was efficient to verify the vegetation behavior in the watershed and according to Aquino and Oliveira (2012) with the NDVI methodology from the

Landsat images, it was satisfactory, since it provided valuable information about the vegetation behavior between the different years and the different seasons of the year.

Santos and Galvncio (2013) verified in areas with sparse vegetation, with a predominance of shrub caatinga, NDVI values between 0.51 and 0.70 and in areas with dense vegetation, where there is a predominance of dense caatinga, ranging from 0.71 to 0.80. Chagas et al. (2008), mapping the vegetation of the municipality of Arcoverde - PE by means of NDVI, and observed that the class of dense caatinga vegetation

were present in areas with high altitudes presenting Gusmão et al. (2013) found NDVI values in the anthropic areas, ranging from 0.10 to 0.30. Freire et al. (2011), using images TM on the dates 13 and 20/11/2009, in the orbits / points 215, 216/65, 216, 215/66, found in the soil use and cover evaluation in the Pajeú basin exposed soil with occurrence at the mouth of the Pajeú River with an average of 0.17 for NDVI.

values higher than 0.7.

Table 1 shows the NDVI values, where they ranged from a minimum of -0.61 for the image of 10/12/2013 to a maximum of 0.84 for the same year. Gomes et al. (2012) performed thematic mapping in the Sertão do São Francisco Alagoano found NDVI values ranging from -0.99 to 0.77 for TM Landsat-5 image, on 07/07/2006.

Table 1 - Values of statistical parameters, maximum, minimum, average, median, mode, standard deviation (SD) and coefficient of variation (CV), obtained in statistical analysis of NDVI vegetation index map.

Figures dates	Vegetation Index - NDVI						
	Maximum	Minimum	Average	Median	Mode	SD	CV
10/12/2013	0.84	-0.61	0.358	0.332	0.298	0.099	0.27
14/11/2015	0.78	-0.58	0.325	0.305	0.305	0.088	0.27
12/08/2016	0.79	-0.30	0.425	0.402	0.372	0.115	0.27

The mean values and standard deviation of the NDVI presented a small variation between scenes, highlighting 14/11/2015 with the lowest mean value (0.325) and 12/08/2016 with the highest value (0.425) between the periods analyzed. The table also shows that CV values were the same in all scenes. Ribeiro et al. (2016), in a study of the Pajeú river, found between the mean values for NDVI the lowest value of 0.42 and

the highest value 0.63 and a standard deviation of 0.36 as the highest value.

For SAVI (Figure 3), the same NDVI intervals were used. The results of the SAVI showed similarities to the results obtained with the NDVI values, but as expected, they had a higher presence in the vegetation indexes, because the "L" constant decreases the influence of the soil spectral response on the SAVI calculation.

