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METHOD FOR EVALUATING PLANT COVER AND QUANTIFICATION USING PIXEL TO PIXEL CORRELATION INDICES

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Abstract: This study brings results on Normalized Difference Vegetation Index (NDVI), the Adjusted Vegetation Index of Soil (SAVI) and the Index of Water by Normalized Difference (NDWI) through a method that uses correlation matrices built on a pixel to pixel combination for spatial and temporal analysis of plant cover. The study was developed by using Landsat 8 images from January and August, 2015. Image processing was performed with ArcGis and Matlab building correlation matrices to evaluate variations of each index in Brazilian vegetation. Results showed decreasing values of the three indices from wet to dry period. Climatic conditions influenced on the vigor and moisture content of vegetation. The pixel to pixel correlation method is appropriated to study vegetation changes and quantify increase, decrease or maintenance of vegetation.

Keywords: Vegetation index; remote sensing; correlation matrixes; pixels, plant cover

INTRODUCTION

Monitoring of plant cover has been one of the main focuses of global environmental conservation. Studies have shown the importance of monitoring, considering the high impact of vegetation on physicochemical processes, water bodies conservation, changes in carbon cycle behavior and climate change. Monitoring adds information to studies that investigate conservation scenarios and changes in patterns of occupation of these areas (Balestrini *et al.*, 2011; Lourenço *et al.*, 2014; Kennel *et al.*, 2015).

Moreover, studies on plant cover have contributed to minimize anthropic effects on forested areas, such as the research in the area of Atlantic Forest biome, which is a biodiversity hotspot but with high degree of anthropogenic intervention. Annual rate of plant loss corresponded to 18,576 hectares in the Atlantic Forest on the last three years, ranking it as one of the 22 threatened biomes in the world (Ribeiro *et al.*, 2009; MCT, 2015).

Quantification and monitoring of plant cover have been carried out with studies based on the application of vegetation indices, combining techniques and tools of remote sensing. These indices are based on the values of reflectance or radiance presented by vegetation in spectral regions of visible, near infrared and short-wave infrared. Photosynthetically active biomass and the presence of water in the foliage are measured through these spectral regions (Jensen, 2007; Ponzoni *et al.*, 2012; Schucknecht, 2013).

Among the main approaches, three different indices stand out. Dominant indexes in studies correlating quantification and monitoring of plant cover. The Normalized Difference Vegetation Index (NDVI) developed by Rouse *et al.* (1973) involves the ratio of linear combinations in spectral regions of red and near infrared. NDVI values vary from -1 to 1: vegetation is associated to positive values, water bodies and wetlands to negative values and those values close to zero represent exposed soil or no vegetation (Lourenço; Landim, 2004; Pau *et al.*, 2012; Rafique *et al.*, 2016).

The Soil Adjusted Vegetation Index (SAVI) was developed by Huete (1988), incorporated a soil adjustment constant minimizing soil background effects and optimizing vegetative spectral response. Soil bottom conditions influence on the canopy significantly in calculated vegetation indices, which can be minimized according to the type of vegetation and use of constants varying from 0.25 to 1. SAVI values range from -1.5 to 1.5 with the same associations of NDVI. Thus, vegetation is mapped to positive values, water bodies and wetlands to negative responses and those values close to zero represent exposed soil or no vegetation (Gillabert *et al.*, 2002; Jiang *et al.*, 2008; Gontia & Tiwari, 2010).

Finally, the Normalized Difference Water Index (NDWI), initially developed by McFeeters (1996) from the NDVI, aims at delineating features present in the aquatic environment and highlighting their presence in the images. Nevertheless, NDWI methodology developed by Gao (1996) applied the index based on the near infrared and infrared spectral regions, correlating it to water content in plants, biomass variation and plant stress. The values of NDWI vary from -1 to 1. Negative values represent absence of vegetation, positive values indicate water in the vegetation. The more water content in the foliage the closer to zero is the index (Jensen, 2007; Oliveira *et al.*, 2010).

Although indeces contribute to the efficiency of land surface monitoring model and assist in plant cover evaluation, results depend on the type of vegetation, climatic conditions and topography. Schucknecht (2013) and Ávila *et al.* (2014) investigated the use of NDVI to evaluate vegetative vigor of Atlantic Forest under precipitations and identified direct relationship between high NDVI scores and high rainfall. The study by Rafique *et al.* (2016) found NDVI best results for tropical and temperate regions over a period of 28 years when compared to boreal and extratropical regions.

Studies addressing SAVI are constantly associated to NDVI, seeking evidence of influence of activities on the scores of qualitative vigor of vegetation and identification of standards.

This study shows a method to quantify areas ofincrease, decrease or maintenance of vegetative vigor and water content in leaf structures using correlation matrices of an index built on a pixel to pixel basis. Results and discussion on the method application to a hydrographic basin located in the city of Ibiúna, State of São Paulo, Brazil are also provided.

MATERIALS AND METHOD

Study area

The study was carried out in a river basin called Una River and located in the State of São Paulo, Brazil (Figure 1). The area is fragmented and shows marked human occupation with different levels of disturbance on water and biotic resources. There are also important rivers to the urban water.

The region has rainy summer (January) and dry winter (August) characterized by tropical climatic factors of high temperatures (average of 25º C) and high precipitation. The vegetation is characterized by important fragments of Atlantic Forest with dense ombrophylous forest type (IBGE, 2012).

Vegetation Index

Vegetation indices were generated from the OLI/Landsat 8 sensor images, corresponding to the orbit point 219/076, of January, 10th and August, 22nd, 2015, obtained from the United States Geological Survey (USGS, 2015). The spectral bands used were OLI4 (red), OLI5 (near infrared) and OLI6 (short wave infrared).

