# DETECTION OF SALINE AND NON-SALINE LAKES ON THE PANTANAL OF NHECOLÂNDIA (BRAZIL) USING OBJECT-BASED IMAGE ANALYSIS

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**ABSTRACT:**

The Pantanal (Brazil) is one of the world's largest tropical wetlands. A natural phenomenon that encourages more detailed scientific studies on this region is the genesis and behavior of innumerable small lakes and ponds with open-water surfaces on the Nhecolândia region at the Taquarí alluvial fan. In this paper, we suggest a new approach to detect and differentiate lakes among saline and non-saline using solely remote sensing data and object-based image analysis, which have still been undertaken towards this end. In all experiments the visible and near-infrared bands of the ASTER sensor were used. The methodology involved segmentation steps using the multi-resolution segmentation algorithm available on the Definiens Developer system as well as rule-based classifications and merging of objects. The classification model was structured as s process-tree. Initially, a segmentation and classification step was carried out with the purpose of precise detection and delineation of all lakes. Following, sand belts were detected also through a segmentation and classification process. Finally, the differentiation between saline and non-saline lakes was done based on the criterion of relative border to sand belts. A qualitative analysis of the resulting thematic map indicated a good result. Quantitatively, the error matrix scored an overall accuracy of 73% as well as a Kappa index of 0.64. Most of the classification errors were ascribed to intermittent lakes on different drought conditions. The object-based classification approach has proven to be very efficient for the detection of lakes and their differentiation between saline and non-saline in the region of Pantanal of Nhecolândia.

## 1. INTRODUCTION

The Pantanal in the central-west of Brazil is a wetland of over 138.000 Km$^2$ of area (Silva and Abdon, 1998) located in the Upper Paraguay River Basin. Being recently designated by UNESCO as both a Biosphere Reserve and World Heritage Site, Pantanal is an ecosystem worldwide recognized for its natural resources and biodiversity (Assine, 2003). The landscapes of Pantanal are arranged in eight sub-regions (each named with the prefix "Pantanal of"): Barão de Melgaço, Cáceres, Nabileque, Nhecolândia, Paiaguás, Paraguay e Poconé (Junk et al., 2006). Despite this landscape mosaic and the importance of this ecosystem as a whole, reliable detailed knowledge about Pantanal is still scarce. Several subjects related to the evolution and dynamics of its landscapes are still being discussed in the specialized literature.

However, the growing availability of remote sensing data with different spatial, radiometric, spectral and temporal resolutions is encouraging the use of this technology for (previously impossible) natural landscapes studies (Almeida et al., 2003; Gomes et al., 2006; Costa and Telmer, 2006; Costa and Telmer, 2007). Moreover, the object-based image analysis (OBIA) approach has been showing to be an efficient tool for image analysis due to its several advantages for spatial information extraction, such as: the options of multi-scale segmentation; exploration of textural, geometric and contextual features; definition of hierarchical and semantic relationships between classes and the possibility of combining data from different sensors and different formats (Benz et al., 2004). Despite the works of Burnett and Blaschke (2003), Hamilton et al. (2007), and the increasing number of publications (Blaschke, 2010), there is much field to expand the use of OBIA in natural landscapes studies.

A natural landscape phenomenon that needs further study is the genesis and behavior of innumerable small lakes and ponds with open-water surfaces on the Nhecolândia region at the Taquarí alluvial fan (Costa et al., 2006). Such small lakes and ponds may be freshwater, brackish water (i.e. lakes with high concentration of calcium carbonate) or even saltwater (also referred as "saline lake") (Abdon et al., 1998; Pott and Pott, 2000; Medina-Junio and Rietzeler, 2005). To this moment no methodology has been proposed for automatically mapping all lakes in the Pantanal of Nhecoândia and distinguishing them among saline and non-saline. In this context, the objective of this work is to create a model for automatic detection of lakes and their differentiation between saline and non-saline in the region of Pantanal of Nhecolândia using OBIA techniques.

## 2. STUDY AREA

The study area of this research is a section of the Pantanal of Nhecolândia located between the Taquari River and the Negro River. The rectangle extent of the study area is defined by the coordinates 19º 20' 07"S, 56º 47' 53"W (lower left) and 19º 32' 08"S, 55º 23' 53''W (upper right) (Figure 1).