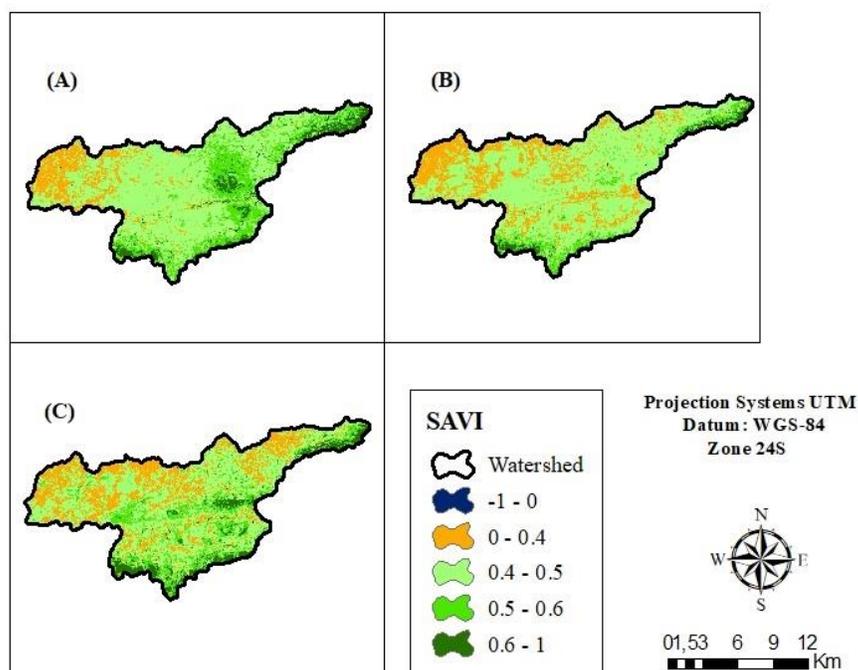


Figure 3 - Thematic map of the spatial and temporal distribution of SAVI on the dates: 10/12/2013 (A), 14/11/2015 (B), 12/08/2016 (C).

For Almeida (2012) with the values obtained from the SAVI, it is possible to verify in a more reliable way the level of degradation of the vegetal cover in semiarid areas in view of the contribution that the factor of soil adjustment provides.

According to Braz et al. (2015), in a study on the vegetation cover dynamics in the Córrego Ribeirãozinho watershed in the municipality of Selvíria - MS, found similarities in their results for NDVI and SAVI, with SAVI showing more reliable results in the application of this study, regarding the representation of the vegetation.

Miranda and Nascimento (2013) point out that SAVI when compared to NDVI, separates soil areas from vegetation areas and ponders different weights for each of these classes, making the soil effect more evident and less expressive.

Table 2 shows the values of the statistical parameters obtained in the statistical analysis of the SAVI vegetation index. The respective maximum and minimum values ranged from 0.78 to -0.35 that was found on 10/12/2013. The highest average value was 0.357 for the year 2016.

Table 2 - Values of statistical parameters, maximum, minimum, average, median, mode, standard deviation (SD) and coefficient of variation (CV) obtained in the statistical analysis of SAVI vegetation index.

Figures dates	Vegetation Index - SAVI						
	Maximum	Minimum	Average	Median	Mode	SD	CV
10/12/2013	0.78	-0.35	0.298	0.277	0.255	0.081	0.27
14/11/2015	0.72	-0.31	0.278	0.262	0.254	0.070	0.25
12/08/2016	0.72	-0.23	0.357	0.334	0.301	0.096	0.27

Santos et al. (2015), analyzing the parameters NDVI and SAVI in an irrigated area located near the city of Paranapanema - SP, found for the SAVI the mean values of 0.48 (01/30/2014) and 0,338 (09/09/2014), respectively.

The values of standard deviation and coefficient of variation were close. Ribeiro et al. (2016) obtained the highest value of the standard deviation (0.181) for the year 2005 and less than 0.113 in the year 2012 in the Pajeú river.

The information contained in the Figure 4 represents the result of the LAI as being a biophysical variable, defined as the leaf area density (vegetation cover). The highest LAI values are in the presence of dark green tones in the well-vegetated areas of the basin, while the orange tone indicates very little presence of leaves and the red tone presence of water.

Souza (2014) observed the lowest values of LAI in water and exposed soil area, with the highest values being on areas with vegetation, be it herbaceous or arboreal/shrub.

As for the LAI data, the same ones when represented cartographically are largely equivalent to the data obtained by calculating the SAVI. Varying only in the division and measurement of classes by index of leaf area.

Table 3 shows the statistical parameters of LAI, where the minimum value varied from 0.10 m² m⁻², and the maximum was 6 m² m⁻² for all years. The mean values observed were at a minimum of 0.418 m² m⁻² on November 14, 2015 and a maximum of 0.6 m² m⁻² on August 12, 2016.

Jordão et al. (2015) when analyzing the variability and spatial dependence of leaf area index (LAI) values in natural areas of 'low' field, 'high' field and transition forest in the South of Amazonas, found the average value of the area index (LAI) in the transition forest (4.42), followed by the 'high' field (2.03) and the 'low' field (1.72).

