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Relation of leaf water content with real evapotranspiration and biomass in Caatinga biome, using remote sensing data

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R E S U M O

A Caatinga é um biome que sofre com grande variabilidade climática anual e intraanual. Essa variabilidade climática faz com que o bioma em grande parte do ano sofra com grande estresse hídrico. Estudar as relações existentes entre o conteúdo de água na planta e outras variáveis do ecossistemas, tais como: biomassa e evapotranspiração pode auxiliar e prever impactos da escassez hídrica e seca climatológica sobre a produção de biomassa do bioma Caatinga. Assim, este estudo pretende analisar as relações existentes entre o conteúdo de água na folha com a biomassa e evapotranspiração em área do bioma caatinga localizado em São José do Sabugi, Paraiba, Brasil. Foi utilizado o algoritmo SEBAL-Surface Energy Balance para estimar a evapotranspiração e o foram calculados os índices de vegetação NDVI- Normalized Difference Vegetation Index, SAVI- Soil Adjusted Vegetation Index e o índice de conteúdo de água na folha LWCI- Leaf Water Content Index. Os resultados mostraram uma boa relação existente entre os índices de vegetação e o conteúdo de água na folha, sendo r=0.76 para o SAVI e 0.64 para o NDVI. Para a evapotranspiração a correlação foi de r =0.386. Conclui-se que a quantidade de água na folha está altamente correlacionada com a biomassa.
Palavra chave: bioma, sazonalidade, seca, semiárido.

A B S T R A C T

The Caatinga is a biome that suffers from high annual and intra-annual climatic variability. This climatic variability makes the biome in great part of the year suffer with high great water stress. To study the relationships between water content in the plant and other ecosystem variables, such as: biomass and evapotranspiration can help and predict impacts of water scarcity and climatological drought on the biomass production of the Caatinga biome. Thus, this study intends to analyze the relationship between water content in the leaf with biomass and evapotranspiration in the area of the caatinga biome located in São José do Sabugi, Paraiba, Brazil. The SEBAL-Surface Energy Balance algorithm was used to estimate the evapotranspiration and NDVI-Normalized Difference Vegetation Index, SAVI-Soil Adjusted Vegetation Index and the water content index in the LWCI- Leaf Water Content Index. were calculated. The results showed a good relationship between vegetation index and leaf water content, with r = 0.76 for SAVI and 0.64 for NDVI. For evapotranspiration the correlation was r = 0.386. It is concluded that the amount of water in the leaf is highly correlated with the biomass.
Keywords: biome, seasonality, dry, semiarid

Introduction

Water stress caused by drought limits plat productivity and crop yields by reducing photosynthesis and leaf growth (Hunt at al. 1987, Boyer, 1982; Bradford and Hsiao, 1982). The caatinga has a strategy for surviving the great water shortage. Detection of water stress is a major application of remote sensing (Knipling, 1970; Wiegand et al., 1981).

According to Giongo (2011), several works have been development to estimate biophysical variables of the vegetation through orbital images, such as the of NDVI (Rouse et al., 1973) and the Soil Adjusted Vegetation Index-SAVI (Huete, 1988). More recently, the NDWI Moisture Index has been highlighted in the monitoring of water stress in semi-arid environment. The amount of water in the vegetation is strongly correlated to the near-infrared, allowing estimation of amount of water in cultures (Hardinsky et al. 1983; Gao, 1996; Oliveira et al., 2010).

As the water content of leaves in vegetation canopies increases, the strength of the absorption around 1599 nm increases. Absorption at 819 nm is nearly unaffected by changing water content, so it is used as the reference. Applications include canopy stress analysis, productivity prediction and modeling, fire hazard condition analysis, and studies of ecosystem physiology.

This study has the objective to analyze the relationship between water content in the leaf with biomass and evapotranspiration in the area of the Caatinga biome located in São José do Sabugi, Paraiba, Brazil.