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Inserted into an important geomorphologic feature known as the mega fan of the Taquari River (Braun, 1977), this is a wetland area surrounded by highlands. The local altitudes vary from 80 m to 190 m above sea level and the climate is highly seasonal (i.e. hot and wet summers and cold and dry winters). This seasonality creates two distinguishable time periods: the dry months from May to October and the wet months from November to April, associated to the rain events at the headwaters of the Paraguay River. Significant changes in the landscape can be observed from a period to another.

The freshwater lakes are fed both by rain and underground water on humid periods and frequently contain aquatic vegetation. As for the saline lakes, these are perennial in relation to other water bodies of this area due to the presence of impervious salt deposits at the water level. Almeida et al. (2003) observed that the dynamic of seasonal flooding is associated to the evaporation of the lakes. After the humid period, the less deep lakes dry out while the deepest ones (generally the alkaline and saline ones) persist and exhibit white sand beaches.
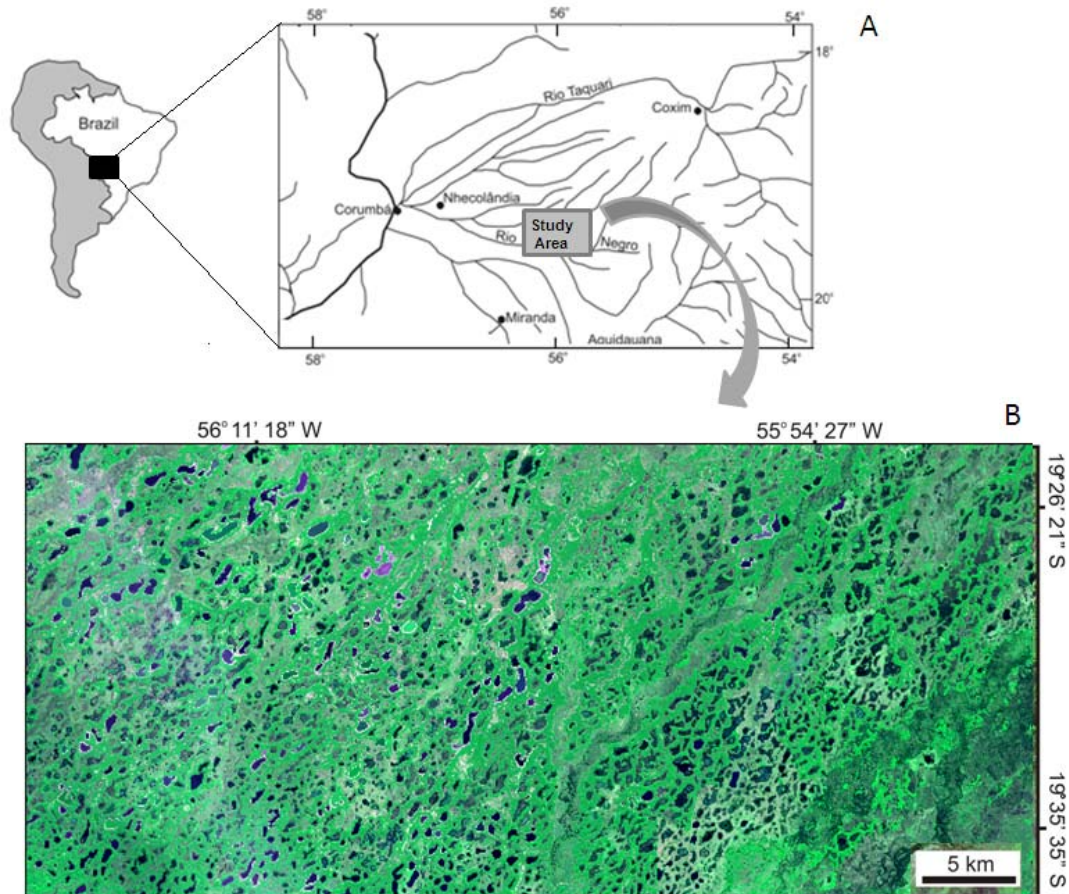


Figure 1 – A) The study area and the main rivers and cities of the region; B) Extent rectangle of the study site.

## 3. MATERIALS AND METHODS

### 3.1 Materials

For the realization of this study images from the ASTER sensor were used. The files were obtained from the Land Processes Distributed Active Archive Center (LP-DAAC). Only the bands located in the red and near-infrared part of the spectrum were used (band 1 - 0,52 a 0,60 μm; band 2 -0,63 a 0,69 μm; band 3 – 0,76-0,86). These three bands of the ASTER sensor have a spatial resolution of 15m. The images, acquired on August 3rd 2001, are already corrected for atmospheric effects and the pixel values are converted into surface reflectance according to the standards of the AST07 product (Abrams e Hook, 2002).

