Analysis of land-use and land-cover changes in the Primavera do Leste Region, Mato Grosso, Brazil

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Abstract. The State of Mato Grosso (MT) in Brazil has experienced a rapid process of land cover conversion in recent decades, which is still poorly documented. Accurate information on land-use and land-cover (LULC) changes have crucial importance as they can greatly contribute to the understanding of impacts on the environment and the pursuing of a sustainable management of natural resources. The aim of this paper is to map historical LULC changes in the southeast part of the MT State (Primavera do Leste region), where the Cerrado (Brazilian savannas) has been intensively converted into agricultural land uses (crops/pasture). The methodology employed consists of a supervised classification approach for LULC mapping and a post-classification change detection technique for quantifying the changes. The results indicated an important loss of natural vegetation in the period from 1985 to 2005, with 45 % (7075 km^2) of the Cerrado vegetation converted to agricultural land-uses.

Keywords: Land-use and land-cover, remote sensing, change detection, Cerrados

1. Introduction

Although anthropic modifications of the landscapes around the world have happened throughout human history in order to obtain food and other essentials, the pace and magnitude of recent changes has been unprecedented and has affected ecosystems and environmental processes at different scales (Ellis and Pontius, 2007).

The State of Mato Grosso (MT), where the study area is located, has experienced in recent decades a rapid conversion of vegetation cover of its two main biomes, the Cerrado (Brazilian savannas) and the Amazon Forest which are undergoing some of the highest rates of deforestation in the Brazilian Legal Amazon (BLA) (Lima *et al.*, 2005). The present paper is focused particularly on the pressure agriculture has exerted on the Cerrado biome during the last decades with the expansion of crops and pastures.

The Cerrado is a rich and complex biome which is considered a biodiversity hotspot (Myers *et al.*, 2000); however, it is one of the least protected ecosystems in Brazil and has suffered heavy losses due to the advance of soybean cultivation (Fearnside, 2001). In fact, until the 1970s the lands of the Cerrados of central Brazil were considered unsuitable for agricultural use due to poor soils characteristics; however, the situation has changed dramatically in the past 30 years, due to subsidies from government programs and technological and agronomical advances, with the result that the Cerrados have became an important agricultural producing region (Bickel and Dros, 2003).

The agribusiness predominating in the MT State was consolidated with public subsidies and is maintained at the expense of high social and environmental costs (Puhl, 2006). Moreover, the patterns of change in the Cerrado are still poorly studied (Brannstrom *et al.*, 2008). In this context, there is an increasing need to understand the past and present land cover changes in order to assess the environmental implications and plan a more sustainable future for this region.

Remote sensing technology has emerged as a key tool in land change studies by providing cost-effective ways of assessing changes at different scales (Lunetta *et al.*, 2002) and has many advantages for change detection especially because of "…repetitive data acquisition, its synoptic view, and digital format suitable for computer processing…" (Lu *et al.*, 2004). Several articles have reviewed change detection techniques and their positive and negative aspects for different applications (Coppin *et al.*, 2004; Lu *et al.*, 2004; Lunetta and Elvidge, 1999; Singh, 1989). In agricultural landscapes, because of the intense dynamics of LULC, change detection methods based on classification (e.g. post-classification methods) are more recommended than, for example, methods based on the determination of thresholds, such as image algebra, which can lead to misleading results (Lu *et al.*, 2004).

The objective of the present paper is to map the conversion of the Cerrado vegetation into agricultural land use using a multi-temporal remote sensing dataset, in an area of major grain production in the MT State and that has undergone important LULC changes in the past decades.

1.1 Study area

The study area is located in the Primavera do Leste region, southeast portion of the State of Mato Grosso (MT) (Figure 1), within the geomorphological unit of "Planalto dos Guimarães". The relief of this plateau is mostly flat to very gently undulating and the climate is marked by a pronounced dry season from May to September. The remaining natural vegetation, concentrated in the "Sangradouro/Volta Grande" Indigenous Protected Area and along the rivers, is dominated by the Cerrado physiognomies and gallery forests.

Figure 1. Study area location.

Land-use in this region is predominantly agricultural - it is one of the principal production areas of grain and fibre in MT State, with a highly technified cropping system (Matsuoka *et al.*, 2003). The selected region of interest (ROI) is a subset (approximately 15 550 km^2) of the Landsat scenes 225/70 and 225/71 comprehending part of the upper "Rio das Mortes" river basin.

