Comparison of methods of Humidity Index processing in the Irrigated Perimeter Nilo Coelho, Northeast of Brazil

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Abstract

The use of remote sensing techniques in support of hydrological studies became common in recent years, through the application of orbital images that are used the reflectance values of the water, for mapping, delineation of water bodies and moisture monitoring in the internal structure of vegetable biomass. Among the methods and techniques of remote sensing image processing with the hydrological analysis, here the Normalized Difference Water Index (NDWI), object of study in the present work, in order to compare the application of the index through different methods. The present study was developed in the territorial part of the Nilo Coelho Irrigated Perimeter located in the Semiarid Northeastern region and covers the municipalities of Casa Nova-BA, Petrolina-PE and Juazeiro-BA, using TM-Landsat 5 sensor images from 30/07/2006. This comparison of the NDWI provided the best application for each index, as well as evaluate the potentiality of the index according to the applied method.

Keywords: precipitation, remote sensing, NDWI.

1. Introduction

The application of Remote Sensing techniques has been widely used for the monitoring and mapping of natural resources, thus allowing a broad view of the mapped area and serving as an analysis tool in the dynamic change of the landscape on a temporal scale. In the Northeast region of Brazil Remote Sensing has been used in several studies, due to the set of information that can be extracted from the satellite images, such as vegetation indices, which indicate the relative abundance and vegetation activity, percentage of green cover, chlorophyll content, green biomass and photosynthetically absorbed radiation (Jensen, 2011).

Albuquerque et al. (2014), comment that among the applied indexes in Remote Sensing, the Normalized Difference Water (Normalized Difference Water) stands out. This index was developed by McFeeters (1996) for to purpose of delineating features present in aquatic environments, and enhancing water bodies, automating the distinction of terrestrial vegetation and soils, using

the green band, to obtain better results aimed at Water. Gao (1996), on the other hand, applies the index based on the bands of the near infrared and the average infrared, which correlated it with the water content in the plants, and contributing to better detect changes in biomass and stresses of plant moisture, allowing the remote detection of the presence of liquid water in the vegetation.

Among the proposals to obtain the NDWI proposed by Gao, Oliveira et al. (2013), for example, could evaluate the value of NDWI in the Tapacura River Watershed, where in that area it was found that the highest values of NDWI represent the vegetation that has the highest water content in its internal structure, and the lowest values indicate the lowest amount of water, characterizing water stress in the basin for the year of 2007 analyzed in the study.

In addition, Ferreira et al. (2011) found that this NDWI index allows a greater discrimination of irrigated agriculture in relation to native vegetation, in a research carried out to evaluate the biophysical parameters of the

vegetation of caatinga and irrigated agriculture of the municipality of Petrolina, Pernambuco.

In addition, other works such as de Brenner and Guasselli (2015), using the NDWI suggested by McFeetrs, showed the application of the index to identify active meanders in the bed of the Gravataí river channel using a time series of orbital images. In a subsequent study, Andrade et al. (2015) analyzed the temporal and spatial variation of suspended sediment load in the Lagoa dos Patos estuary, Rio Grande do Sul.

The area of the Irrigated Perimeter Nilo Coelho stands out due to the great production of fruits that are commercialized and transported to other states, contributing in the relevant generation of employment and income. Research on vegetation indexes has contributed to the monitoring of biomass change related to water content, mapping of wetlands and enhancement of water bodies, especially in irrigated perimeter areas.

This work aims to apply the different methodologies to analyze the potentiality of the NDWI humidity index, extracted from the image of the TM sensor Landsat5, providing the best identification and mapping in the area of the Nilo Coelho Irrigated Perimeter.

2. Materials and methods

2.1 Characterization of the study area

The study area comprises a part of the territory of the Nilo Coelho Irrigated Perimeter, which is comprised by the municipalities of Casa Nova, Juazeiro and Petrolina (Figure 1). The Nilo Coelho Perimeter started operating in 1984, when the economic viability of these investments had already been observed for the region (Sobel and Ortega, 2010).

Figure 1 - Irrigated Perimeter Area Nilo Coelho, Brazilian Semi-Arid Northeastern region.

The natural factors (soil, climate, topography, etc.) in which the study area is inserted are exceptional constraints for the development of fruit growing, in which the availability of water in quantity and quality,

offered for irrigation by the São Francisco River, contributes for the development of irrigated perimeter enterprises (Sobel and Ortega, 2010).

In addition, the region of the study is in the Brazilian Semi-Arid Northeastern region, and presents an semi-arid climate, resulting from average annual rainfall of less than 800 mm, average annual temperatures of 23° to 27° C and strong insolation, which characterizes an intense negative water balance (Moura et al., 2007).