The values of standard deviation and coefficient of variation varied to the minimum in the DP value of 0.245 as of 14/11/2015 and a maximum of 0.417 as of 12/08/2016. Souza (2014) found standard deviation ranging from 0.2 to 0.8.

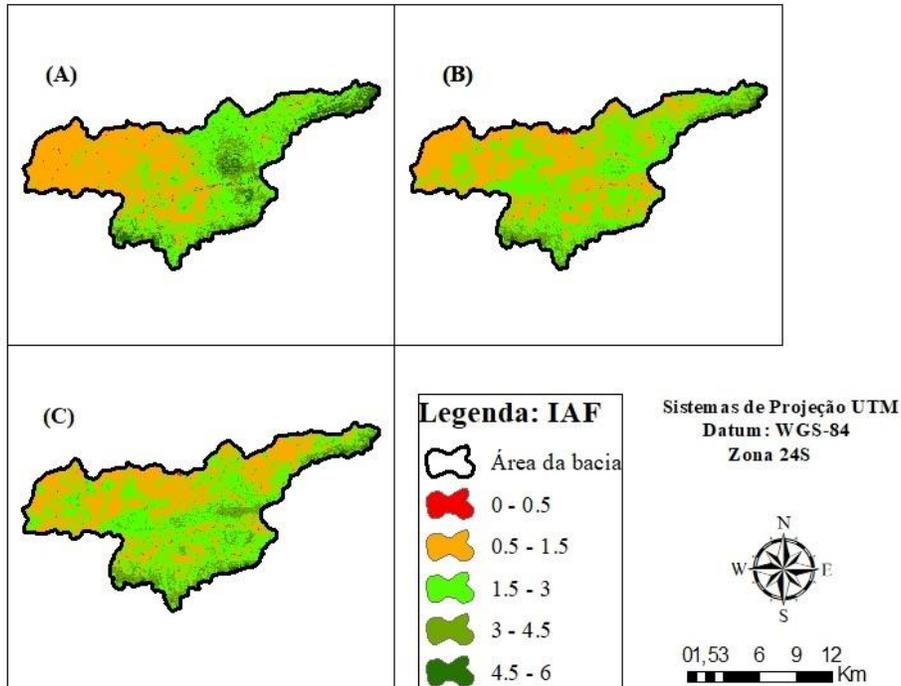


Figure 4 - Thematic map of the spatial and temporal distribution of the LAI on the dates: 10/12/2013 (A), 14/11/2015 (B), 12/08/2016 (C).

Table 3 - Values of statistical parameters, maximum, minimum, average, median, mode, standard deviation (SD) and coefficient of variation (CV) obtained in the statistical analysis of LAI vegetation index cards.

Pictures dates	Index of vegetation - LAI (m ² m ⁻²)						
	Maximum	Minimum	Average	Median	Mode	SD	CV
10/12/2013	6.00	0.10	0.484	0.386	0.315	0.315	0.65
14/11/2015	6.00	0.10	0.418	0.339	0.316	0.245	0.58
12/08/2016	6.00	0.10	0.694	0.553	0.410	0.417	0.60

In the Figure 5 below presents the thematic map of Surface Temperature in the High Ipanema watershed, for the following dates: 10/12/2013 (A), 14/11/2015 (B) and 12/08/2016 (C). The lowest surface temperature values (15-22) were found in the water and where vegetation was present, which were represented by the blue and light green shades.

The red tonality represents the highest temperature that is found in exposed soils (37-45). Gusmão et al. (2013) obtained average temperatures lower than 21 °C in water bodies, observing, also, the same behavior for sites with the presence of the larger native vegetation along all the studied days.