All classification-related tasks were performed in the Definiens Developer system (Definiens, 2007), which is presently the most disseminated commercial software that performs OBIA.

### 3.2 Methods

The methodology applied for the automatic detection of lakes and their differentiation between saline and non-saline is actually a series of image processing routines (e.g. segmentation, classification, merging of segments) structured as a process tree. In Definiens Developer a process tree is a hierarchical and sequential structure of image processing tasks that together represent the image interpretation model. This model can then be applied over other areas and dates maintaining the same process configurations.

The first step of the classification process was the segmentation of the ASTER images using the multi-resolution segmentation algorithm and parameters exhibited on column PS 1 of Table 1. Then the segments were classified as belonging either to class 'Lake' or 'Non-Lake'. This was done using the features 'Mean pixel value of band 2' and 'Roundness'. All segments with a mean pixel value of band 2 lower than 150 and roundness above 0.5 were classified as 'Lake'. The resting objects were classified as 'Non-Lake' using the 'not class Lake' operator. All segments belonging to class 'Lake' that shared borders were merged. This was done using the 'merge region' process and enabling the option 'loop while something changes'. Next, the area belonging to 'Non-Lake' was once again segmented. Here also the multi-resolution algorithm was used. The parameter set shown on column PS 2 of Table 1 was applied. Among these segments, the ones belonging to class 'Sand' were extracted selecting segments with the value of the feature 'Mean pixel value of band 3' higher than 170. Once again the algorithm 'merge region' enabling the option 'loop while something changes' was used for merging the segments still belonging to class 'Not-Lake'. Then, the 'Not-Lake' areas were once more segmented using the multi-resolution segmentation algorithm and the parameter set shown on column PS 1 on Table 1. At last, all segments with a relative border to class 'Sand' higher than 60% were classified as 'Saline Lakes'.

Table 1 – Parameter sets applied in the classification process.

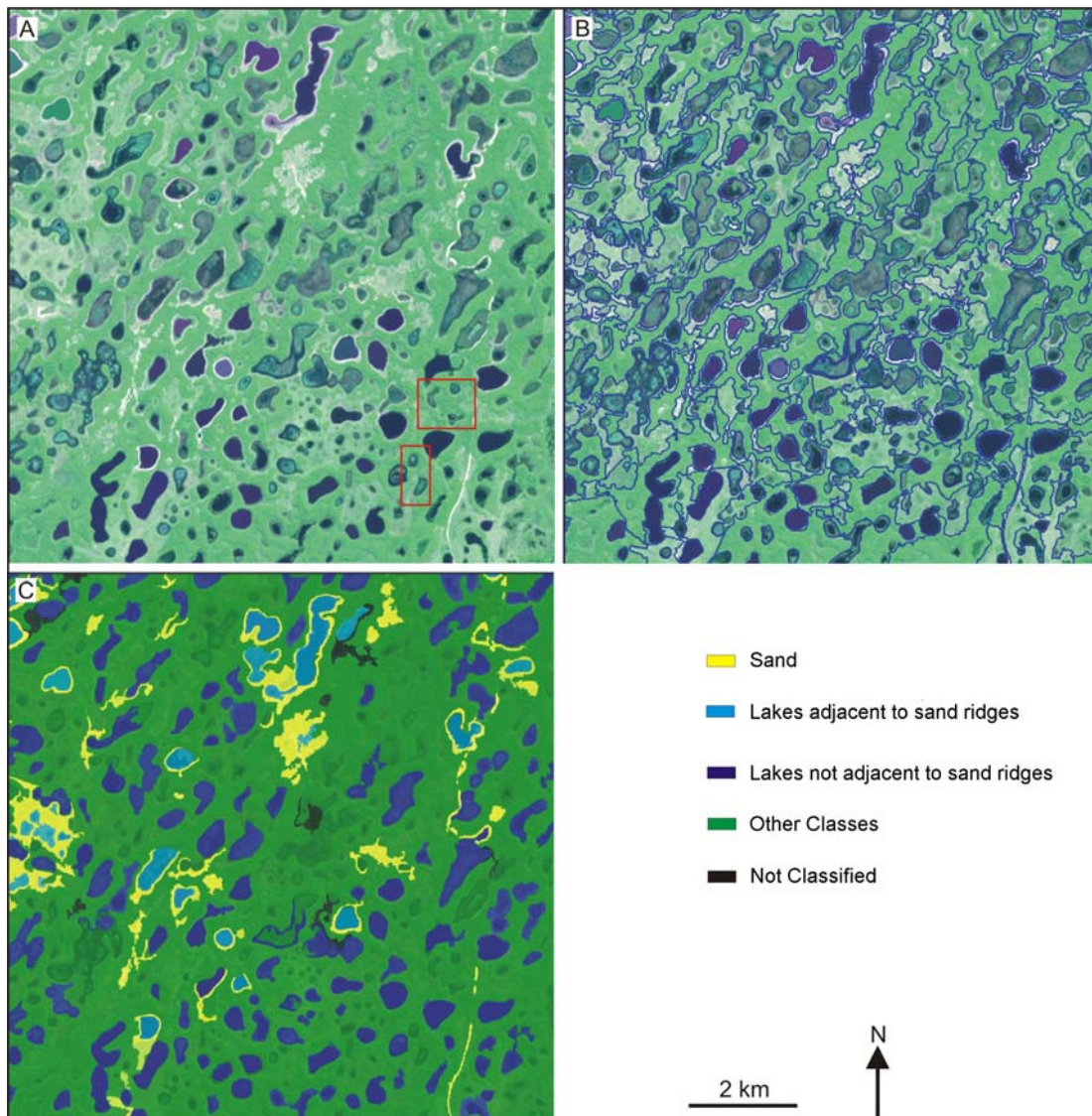| Parameters | PS 1 | PS 2 |
|---|---|---|
| Scale factor | 100 | 40 |
| Shape | 0.1 | 0.1 |
| Compactness | 0.35 | 0.5 |



