An automatic method for open water detection using MUX/CBERS-4 images

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Abstract. Most of the rivers in the planet have been dammed for providing water storage for human needs such as energy production, irrigation and for domestic and industrial use. At present, there are thousands of reservoirs in the world in need of frequent monitoring to support proper water resources management. Remote sensing provides a large amount of data for monitoring the Earth surface but faces time consuming processes for extracting the information needed hampers its use for real time management. This paper describes an automatized method for mapping open water bodies using MUX/CBERS-4 images in order to speed the process. The method consists in applying colour transformation in all RGB combinations of MUX bands transformed to HSV (Hue Saturation Value) images and empirically defining the optimum Hue interval for splitting image pixels between two classes: water and non-water. In order to do that, all RGB compositions of MUX bands were transformed to HSV images and tested to select the set providing the best separation between water and non-water. The Hue interval was used as input for the LEGAL (Linguagem Espacial para Geoprocessamento Algébrico) available at Spring 5.2.7 to split the Hue image into water and non-water pixels. A statistical analysis was applied to aid the choice of the best composition. The RGB 587 was chosen as the best composition to identify water bodies in MUX images. Future work recommendations include applying distinct confidence intervals and performing a pre-processing of the images, including image calibration and atmospheric correction.

Key words: HSV Transformation, Water Monitoring, Remote Sensing, Spring software.

1. Introduction

Brazil has been facing water scarcity due to the mismanagement of the water resources. Inland waters are important not only for drinking purposes, but also in terms of ecosystem regulation, maintenance and for the economic development (Mouw et al., 2015).

For example, hydroelectricity is the major source of energy in Brazil and the Sao Francisco river basin (NE, Brazil), with a total potential of 10.473 MW (ANA, 2016) has a large number of reservoirs whose impacts are still not totally understood yet. Northeast Brazil region is a semi-arid characterized by irregular rainfall with a history of constant drought, which affects water availability and increases the conflicts for the use of the water (Medeiros et al., 2012).

For these reasons, monitoring reservoirs is important for the maintenance of a healthy society and environment. Moreover, monitoring is one of the most important sources of data for supporting water management policies. In this scenario, remote sensing can be an useful tool to provide information about remote and large areas in short time intervals (Bonansea, 2015).

However, satellites that are currently operating are not designed for inland water studies. Therefore, it is recommended to adapt data from others sensors. This imply in using data with poor radiometric and spectral resolution (Palmer et al., 2015).

Remote sensing can generate large volumes of data and extraction of information is a time-consuming task. Hence, it is necessary to develop methods for the automatic processing of those data sets to make them useful for monitoring and managing reservoirs. Image processing techniques can help to create routines to process large volumes of data and to extract the information needed.

There are several studies that focus on monitoring changes in water bodies and each of them propose different indexes. The normalized difference water index (NDWI), Equation 1, allows the discrimination between open water and vegetated surfaces (McFeeters, 1996).

$$NDWI = \frac{\rho_{green} - \rho_{NIR}}{\rho_{green} + \rho_{NIR}} \quad (1)$$

The modified normalized difference water index (MNDWI), Equation 2, is based on the NDWI, but replaces the near infrared band by the middle infrared band and is particularly suitable for turbid water bodies (Xu, 2005). This index has become the most commonly used method for water bodies' detection on Landsat images. However, these methods are highly affected by illumination, presence of sediments and mixed pixels. A technique that can overcome these effects is based on the use of the Hue component from the colour transformation from the RGB space to the HSV space, resulting in fewer pixels in the region where water and no water classes colour overlaps (Namikawa, 2015).

$$MNDWI = \frac{\rho_{green} - \rho_{MIR}}{\rho_{green} + \rho_{MIR}} \quad (2)$$

CBERS satellites are operated by Brazil and China and they have several sensors on board, a wide field of view camera (WFI), a high resolution pancromatic camera (PAN), a multispetral and thermal imager (IRS) and a multispectral camera (MUX). The MUX sensor has a good spatial resolution (20m) and a field of view of 120km; it also has four spectral bands and despite the low revisit rate (26 days), it can be used to complement WFI images. Due to its temporal and spatial resolution and data availability in Brazilian territory, and because these are freely distributed by INPE (National Institute of Space Research), it is important to assess their application for inland water studies.