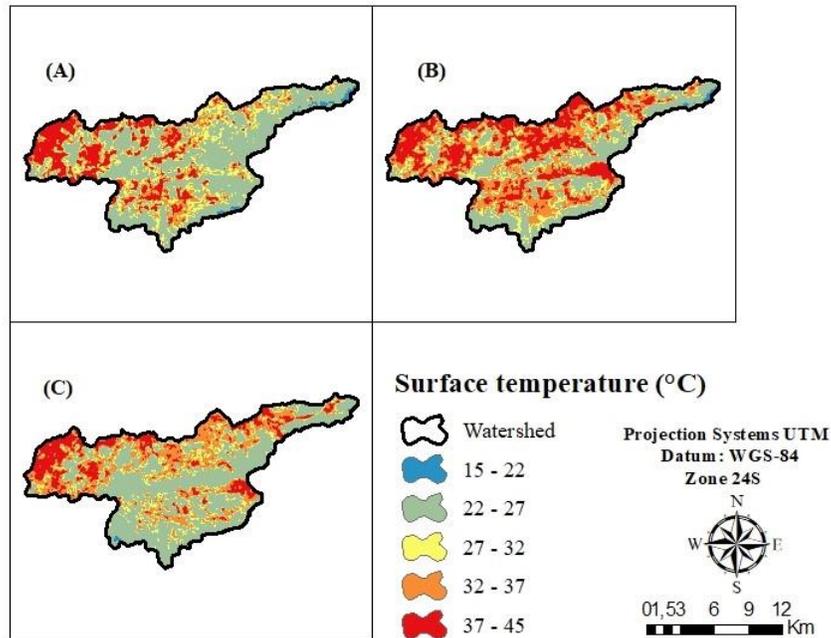


Figure 5 - Thematic map of the spatial and temporal distribution of surface temperature on the dates: 10/12/2013 (A), 14/11/2015 (B), 12/08/2016 (C).

Table 4 shows the statistical parameters obtained in the statistical analysis of T_s charts ($^{\circ}\text{C}$). It is observed that T_s had 36.5°C as minimum temperature on 12/08/2016 and for maximum of 47°C on 10/12/2013. The year 2015 also had the highest average with 38.93°C .

Oliveira et al. (2012) found a sharp change in T_s class between days 10/7/1989 and 29/8/2007, in the values of $18-23^{\circ}\text{C}$ and $23-30^{\circ}\text{C}$, respectively, and T_s even higher than 30°C for this last day, in the urban areas of the towns at Pombos and Vitória de Santo Antão – PE.

Table 4 - Values of statistical parameters, maximum, minimum, average, median, mode, standard deviation (SD) and coefficient of variation (CV), obtained in the statistical analysis of surface temperature - T_s ($^{\circ}\text{C}$).

Pictures dates	Temperatura da superfície - T_s ($^{\circ}\text{C}$)						
	Maximum	Minimum	Average	Median	Mode	SD	CV
10/12/2013	47.00	25.26	35.80	35.93	36.19	3.031	0.08
14/11/2015	46.90	27.55	38.93	39.21	41.02	3.192	0.08
12/08/2016	36.50	19.60	28.13	28.25	28.72	2.991	0.09

In general, the analyzed parameters behaved according to the results observed in the literature, showing an excellent applicability of the SEBAL to the region, through the responses of vegetation indexes and temperature, confirming the importance of these to subsidize the monitoring of natural resources quickly and efficiently.

4. Conclusions

The use of OLI - Landsat 8 images enabled the elaboration of maps of biophysical parameters in the

Alto Ipanema watershed in the Pernambuco's semi-arid.

The analysis of the parameters estimated in SEBAL has consistently allowed to conclude that in the areas, when the biophysical parameters maps are observed, there are indications of areas with exposed soil that may be in the process of degradation or already degraded, mainly the northwest part of the watershed management actions and environmental protection are necessary, avoiding evolutionary processes and that can lead to the permanent degradation of the area.

Finally, it is concluded that the use of vegetation indexes (NDVI, SAVI and LAI) and surface temperature are important tools to identify changes in vegetation cover.

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