Figure 2 – A) Color composition of the ASTER bands (R2G3B1) (the reddish rectangles indicate lakes not indentified in the final map); B) segments used in the classification of the ASTER images and C) the final thematic map.

# 4. RESULTS

Considering the complexity of the area due to the existence of lakes with different shapes, sizes and geochemical composition, a high correlation can be observed between what a visual interpretation of the ASTER images would be and the actual classification (Figure 2). It can be notice on Figure 2A two distinct types of lakes: the ones with sand ridges in their banks (located mainly in the northern sector of the figure), and the ones that do not have sand ridges in their banks (concentrated mainly in the southern portion of the figure). Nevertheless, one can also observe on Figure 2A (rectangles in red color) that some small sized lakes were not detected at the final thematic map (Figure 2C). The reason might that the segmentation parameters used could not segment these small lakes.

Due to the fact that the ASTER images used in this study were obtained in the dry period, some lakes with water deficit could not be identified. The water deficit causes the reduction of the size of the water body, which consequently increases the difficulty of segmenting these lakes preserving at the same time its borders to neighbor objects, especially to the humid areas adjacent to the lakes. Considering that the high-salinity lakes are perennial in relation to freshwater lakes (Almeida and Lima, 1959), which are filled only in the humid season, the dry lakes should be interpreted as former freshwater lakes.

