MAPPING WETLAND ENVIRONMENTS IN THE BRAZILIAN SAVANNAH FROM HIGH RESOLUTION IKONOS IMAGE DATA

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ABSTRACT:

Wetlands are complex ecosystems hosting a high diversity of landscape associated with water, soil and vegetation variations. It provides several essential resources for wildlife and human populations and supports a miscellany of aquatic plant species. The *Pandeiros* Wildlife Sanctuary is a unique wetland ecosystem surrounded by semiarid savannas. It supports large communities of macrophytes and terrestrial plants and stores large quaqntities of organic matter. In this article we propose a methodology for classifying these wetlands using their spectral and textural signature extracted from Ikonos image data. The main plant communities were identified from low altitude photographs acquired with a microlight aircraft. Ground data also complemented these photographic records. Classification trials were made using both spectral and spatial feature (texture) to assess the most appropriate approach. As a result five classes of macrophytes (as dominant specie) and four terrestrial classes were identified with an accuracy of over 80%. Texture data brought a significant improvement to the classification.

RÉSUMÉ:

Les zones humides sont des écosystèmes complexes accueillant une grande diversité de paysages associée à l'eau, aux sols et aux variations de la végétation. Il offre plusieurs ressources essentielles pour la faune et les populations humaines et soutient une grande variété d'espèces de plantes aquatiques. Le Refuge Faunique du *Pandeiros* est un écosystème humide unique entouré par la savane semi-aride. Il supporte de grandes communautés de macrophytes et les plantes terrestres et une quantité importante de matière organique. Dans cet article, nous proposons une méthodologie de classification de ces zones humides basée sur leur signature spectrale et texturale extraite à partir des données d'image Ikonos. Les principales communautés végétales ont été identifiées à partir de photographies à faible altitude acquise avec un ULM. Des données au sol ont également complété ces documents photographiques. Des essais de classification ont été faits en utilisant les caractéristiques spatiales et spectrales (texture) pour évaluer l'approche la plus appropriée. En conséquence cinq classes de macrophytes (comme espèce dominante) et quatre classes terrestres ont été identifiés avec une précision de plus de 85%. Les données de texture ont apporté une amélioration significative à la classification.

1. INTRODUCTION

Wetlands were previously seen as dirty, dangerous and unimportant areas by most Western communities (Gooselink, 2003). Since the Ramsar Convention, a new perception of those environments spread through occident. Several governments agreed in built a framework for the conservation and wise use of these areas (Ramsar 2006). Brazil is one of the signatory parties of the convention and holds numerous wetlands in its territory.

Although Brazil recognize the importance of Wetlands, a lack of definition and specific protecting laws threat this environments. Due to this absence, we adopted the Canada's National Weltands Working Group (1997) concept which considers wetlands areas saturated by water long enough to support aquatic process as indicated by aquatic vegetation, poorly drained soils and biological activity adapted to this particular conditions.

The Pandeiros River Flood Plain presents all this characteristics and is considered an important wetland site in Brazil. It is even more special since it is located in a region of water scarcity surrounded by savanna vegetation. It provides several ecosystem services such as recycling nutrients, fixing carbon and recharging the aquifer. Due to its relevance the State Government acknowledged this site as a Wildlife Sanctuary. However, the recognition as a protected area does not ensure the preservation of this region. Large areas still been used to raise cattle and several small ones are drained and used by communities for family farming (Barbosa, 2009).

Since it is a unique site in Brazil, identifying types of wetlands found in this environment will subsidized its proper management and conservation. Nevertheless, this task is a challenge since Pandeiros host a complex ecosystem with a high diversity of landscapes.

The inventory of wetlands demand field surveys, aerial photo interpretation and satellite imagery. Melack (2004) points out that the use of satellite images is considered the most efficient, since it allows a fast data acquisition and cartographic mapping. A large range of tools are available to classify this sort of data. However, high resolution images require more sophisticated approaches. Texture has achieve expressive results in the classification of those images. For example, Davis et al (2002) obtained an overall accuracy classification of 75% using image texture for riparian zones. Thus, as a starting point, we decide evaluate texture potential of classify different groups of aquatic plants based on Ikonos images.