Considering the aforementioned, this study aims at testing a technique, proposed by Namikawa (2015). That speeds up the image processing for the identification of inland water bodies using CBERS-4, MUX images, consisting in thresholding the Hue component from the conversion of colour system from Red, Green and Blue bands (RGB) to Hue, Saturation, Value (HSV).

2. Materials and methods

CBERS-4 images are available for download at INPE online catalogue (http://www2.dgi.inpe.br/CDSR/). The path/row is 251/111 and corresponds to Sobradinho reservoir area, located in the Sub-Middle region of Sao Francisco River, between Barra and Sobradinho cities, in Bahia state, which is a region of the Brazilian semiarid (Figure 2A). The data acquisition is September 8th of 2015, which correspond to the dry season in northeast Brazil (Costa et al, 2009). The sensor chosen was MUX, with radiometric resolution of 8 bits and four bands (Table1). Its spatial resolution is 20 m, which allows the detection of changes even in small rivers.

Table 1. MUX/CBERS-4 bands.

Number	Wavelength (ηm)	Band
5	450 – 520	Blue
6	520 – 590	Green
7	630 – 690	Red
8	770 – 890	Infrared

The methodology proposed in this study can be divided in three steps: image processing, statistic and analyses (Figure 1). The software used to apply this methodology was Spring version 5.2.7. In the first step, an automatic segmentation was applied using a similarity of 20 and pixel area of 50, to try to separate different targets. The segmented image was them subjected to an unsupervised classification (Isoseg) using all MUX bands. The unsupervised classification was chosen because the supervised classification requires samples and the amount of samples for small water bodies is reduced when compared to large water bodies therefore this could skew the classification (Namikawa, 2015).

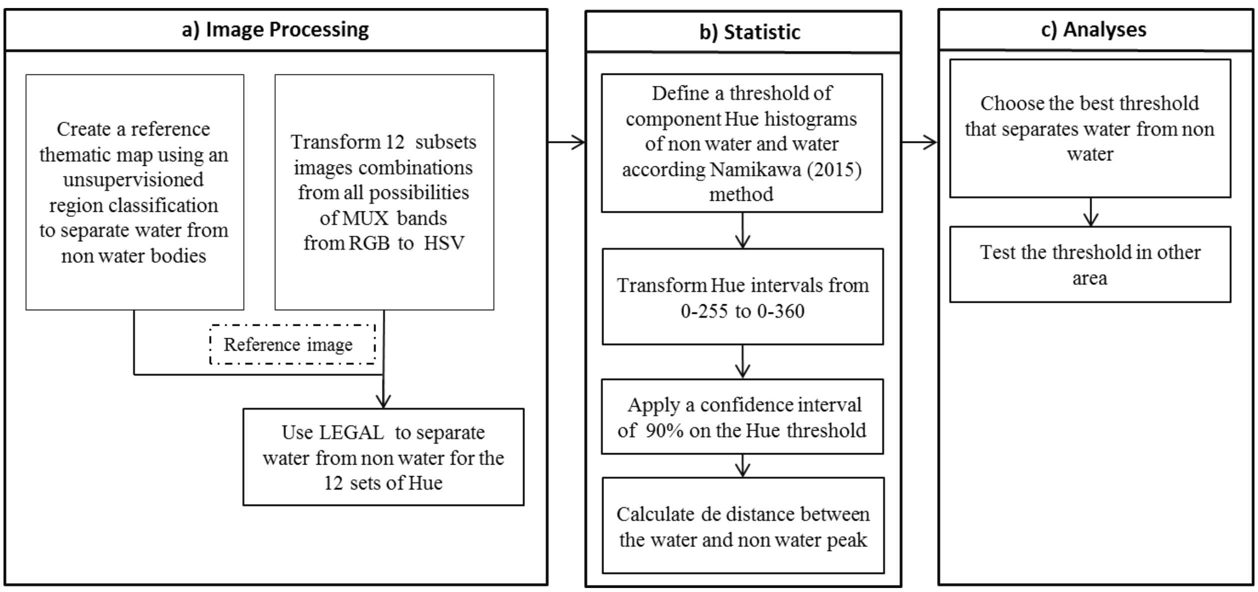

Figure 1. Flow-chart of the methodology applied in this study. Image processing involved the transformation from RGB compositions to HSV and generation of histograms of water and non-water targets (a). Then, a threshold value was defined and others statistics were applied (b) according to that the best threshold was chosen and test in other area (c).

