Space analysis on the cachoeira II-Per reservoir margins with vegetation indexes

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Abstract
This study aimed to analyze the changes on the banks of the Cachoeira II reservoir, located in Serra Talhada-PE, by vegetation indices obtained with remote sensing. Two images of Landsat 5 TM and another image of Landsat 8 OLI / TIRS were used to analyze the changes. These images were used to estimate the Normalized Difference Vegetation Index (NDVI), Vegetation Adjustment Index (SAVI) and Foliar Area Index (LAI). Thereafter, a coverage types classification was performed and a statistical analysis. In addition, the monthly precipitations of the years 2000 and 2017 were obtained, which helped to interpret the changes. The reduction of the water surface area during the evaluation period caused by the drought from 2012 to 2016 was verified. Moreover, it was observed the lack of maintenance of the protected area of riparian vegetation across reservoir area, which can cause deleterious effects in the long term. The irrigated perimeter region maintained its activities over the same period, even with the droughts that affected the region during this evaluation period. Therefore, the use of remote sensing can assist in the monitoring and planning of conservation actions. Moreover, it is necessary to adopt conservation practices on the banks of the Cachoeira II reservoir so that there are no problems of contamination and silting.

Key-words: Geoprocessing, Remote Sensing, Reservoir, Semiarid

Introduction
The efficient management of water resources is one of the main challenges of the 21st century, since it is necessary to meet the different social, economic and environmental demands, ensuring the development of a region. This management is particularly critical difficulty in the semiarid region where it presents accentuated periods of drought, short periods of precipitation and an irregular distribution (Marín et al., 2016).

In view of this situation, it is necessary to use various structures to store precipitated water in the region for a long period of time. A widely used alternative is the construction of reservoirs, as it allows to capture water and store, besides destining to various uses, such as: human, animal, agricultural, industrial, etc. (Mota, 1995).

However, water resources suffer from strong anthropogenic pressures to supply different demands and, in this sense, understanding the water quality of the reservoir is fundamental to allow an adequate availability of water. Therefore, it is necessary to monitor the marginal areas of a reservoir (Santiago et al., 2009).

In order to carry out this monitoring of the reservoir it is possible to record and understand the dynamics of land use changes in the marginal area of the reservoir by geotechnology techniques, as remote sensing and geoprocessing. Within this process, it is possible to emphasize that among the different
information, the vegetation, obtained through vegetation indices, is fundamental for studying degraded areas and planning of actions of priority areas for biodiversity conservation (Cândido et al., 2015).

The understanding of the distribution of the vegetation cover is fundamental for understanding the dynamism of the use and occupation of the soil, since the human activities generate a modification of the vegetation that composes the area. In this way, the use of vegetation indices is essential for this purpose, different types of indices can be used (Bacalhau et al., 2017).

In view of the above, this study intends to analyze the changes occurring in the Cachoeira II Reservoir margins, located in Serra Talhada-PE, through vegetation indices obtained with remote sensing.

Material and Methods

This study was developed with the Cachoeira II Reservoir, located in the municipality of Serra Talhada, in the semi-arid region of Pernambuco (Figure 1). This reservoir is formed by the Cachoeira stream, affluent of the Pajeú River, and has a capacity of 21,031,145 m³, supplying the city of Serra Talhada and the perimeter Irrigado Cachoeira II (APAC, 2018). This reservoir is used for human, industrial and agricultural supply in the municipality and is of significant importance for the region of study.

The region is characterized by the BSwh ‘climate - semi-arid, hot and dry, with annual rainfall of 657 mm year⁻¹ and annual average temperature of 25.8 ºC (Cruz Neto et al., 2017).

In order to monitor the changes occurring around the reservoir margins, images of orbit 216 and point 65 were used, with an image of Landsat 5 TM referring to 27 November 2000 and an image of Landsat 8 OLI for the day 23 November 2017. These images were used due to the fact that they are clouds free and are both of the same period of year.

To assist in the understanding of the changes, the monthly rainfall data were obtained together to rainfall stations Water and Climate Agency Pernambuco were used (APAC) for the years 2000 and 2017, until November.