1.1 Gray Level Co-occurrence Matrix

Several methods can be applied to texture analysis. Among these, the Gray Level Co-occurrence Matrix (GLCM) seems to be the most commonly used (Franklin, 2001) and has been recognized as one of the best tools for specific situations of classification (Clausi, 2000; Maillard, 2003). GLCM is a second order histogram in which each entry reports the join probability of finding a set of two grey levels at a certain distance and direction from each other over some pre-defined window (Maillard, 1999). Haralick et al (1973) was the first to extract texture features in order to classify images. 14 textures measures were originally described by Haralick. However many features are highly correlated which made five of them more popular: Contrast, Angular Second Moment, Entropy, Inverse Difference Moment and Correlation.

In this study, we aimed to evaluate the use of GLCM in the classification and segmentation of high resolution image of a wetland environment. As well as determining the optimal parameters of textures, window size and distance to be used in the study of IKONOS images for this sort of environment.

2. METHODOLOGY

2.1 Study Area

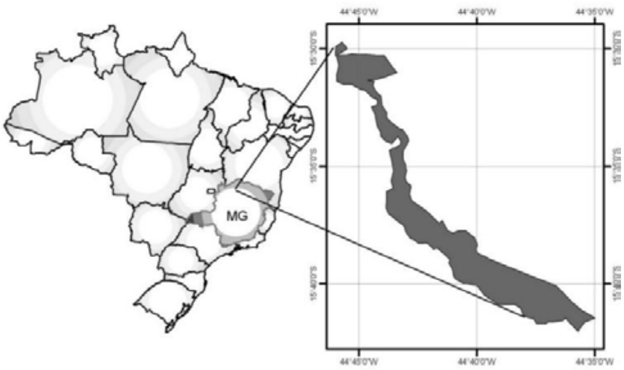


Figure 1. Location of Pandeiros Wildlife Sanctuary in Minas Gerais (MG) – Brazil.

The Pandeiros Wildlife Sanctuary (PWS) is located near the Pandeiros' River mouth, in the Northern part of the State of Minas Gerais (Figure 1). This river is an important affluent of São Francisco River and is the breading grounds of several species of fish. It is also a refuge for numerous rare endemic and threatened bird species (Biodiversitas, 2005). The region is protected by the State government authorities and is managed by the Forest Institute of Minas Gerais (IEF-MG).

It occupies a total area of 6103 ha. and preserves a unique wetland with riparian forests, palm swamps, wet meadows, lakes and ponds (Figure 2). Climate presents two distinct periods: wet season from October to March, and dry from April to September. This variation is characteristic of the Cerrado biome where water deficit spans for about half the year.

2.2 Field Work

The first of Four field campaigns was conducted in September 2008 using a boat and an all-terrain vehicle to access difficult areas for a general reconnaissance approach. During the second one in February 2009 geodetic ground control points were collected for the geometric correction and registration of the image. A specific work area was also defined and data was acquired on the different vegetation physiognomies that could be identified on the Ikonos image. The third campaign in May 2009 was mainly dedicated to acquire low altitude photographs using a micro-light aircraft to serve as complementary validation data. The Fourth and last one in April 2010 allowed acquiring new low altitude photographs and visit a few spots where some botanical inventory was still necessary. During the last three campaigns, printed copies of the Ikonos image (scale 1:5000) were used to identify complexes both in the field and on the image. This data allowed us to divide vegetation of the study area in 9 different classes (Figure 2): *Pontederiaceae*, *Nymphaeaceae*, *Riparian forest*, *Open Water*, *Alismataceae*, *Cyperaceae*, G – *Pasture*, H – *Flooded Pasture*, I – *Bare Soil*.