2.2 Distribution of precipitation for the year 2006

For the generation of the pluviometric graph in the area of the Nilo Coelho Irrigated Perimeter (Figure 02), the precipitation data available and obtained through the website of the Pernambuco State Agency for

Water and Climate (APAC) were used for the year 2006 at the Agedorteorological station of Bebedouro in the municipality of Petrolina, Pernambuco.

Observing the precipitation behavior in the study area (Figure 2), we can see that the precipitated total in the year 2006, considering from January to July, the latter being the month that happened the date of passing the satellite for acquisition of the image in that year, was recorded 266.70 mm. However, between the months of August and December, the rainfall was 100.20 mm, evidencing a lower registry of that period, when compared to the interval of the months of January to July.

Figure 2 - Monthly precipitation in area of the Irrigated Perimeter Nilo Coelho. Source: APAC (2017)

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2.3 Digital image processing

Preprocessing

Initially, the image of the Thematic Mapper (TM) sensor of the Landsat 5 satellite, orbit 217, point 66, has passed in 07/30/2006, corresponding to the dry season, was downloaded and can be downloaded from the Geological Survey United States Geological Survey (USGS, 2017). For image processing and NDWI determination, the free software QGIS 2.8.9 version was used. In addition, the orbital image and the vector files were redesigned for the SIRGAS 2000 Geodetic Reference System (Geocentric Reference System for the Americas), UTM zone 24 South.

After the image was selected, the processing was performed, considering the clipping of the scene according to the study area. The calculation NDWI, the

raster calculator tool of the QGIS 2.8.9 software was used. The flowchart of the image processing steps and

creation of the georeferenced maps containing the index result is shown in Figure 3.

Figure 3 - Flowchart of the processing and preparation steps of the georeferenced charts.

Image Processing

The first step for image processing was the radiometric calibration (Equation 1), where spectral radiance ($L\lambda_i$) of each band is calculated according to the equation proposed by Markham and Baker (1987):

$$L\lambda_i = ai + \frac{bi - ai}{255} ND \quad (1)$$

where ai and bi is the minimum and maximum radiance, respectively, obtained according to Chander et

al. (2007), expressed in $W.m^{-2}.sr^{-1} \mu m^{-1}$ for the sensor of the band in question; ND is the digital pixel number in the band, and ranges from 0 to 255; and i represents the TM band Landsat.

The Landsat 5 TM band description was detailed in Table 1, with wavelength ranges, calibration coefficients (minimum radiance “a”; maximum radiance “b”) and spectral irradiance at the Top Of the Atmosphere (TOA).

Table 1 - Description of Landsat5 (TM) Thematic Mapper Bands.

Bands	Wave-length	Calibration Coefficients ($W.m^{-2} \mu m^{-1}$)		Spectral Radiance at the Top of the Atmosphere $k\lambda_i$ ($W.m^{-2} \mu m^{-1}$)
		a (since 1994)	b (05/05/2003 to 01/04/2007)	
2 (green)	0.528 – 0.609	-2.84	365.0	1796
4 (near infra-red)	0.776 – 0.904	-1.51	221.0	1031
5 (medium infrared)	1.567 – 1.784	-0.37	30.2	220

Source: Adapted from Chander *et al.* (2009)

Therefore, the monochromatic spectral reflectance of each band ($\rho\lambda_i$) (Equation 2) was determined, which is defined as the ratio between the

flux of solar radiation reflected by the surface and the incident global solar radiation flux, obtained through the equation proposed by Allen et al. (2007).

$$\rho_{\lambda i} = \frac{\pi \cdot L_{\lambda i}}{K_{\lambda i} \cdot \cos Z \cdot dr} \quad (2)$$

where $L_{\lambda i}$ is the spectral radiance of each band obtained in Equation 1. $K_{\lambda i}$ is the spectral solar irradiance of each band at the top of the atmosphere (TOA) described in Table 1. Z is the solar zenith angle. In addition, dr is the square of the ratio between the average distance Earth-Sun, and the Earth's distance from the Sun on a given Sequential Day of the Year (SDY); and E refers to the elevation solar angle available in the image metadata.

For determination of dr and $\cos(Z)$, Allen et al. (2007), suggests the Equations 3 and 4:

$$r = 1 + 0,033 \cos\left(\frac{SYD2\pi}{365}\right) \quad (3)$$

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

For the calculation of the Normalized Difference Water Index (NDWI), in the present work, it was necessary to adopt a nomenclature for the applied methods, in order to distinguish the equations from the index. In the method proposed by Gao (1996), this was called NDWIGAO, already in the methodology suggested by McFeetrs (1996), was named NDWIMCF.