2. Methods

2.1 Considerations before Change Detection

Remote sensing data

Landsat TM images were used in this study for land cover mapping and change detection. Working with images from the same sensor is important when performing change detection as it assures that data was acquired almost at the same time of the day (important to eliminate diurnal sun angle effects), in addition to the same spectral, spatial, look angle and radiometric resolution (Jensen, 2005). The LULC were assessed for 1985, 1995, and 2005. These time windows cover the last 20 years, during which agriculture has been increasingly important in the ROI, and allow the characterization of the "long term" conversion of the Cerrado into agricultural land use. Considering that during the rainy season there is persistent cloud cover in the ROI, images from the dry period (June) were used.

Field data was collected in two campaigns (January 2007 and March 2008) to serve as training and accuracy assessment data for the classification of the most recent image and also permitted the collection of information on the cropping calendars, essential in understanding the spectral behaviour of land cover in the area.

LULC in the ROI

The main land cover types are annual crops, planted pasture, Cerrado vegetation and gallery forest. The annual crops include soybean, cotton and corn, as the main crops with millet, sorghum, and second corn used in rotation with the main crops. Rice is also planted, but is less significant, and some bean is found in irrigated areas. Pasture and annual crops were mapped together since the objective was to show the Cerrado conversion into agricultural uses. However, most of the agricultural land use consists of annual crops which occupy the areas of low relief. Pastures predominate in the areas of more undulating relief.

The Cerrado vegetation includes different physiognomies including grassland Cerrado (Savana Parque), woodland Cerrado (Savana arborizada), wet grasslands (Savana Gramíneo-Lenhosa) and wooded Cerrado (Savana Florestada) (Seplan-MT, 2008).

Prior to classification it was necessary to understand the spatial-temporal dynamics of agricultural land use in order to extract the desired information, as for example, the same land use (agriculture), can correspond to different land covers and spectral responses because of different crop types and also shifts in the planting time that can result in different land covers even for the same crop type at the same date.

In view of the research objective to map the conversion of the Cerrados into agricultural land use, a simplified legend was adopted based on *a priori* knowledge derived from field work, available maps and literature review, as follows:

- Natural vegetation (savannas formations and gallery forest)
- Agricultural lands (annual crops and pasture)
- Water bodies
- Urban areas
- Land use/cover in indigenous land

2.2 Extracting LULC Change Information

Data Pre-processing

Accurate spatial registration is essential to digital change detection and a root mean square error (RMSE) ≤ 0.5 pixel is recommended (Jensen, 2005). The geometric correction involved the utilization of an orthorectified image as reference to which the other images were registered in an image to image procedure. Thirty (30) control points per image, nearest neighbour resampling and a second-order polynomial warp function were used. The root mean square error (RMSE) for each image was ≤ 0.5 pixels. Considering that each date was classified independently, and that training data were collected from the image to be classified (same relative scale), the images were not corrected for atmospheric differences (Jensen, 2005).

Image classification

In order to extract information on LULC in the ROI, land cover maps for the selected years were produced independently using a supervised classification approach (maximum likelihood algorithm). The most recent image was classified first and validated based on fieldwork and this guided the classification of the temporal dataset assisted by other available thematic data. Initially it was necessary to hierarchically subdivide the area into subclasses, in order to account for all land cover types present in the ROI. Later the sub-classes were combined in order to produce the simplified legend. The classes Urban and Use in Indigenous Land represent less than 1 % of the area. Considering that these classes are localized and of limited extent, and due to spectral confusion with other classes, they were extracted manually.

Accuracy assessment

Classification accuracy assessment was performed using the error matrix approach, which is one of the most widely used for accuracy assessment (Lu and Weng, 2007). The classification accuracy was measured on the basis of a stratified random sampling (stratification by land cover classes) using 180 field data points for the validation of 2005 classification, and for the validation of 1995 classification 180 points were extracted from the available land use and vegetation map of the State (Seplan-MT, 2008), which had been produced using 1995/96 images. Due to the difficulty in collecting reference data for the 1985 image, no quantitative accuracy assessment was performed for this date.

Change detection

Taking into account that 'from-to' change information was important for the present study and that phenological variation of land cover during the year had to be controlled in order to work with a reduced number of classes, a post-classification method was chosen because it allowed assessment of these aspects. Post-classification change detection consists in the comparison of two independently-classified images, on a pixel-by-pixel basis, using a change detection matrix (Jensen, 2005). The major advantage of this method is its capability of providing a detailed matrix of change information and reducing external impact from atmospheric and environmental differences between multi-temporal images (Lu *et al.*, 2004). However, this method is very dependent on the accuracy of the initial classifications (Coppin *et al.*, 2004).