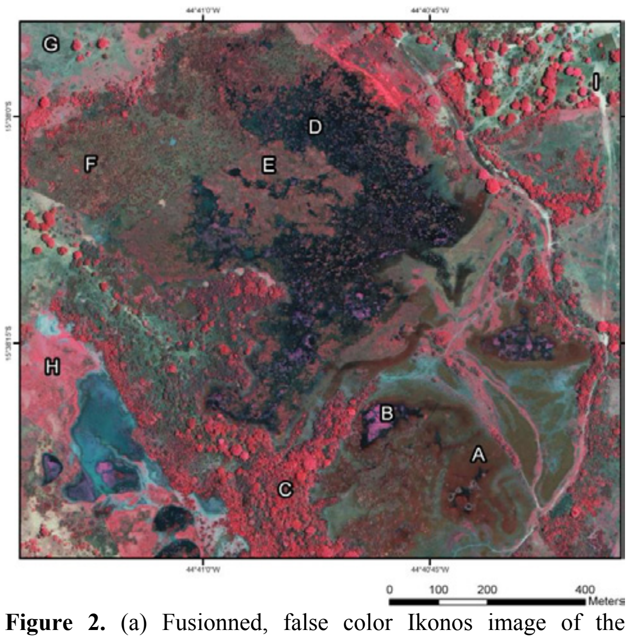


Figure 2. (a) Fusionned, false color Ikonos image of the Pandeiros. The image represents an area of 1200×1200 pixels or 144 ha. Legend: A – *Pontederiaceae*; B – *Nymphaeaceae*; C – *Riparian forest*; D – *Open Water*; E – Alismataceae F – *Cyperaceae*; G – *Pasture*; H – *Flooded Pasture*; I – *Bare Soil*.

Photographic records of different vegetation typology were acquired to constitute a visual inventory of the Pandeiros. The dominant plant groups present on the photographs were identified by two botanists at the Botanic Taxonomy Laboratory of the Universidade Federal de Minas Gerais (UFMG). The aerial photographs proved to be useful for the inventory and as validation data. Since only a navigation GPS was used in the last two campaign, care was taken to note and draw the landscape context for all the ground control points that were mainly acquired for thematic purposes (as opposed to geodetic). These points were essential for understanding the different environments and their respective context. It is during the February campaign that the test area presented here was selected for having the largest possible number of different natural environments within the smallest area. The selected area covers 1.44 km^2 and is illustrated in Figure 2.

2.3 Image Aquisition and Pre-processing

One fusionned Ikonos image[1] registered to a UTM projection of the central part of the PWS was provided by the Forest Institute of Minas Gerais (Figure 2). This image was acquired in September 2006 corresponding to the end of the dry season when the water level is at its lowest. Given the flatness of the relief and geodetic ground control points, registration errors were kept below 5 meters.

2.4 Texture Pre – processing

The Ikono's red band was selected to create the texture features due to the high reflectance response of vegetation in this channel. This band was used as input data in the program MACOOC (Philippe Maillard ©2010) which is able to produce all five texture measures in four directions: 0°, 45°, 90° and 315°. Although data was produced in four directions, we analysed this information grouped.

2.5 Gray Level Co-occurrence Matrix (GLCM) Tests

Initially, we selected a few parameters (pixel pair lag distance, window size and texture features) to conduct the first tests in order to stipulate the best value of distance.

The following values were chosen for lag distance: 3, 4, 5, 6 and 7. We did not use values 1 and 2 because of the high correlation between neighbouring pixels (especially considering the image resolution results from a fusion). A value of 7 was fixed as the maximum given that aquatic plants present homogeneous groups with little or no projection of shadows and the average object size is rarely larger than 7 meters.

Window sizes of 15, 21, 25, 31, 35 and 41 were selected. A maximum window size of 41 was selected once most of the features present in the study do not exhibit homogeneous areas larger than 1.600 m^2. We opted for the most commonly parameters used: Angular Second Moment (ASM), Entropy (Ent.), Constrast (Cont.), Inverse Difference Moment (IDM), and Correlation (Corr.)

Supervised classification method, which demands ground truth data, were performed using the maximum likelihood decision rule (Biehl and Landgrebe, 2002). Areas selected as training and validation samples were chosen based on field data and image interpretation. A few tests were performed to evaluate the effect of window size on the variance of the class. We chose use windows of about 11 × 11 pixels or 121 m^2 in the classification process. The class of bare ground was the only exception and windows of 9 × 9 pixels were chosen to maintain the integrity of the samples considering the difficulty of having "pure" samples of bare soil.