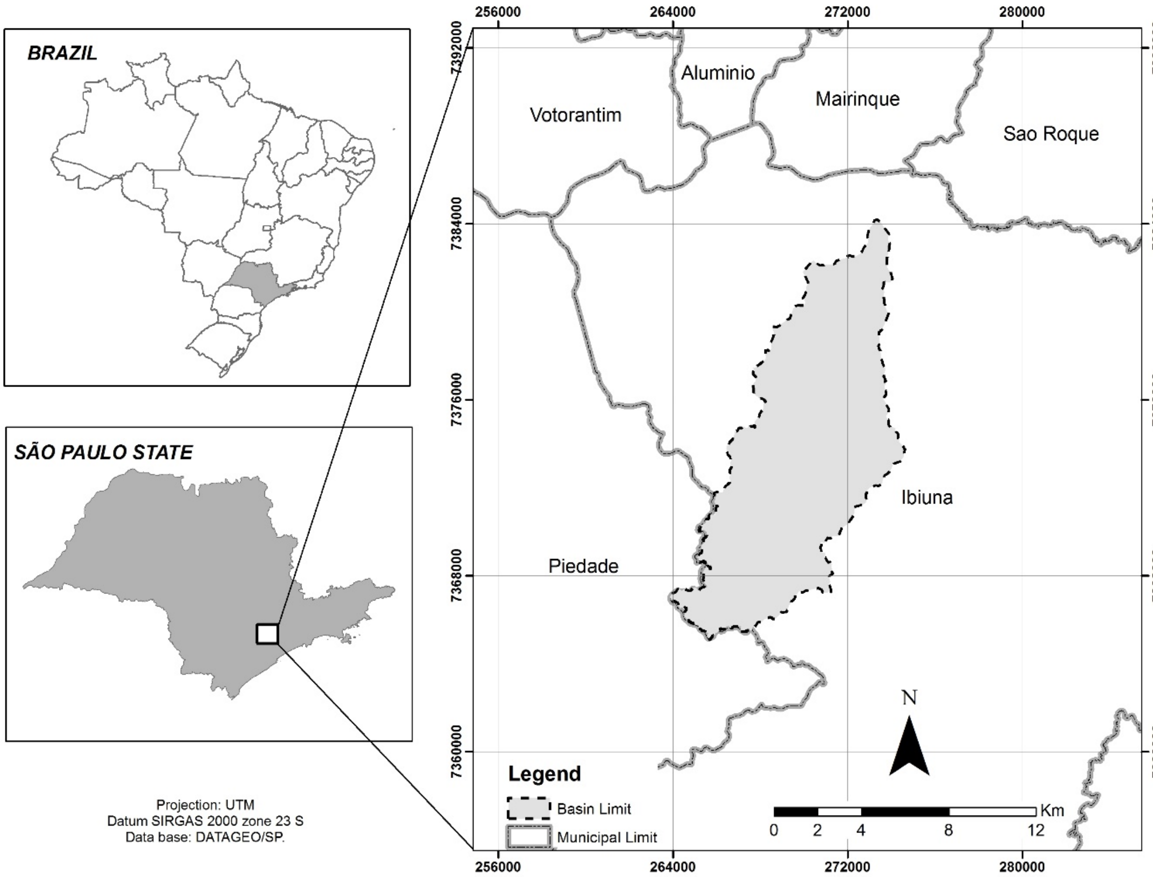

Fig. 1 Location map of the Una River Basin.

Image date selection considered the months of higher and lower rainfall, since rains can significantly influence plant reflectance and absorbance values (Detsch *et al.*, 2016; Rafique *et al.*, 2016). Average precipitation was obtained from the Integrated Agrometeorological Information Center of the State of São Paulo, Brazil for the period 1984 to 2014 (CIIAGRO, 2014). Vegetation indices were calculated in the ArcGis 10.3 software. For NDVI, the following formula was used:

$$NDVI = (NIR - R) / (NIR + R)$$

where NIR is the reflectance in the near infrared band (band OLI5) and R is the reflectance in the red band (band OLI4). SAVI was obtained by:

$$SAVI = (1+L) (NIR-R) / (L+NIR+R)$$

where L is the soil adjustment factor, considering to be 0.5 in this work. NDWI was obtained by:

$$NDWI = (NIR - SWIR) / (NIR + SWIR)$$

where SWIR is the reflectance in the medium infrared range.

Vegetation indices were grouped into classes. All negative values were grouped into a single class, since they did not present vegetation data. Positive values were grouped into 0.1 width interval classes. Thus, seven classes were defined for NDVI, ten classes for SAVI and six classes for NDWI. Images with grouped classes composed 637 lines and 360 columns, resulting in 107.153 pixels.

Quantification pixel to pixel model

Then, correlation matrices were constructed by crossed tabulation of NDVI, SAVI, NDWI vegetation indices for January and August using Matlab in such a way the (i,j) position of respective correlation matrices represented the number of occurrences of a pixel with value i from January index image and the value j from corresponding pixel in the August index image.

Thus, values located on the diagonal of the matrix represent the number of locations with indices that remained with same values in January and August for each of vegetation indices applied. Values positioned in the upper part of diagonal show the number of locations that increased vegetation index, while values positioned in the lower part of diagonal show the number of locations with reduced index value.

ArcGIS software is a geographic information system developed by Environmental Systems Research Institute

(ESRI) for applications in geoprocessing, geostatistics and treatment of images derived from orbital remote sensing. The software consists of applications ArcMap, ArcCatalog and ArcToolbox enabling to elaborate maps, develop projects, manage database and perform spatial analysis tasks of geographic data in vector format (lines, points and polygons) and matrix (pixels), respectively (ESRI, 2014).

MATLAB (MATrix LABoratory) is mathematical language software developed by MathWorks to perform numerical calculations, data analysis, digital image processing, implementation of algorithms and calculation with matrices (CHAPMAN, 2006; MATHWORKS, 2017). The programming for generation of pixel to pixel correlation matrices of vegetation indices in MATLAB software are shown in **Table 1**.

RESULTS AND DISCUSSION

Figure 2 shows historical averages of monthly precipitation for the period 1984-2014 justifying the use of images from January and August in this study. Graphics shows seasonal trend with wet period between October and March and marked reduction in rainfall between April and September. January and August stood out with the highest and the lowest precipitation, respectively. **Figure 3** shows the NDVI map for January and August showing variation of vegetative vigor for each period.

Table 1. Programming to generation of matrices.

