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ORIGINAL ARTICLE

Agricultural land use and cover change in the Cerrado/Amazon ecotone: A case study of the upper Teles Pires River basin

Ana Paula Sousa Rodrigues ZAIATZ[1]*, Cornélio Alberto ZOLIN[2], Laurimar Goncalves VENDRUSCULO[3], Tarcio Rocha LOPES[4], Janaina PAULINO[5]

[1] Universidade Federal de Mato Grosso. Programa de Pós Graduação em Agronomia. Av. Alexandre Ferronato, 1200 - St. Industrial, CEP: 78698-000, Sinop - MT

[2] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Agrossilvipastoril. Rodovia dos Pioneiros MT-222, Km 2,5, Zona Rural, CEP: 78550-970, Sinop – MT

[3] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Informática Agropecuária. Av. André Tosello, nº 209, Campus da Unicamp, Barão Geraldo CEP: 13083-886, Campinas – SP.

[4] Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz". Departamento de Engenharia de Biossistemas. Av. Pádua Dias, 11, CEP: 13418-900, Piracicaba – SP

[5] Universidade Federal de Mato Grosso, Instituto de Ciências Agrárias e Ambientais. Av. Alexandre Ferronato, 1200 - St. Industrial, CEP: 78698-000, Sinop – MT

* Corresponding author: ana.sousa.zaiatz@gmail.com

ABSTRACT

The upper Teles Pires River basin is a key hydrological resource for the state of Mato Grosso, but has suffered rapid land use and cover change. The basin includes areas of Cerrado biome, as well as transitional areas between the Amazon and Cerrado vegetation types, with intensive large-scale agriculture widely-spread throughout the region. The objective of this study was to explore the spatial and temporal dynamics of land use and cover change from 1986 to 2014 in the upper Teles Pires basin using remote sensing and GIS techniques. TM (Thematic Mapper) and TIRS (Thermal Infrared Sensor) sensor images aboard the Landsat 5 and Landsat 8, respectively, were employed for supervised classification using the "Classification Workflow" in ENVI 5.0. To evaluate classification accuracy, an error matrix was generated, and the Kappa, overall accuracy, errors of omission and commission, user accuracy and producer accuracy indexes calculated. The classes showing greatest variation across the study period were "Agriculture" and "Rainforest". Results indicated that deforested areas are often replaced by pasture and then by agriculture, while direct conversion of forest to agriculture occured less frequently. The indices with satisfactory accuracy levels included the Kappa and Global indices, which showed accuracy levels above 80% for all study years. In addition, the producer and user accuracy indices ranged from 59–100% and 68–100%, while the errors of omission and commission ranged from 0–32% and 0–40.6%, respectively.

KEYWORDS: Amazon Basin, remote sensing, GIS, territorial management

Mudança do uso e cobertura do solo na zona de transição entre os biomas Amazônia e Cerrado: Estudo de caso da bacia do alto Rio Teles Pires

RESUMO

A bacia hidrográfica do alto Teles Pires é estratégica e de grande importância para o estado de Mato Grosso e vem sofrendo mudanças significativas em seu uso e ocupação do solo. A bacia está inserida no bioma Cerrado, bem como em áreas de transição entre os biomas Amazônia e Cerrado, com intensa atividade agropecuária em toda sua extensão. O objetivo do presente trabalho foi estudar a dinâmica espaço-temporal das mudanças do uso e ocupação do solo na bacia do alto Teles Pires entre 1986 a 2014. Para tanto, imagens do sensor TM (Thematic Mapper) e TIRS (Thermal Infrared Sensor) a bordo dos satélites Landsat 5 e Landsat 8, respectivamente, foram empregadas para uma classificação supervisionada utilizando o "Classification Workflow" disponível no software ENVI 5.0. Para avaliar a acurácia da classificação, uma matriz de erros foi gerada e os índices Kappa, exatidão Global e os erros de omissão, comissão, usuário e produtor foram calculados. As classes que apresentaram as maiores variações durante o período de estudo foram "Agricultura" e "Floresta". O estudo indicou que as áreas desmatadas são frequentemente substituidas por pastagem e, em seguida, por agricultura. Em contraste, áreas convertidas diretamente para agricultura são menos representativas. Os índices de acurácia apresentaram valores satisfatórios, com valores do índice Kappa e exatidão Global acima de 80% em todos os anos avaliados. Adicionalmente, os erros do produtor e usuário variaram entre 59-100% e 68-100%, ao passo que os erros de omissão e comissão variaram entre 0-32% e 0-40.6%, respectivamente.