With the classification results, a thematic map was generated with two classes: water and non-water. This map was used to separate the classes on Hue map and generate the histogram of each class of the composition, using LEGAL program. This process was applied for the 12 sets of HSV transformations of MUX band RGB colour composites (Table 2).

Table 2. MUX/CBERS - 4 bands combinations analysed.

MUX/CBERS – 4 bands composition			
R5 G6 B8	R6 G7 B5	R7 G5 B6	R7 G6 B8
R5 G7 B8	R6 G7 B8	R7 G5 B6	R7 G8 B6
R5 G8 B7	R6 G8 B5	R7 G6 B5	R8 G5 B6

It is worthy noticing that Hue values are circular and range from 0 to 360 degrees, being 0 and 360 the red colour, 120 green and 240 blue. Therefore, a histogram normalization had to be performed in order to transform the pixel range from 0 to 255 values to 0 to 360 values.

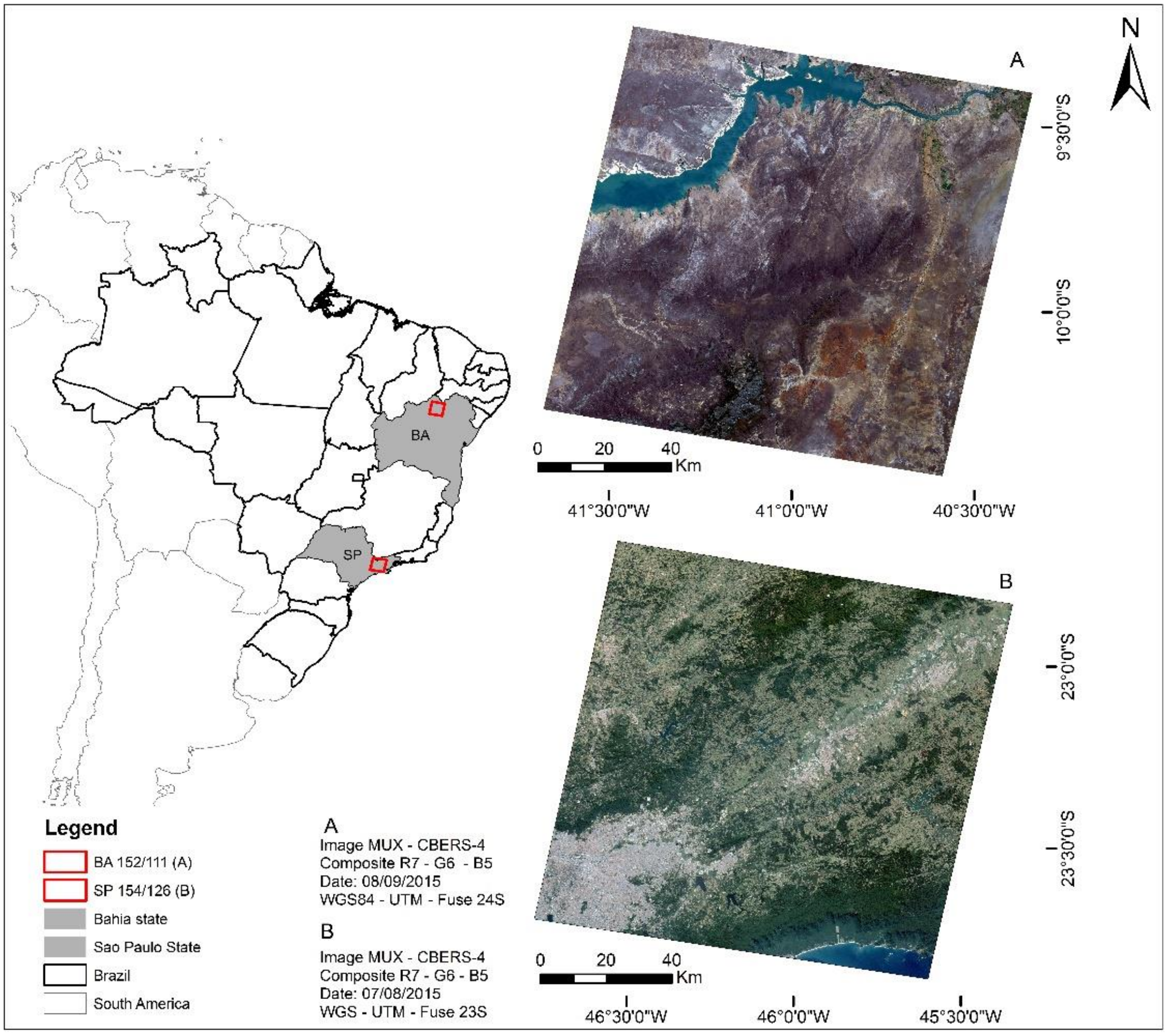

Figure 2. Sobradinho reservoir (A) in Bahia state and Jaguari & Jacarei reservoir (B) in Sao Paulo, Brazil.

The resulting 12 Hue histograms were statistically analysed to calculate hue distances between water and non-water classes. The discrimination was only accepted if the intersection between water and non-water was empty or near empty, indicating little confusion between the analysed classes.