In order to perform the analysis it was used the software QGIS 2.18, using the function of raster calculator with the visible and near infrared bands. Using these spectral bands, NDVI, SAVI and IAF vegetation indices were determined, according to the methodology presented in SEBAL (Allen et al., 2002; Giongo and Vetorazzi, 2014).

The main estimates of the analyzed parameters are observed in the following mathematical models. For Landsat 5 TM, the determination of the Radiance of each pixel from the Digital Level, ND, is performed according to equation 1.

\[ L_{\lambda_i} = a_i + \frac{b_i - a_i}{255} \times ND \]  

Where, \( a \) and \( b \) are the minimum and maximum Radiations (W.m⁻².m⁻¹), detected by the TM sensor of landsat; \( ND \) is the digital image level corresponding to a range from 0 to 255 and \( i \) is referring to the band of the satellite being studied.

Subsequently, the reflectance which is the ratio of the flux of radiation reflected by a surface and the incident radiation flux (equation 2).

\[ \rho_i = \frac{\pi \times L_{\lambda_i}}{k_{\lambda_i} \cos Z \cdot d_r} \]  

Where, \( L_{\lambda_i} \) is the spectral radiance of each band; \( k_{\lambda_i} \) is the solar spectral irradianc of each band at the top of the atmosphere; \( Z \) is the zenith angle and \( d_r \) is the inverse of the square of the relative earth-sun distance.

While the determination of the radiance in each Landsat 8 OLI band was used Equation 3 (Chander and Markham, 2003; Silva et al., 2016).

\[ L_b = A_d \cdot \text{rad} + M_d \cdot \text{rad} \cdot ND_p \]  

Where: \( L_b \) (W m⁻² sr⁻¹ µm⁻¹) is the spectral radiance in each band of the OLI sensor, based on
the addrad and multiplicative terms (Multrad) relative to the radiance of each band (terms extracted from the images metadata) and NDb is the intensity of each pixel in each band.

The reflectance was determined from Equation 4 (Chander and Markham, 2003; Silva, 2016).

\[
rb = \frac{(\text{Addref} + \text{Multref} \cdot \text{NDb})}{\cos \theta \cdot d_r}
\]  

(4)

Where: \(rb\) \((\text{W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1})\) is the monochromatic reflectance in each band, based on the addref and multiplicative terms (Multref) related to the reflectance (terms extracted from the metadata), \(\cos \theta\) (dimensionless) is the cosine of the solar zenith angle, obtained from the angle of elevation of the Sun \((E, \text{degrees})\), observed in the metadata (Equation 5) and \(d_r\) (dimensionless) was obtained according to Equation 6 (Iqbal, 1983).

\[
\cos \theta = \cos \left( \frac{\pi}{2} \cdot E \right) = \text{sen} (E)
\]  

(5)

\[
d_r = 1 + 0.033 \cdot \cos \left( \frac{D_S A \cdot 2 \cdot \pi}{365} \right)
\]  

(6)

Where: DSA is the sequential day of the year and the argument of the cos function is in radians.

The normalized Difference Vegetation Index (NDVI) is determined based on the ratio of the near infrared \((rbIV)\) and red \((rbV)\) reflectances, to observe equation 7. This index is sensitive to the vigor of the plants, that is, to the quantity of green vegetation in the area and can range from -1 to +1.

\[
\text{NDVI} = \frac{rbIV - rbV}{rbIV + rbV}
\]  

(7)

Where: NDVI is the Normalized Difference Vegetation Index; RbIV is the Reflectance of the near Infrared band; rbV is the Reflectance of the Red band.

Since the soil reflects a lot of radiation, it is possible that when determining the NDVI there is an overestimation of the vigor of the plant. Thus, the soil-adjusted Vegetation Index (SAVI) seeks to minimize the effects of soil reflectance. This parameter is determined according to equation 8.

\[
\text{SAVI} = \frac{(1 + L) \cdot (rbIV - rbV)}{(L + rbIV + rbV)}
\]  

(8)

Where: SAVI is the Vegetation Index adjusted to the soil; \(L\) is the soil adjustment constant, depends on the soil type, the most recommended value for this region being 0.1; RbIV is the Reflectance of the near Infrared band; rbV is the Reflectance of the Red band.