3. Results and Discussion

Classification results for the selected years are presented in Figure 2. The classes mapped were natural vegetation (savannas formations and gallery forests); agricultural lands (annual crops and pasture); water bodies; urban areas and land use/cover in the indigenous protected area. Due to the fact that urban areas, uses in indigenous land and water bodies together represent less than 1 % of the total area, they are sometimes not represented in the graphics.

The overall accuracy for the 2005 classification was 95 % (overall Kappa of 0.90) and for 1995 classification was 85 % (overall Kappa of 0.71).

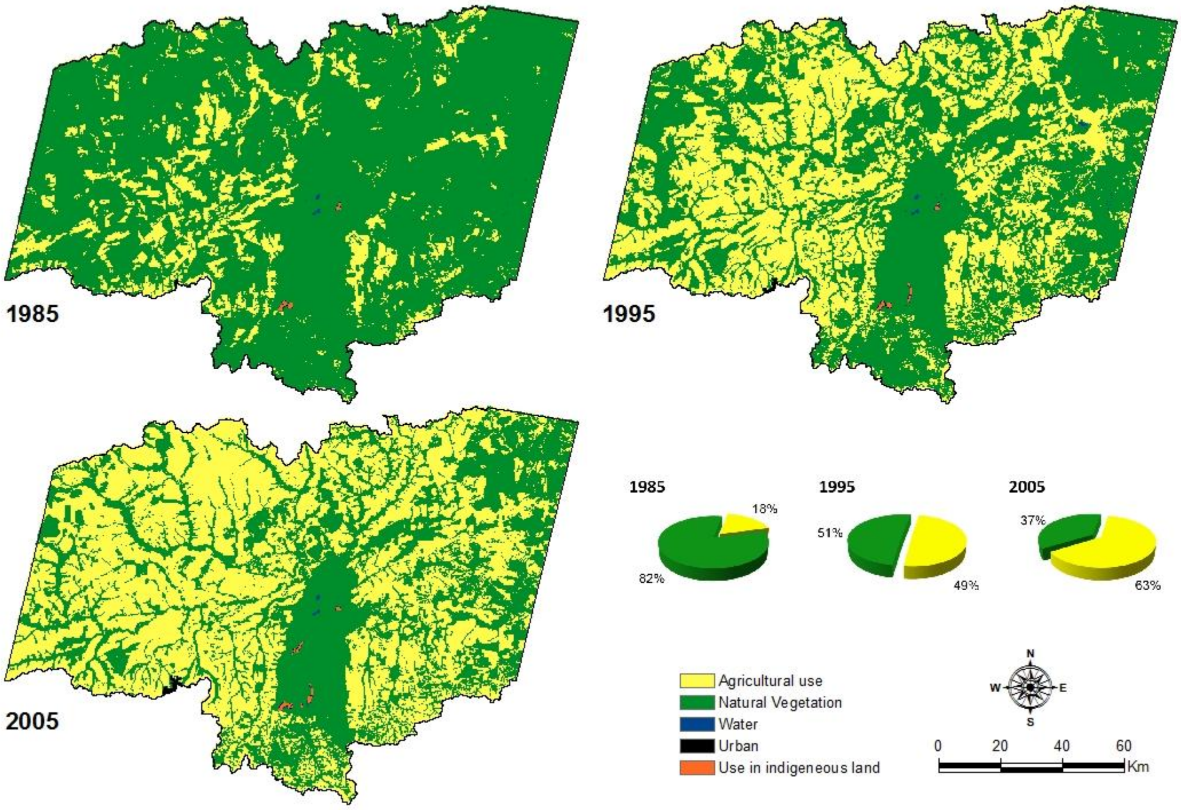

Figure 2. Classification results for 1985, 1995 and 2005.

Classification results indicate that in 1985, 82 % of the ROI was still covered by natural vegetation. The Cerrado vegetation was subsequently intensively converted. By 2005, this percentage was reduced to 37 %, remaining mainly in the Sangradouro/Volta Grande indigenous reserve, along drainages and in more sloping terrains. Agricultural land use (crops/pasture) has been present in the area for more than 20 years. In 1985, it occupied 18 % of the ROI, increasing to 49 % in 1995, and to 63 % in 2005, becoming the predominant element in the landscape.