A detailed visual analysis of the classified image corroborates the good quality of the classification, especially to what it refers to sand ridges delineation on the borders of the lakes (Figure 3). However, Figure 3C shows dotted red circles that indicate saline lakes (with sand ridges) that were misclassified as non-saline lakes (Figure 3A). Such errors support that further tests of segmentation parameter sets and classification thresholds are necessary.
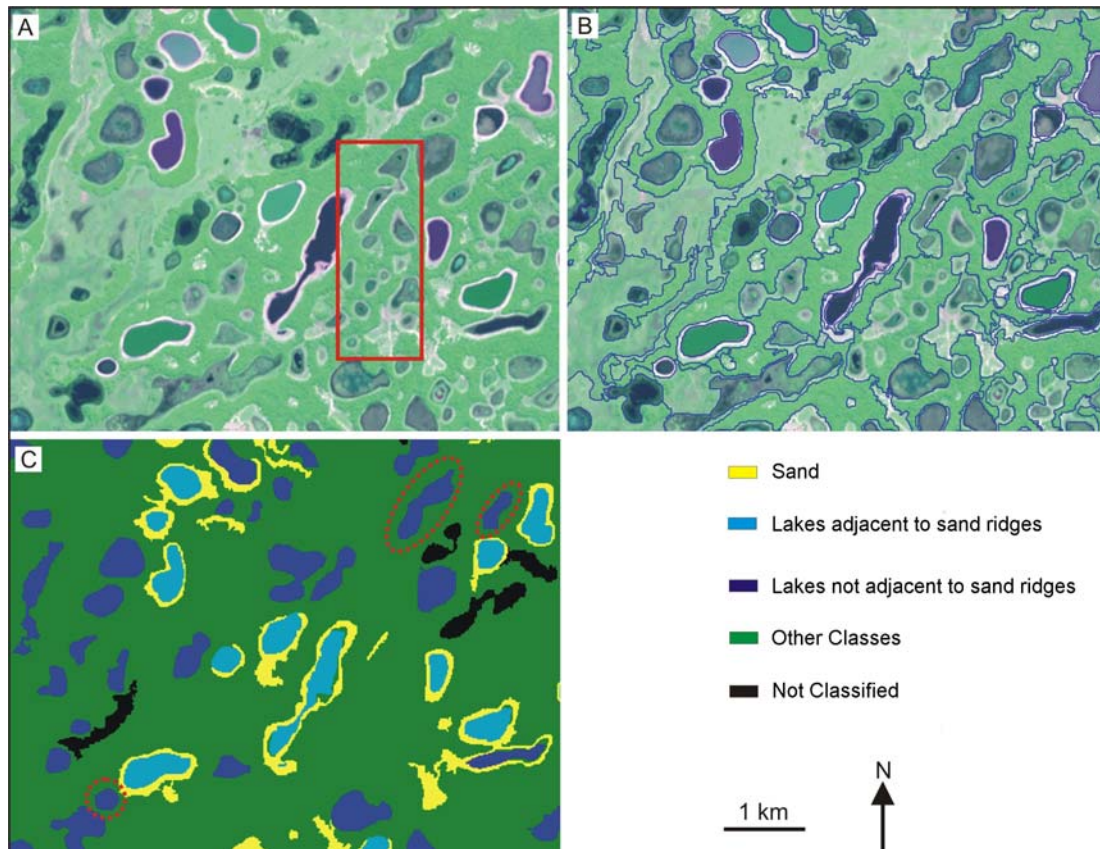


Figure 3 – A) Color composition of the ASTER bands (R2G3B1) (the reddish rectangle indicates lakes not detected in the final map); B) segments used in the classification of the ASTER images and C) the final thematic map. One can notice on letter C the good delineation of the sand ridges. The dotted circles refer to classification errors occurred due to misdetection of sand ridges.

In this work the precise detection of sand ridges adjacent to the lakes was very important for the distinction of saline and non-saline lakes. This is because saline lakes usually have sand ridges on its banks (the high-salinity water impedes the progress of the vegetation toward the lake) and the ponds without sand ridges have low salinity water (Almeida et al., 2003). As the ASTER scene was obtained in the dry period (when the lakes suffer a reduction of its water body), the detection of the sand ridges was facilitated because of their exposure. Therefore, the lakes with sand ridges were interpreted as saline lakes and the ones without sand ridges were interpreted as non-saline or low saline lakes (Figure 2C and 3C).
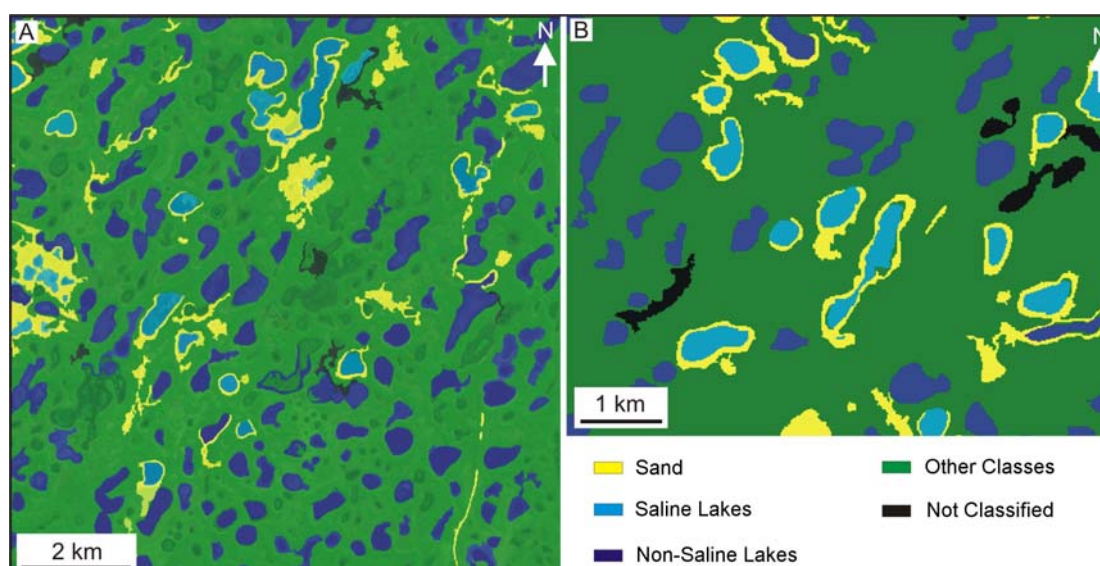
Figure 4 – A and B) Final classification already shown on figures 2C and 3C.