[1] Fusionning involves resampling the 4 m multispectral to 1 m using the panchromatic channel.

After apply the Supervised method to images compound by texture and spectral bands, a five steps Knock-out process (table 01) was performed in order to reduce the features types and frequencies that play the most important role in the classification process. All the combinations that achieved equal or higher values than 80% of overall accuracy were ranked and analyzed.

In a second step, tests combining the five variables of texture with 18 different sizes of window 11, 13, 15 .... 45) were conducted using only the value 3 for distance. We submit data to classification and Knock- out process as previously mentioned.

The third step had consisted in apply the classification to each parameter of texture separately and combined with the spectral bands. All the results higher than 80% were used to find the best window size.

wind + dist	15 + 04				
Tex+S	78,1				
Cont	ASM	IDM	Ent	Corr	Spectral
79,4	78,4	79,9	76,1	77,3	59
81,3	79,8		78,4	77,8	60,3
	78,9		77,8	79,8	65
	82,5		80,5		40,1

Table 1. Knock – out example. Legend: wind+dist (window + lag distance), Tex+Spec (Texture + Spectral bands), Constrast (Cont.), Angular Second Moment (ASM), Inverse Difference Moment (IDM), Entropy (Ent.), and Correlation (Corr.).

2.6 Validation

Access in wetland areas can be very difficult and a fully systematic or random sampling scheme was impossible. Additionally, although the PWS is a protected area, most of it is still privately owned and we were not always able to have permission of access from landowners. Still, we were able to visit a total of 72 sampling sites chosen from the interpretation of image data to serve as training and validation data. To overcome the access limitations, we also used a micro-light aircraft flown at low altitudes (< 500 m) to acquire over 700 oblique photographs of the area using a digital camera (Nikon D40X) equipped with a zoom (Nikkor 18-200 mm 1:3.5-5.6). Data from the tracking log of a navigation GPS (Global Positioning System) set at a 50 m distance interval was coupled with the acquisition time of the photographs to account for the aircraft position at each shot (the camera and the GPS were previously synchronized). The level of detail on these photographs was such that the dominant plant families could easily be interpreted with the help of two botanists and the ground samples.

3. RESULTS AND DISCUSSION

This paper results are presented in three blocks: Distance definition, window definition and behaviour of textures features.

3.1 Distance definition

A supervised classification based solely on spectral bands of the Ikonos image has reached an overall accuracy of 72,5%. This is a control value to verify the efficiency of add texture features in the classification process.

After perform 150 classification according to the knock-out process, 68 results achieved values higher than 80% of overall accuracy (Combinations of lag distances 3 to 7 and windows size 15 to 41). The distance 3 was present in most of the results (34%) and there was no prevalence of a given window size. The texture features compound the results in the following percentages: ASM (72%), IDM (54%), Ent (50%), Corr (26%) and Cont (18%). However, when we consider the results with one single feature of texture, Ent. represents 40% of the results and Cont 40%. as well. The best result reached was 86,5% with a lag distance of 3, a window size of 41 and using IDM and Ent. (Table 1)

Bands	Distance	Window	Overall Acurracy
IDM+Ent+S	3	41	86,5
ASM+IDM+Ent+S	3	35	85
Ent+S	3	41	84,9
Ent+S	6	31	84,1
Ent+Vis	5	21	83,9
Cont+ASM+IDM+ Ent+Cor+S	3	35	83,9
ASM+IDM+Ent+S	3	21	83,8
Cont+S	4	41	83,2
IDM+Ent+S	5	21	83
ASM+IDM+Ent+S	3	25	83

Table 2. Ten best classification results of Knock – out using all 5 texture features combined with spectral bands, lag distances between 3 and 7 and the following window sizes: 15, 21, 25, 31, 35 and 41.