<table>
<tr><th>NDVI</th><th>SAVI</th><th>NDWI</th></tr>
<tr><td>A=imread('image_ndvi_jan.bmp');</td><td>A=imread('image_savi_jan.bmp');</td><td>A=imread('image_ndwi_jan.bmp');</td></tr>
<tr><td>B=imread('image_ndvi_aug.bmp');</td><td>B=imread('image_savi_aug.bmp');</td><td>B=imread('image_ndwi_aug.bmp');</td></tr>
<tr><td>tam=size(A);</td><td>tam=size(A);</td><td>tam=size(A);</td></tr>
<tr><td>n=0;</td><td>n=0;</td><td>n=0;</td></tr>
<tr><td>for i=1:tam(1,1)</td><td>for i=1:tam(1,1)</td><td>for i=1:tam(1,1)</td></tr>
<tr><td>for j=1:tam(1,2)</td><td>for j=1:tam(1,2)</td><td>for j=1:tam(1,2)</td></tr>
<tr><td>if(A(i,j)==8)</td><td>if(A(i,j)==11)</td><td>if(A(i,j)==7)</td></tr>
<tr><td>i</td><td>i</td><td>i</td></tr>
<tr><td>j</td><td>j</td><td>j</td></tr>
<tr><td>n=n+1</td><td>n=n+1</td><td>n=n+1</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>tam=size(B);</td><td>tam=size(B);</td><td>tam=size(B);</td></tr>
<tr><td>n=0;</td><td>n=0;</td><td>n=0;</td></tr>
<tr><td>for i=1:tam(1,1)</td><td>for i=1:tam(1,1)</td><td>for i=1:tam(1,1)</td></tr>
<tr><td>for j=1:tam(1,2)</td><td>for j=1:tam(1,2)</td><td>for j=1:tam(1,2)</td></tr>
<tr><td>if(B(i,j)==8)</td><td>if(B(i,j)==11)</td><td>if(B(i,j)==7)</td></tr>
<tr><td>i</td><td>i</td><td>i</td></tr>
<tr><td>j</td><td>j</td><td>j</td></tr>
<tr><td>n=n+1</td><td>n=n+1</td><td>n=n+1</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>for i=1:7</td><td>for i=1:10</td><td>for i=1:6</td></tr>
<tr><td>for j=1:7</td><td>for j=1:10</td><td>for j=1:6</td></tr>
<tr><td>m(i,j)=0;</td><td>m(i,j)=0;</td><td>m(i,j)=0;</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>for i=1:tam(1,1)</td><td>for i=1:tam(1,1)</td><td>for i=1:tam(1,1)</td></tr>
<tr><td>for j=1:tam(1,2)</td><td>for j=1:tam(1,2)</td><td>for j=1:tam(1,2)</td></tr>
<tr><td>if(A(i,j)==0 | B(i,j)==0 |
A(i,j)==8| B(i,j)==8)</td><td>if(A(i,j)==0 | B(i,j)==0 |
A(i,j)==8| B(i,j)==11)</td><td>if(A(i,j)==0 | B(i,j)==0 |
A(i,j)==8| B(i,j)==7)</td></tr>
<tr><td>i</td><td>i</td><td>i</td></tr>
<tr><td>j</td><td>j</td><td>j</td></tr>
<tr><td>else</td><td>else</td><td>else</td></tr>
<tr><td>if(A(i,j)<8 & B(i,j)<8)</td><td>if(A(i,j)<11 & B(i,j)<11)</td><td>if(A(i,j)<7 & B(i,j)<7)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>m(A(i,j),B(i,j))=m(A(i,j),B(i,j))+1;</td><td>m(A(i,j),B(i,j))=m(A(i,j),B(i,j))+1;</td><td>m(A(i,j),B(i,j))=m(A(i,j),B(i,j))+1;</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
<tr><td>end</td><td>end</td><td>end</td></tr>
</table>

end	end	end

NDVI ranged from -0.21 to 0.63 in January and from -0.12 to 0.54 in August. By comparing the maps in Figure 3 (a) and Figure 3 (b), the most significant change in vegetation vigor occurred in northwest and south regions of study area. Decreased NDVI in August NDVI compared to January is partly due to the climate influence, since low precipitation influences on spectral response of vegetation.

Studies on vegetation also identified high NDVI scores for fragments of dense ombrophilous forest associated to the wet period, reaffirming the higher the precipitation, the higher the phyto formation of biomass forest in these areas (Gurgel, Ferreira, 2003; Detsch *et al.*, 2016; Rafique *et al.*, 2016).

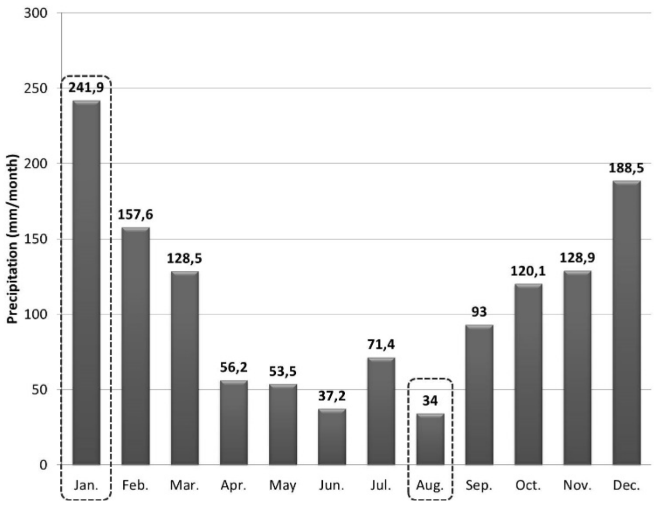

Fig. 2. Average of monthly precipitation for Ibiúna city (1984 - 2014)