A new MUX/CBERS-4 (154/126) scene containing the Jaguari & Jacarei reservoirs, located in Sao Paulo State (Figure 2B), was acquired in August 7th of 2015 (dry season in southeast Brazil). This second image is an area with different characteristics from Sobradinho - BA. It is a more complex scene with more urban areas, water reservoirs of different sizes and shapes, a stretch of the coastline, vegetation and a more complex topography. This scene was used to validate the band composition chosen and the Hue threshold for water extraction established for the first scene.

3. Results and discussion

The result of the extraction using the LEGAL program, on the RGB transformed into HSV image for Sobradinho, is illustrated in Fig. 3, it is possible to notice that the open water class is clearly discriminated from the non-water class.

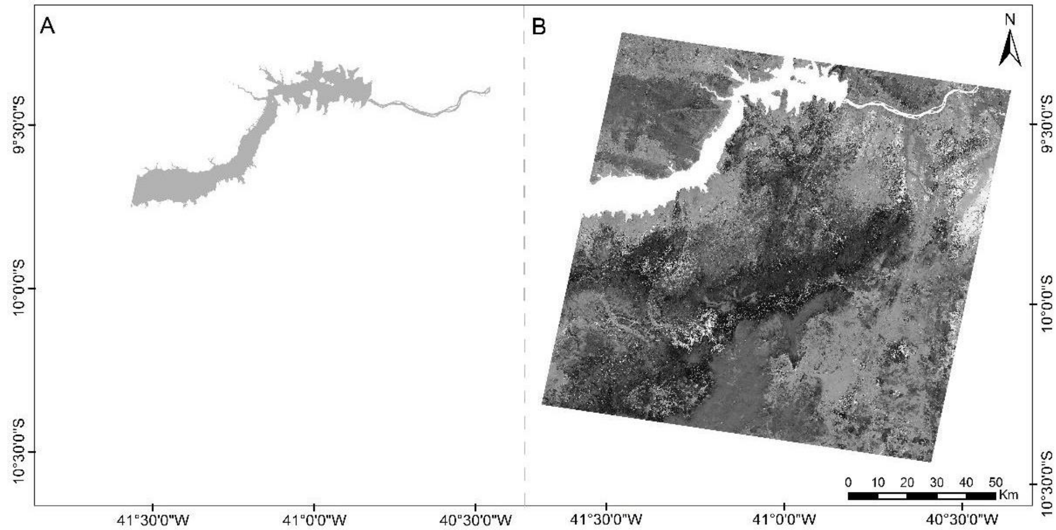

Figure 3. Hue classification of combination RGB 587 in Sobradinho reservoir image, where the class of interest is presented in (A) class water and all the other classes are in (B) class non-water.