Material and methods

Study area

The municipality of São José do Sabugi, located in the state of Paraíba - Brazil (Figure 1), is included in Borborema mesoregion and Caatinga biome (PROBIO, 2004). It is located in the area of the semi-arid region, presenting a hot and dry climate, with a total annual rainfall of about 600 mm (AESA - Paraíba State Water Management Executive Agency) and temperatures ranging from 21ºC at 36ºC (Galvíncio et al., 2009).

In terms of land use and cover, there is a predominance of cattle raising, aesthetical savanna, and aesthetical savanna (PROBIO, 2004), characterized by a tree cover composed of small spiny trees and several cacti, covering a gray stratum.

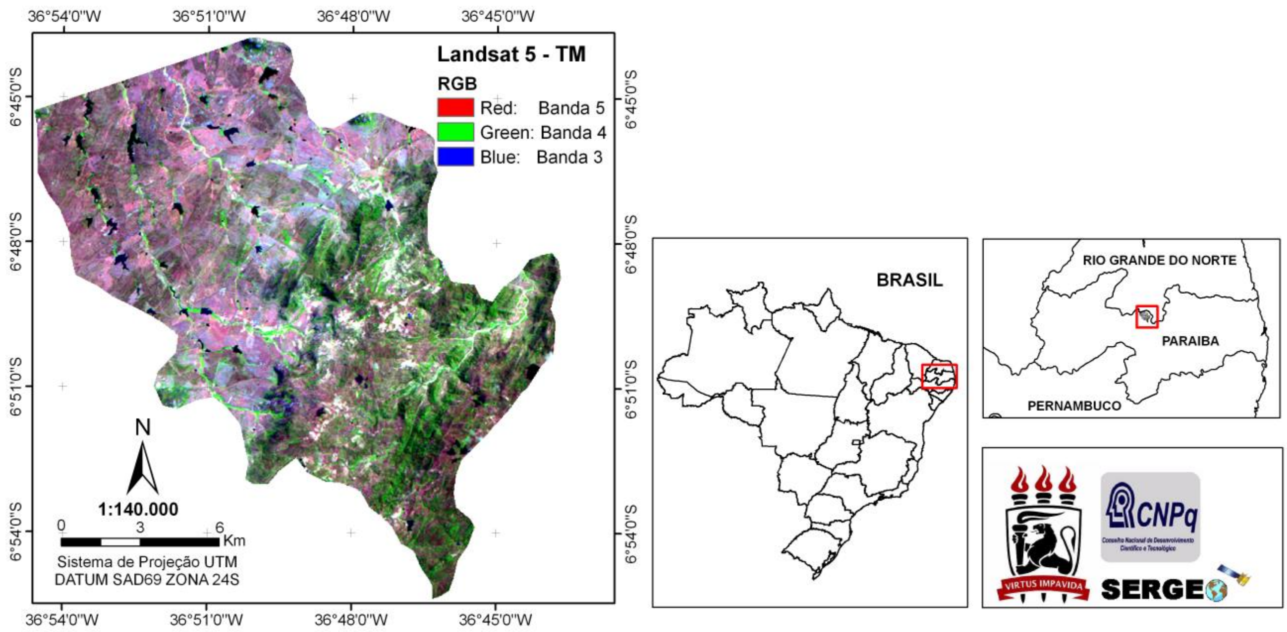

Figure 1. Study área location.

Radiometric data

The images used for the development of this work were the TM sensor (Thematic Mapper) on board the Landsat-5 satellite obtained from the Image Generation Division of the National Institute for Space Research (INPE). Images of the orbit and point 215/65 with date of passage of the satellite were used on June 19, 2008.