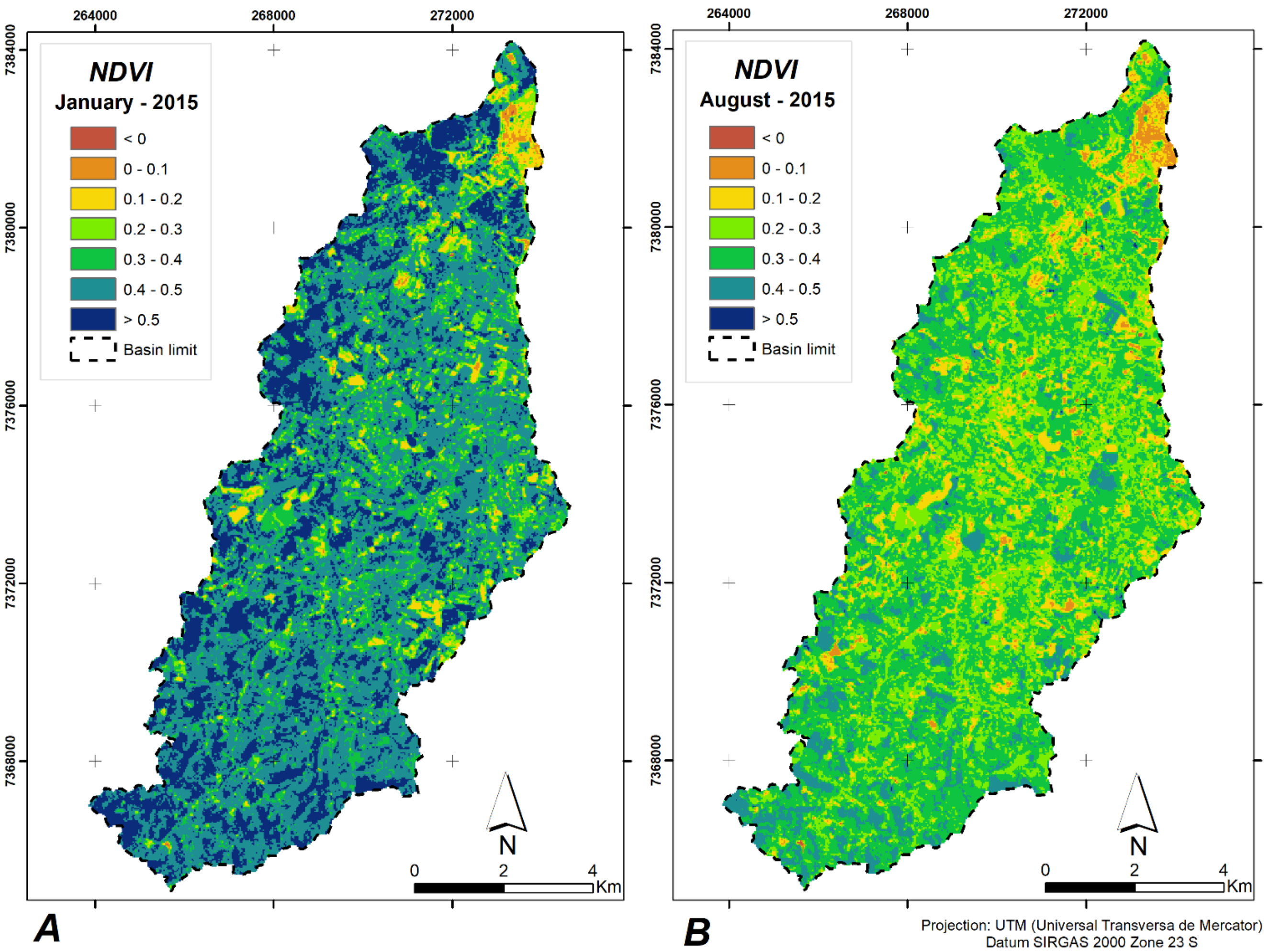

Fig. 3 NDVI for January (a) and August (b).

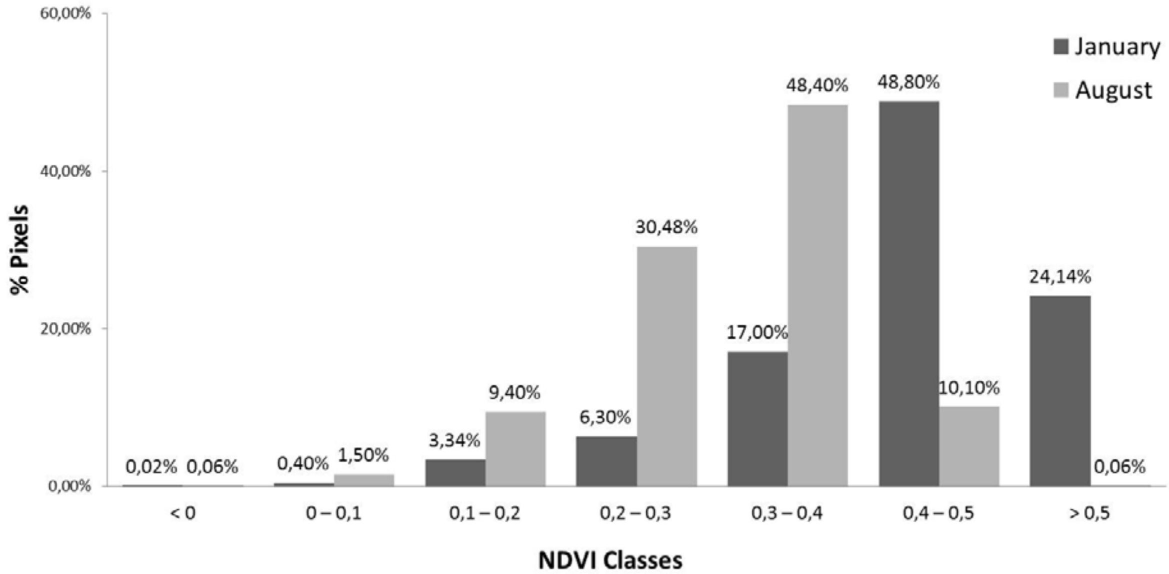

Fig. 4. Percentage distribution of NDVI by classes for January and August.

Figure 4 shows NDVI values compared by percentage of classes for wet and dry periods. In January, 48.8% of locations ranged between 0.4 - 0.5 and in August and 48.4% were positioned between 0.3 - 0.4. In January, 72.94% of locations had NDVI values above 0.4 and in August and 89.84% of locations showed values below 0.4. Each location is defined by a pixel in the index image.

Table 2 shows pixel to pixel correlation matrix between January and August for NDVI. In general, 87.5% of pixels with positive NDVI values in January registered decreased index values in August, indicating reduced plant cover vigor. These expressive values are underlined in the matrix (**Table 2**) as follows: 16387, 30488, 16253 representing 15.3%, 28.45% and 15.2% of the total number of evaluated pixels, respectively.