The 5 histograms that best separated the classes were used in the next steps of the analyses (Figure 4). To confirm the best composition a percentile analysis based on 90% confidence was performed. For each of the five chosen histograms the range of Hue values associated to the first 90% of water pixels and non-water pixels was defined. Also, the distance between the pixels corresponding to the maximum peaks from those chosen classes were evaluated (Table 3).

Table 3. Hue values of MUX/CBERS - 4 bands combinations for 90% range.

Colour composition	Hue range		Maximum distance
	Water	Non-water	
R5 G7 B8	14º - 30º	150º - 343º	200
R5 G8 B7	328º - 343º	20º - 313º	200
R6 G7 B8	17º - 28º	76º - 337º	156
R6 G8 B5	250º - 267º	0º - 265º	183
R7 G6 B8	89º - 100º	99º - 309º	100

The criteria for selecting the best band composition was: i) the largest distance between histogram maximum; ii) in the case of similar distance between histogram maximum the tiebreaker criteria was the peak position, nearer to the histogram center, due to its circular values (0°-360°). In this work, the best band composition found was the RGB587.

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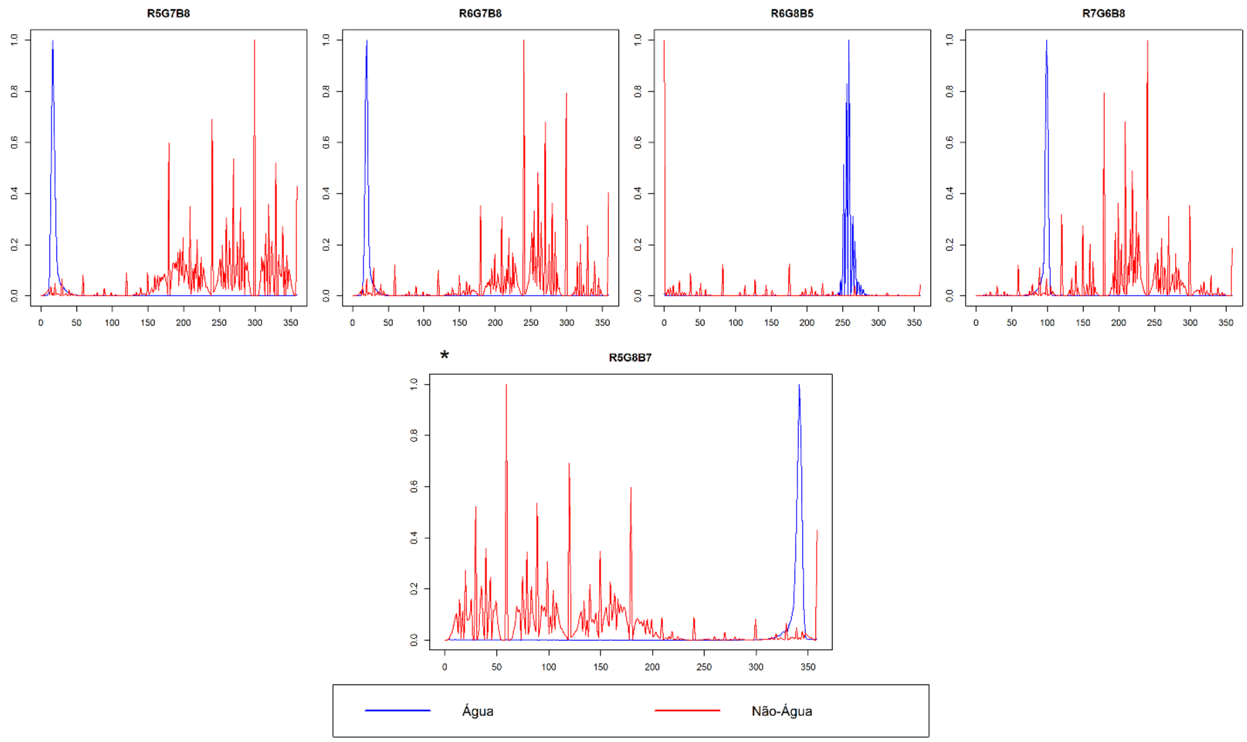

Figure 4. Comparison between the Hue components obtained from the five best combinations of MUX bands for water extraction in the Sobradinho image. The blue line is the water class and the red line is non-water class. In addition, the image on the bottom with and asterix represents the best combination of bands.