PALAVRAS-CHAVE: Bacia Amazônica, sensoriamento remoto, GIS, gestão territorial

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INTRODUCTION

From the perspective of Brazilian domestic, as well as international agricultural production, the state of Mato Grosso is recognised as one of the largest global agricultural granaries. To guarantee extensive production, the current agricultural model combines monoculture, mechanization and intensive agrochemical usage (Theodoro 2002; Machado and Guarim 2013). On the other hand, while this has had economic benefits, the expansion of agriculture activities is also one of the main driving factors in the clearing of forests and savannas in this part of Brazilian Amazonia, with important impacts on greenhouse-gas emissions, as well as biodiversity (Fearnside *et al*. 2009; Geist and Lambim 2002). Such a major expansion of croplands under heavily mechanized agriculture imposes a significant new dynamic on land use and cover changes, which is likely to result in extensive environmental impacts (Forster *et al*. 2007) and, therefore, deserves attention.

The natural cover in the region was originally Cerrado, and Amazon/Cerrado transition vegetation. In this context, it is important to mention that, while the Cerrado biome is the second largest biome in Brazil, only 0.85% of its area is legally protected. At the same time, more than 50% of the area formerly occupied by Cerrado (approximately 2 million km^2) has been converted into pasture and agricultural land in recent decades (Klink and Machado, 2005) at rates of 1.2-1.5% per year (22,000 to 30,000 km^2 year^{-1}) (Machado *et al.* 2004). This has made the Cerrado biome the most important area in terms of grain production in Brazil. Additionally, its natural and anthropogenic coverage is one of the most difficult to map of all Brazilian biomes due to its large extension, high seasonality and the rapid and dynamic nature of spatio-termporal changes in land cover (Sano *et al*. 2008; Probio 2007).

The upper Teles Pires basin includes some of the prime centers for soybean and corn production in Brazil, including Lucas do Rio Verde, Sorriso, Nova Mutum and Sinop municipalities. More than 17% of the total GDP of Mato Grosso is generated in the municipalities that are within (totally or partially) this river basin (EPE 2009; SEPLAN 2017).

As the upper Teles Pires basin is of such great economic and agricultural significance for Mato Grosso, a spatiotemporal analysis of land use and land cover is paramount to provide an informed platform for decision making and regional planning. The conducted analysis involved using Geographic Information Systems (GIS) and Remote Sensing (RS) techniques to conduct a systemic and integrated study of the landscape factors.

GIS and RS techniques have been efficiently used to monitor Cerrado and Amazon biomes, as well as to provide significant support for policies and initiatives aimed at sustainable development. An example of this has been Brazil's Soy Moratorium (SoyM) initiative, which was the first voluntary zero-deforestation agreement implemented in the tropics, wherein response to pressure from retailers and non-governmental organizations (NGOs), major soybean traders signed the SoyM, agreeing not to purchase soy grown on lands deforested after July 2006 in the Brazilian Amazon (Gibbs *et al.* 2015). Moreover, the Brazilian National Institute for Space Research (INPE) has also used the aforementioned techniques to produce data on spatial extent of deforestation in the Amazon since 1988 through the Program for Deforestation Monitoring in the Brazilian Legal Amazon (PRODES). Another important initiative is the TerraClass project, which complements PRODES by adding information on land use and its spatial distribution, as well as regional statistics for the deforested areas up to 2008 (Almeida *et al.* 2016). In addition, the partnership between the Brazilian and Norwegian governments, where Norway agreed to pay US$1 billion to Brazil's Amazon Fund to finance the reduction of deforestation in the Amazon, has also played a major role in the reduction in land cover change and deforestation-promoting land use in this part of Brazil.