In the method proposed by Gao (1996), the author presents the relationship between bands 4 and 5

of TM Landsat 5 for the calculation of the NDWIGAO index (Equation 5), corresponding respectively to the near infrared (ρ_{IV}) and medium infrared (ρ_{mir}):

$$NDWI_{Gao} = \frac{\rho_4 - \rho_5}{\rho_4 + \rho_5} \quad (5)$$

where ρ_4 and ρ_5 are the reflectances of bands 4 and 5, respectively, for TM - Landsat 5.

McFeetrs (1996), in turn, presents another equation for calculating the NDWIMCF index (Equation 6), which index is calculated as the ratio between bands 2 and 4, corresponding respectively to the green band (ρ_{VD}) and the band near infrared (ρ_{IV}), highlighting the water in relation to the other targets.

$$NDWI_{MCF} = \frac{\rho_2 - \rho_4}{\rho_2 + \rho_4} \quad (6)$$

where ρ_2 and ρ_4 are the reflectances of bands 2 and 4, respectively, for TM Landsat 5.

3. Results and discussion

To classify the physical indexes applying the methodologies proposed in the present study, five classes were determined, where the reflectance values obtained were organized considering the classification by grouping, associating the classes: Very Low, Low, Medium, High and Very high at intervals between -0.42 and < 0.34 for the NDWIGAO method, and -0.71 and < 0.34 for NDWIMCF (Table 2).

Table 2 - Reflectance values considering the intervals for the classes in the indexes applied by the methodologies of NDWIGAO and NDWIMCF.

Class	NDWIGAO	NDWIMCF
Very low	-0.42 a -0.18	-0.71 a -0.18
Low	-0.18 a -0.05	-0.18 a -0.05
Medium	-0.05 a 0.13	-0.05 a 0.13
High	0.13 a 0.34	0.13 a 0.34
Very low	< 0.34	< 0.34

For the classes established using the methodologies of NDWIGAO and NDWIMCF, it was observed the distinction between the lowest value for the Very Low class, but the other values for the other classes are the same.

In Figure 4, it was possible to observe the NDWI calculated by the methods proposed in the region in the

area of the Nilo Coelho Irrigated Perimeter for the orbital image in the year 2006.

When analyzing the georeferenced maps of the Normalized Difference Water Index (Figure 4), modeled with the NDWIGAO method, the Very Low class show values lower than 0 (zero), indicating the representation of the areas of exposed soil, urbanization and vegetation

with low humidity. Leivas (2013), in the monitoring of drought in the Bahia Estate applying NDWI, this index presented a predominance of values lower than zero (-0.2 to -0.6), indicating a condition of low humidity in the vegetation, corroborate the values obtained in this study.

However, for the same class (-0.6 to -0.2), using the NDWIMCF method, we note the suspended sediments in the river channel. Borges et al. (2015) when using the NDWI for the delimitation of sediment flows in the Araguaia River, it can be observed that the lower values corroborate its association with the concentration of sediment in suspension, showing the concentration in sediment suspension due to high accumulation.

Besides that, the very low class represents the vegetation with high moisture content representing the areas of cultivation, in this methodology, thus evidencing the difference between the applied methods for the index, when analyzed the amount of moisture present in the vegetal canopy for the class in question. This result agrees with Brenner and Guasselli (2015), when they obtained negative values of (-0.10 to -1.00) referring to the areas of agricultural use in the bed of the Gravataí river channel.

Using the class Very high, which presents values greater than 0.34, it is verified that when

NDWIGAO is used, the water bodies and the photosynthetically active vegetation are shown, due to the good water availability internally in the vegetation. Oliveira et al. (2013) used the index in the Tapacurá-PE Basin, it was verified that the higher values of NDWI represent the vegetation with higher water content in its internal structure. In a subsequent study, Albuquerque et al. (2014) note in the existing areas of irrigated cultivation, this index presented high values (0.20 to 0.80) indicating the presence of greater amount of water in the vegetation, which proves the analyzes of the present study.

Furthermore, by applying the NDWIMCF method, the highlight of the bodies of water is observed in the very high class. Brenner and Guasselli (2015), in a study, showed that the highest values of NDWI (> 0.0) correspond to the highlighted water bodies, emphasizing the presence of water flow and mass. On the other hand, despite the ability to highlight and delimit watercourses, the proposed index does not completely remove the effects of ground reflectance, and the information extracted from the water can be confused with constructed areas, presenting positive values in the image derived from the index for built-up areas and exposed soil (Gao, 1996; Xu, 2007).

Figure 4 - a) NDWIGAO - Water Index by Normalized Difference Gao method; b) NDWIMCF - Water Index by Difference Normalized McFeeters method.