The value 16.387 is the total number of locations with NDVI between 0.4 - 0.5 in January and values reduced to the range 0.2 - 0.3 in August were. is NDVI in the class 0.4 - 0.5 is represented by 30.488 in January and, , values in the class 0.3 - 0.4 were registered in August. The value 16253 shows the number of locations with NDVI above 0.5 in January and values in the range of 0.3 - 0.4 in August.

Regarding NDVI increase, 2.9% of total locations showed increased index and consequently better vegetation vigor, even under dry conditions. Total number of locations with same NDVI between rainy and dry periods corresponded to 9.6%. **Table 3** presents shows comparative results of pixel to pixel correlation method to identify seasonal changes in vegetation, according to locations of each class and their percentages for both index images and correlation matrix results.

Table 3 shows the quantitative number of locations per class for each period, the area in square kilometers for each class, and the percentage locations whose NDVI increased, decreased or remained the same.

The highest number of locations is represented by the interval 0.3 - 0.4 in August (51.846), accounting for 48.41% of total area. The column "Locations with Reduced Values" represents those locations that migrated to lower classes from January to August. NDVI range 0.3 - 0.4 had high number of occurrences (46.741 locations), accounting for 43.64% of total area and indicating reduced NDVI and reallocation of sites in lower classes when compared to January.

Columns "Locations with the same values" and "Locations with increased values" show the interval 0.3 - 0.4 presenting the highest occurrences. NDVI is generated by combining spectral bands with wavelengths of absorption and reflectance to measure vegetation density; therefore, intervals suffering major changes are related to plant cover (Ahamed *et al*., 2011; Jamali *et al*., 2014; Johansen & Tommervik, 2014).

SAVI had higher values than NDVI, as expected, due to the soil adjustment factor incorporated to index calculation. For SAVI, darker tones refer to vegetation with greater vigor (Figure 5).

SAVI ranged from -0.31 to 0.95 in January and from -0.18 to 0.80 in August. The percentage distribution of SAVI is shown in Figure 6. Classes with high values are between 0.6 - 0.7 and 0.7 - 0.8 in January, adding up to 26.7% and 41.2%, respectively.

Values in classes 0.4 - 0.5 and 0.5 - 0.6 were predominant in August. The tendency of classes with lower SAVI values was higher in the quantitative of locations in August, which reaffirms the decrease of vegetative vigor in drier periods and ratifies rainfall influence on the vegetative quality.

Table 3. Quantitative NDVI image description obtained from pixel to pixel correlation matrix.

Classes	NDVI (January)			NDVI (August)			Pixel to pixel correlation matrix								
							Locations with reduction of values			Locations with the same values			Locations with increased values		
	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area
< 0	26	0.02	0.02	71	0.06	0.06	48	0.04	0.04	23	0.02	0.02	-	-	-
0 – 0.1	424	0.38	0.39	1599	1.44	1.49	1268	1.14	1.18	328	0.30	0.31	3	0.003	0.003
0.1 – 0.2	3584	3.22	3.34	10073	9.06	9.40	8552	7.70	7.98	1480	1.33	1.38	41	0.04	0.04
0.2 – 0.3	6737	6.06	6.29	32663	29.4	30.5	29690	26.70	27.7	2356	2.12	2.20	617	0.56	0.58
0.3 – 0.4	18234	16.4	17.0	51846	46.6	48.4	46741	42.04	43.6	3445	3.10	3.22	1660	1.49	1.55
0.4 – 0.5	52280	47.0	48.8	10830	9.74	10.1	7422	6.68	6.93	2621	2.36	2.45	787	0.71	0.73
> 0.5	25868	23.2	24.1	71	0.06	0.06	-	-	-	29	0.03	0.03	42	0.04	0.04
TOTAL	107153	96.4	100	107153	96.4	100	93721	84.30	87.5	10282	9.26	9.61	3150	2.84	2.94

NL = Number locations.