Despite several studies of land use and cover change in the Amazon and Cerrado biomes (Fearnside *et al*. 2009; Morton *et al*. 2006; Gibbs *et al*. 2015; Rudorff *et al*. 2011) there is still a lack of information on the Teles Pires River basin, a key region for Mato Grosso and Brazilian agriculture. Such studies are crucial for informed strategies for land management and improved planning of agricultural activities in the region.

Thus, the objective of this study was to assess the dynamics of land use and cover change in the the Amazon/Cerrado ecotone of the upper Teles Pires sub-basin from 1986 and 2014, in order to support land management and improve planning of agricultural activities in the basin.

MATERIAL AND METHODS

The study area covered a portion of the Teles Pires River basin, which covers 141,278.62 km^2, and links into the Amazon River basin. The Teles Pires River marks the territorial division between the states of Mato Grosso and Pará (Figure 1) between its outlet to the Tapajós River, and the outlet of the Paranaíta River. The upper Teles Pires sub-basin covers some 37.444 km^2, has an average slope of 0.79 m/km^{-1},and a mean annual rainfall of 2000 mm. The highest specific average flow of the basin was recorded at 28.14 L s^{-1} km^{-2} (the Middle and Lower Teles Pires report 24.39 L s^{-1} km^{-2} and 23.13 L s^{-1} km^{-2}, on average, respectively) (EPE 2009).

Six image compositions (containing three bands each) from the TM (Thematic Mapper) sensor aboard the Landsat 5 and TIRS (Thermal Infrared Sensor) sensor aboard the Landsat 8 satellites were used to compose a picture of the upper Teles Pires basin. These were provided by the National Institute for Space Research (INPE) and covered the period between 1986 and 2014.