Based on SAVI it is possible to determine the Foliar Area Index (LAI), obtained as the area ratio of all leaves in the vegetation per unit area (equation 9). This indicator allows you to determine the biomass of each pixel in the image.

It is important to highlight that the maximum value for the LAI is 6, which corresponds to the maximum SAVI of 0.687. For values beyond 0.687, the SAVI value saturates with the IAF increment and does not change significantly.

\[
\ln \left( \frac{0.69 - \text{SAVI}}{0.59} \right) = \frac{\text{LAI}}{0.91}
\]  

(9)

Where: LAI is the Foliar Area Index; SAVI is the Vegetation Index Adjusted to the Soil.

The images of each vegetation index were classified according to the soil cover type, according to some methodologies proposed in the literature. The NDVI index was based on the proposals by Chagas et al. (2008) and Santiago et al. (2009), this last work also served as a basis for classification of SAVI and IAF images.

An analysis of the descriptive statistics was carried out on the vegetation indices for each date of acquisition of the images, using data of minimum, medium and maximum values.

Results and discussion

It is possible to observe that the period of greatest precipitation covered the months of February, March and April, however, for the year 2017 the month of June presented a marked value of 174 mm. In the accumulated years until November, the analysis period in question, 2017 presented a value of 647.5 mm, while the year 2000 obtained 584.4 mm.

Lins et al. (2017) used quantiles to characterize the precipitation regime of the municipality of Serra Talhada for the years 1986 to 2016, and were able to classify the year 2000 as Seco and the previous five years (1999, 1998, 1997, 1996 e 1995) as Dry, very Dry, Rainy, Rainy and normal, respectively.
On the other hand, the year 2017 presented a precipitation of 647.5 mm up to November, which is close to the region’s average rainfall, and can infer that the year had a minimum normal performance. However, the previous five years (2016, 2015, 2014, 2013 and 2012) were classified, by the authors mentioned above, as: Very Dry, Dry, Normal, Dry and Very Dry, respectively. Therefore, the region went through a period of drought, as well as the entire semiarid (Marengo et al., 2016).

![Fig. 2. Precipitation of the years 2000 and 2017 for Serra Talhada-PE.](image)

In this study, the first index used was NDVI (Figure 3) and this index is an indicator of the condition of vegetation vigor. With the NDVI images, a classification was made in regions of water, exposed soil and vegetation under different conditions. However, in the classification used in Figure 3, there was aggregation of sparse vegetation and transition through sparse vegetation or crop.

It is observed in figure 3, in the central region of the image, the reduction that the Cachoeira II Reservoir during the 17 years of evaluation. This is mainly due to the severe drought that occurred during the period 2012 to 2016 that affected the region.

Furthermore, in the northern region of the image, on both dates, there is an area of dense and sparse vegetation, which follows the drainage line of the Cachoeira creek that supplies the reservoir. While in the southeastern region of the images, downstream of the reservoir, it is observed an area with vegetation with greater vigor in both dates. This portion of the image corresponds to the irrigated perimeter Cachoreira II.

The large-scale reservoir construction is designed to meet the large urban demands of water supply and agricultural activities (Lima et al., 2011). Therefore, the reservoir has fulfilled with the proposed objective and helping to face the droughts that characterize the semiarid region.

![Fig. 3. NDVI in Cachoeira II Reservoir margins, Serra Tallhada.](image)

Figure 4 presents the SAVI images for the evaluation dates. This index is interesting because it allows to minimize the effect of the presence of the soil in the middle of the vegetation. It is possible to observe the maintenance of the distribution pattern of the vegetation cover area obtained by the NDVI images, with few variations in the values of the indices, a similar situation happened in Braz et al. (2015) in a study carried out in the cerrado area.