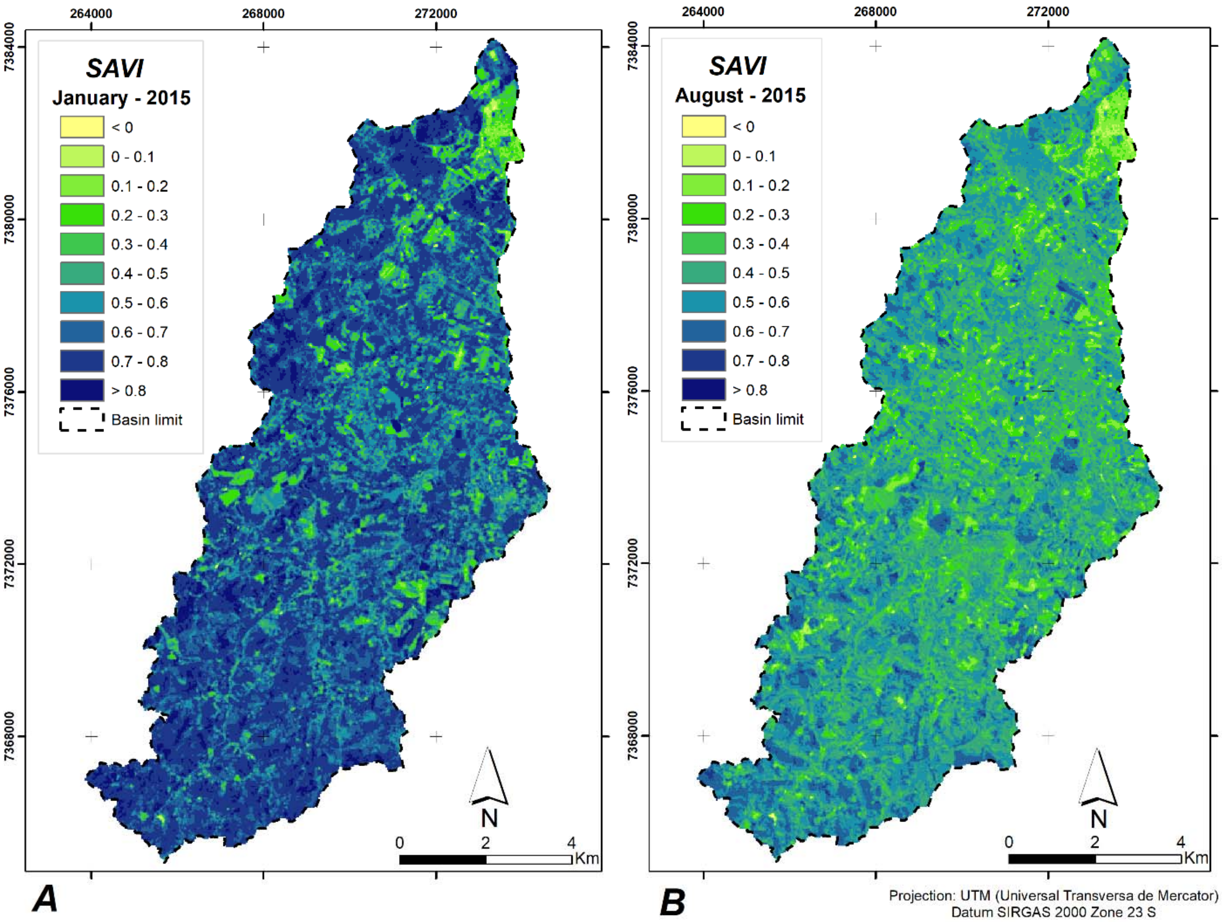

Fig. 5 SAVI in January (a) and August (b).

The pixel-to-pixel correlation matrix of SAVI in **Table 4** shows 92% of locations with reduced index values from January to August. Only 4.7% remained unchanged and 3.3% of locations had increased vegetative vigor from wet to dry season. Such increase, represent areas of forestry in the initial stage of development and active photosynthetic production of vegetation. Among numbers of locations with reduced SAVI values, the highest occurrences are underlined in **Table 4**. The value of 21,906 corresponds to the number of locations with SAVI between interval 0.7 - 0.8 in January while values between 0.5 and 0.6 were registered in august. SAVI values were between 0.6 and 0.7 in 14.864 locations in January and between 0.4 - 0.5 in August. Still, 12,738 locations had SAVI values between 0.7 and 0.8 in January and 0.4 - 0.5 in August. The loss of vegetation vigor showed by SAVI is significant and suggests the need to investigate vegetation specificity to identify the occurring species, their vegetative physiology and differentiate relationship with rainfall.

Table 5 shows quantitative description of SAVI in the pixel to pixel bases. The SAVI interval 0.7 - 0.8 had reduced number of locations from January to August dropping from 44.195 to 600. In August, class 0.4 - 0.5 showed important increase from 6.634 to 35.708 locations. Besides, 88.58% of the areas showed reduced SAVI values with most locations corresponding 0.3 and 0.6 interval.

The number of locations unchanged in the period was 5,039, representing 4.69% of total area. Values between 0.4 and 0.6 were predominant. Values increased in 3,623 locations or 3.39% of total area, and most of them at the interval between 0.3 and 0.6.

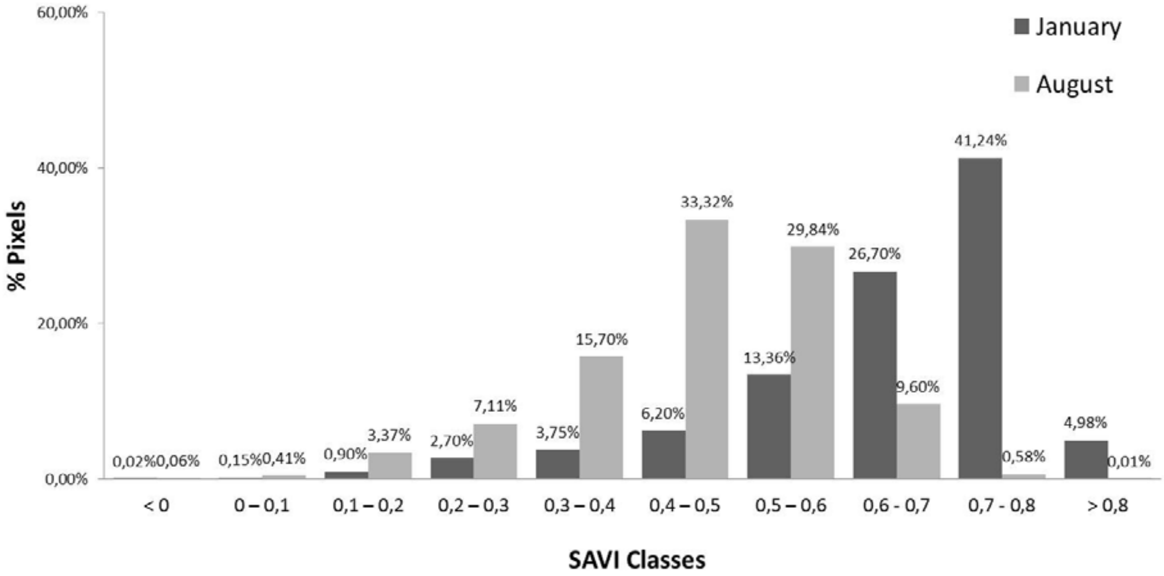

Fig. 6 Percentage distribution of SAVI by classes in January and August.