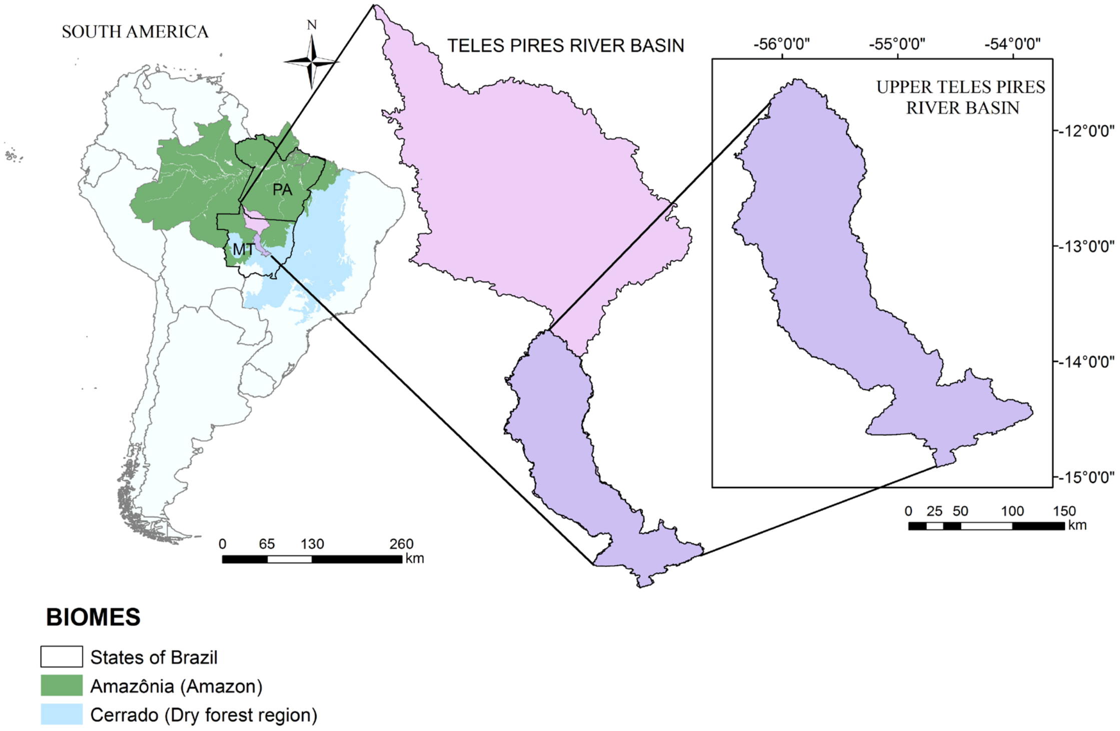

Figure 1. Maps of the Teles Pires River and upper Teles Pires River basins and their location within the Brazilian territory. This figure is in color in the electronic version.

Colored bands 3 (blue), 4 (green) and 5 (red) were produced by the Landsat-5 satellite, thus providing sharper and improved visual quality, and enabling the visualization and categorization of land cover and its usage (Rizzi and Rudorff 2005). Use of images from Landsat-8, added more spectral bands and allowed the construction of RGB color compositions. For Landsat-8 images, bands 4, 5 and 6 were used to guarantee wavelength correspondence with the Landsat-5 images. Selection was made based upon available image quality, and a lowest degree of cloud cover. Intervals of two years or more are preferred for significant changes to be noted within the study time period (Rozon *et al.* 2015).

Reflectance corrections were incorporated while preprocessing images to decrease the influence of atmospheric dispersion. For this purpose, the Internal Average Relative Reflectance (IAR) algorithm, available in ENVI 5.0 software, was applied.

The supervised classification was performed with "Classification Workflow" in ENVI 5.0 software, employing 100 training samples (polygons) for each class, which the classifier subdivided for individual characterization of the thematic classes, to produce a final total of 600 samples. Locations and areas of the training samples were kept as similar as possible for all classes, barring slight variations resulting from the relative differences in area and segmentation, as well as the spatial extension of each class (Furtado *et al.* 2015).

Visual analysis and photo-interpretation of images allowed classification and mapping of landscape elements and facilitated the multitemporal analysis of land use and occupation according to such elements as color, tone, texture, form, size, presence of shadows, brightness, and location of infrastructure (Tavares *et al.* 2012, Wan *et al.* 2015). The agricultural calendar, and the associated annual land use changes for Mato Grosso, was drawn up based on the images collected during the harvest of 2014.

Classes used were: "Agriculture", "Rainforest", "Water", "Pasture" and "Burned". "Agriculture" was considered to be predominantly regions of annual crops. As the images were recorded between August and September, which is the dry season, with reduced cloud cover, these areas were characterized by fallow (bare ground) areas awaiting the onset of the rains for planting. "Pasture" was the class predominantly associated with pasture; however, this cover class may be also associated with capoeira (secondary vegetation in early stages) and other types of shrub vegetation.

During periods when the atmospheric correction was inadequate to totally rule out the effects of clouds on the satellite image(s), the "Cloud" class was included in the analysis. Additionally, classes with small overall summed areas (e.g. cities, roads and flooded areas) were excluded due to difficulties of gathering a sufficient number of samples. The class was also confounded by small numbers of sample pixels; on such occasions, larger fragments were scanned and areas counted as the locally predominating category (Prado *et al.* 2007). As a result, though detectable, items such as highways, railways and cities were excluded from the analysis as specific entities or as a class.

Quantification of the rate (%) of homologous variation among the different classes during the study period was conducted using the method of Puyravaud (2003), in line with Equation (1), where A1 and A2 refer to the soil cover at times t1 and t2 (percent per year).

$$r = (1 / (t2-t1)) * \ln (A2 / A1) \qquad (1)$$

The maps and fields thus generated were compared using accuracy indices, and ground-truthing field checks. Field checks were conducted at 39 locations during 2011, located throughout the Teles Pires basin, 13 of which related to "Pasture", 16 to "Agriculture", 8 to "Rainforest" and 2 to "Water". Of these, 16 were within the upper Teles Pires basin (see Table 1).