Table 3 presents five samples points within the study area, being established by the targets associated with the identifiable elements such as central pivot, suspended sediments, river, irrigated perimeter and exposed soil, which are equivalent to the categorization

of the classes of the indices studied. In addition, reflectance values were collected for each point according to the index method used to determine if the value acquired comprises the interval according to the class analyzed.

Table 3 - Reflectance values for each point according to the applied methodology for the index.

Points	Class NDWIGAO	Points reflectance NDWIGAO	Class NDWIMCF	Points reflectance NDWIMCF
P1 central pivot	Very low (-0.42 a -0.18)	P5 (- 0.20)	Very low (-0.71 a -0.18)	P1 (-0.46) P2 (-0.27) P5 (-0.21) P4 (-0.54)
P2 suspended sediments	Low (-0.18 a -0.05)	P2 (- 0.08)	Low (-0.18 a -0.05)	-
P3 river	Medium (-0.05 a 0.13)	-	Medium (-0.05 a 0.13)	-
P4 irrigated perimeter	High (0.13 a 0.34)	P1 (0.30)	High (0.13 a 0.34)	-
P5 ground exposed	Very high (< 0.34)	P3 (0.58) P4 (0.44)	Very high (< 0.34)	P3 (0.65)

The values shown in Table 3 confirm that the sample points are consistent with the established classes, where when applying the methodology of generating the values for the NDWIGAO index it is observed that the Very high class prevails in relation to the number of points belonging to the (Figure 5). In this case, the high values shown are water bodies, specifically the river, and photosynthetically active vegetation. which is characterized by irrigated perimeters. Also, when applying the NDWIMCF method, we notice the predominance of negative values for points P1, P2, P5 and P4, associating them with Very low class. However, it is verified that the point P3 is part of the class Very High, which means high values of reflectance, due to the sample point analyzed in the river, thus highlighting the body of water (Figure 5).

The Figure 5 displays the points that refer to Table 3, where the data were collected identifying the elements through the Google Earth image (2017), and visually comparing with the images generated for the $NDWI_{GAO}$ and $NDWI_{MCF}$.

In analyzing Figure 5, it is found that the identified points express similarities regarding the results obtained with NDWI (Figure 4) as well as with

the values shown in Table 3.

The NDWIGAO is more prominent in relation to the irrigable areas (points 1 and 4), because the vegetation belonging to these areas has good water content in the internal structure, providing better monitoring of the changes in biomass and in the moisture stresses of the plants. Also for this same methodology, the São Francisco river (point 3, surface of the river) is associated with a very high class (0.58), characterizing the identification of water surfaces in this method. For these same points, when analyzing the NDWIMCF method, a homogeneity of colors (red color) is observed, not allowing the identification of the irrigable territorial areas. However, it is observed in the surface of the river (points 2 and 3), when compared to the NDWIGAO methodology with NDWIMCF, the latter is more appropriate for the identification of suspended sediments (point 2) and water flow delineation (point 3), better emphasizing the edges of the water resource seen in the image, unlike the NDWIGAO method that even identifying the surfaces of water bodies, this does not result in a precise delineation as the NDWIMCF method.

a) Image Google Earth

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Coordinate Systems: Universal Transverse Mercator - UTM
Geodetic Reference System - SIRGAS 2000 - Zona 24 SUL
Elaboration: Antônio Celso de Sousa Leite

b) NDWI_{GAO}

c) NDWI_{MCF}

Figure 5 - (a) Google Earth image with the points identified, (b) NDWIGAO - Water Index by Difference Normalized Gao method; (c) NDWIMCF - Standard Water Difference Index McFeeters method.

Finally, when analyzing the areas of soil exposed (point 5) using the NDWIGAO method, it is more efficient to characterize these areas, when compared with NDWIMCF, considering that it presents a better spatial distinction than the other observed elements in the image, whereas the NDWIMCF, when situations with water stress, presenting low humidity, where the irregularity and scarcity of the pluviometric regime contributes to this situation, which can be taken

4. Conclusions

The analysis of the indices applying the NDWIGAO and NDWIMCF methodologies in the area of the Nilo Coelho Irrigated Perimeter provided to reveal and identify differences between the functionality of the methods.

The Normalized Difference Water Index (NDWI) applying the methodologies used presented

used, can confuse water with built-up areas and exposed soil.

It can also be evidenced that in the Very Low class (-0.42 to -0.18) of the NDWIGAO the values of these classes are related to vegetation

into account in the study area, since the precipitation recorded in July was 7,2 mm.

different functional characteristics, evidencing the potential of each method in support of hydrological and biophysical studies.

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