Visually the image of the year 2017 presents higher values of the index, which indicates a greater vigor of the plants for the date. In the other hand, there is a predominance of vegetation with low photosynthesis activity in the year 2000, because the climatic and water conditions of that year. (da Silva and Cruz, 2016).

![Fig. 4. SAVI in Cachoeira II Reservoir margins, Serra Tallhada.](image)
The other index used for analysis was the Leaf Area Index (LAI), Figure 5, which represents the leaf area of the vegetation per unit area and works as an indicator of biomass. The results obtained allow the detection of vegetation contrasts, as this index is an indicator of crop growth and development.

Thus, the area corresponding to the irrigated perimeter, southeast of the dam, has a dense vegetation and crop response. In addition, the northern part of the reservoir, following the main drainage line of the creek, has a dense vegetation cover, as detected by Cunha et al. (2012) under study in the semiarid Paraibano.

Therefore, it is possible to observe that around the water surface area, it is verified that certain regions present the greatest presence of vegetation cover, while other areas do not present the riparian forest, both in NDVI images (Figure 3), SAVI (Figure 4) and IAF (Figure 5).

In addition, in 2000, a larger portion of areas with sparse vegetation was seen around the water mirror, whereas in 2017, there was a significant amount of exposed soil on the left bank of the reservoir. This region of exposed soil is probably due to the fact that it is used for cultivation of crops with short cycle, such as beans and corn, since the rainfed production is the most common in the region.

However, it is important to highlight that exposed soil areas can potentiate the desertification process and contribute to the sedimentation of the reservoir, thereby reducing the reservoir's storage capacity. Da Silva et al. (2017) remarked that the exposed soils are more vulnerable to this degradation process, because the soil particles are more vulnerable to the precipitation effects, causing the loss of the superficial layer and nutrients.

It is verified that the image of the 11/26/2017 has a mean of the pixels bigger than the images of the 11/27/2000 (Table 1), for all the indices of evaluated vegetation. As for NDVI, the average for 2017 was close to that obtained by Bacalhau, de Neto and de Oliveira (2017) in the Algodões Reservoir area, in the Pernambuco semiarid, with images from 2016 and Bezerra et al. (2014) in an area of Caatinga in Rio Grande do Norte.

### Table 1. Descriptive Statistics of Vegetation Indices.

<table>
<thead>
<tr>
<th>Vegetation Indices</th>
<th>Date</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>27/11/20 00</td>
<td>-0.596</td>
<td>0.147</td>
<td>0.772</td>
</tr>
<tr>
<td></td>
<td>26/11/20 17</td>
<td>-0.786</td>
<td>0.284</td>
<td>0.777</td>
</tr>
<tr>
<td>SAVI</td>
<td>27/11/20 00</td>
<td>-0.365</td>
<td>0.125</td>
<td>0.728</td>
</tr>
<tr>
<td></td>
<td>26/11/20 17</td>
<td>-0.302</td>
<td>0.245</td>
<td>0.724</td>
</tr>
<tr>
<td>IAF</td>
<td>27/11/20 00</td>
<td>0.000</td>
<td>0.108</td>
<td>6.000</td>
</tr>
<tr>
<td></td>
<td>26/11/20 17</td>
<td>0.000</td>
<td>0.336</td>
<td>6.000</td>
</tr>
</tbody>
</table>

This higher value in vegetation indices, even after a drought period in the region, is justified by the fact that rainfall occurred prior to the acquisition of the images was higher in 2017 (Figure 2), especially in June.

In view of the observed results, it is necessary to implement the permanent preservation area along the margins of the Cachoeira II Reservoir. Since the anthropic activities developed in these regions can negatively impact the amount of water in the water supply (Morais et al., 2014). As this water is used for both irrigated perimeter and water supply, maintaining good quality and availability is key to local development.

### Conclusion

The use of remote sensing can be used to monitor a reservoir through vegetation indices, and can serve as a tool for planning actions to minimize socioeconomic and environmental impacts. In addition, the comparison of the images allowed to
understand the impact of the drought of the period 2012 to 2016 in the Waterfall II Reservoir and the reduction of the available water volume.

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