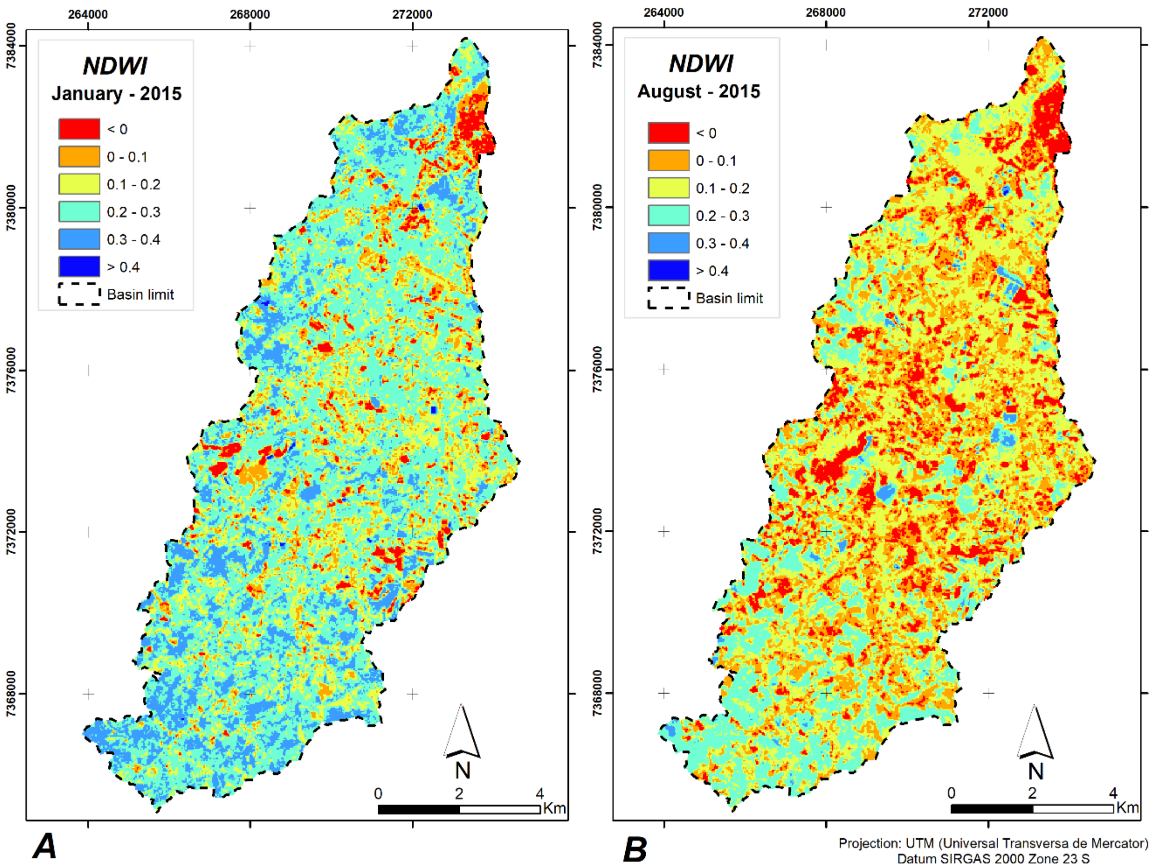

Fig. 7 NDWI in January (a) and August (b).

Table 4. Correlation matrix pixel to pixel between SAVI January and August

		SAVI August									
		< 0	0 –0.1	0.1 – 0.2	0.2 – 0.3	0.3 – 0.4	0.4 – 0.5	0.5 – 0.6	0.6 – 0.7	0.7 – 0.8	> 0.8
SAVI January	< 0	23	3	0	0	0	0	0	0	0	0
	0 – 0.1	27	100	33	2	6	1	0	0	0	0
	0.1 – 0.2	17	191	485	71	39	85	52	25	6	0
	0.2 – 0.3	1	51	1011	631	306	437	301	111	19	0
	0.3 – 0.4	1	16	513	1605	776	577	375	126	29	1
	0.4 – 0.5	0	4	231	1618	2975	1136	474	169	26	1
	0.5 – 0.6	0	13	388	1427	5716	5468	1009	264	37	0
	0.6 – 0.7	1	47	639	1487	4990	14864	5889	655	46	1
	0.7 – 0.8	0	15	214	654	1825	12738	21906	6619	223	0
	> 0.8	1	1	97	125	191	402	1975	2324	214	1

Table 5. Quantitative description of the SAVI image obtained from pixel to pixel correlation matrix.

Classes	NDVI (January)			NDVI (August)			Pixel to pixel correlation matrix								
							Locations with reduction of values			Locations with the same values			Locations with increased values		
	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area
< 0	26	0.02	0.02	71	0.06	0.06	48	0.04	0.04	23	0.02	0.02	-	-	-
0 – 0.1	169	0.15	0.16	441	0.39	0.40	338	0.30	0.32	100	0.09	0.09	3	0.003	0.003
0.1 – 0.2	971	0.87	0.90	3611	3.24	3.36	3093	2.78	2.89	485	0.44	0.45	33	0.03	0.03
0.2 – 0.3	2868	2.58	2.68	7620	6.85	7.11	6916	6.22	6.46	631	0.57	0.59	73	0.07	0.07
0.3 – 0.4	4019	3.61	3.75	16824	15.14	15.71	15697	14.13	14.65	776	0.70	0.72	351	0.32	0.33
0.4 – 0.5	6634	5.97	6.19	35708	32.13	33.33	33472	30.10	31.23	1136	1.02	1.06	1100	0.99	1.03
0.5 – 0.6	14322	12.88	13.36	31981	28.78	29.86	29770	26.77	27.78	1009	0.91	0.94	1202	1.08	1.12
0.6 – 0.7	28619	25.75	26.71	10293	9.26	9.61	8943	8.05	8.35	655	0.59	0.61	695	0.63	0.65
0.7 – 0.8	44194	39.77	41.26	600	0.54	0.56	214	0.19	0.20	223	0.20	0.21	163	0.15	0.15
> 0.8	5331	4.79	4.97	4	0.003	0.003	-	-	-	1	0.001	0.001	3	0.003	0.003
TOTAL	107153	96.4	100	107153	96.4	100	98491	88.58	91.92	5039	4.54	4.69	3623	3.28	3.39

Table 6. NDWI correlation matrix between January and August.

		NDWI August					
		< 0	0 – 0.1	0.1 – 0.2	0.2 – 0.3	0.3 – 0.4	> 0.4
NDWI January	< 0	2325	880	520	268	99	4
	0 – 0.1	3982	4468	965	419	122	4
	0.1 – 0.2	3803	14557	5896	741	304	3
	0.2 – 0.3	2084	8792	31930	9165	87	5
	0.3 – 0.4	363	596	3397	10651	588	11
	> 0.4	61	31	13	3	16	0

Figure 7 shows NDWI index maps, where darker gray level values are associated with higher water vegetation content and lighter shades to smaller ones. Values ranged from -0.15 to 0.49 in January and from -0.16 to 0.44 in August. NDWI also showed influence of climatic seasonality on vegetation moisture content. **Figure 8** shows NDWI with more than 60% of locations presenting vegetation humidity values higher than 0.2 in January. In August, approximately 80% of locations show values lower than 0.2, evidencing drop of water content due to decreased rainfall intensity in the period.