Between 1985 and 2005, approximately 45 % (7075 km^2) of the natural vegetation was converted into agricultural use (Table 1). However, a more detailed assessment showed that the majority of the conversion took place between 1985 and 1995, with approximately 32 % of Cerrados converted in this period.

The change map for the 1985 - 2005 period is presented in Figure 3. Shown in green is the remaining natural vegetation in 2005, and in red are the areas that were converted from natural vegetation to agricultural land-use (crops/pasture) during the 20 year period.

Table 1. Change matrix from 1985 to 2005.

		“To” 2005 (% area)		
“From” 1985		Agricultural lands	Natural Vegetation	Total
	Agricultural lands	17	<1	18
	Natural Vegetation	46	36	82
	Total	63	37	100

No - change From natural vegetation to crop/pasture Minor changes

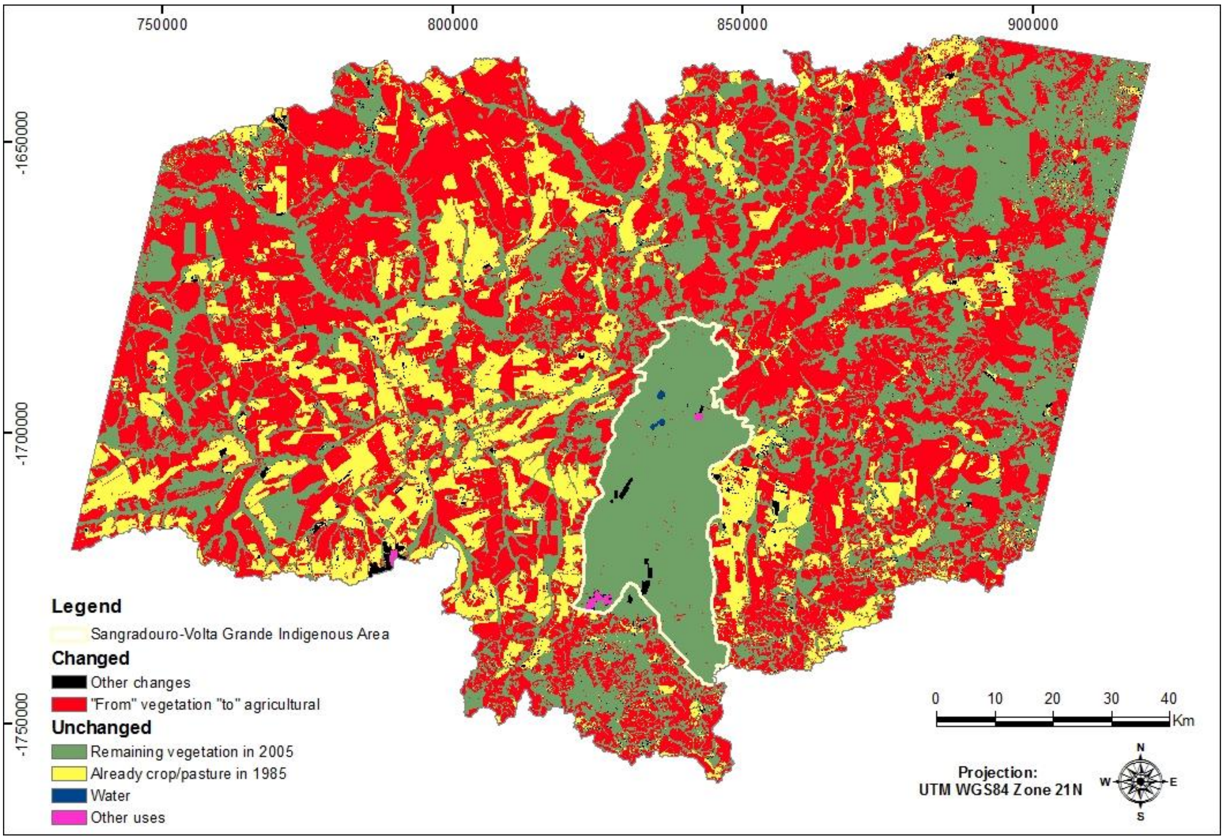

Figure 3. LULC Change map for the 1985 – 2005 period.

Assessing the natural vegetation in 2005 it is noticeable that the largest continuous tract of Cerrado remaining corresponds to the “Sangradouro/Volta Grande” indigenous reserve. All the surroundings of this reserve was intensively converted between 1985 and 2005, which might imply that if this had not been a protected area, most of the natural vegetation would have been converted. Preliminary comparison of the LULC results with available thematic maps shows that from 1995 to 2005, the annual crops encroached onto more sensitive areas, including wetlands, and highly erosion-susceptible soils.