The five best results include band 8 of CBERS-4, which corresponds to the Infrared (IR) band. Water absorbs IR radiation in all wavelengths whereas bare soil and vegetation reflects them. Since Sobradinho reservoir is in the semi-arid region of Brazil, where the main landscape is bare soil, and shrub vegetation, a high contrast between the open water surface and non-water (soil, vegetation and urban region) is observed.

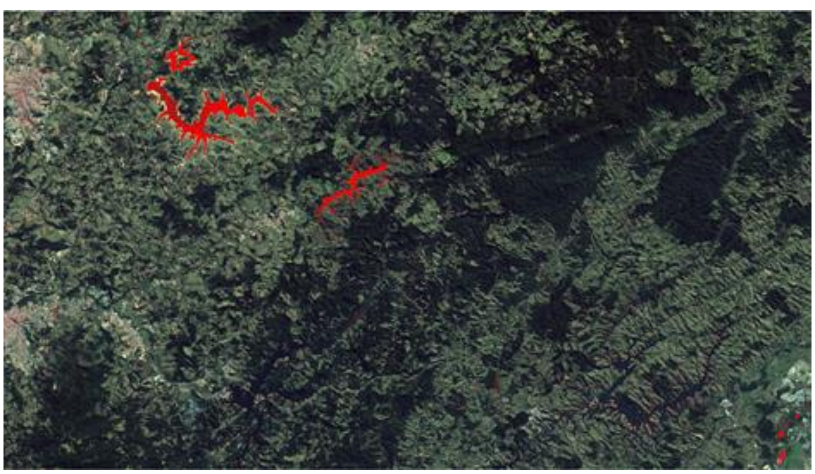

Figure 5. Part of the Jaguari & Jacarei reservoir image in true colour compositon (R7 G6 B5) and water is identified (in red) by the select Hue threshold.

The second scene was analysed with the RGB 587 band composition and Hue threshold obtained in the first experiment. The band composition was also efficient in highlighting water bodies in the more complex landscape at Jaguari & Jacarei reservoir. However, the Hue threshold did not extract all water bodies in the image occurring also commission error with urban areas classified as water bodies (Figure 5).

The results obtained for the open water extraction were different in each image analysed due to the different spectral behaviour of the water. In the Sobradinho image, the water is pure with little suspended sediments, thus it absorbs preferably in the red and infrared and reflects in the blue region of the spectrum. Moreover, the terrain is flat, resulting in little shadow in the image. Oppositely, the Jaguari & Jacarei image, covers a region where the water has a significantly higher amount of dissolved organic matter and suspended sediment due to the weathered soil. The reservoirs are narrower, dendritic, and surrounded by a mountainous topography which increases a shadow component in the scene. This results in a scene with intrinsic differences in colour and therefore in the transformed colour for both water and non-water classes.

4. Conclusions and future recommendations

The thresholding of the Hue component, presented in this study, has proved to be useful to quickly map the boundaries of the Sobradinho reservoir. However, in the Jaguari & Jacarei region the water classes were not properly identified, possibly because of a high diversity of targets and because of the different optically active components present in the water surface, such as suspended sediment and dissolved organic matter.

Although, the Hue component is not highly affected by illumination, the presence of sediments, the lack of atmospheric correction and reflectance transformation in images from CBERS-4, results in different digital levels in each image leading to different colour representation.

Future works should perform a pre-processing of the images, including image calibration and atmospheric correction to avoid target confusion in complex areas and test new Hue thresholds. Moreover, new statistic tests with 95 and 99% of confidence interval should be included, which may refine the histogram analysis and could reduce the number of band combinations, helping to accelerate the identification of water bodies.

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