3.2 Window definition

With a fixed distance of tree, 90 new classifications were performed following the knock-out approach and 67 results showed an overall accuracy exceeding 80%. Again, there was no prevalence of a given window size. We expected this result since the Knock-out technique aimed to find the best result for each size of window. In this case, 76% of the results were related with texture feature ASM, 60% with Ent, 50% with IDM, 30% with Cont and 20% with Corr. The results compound by one Texture band were analysed and the same result order was achieved. (ASM - 47%, Ent. – 29%, IDM – 18%, Cont. 12% and Corr. 0%). The best result reached was 86,7% with a window size of 41 using only contrast. (Table 2)

Bands and features	Distance	Window	Overall Acurracy
Cont+S	3	37	86,7
IDM+Ent+S	3	41	86,5
IDM+Ent+S	3	43	86,4
Ent+S	3	45	86,4
IDM+Ent+S	3	45	86,2
Ent+S	3	43	85,7
ASM+IDM+Ent+S	3	35	85
Ent+S	3	41	84,9
Ent+S	3	39	84,8
IDM+Ent+S	3	39	84,6

Table 3. Ten best classification results of Knock – out using all 5 texture features combined with spectral bands. a fixed lag distances of 3 and odd values of window sizes between 11 and 45.

This result was unexpected and led us to evaluate separately the performance of each texture features, alone and combined with spectral Ikono's bands. During this process we have conducted 180 processes, 90 of each combining texture with the spectral bands and 90 only with each texture feature. 56 results obtained values superior to 80%. Entropy responded by 32% of cases. The contrast was surprisingly the second best feature of texture with 34% followed by IDM (23%) and ASM (18%). The top 3 results for image classification using a combination of a unique texture with the spectral bands were obtained with the contrast and the following window sizes: 37, 41 and 43.

Window	Contrast	Window	Entropy
37	86,7	45	86,4
41	86,5	43	85,7
43	86,5	41	84,9
39	86,4	39	84,8
45	85,6	27	84,2

Table 4. Ten best results of image classifications using each texture feature separately combined with spectral bands, .a fixed lag distances of 3 and odd values of window sizes between 11 and 45.

When we evaluate the dispersion of the overall accuracy of classification by size of the window, we notice a general trend in

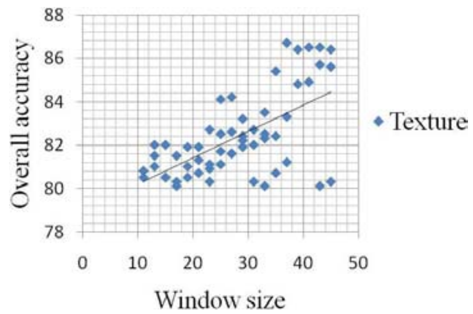


Figure 3. Graph of general dispersion of classification results of texture features according to window size.

3.3 Texture features Behaviour

Entropy is negatively correlated with window size when tested separately. However, when combined with the spectral bands tends to increase as the window size raises. The contrast is correlated positively with window size in both, when tested separately and when combined with spectral bands. In turn, the ASM presents negative correlation in both situations.

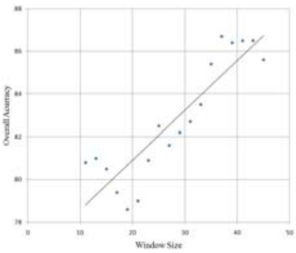
This indicates that the second angular momentum may play an important role when the window size varies between the values 11 and 30. Unlike the contrast that reaches the best results with windows between 30 and 45. Entropy presents a peculiar behaviour because it presents very significant results in all sizes of windows, but these tend to improve as the window size increases. In the Entropy plus Spectral graph, we can observe two peaks: one for windows of size 27 and one for windows of size higher than the 39.