4. Conclusion

The study reveals that agricultural land use has played a major role in land cover changes in this region in the past decades, and that the ROI has lost important amounts of natural vegetation. Between 1985 and 2005, 7075 km^2 of Cerrados were converted to agricultural land uses (from a total area of 15 550 km^2), which indicates the intense pressure of agricultural expansion over the natural vegetation resource. The accuracy obtained for the change mapping demonstrates that remote sensing is a reliable tool for understanding the historical transformations that have taking place in recent decades in this region and that consequently they can contribute in the formulation of land use decisions in the future.

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6. References

Bickel, U., & Dros, J. M. (2003). The impacts of soybean cultivation on Brazilian ecosystems: three case studiespp. 33). Available from http://assets.panda.org/downloads/impactsofsoybean.pdf

Brannstrom, C., Jepson, W., Filippi, A. M., Redo, D., Xu, Z., & Ganesh, S. Land change in the Brazilian Savanna (Cerrado), 1986-2002: Comparative analysis and implications for land-use policy. **Land Use Policy**, v. 25, n. 4, p. 579-595, 2008.

Coppin, P., Jonckheere, I., Nackaerts, K., Muys, B., & Lambin, E. Review ArticleDigital change detection methods in ecosystem monitoring: a review. **International Journal of Remote Sensing**, v. 25, n. 9, p. 1565-1596, 2004.

Ellis, E., & Pontius, R. **Land-use and land-cover change.** Encyclopedia of Earth: Washington, D.C**.** Retrieved from: http://www.eoearth.org/article/Land-use_and_land-cover_change. Last accessed: April 1, 2010.

Fearnside, P. M. Soybean cultivation as a threat to the environment in Brazil. **Environmental Conservation**, v. 28, n. 1, p. 23, 2001.

Jensen, J. R. **Introductory Digital Image Processing: a Remote Sensing Perspective.** Upper Saddle River: Pearson Prentice Hall, 2005. 526 p.

Lima, A., Anderson, L. O., Shimabukuro, Y. E., & Torezan, J. M. D. Status da proteção das formações vegetais no Mato Grosso: análise de representatividade de ecossistemas em unidades de conservação e territórios indígenas. In: Simpósio Brasileiro de Sensoriamento Remoto, 12, 2005, Goiânia, Brasil. Anais... São José dos Campos: INPE, 2005. Articles, p. 2229-2236. CD-ROM, On-line. Retrieved from: http://marte.dpi.inpe.br/col/ltid.inpe.br/sbsr/2004/11.12.11.54/doc/2229.pdf. Last accessed: March 1, 2010

Lu, D., Mausel, P., Brondízio, E., & Moran, E. Change detection techniques. **International Journal of Remote Sensing**, v. 25, n. 12, p. 2365-2401, 2004.

Lu, D., & Weng, Q. A survey of image classification methods and techniques for improving classification performance. **International Journal of Remote Sensing**, v. 28, n. 5, p. 823-870, 2007.

Lunetta, R. S., Ediriwickrema, J., Johnson, D. M., Lyon, J. G., & McKerrow, A. Impacts of vegetation dynamics on the identification of land-cover change in a biologically complex community in North Carolina, USA. **Remote Sensing of Environment**, v. 82, n. 2-3, p. 258-270, 2002.

Lunetta, R. S., & Elvidge, C. D. **Remote sensing change detection: environmental monitoring methods and applications.** London: Taylor & Francis, 1999. 318 p.

Matsuoka, M., Mendes, C., & Loureiro, F. Biomassa microbiana e atividade enzimática em solos sob vegetação nativa e sistemas agrícolas anuais e perenes na região de primavera do leste (MT). **Revista Brasileira de Ciencias do Solo**, v. 27, n., p. 425-433, 2003.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A., & Kent, J. Biodiversity hotspots for conservation priorities. **Nature**, v. 403, n., p. 853-858, 2000.

Puhl, J. I. **De uma agricultura sustentada à sustentável.** Cuiabá: Defanti, 2006. 98 p.

Seplan-MT. **Zoneamento Sócio-Econômico Ecológico do Estado do Mato Grosso.** Cuiabá: Governo do Estado de Mato Grosso, 2008. 338 p.

Singh, A. Digital change detection techniques using remotely-sensed data. **International Journal of Remote Sensing**, v. 10, n. 6, p. 989-1003, 1989.