Table 6 shows correlation matrix of NDWI. NDWI remained the same in 21% of analyzed locations from January to August, that is, they did not present changes in foliage water. However, 74.87% of locations registered reduction in NDWI, indicating water loss of vegetation comparing wet to dry periods. Even under drought conditions, 4.13% of locations recorded increase in NDWI.

In the pixel-to-pixel correlation matrix (Table 6), 31.930 is the most expressive value among the number of locations with water loss, representing NDWI values at the interval 0.2 - 0.3 for wet period, and in the class of 0.1 - 0.2 for the dry one. Among the number of locations with the same value in both periods, 9.165 registered values between 0.2 - 0.3. The class interval between 0.1 - 0.2 represents the highest number of locations with increased water content summing up to 965 pixels.

The intervals 0.2 - 0.3 and 0.3 - 0.4 recorded the highest losses in number locations from January to August, accounting for 45.206 locations, as observed in the quantitative pixel to pixel description of NDWI in **Table 7**.

Table results also show 74.91% of total area (80279 locations) recorded reduction in NDWI values between January and August, and classes 0 - 0.1 and 0.1 - 0.2 were those with the highest number of locations due to reduced values in other classes. Even under drought conditions, 4432 locations showed increased humidity values, representing 4.14% of total area and most of them showed NDWI between 0.1 - 0.3. Locations that remained unchanged were 22442, comprising 20.95% of total area.

Table 7. Quantitative description of NDWI image obtained from pixel to pixel correlation matrix.

Classes	NDVI (January)			NDVI (August)			Pixel to pixel correlation matrix								
							Locations with reduction of values			Locations with the same values			Locations with increased values		
	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area	NL	Area km²	% Area
< 0	4096	3.69	3.82	12618	11.36	11.78	10293	9.26	9.61	2325	2.09	2.17	-	-	-
0 – 0.1	9960	8.96	9.29	29324	26.38	27.37	23976	21.56	22.37	4468	4.02	4.17	880	0.79	0.82
0.1 – 0.2	25304	22.76	23.61	42721	38.43	39.86	35340	31.79	32.98	5896	5.31	5.50	1485	1.34	1.39
0.2 – 0.3	52063	46.83	48.60	21247	19.12	19.83	10654	9.58	9.94	9165	8.25	8.56	1428	1.29	1.33
0.3 – 0.4	15606	14.05	14.56	1216	1.09	1.13	16	0.01	0.01	588	0.53	0.55	612	0.55	0.57
> 0.4	124	0.11	0.12	27	0.02	0.03	-	-	-	0	0.00	0.00	27	0.02	0.03
TOTAL	**107153**	**96.40**	**100**	**107153**	**96.40**	**100**	**80279**	**72.21**	**74.91**	**22442**	**20.20**	**20.95**	**4432**	**3.99**	**4.14**

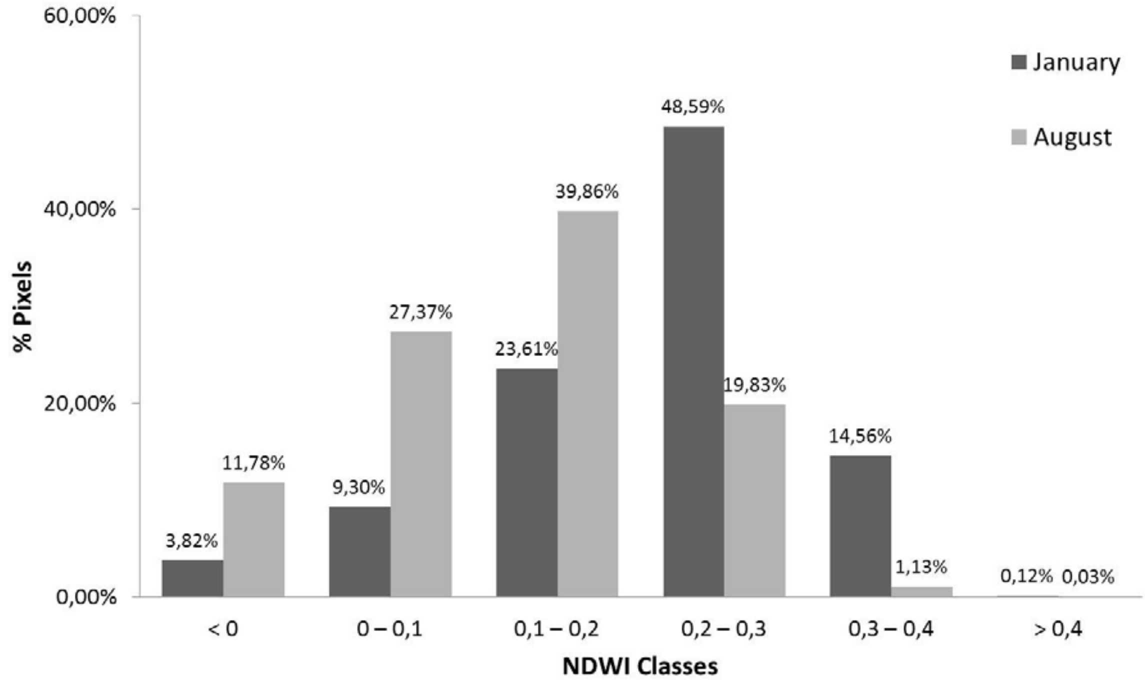

Fig. 8 Percentage distribution of NDWI by classes in January and August.

CONCLUSION

Indices showed seasonal changes, evidencing close relationship between atmospheric humidity and precipitation in the density of plant cover and presence of water in leaf structures. This method allows studies on quantification and dynamics changes of vegetation content and vigor, identifying quantitative variation of biomass and water content of vegetation for different periods. Furthermore, pixel-to-pixel correlation methodology can help to detail and quantify areas with increase, decrease or constant vegetative vigor and water content in leaf structures, especially regarding indices addressed in this study. The possibility of quantifying changes from correlation matrices is useful in vegetation evaluation and can contribute to the numerous methodologies already existing in the literature, especially for areas of great climate variability.

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