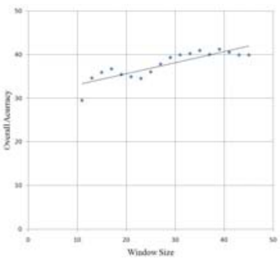
	Window	Cont +S	ASM +S	IDM +S	Ent +S	Corr +S
Window	1,00					
Cont+S	0,89	1,00				
ASM+S	-0,83	-0,87	1,00			
IDM+S	0,38	0,08	0,13	1,00		
Ent+S	0,86	0,79	-0,66	0,27	1,00	
Corr+S	-0,60	-0,58	0,75	0,29	-0,46	1,00

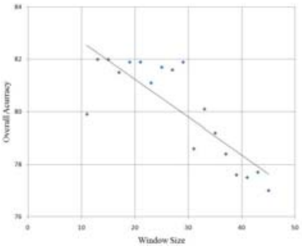
Table 5. Correlation Matrix of all classification results using each texture feature separately combined with spectral band, a fixed lag distances of 3 and odd values of window sizes between 11 and 45.

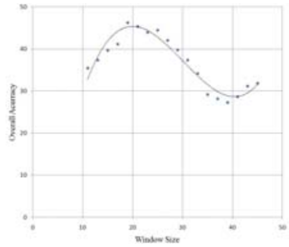
	Window	**Cont**	**ASM**	**IDM**	**Ent**	**Corr**
Window	1,00					
Cont	0,86	1,00				
ASM	-0,69	-0,61	1,00			
IDM	-0,71	-0,74	0,84	1,00		
Ent	-0,63	-0,69	0,44	0,65	1,00	
Corr	-0,94	-0,69	0,67	0,63	0,44	1,00

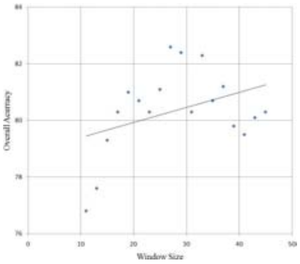
Table 6. Correlation Matrix of all classification results using each texture feature separetely, a fixed lag distances of 3 and odd values of window sizes between 11 and 45.

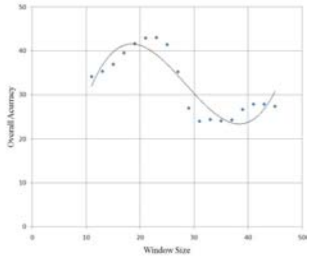

(a) Cont.+Spectral

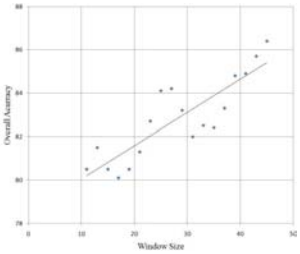

(b) Cont.

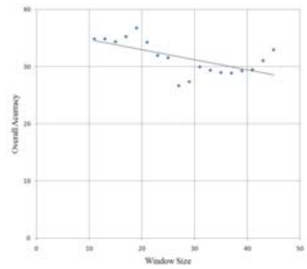

(c) ASM+Spectral

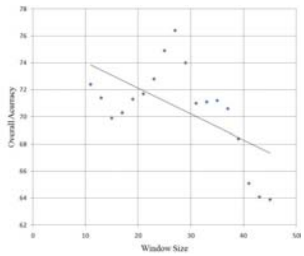

(d) ASM


(e) IDM+Spectral


(f) IDM


(G) Ent.+Spectral


(H) Ent


(I) Corr.+Spectral

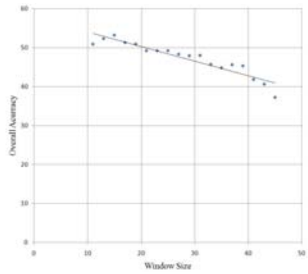

(J)Corr.

Figure 4. Dispersion Graphs of classification results of texture features according to window size for each feature processed combined and not combined with spectral bands.

4. CONCLUSION

The red band of the IKONOS image proved to be suitable for extraction of texture information to be used in the classification of aquatic vegetation in high-resolution images. Smaller distances were more efficient for image classification, as well as window sizes larger fared better. The use of a single texture feature combined with the spectral bands was very efficient. Among the parameters of texture Entropy combined with spectral bands produced good results for classification in all window sizes. While the contrast obtained the best results in windows of larger sizes and Second Angular Momentum showed good results in the windows of smaller sizes.

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