Image processing and layout assembly

Initially, the image was recorded using a recorded Landsat image obtained from the Remote Sensing Center - SISCOM - IBAMA and later verification of the record through GPS points collected during field activity carried out in the city. For the processing of Landsat-5 satellite images in relation to SEBAL, models were created in the Model Maker tool of the ERDAS Imagine 9.3 software. The division into classes and the final assembly of the maps was done through ArcGIS 9.3 software. Both are licensed by the Department of Geographical Sciences of the Federal University of Pernambuco.

Methodology

In this study was used the SEBAL- Surface Energy Balance algorithm for Land. All, descriptions methodology can see in Oliveira et al (2017); Machado et al. (2014); Oliveira et al. (2010) and Allan et al. (2002).

Leaf Water Content Index – LWCI

To obtain of the water content of leaf was utilized the equations:

$$LWCI = (-\log(1-(TM4-TM5)))/(-\log(1-(TM4_{FT}-TM5_{FT})))$$

where $TM4_{FT}$ and $TM5_{FT}$ are the maximum reflectance of TM4 and TM5

The statistics methods used was correlations and regressions with significance level

0.01. The descriptive statistics of the samples was obtained.

Evaluation criteria

Variance inflation factors (VIF) measure how much the variance of the estimated regression coefficients are inflated as compared to when the predictor variables are not linearly related.

Use to describe how much multicollinearity (correlation between predictors) exists in a regression analysis. Multicollinearity is problematic because it can increase the variance of the regression coefficients, making them unstable and difficult to interpret.

Use the following guidelines to interpret the VIF:

VIF	Status of predictors
VIF = 1	Not correlated
1 < VIF < 5	Moderately correlated
VIF > 5 to 10	Highly correlated

Results

The descriptive statistics was obtained to N=66, Table 1. In mean LWCI was 1.88%, is low and NDVI was 0.462 is great for area, in June we have the end of rain period.

Table 1 - Descriptive Statistics

	Mean	Std. Deviation	N
NDVI (dimensionless)	.462	.215	66
ETReal_24h (mm)	2.651	.392	66
Evaporative fraction(dimensionless)	.613	.065	66
LE (W/m^2)	75.180	11.122	66
LWCI (percentage)	1.885	1.313	66
SAVI (dimensionless)	.390	.128	66

A good relationship between vegetation index and leaf water content, with r = 0.76 for SAVI and 0.64 for NDVI. For evapotranspiration the correlation was r = 0.386, Table 2. According to Figure 2 and 3 the standard of the spatial variations of NDVI, SAVI and LWCI was similar. Thus, is possible to estimate the LWCI using the NDVI.

The equations obtained between LWCI, NDVI and SAVI, where the r was 0.85. Or, the model development to estimate LWCI using NDVI and SAVI showed good results, Table 3 and Table 4.. The VIF is highly correlated.

Results similar to those obtained in this study can be seen in Anazawa et al. (2001) in which it evaluated the relationship between LWCI and NDVI in different forest and cultivated fields. Vina et al. (2011) also found a good relationship between vegetation indexes and water content in the plant. The Table 5 showed coefficients to new model. The equation is:

$$LWCI=22.798SAVI-9.277NDVI-2.736$$

In general, the Figure 4 showed that the new model underestimate the observed data.

The Figure 5 showed the spatial variation of the plant water content estimated with LWCI new modelling to São José do Sabugi. In general the São José do Sabugi municipality show low water content in june. Ist important to talk that June is a month in this area that has your major water content in plant because is the end of the rain period, but yet is low.

Conclusions

It is possible to estimate the water content in the plant using NDVI. Data from drones images it is estimated NDVI concludes that it is possible to estimate water content in the plant using images of drones.

It is recommended that further research be developed on LWCI for drought monitoring, climate mitigation mechanisms, water balance estimation, evepotranspiration estimation and carbon sequestration.