The accuracy assessment of the classification was done based on a confusion matrix created with 115 samples (i.e segments) randomly collected over the image. The indexes Kappa, Global Accuracy and user's and producer's accuracies were used. All these accuracy indexes are derived from the confusion matrix (Congalton and Green, 1999) and have been widely used by remote sensing researchers to evaluate the quality of automatically produced maps. A global accuracy of 73% and a Kappa of 0,64 were obtained. According to the categorization of the Kappa index proposed by Landis e Koch (1977), the quality of the classification can be considered very good. When analyzing the confusion matrix one can notice that few 'Non-saline lakes' objects were classified as 'Other Classes'. When verifying such objects, it was observed that the reason is that these lakes are almost dry, which makes difficult their delineation and classification with the parameters and

thresholds we used, as mentioned. The verification of the classification errors referring to class 'Saline Lakes' showed that the samples of this class that were confounded with 'Non-Saline Lakes' all had the same characteristic of not being adjacent (at least by no more than 60%) to a sand ridge, despite the fact that these did exist but were not classified as such. It should also be stressed that the level of accuracy is related to the spatial resolution of the sensor. In that context the 15m resolution of the ASTER sensor was capable of extracting the desired information. However, most of the errors are associated to small sized objects. Despite the fact that using finer (smaller) segments and testing other thresholds for the classification may improve the results, the use of higher spatial resolution sensors should be tested, especially on the present days where the availability of such sensors is increasing very fast.

Table 2 – Confusion matrix of the classification of lakes at Pantanal of Nhecolândia.

| Classification | Reference Samples | | | | | | |
| | Sand | Non-Saline Lakes | Saline Lakes | Other Classes | **Total Samples** | User´s Accuracy | Producer´s Accuracy |
|---|---|---|---|---|---|---|---|
| Sand | 15 | 1 | 0 | 4 | 20 | 0,75 | 0,83 |
| Non-Saline Lakes | 3 | 26 | 9 | 0 | 38 | 0,68 | 0,65 |
| Saline Lakes | 0 | 0 | 23 | 0 | 23 | 0 | 0,59 |
| Other Classes | 0 | 13 | 1 | 20 | 34 | 0,59 | 0,83 |
| **Total Samples** | 18 | 40 | 33 | 24 | **115** | | |

### 5. SUMMARY AND FUTURE WORK

The use of OBIA has shown to be an efficient approach for the detection and accurate delineation of lakes at the Pantanal of

Nhecolândia in Brazil. A visual comparison of the ASTER images and the classified image show that there is high correlation between the two. Most of the water bodies and sand ridges were detected and well delineated using segmentation and simple rule-based classification techniques. Additionally,

the lakes and ponds of the area were distinguished between saline and non saline lakes based on a contextual criterion. A high overall accuracy was obtained and according to a widely used categorization of the Kappa index the classification can be considered of very good quality. Most of the classification errors are related to small sized objects that could not be correctly segmented and classified. We suggest that a more fine segmentation followed by the use of the segment merger tool could help increase the accuracy of the classification. We also suggest that higher spatial resolution sensors are tested in future work, despite the higher cost to map the same area in relation to ASTER imagery. In future works we will evaluate the accuracy of the differentiation of saline and non-saline lakes based on field data. As this paper had the intention of being merely a experimental exercise, we felt encouraged to pursue the improvement of the methodology both for classification and accuracy assessment.

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