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Table 2- Correlations

		NDVI	ETReal_24h	Evaporative fraction	LE	LWCI	SAVI
NDVI	Pearson Correlation	1	-.386**	-.222	-.386**	**.643****	.969**
	Sig. (2-tailed)		.001	.074	.001	.000	.000
	Sum of Squares and Cross-products	3.017	-2.120	-.203	-60.113	11.827	1.746
	N	66	66	66	66	66	66
ETReal_24h	Pearson Correlation	-.386**	1	.942**	1.000**	.006	-.347**
	Sig. (2-tailed)	.001		.000	.000	.960	.004
	Sum of Squares and Cross-products	-2.120	10.000	1.567	283.560	.212	-1.140
Evaporative fraction	Pearson Correlation	-.222	.942**	1	.942**	.099	-.192
	Sig. (2-tailed)	.074	.000		.000	.428	.122
	Sum of Squares and Cross-products	-.203	1.567	.277	44.430	.553	-.105
LE	Pearson Correlation	-.386**	1.000**	.942**	1	.006	-.347**
	Sig. (2-tailed)	.001	.000	.000		.960	.004
	Sum of Squares and Cross-products	-60.113	283.560	44.430	8040.763	6.020	-32.321
LWCI	Pearson Correlation	.643**	.006	.099	.006	1	.761**
	Sig. (2-tailed)	.000	.960	.428	.960		.000
	Sum of Squares and Cross-products	11.827	.212	.553	6.020	112.088	8.369
SAVI	Pearson Correlation	.969**	-.347**	-.192	-.347**	**.761****	1
	Sig. (2-tailed)	.000	.004	.122	.004	.000	
	Sum of Squares and Cross-products	1.746	-1.140	-.105	-32.321	8.369	1.078

**. Correlation is significant at the 0.01 level (2-tailed).

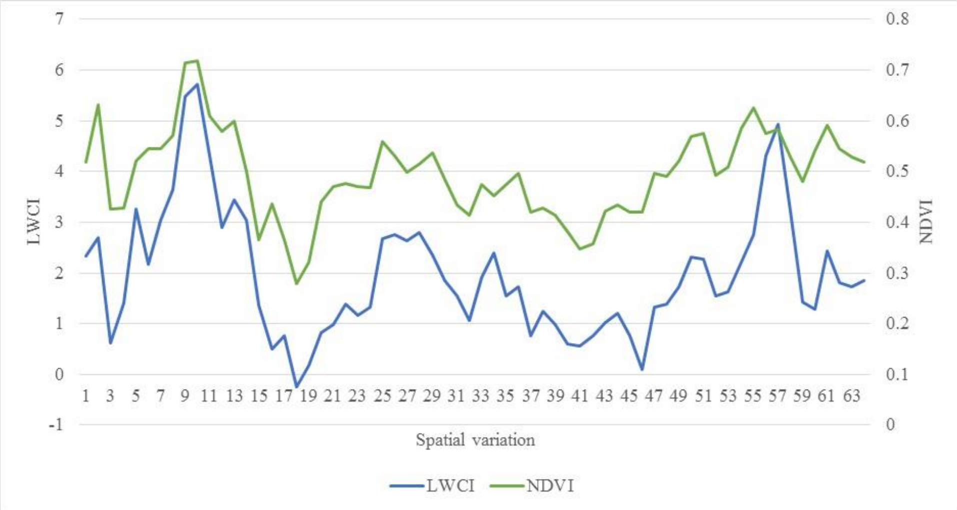

Figure 2 – LWCI and NDVI profiles in Caatinga biome (São José do Sabugi-Paraiba-Brazil).

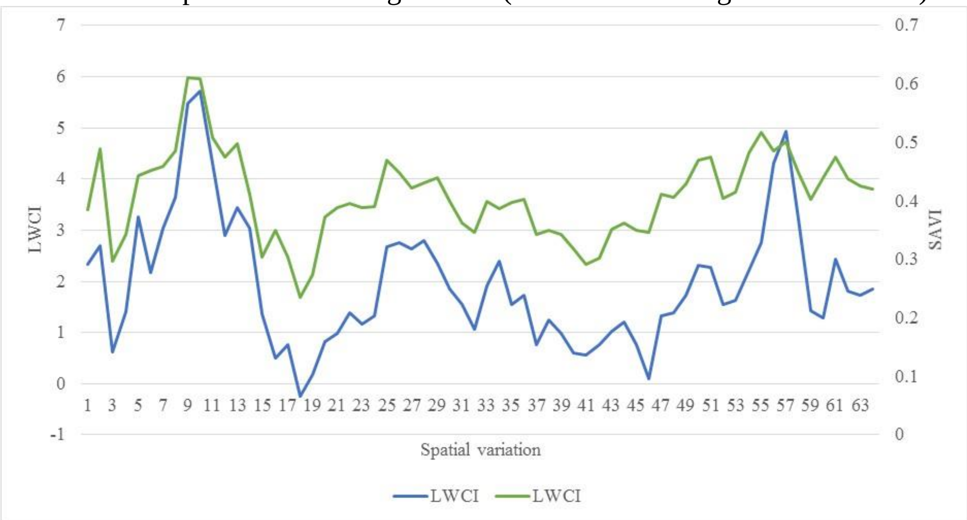

Figure 3 – LWCI and SAVI profiles in Caatinga biome (São José do Sabugi-Paraiba-Brazil).

Table 3- Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.850[a]	.723	.715	.701609968871921	1.035

a. Predictors: (Constant), SAVI, NDVI

b. Dependent Variable: LWCI

Table 4- ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	81.076	2	40.538	82.351	.000[b]
	Residual	31.012	63	.492		
	Total	112.088	65			

a. Dependent Variable: LWCI

b. Predictors: (Constant), SAVI, NDVI

Table 5. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-2.736	.393		-6.966	.000	-3.521	-1.951					
	NDVI	-9.277	1.623	-1.522	-5.717	.000	-12.520	-6.035	.643	-.584	-.379	.062	16.137
	SAVI	22.798	2.715	2.236	8.398	.000	17.373	28.224	.761	.727	.557	.062	16.137

a. Dependent Variable: LWCI

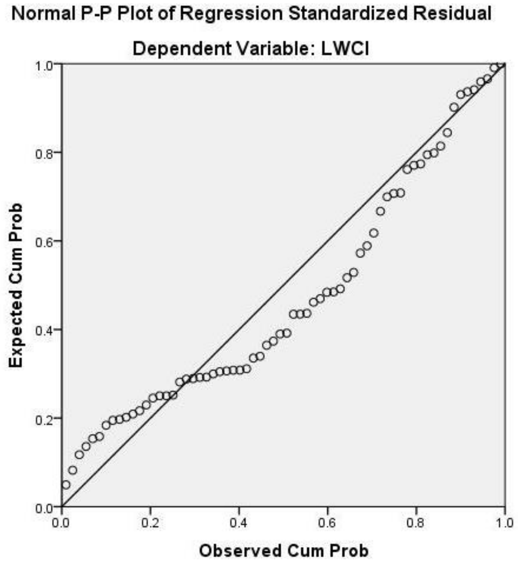

Figure 4 – Relationship between observed and expected of the LWCI.

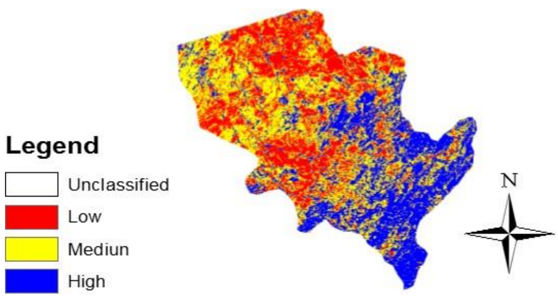

Figure 4 – Spatial variation of water content of plant in Caatinga biome (São José do Sabugi-Paraiba-Brazil).

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