To test for accuracy, 100 locations from each class were sampled from the processed satellite images through visual analysis according to the criteria of Panizza and Fonseca (2011), taking these to be true fields to establish that the unbiased results of the analyses did not sample the same locations used as references for classification. After transformation into raster format, points were incorporated into the land use classification. The ranked file for each year was converted to a vector file (shape file) to calculate respective their areas.

The error matrix was generated using the "R" statistical programming language, and included the following parameters: kappa index, overall accuracy, errors of omission and commission, user accuracy, and producer accuracy. The classification quality can be defined based on the following ranges of the Kappa index: bad (< 0.20), acceptable (0.20–0.40), good (0.41–0.60), very good (0.61–0.80), and excellent (0.81–1.00) (Landis and Koch 1977). According to Congalton (1991) and Ferreira *et al.* (2005), inferences can cause misunderstanding if they are based solely on the overall accuracy index. In light of these observations, and to achieve greater accuracy in the analysis, producer and user accuracies were also calculated. The producer accuracy index represents the number of pixels correctly classified in a particular category as a percentage of the total number of pixels actually belonging to that category in the image, while the user accuracy indicates how often the class on the map will actually be present on the ground, which is also referred to as ´reliability´. Regarding to commission errors, they reveal the points that were erroneously included in a category. Finally, the degree of linear relationship between the six evaluated classes was also assessed using correlation analysis.

Table 1. Location of the field checks within the upper Teles Pires River basin, Brazil. WGS-84 datum.

Municipality	Latitude	Longitude
Ipiranga do Norte	-12.3722	-56.2677
Nova Mutum	-13.9007	-56.0675
	-13.8702	-56.1847
	-13.8062	-55.7667
Nova Ubiratã	-13.0345	-55.2503
	-13.0109	-55.0013
	-13.0243	-54.9841
Paranatinga	-14.4341	-54.0502
	-14.4341	-54.0502
	-14.9678	-54.0513
Sinop	-11.8724	-55.5848
	-11.5834	-55.6005
	-11.8315	-55.3339
Sorriso	-12.5001	-55.735
	-12.4524	-55.718
	-12.5662	-55.7173

RESULTS

Ten thematic maps were obtained from the pre-processing and supervised classification of the images. These showed changes in land use and land cover in the upper Teles Pires River basin for the years 1986, 1989, 1993, 1996, 1999, 2004 2006, 2009, 2011 and 2014 (Figure 2).

Spectrally more homogeneous classes, like "Rainforest", showed less overlap with other classes due to the small extent of tonal variation, despite the relatively heterogeneous texture. On comparing the field samples and supervised classification, 100% agreement was found for the "Rainforest" class, and 76.92% and 94.22% for "Pasture" and "Agriculture" classes respectively. Estimates generated from the thematic maps (Figure 3) quantified the areas of each class as a percentage over the study period (1986–2014).

In 1986 land use was mainly represented by "Rainforest", accounting for 44.06% (15,149.65 km²) of the total upper Teles Pires basin catchment area. A significant change in the "Rainforest" class were visible between 1996 (15,711.7 km²) and 1999 (13,425.8km²), with a decrease of 14.5% in Rainforest cover. A deforestation peak (of 3,316.87 km²) was recorded between 1999 and 2006 (Figure 4).

The "Agriculture" class covered 22.3% of the total area of the river basin in 1986. In 2011, this same class covered 67.8% of the total area, but then dropped to 47.8% in 2014 (Figure 3). The six classes shown in Figure 3 were subjected to correlation tests, which showed a strong negative correlation ($r = - 0.71$) for both the class pairs of "Agriculture" vs "Pasture" and "Agriculture" vs "Rainforest" ($p < 0.001$).

The class "Pasture" doubled between 2011 (10.17%) and 2014 (26.11%). This pronounced increase may have been due to the fact that satellite images were collected during the harvest of 2014, which may have resulted in the classification of areas of recently harvested fields as areas of sparse natural vegetation. The class equivalent to "Pasture" also had the

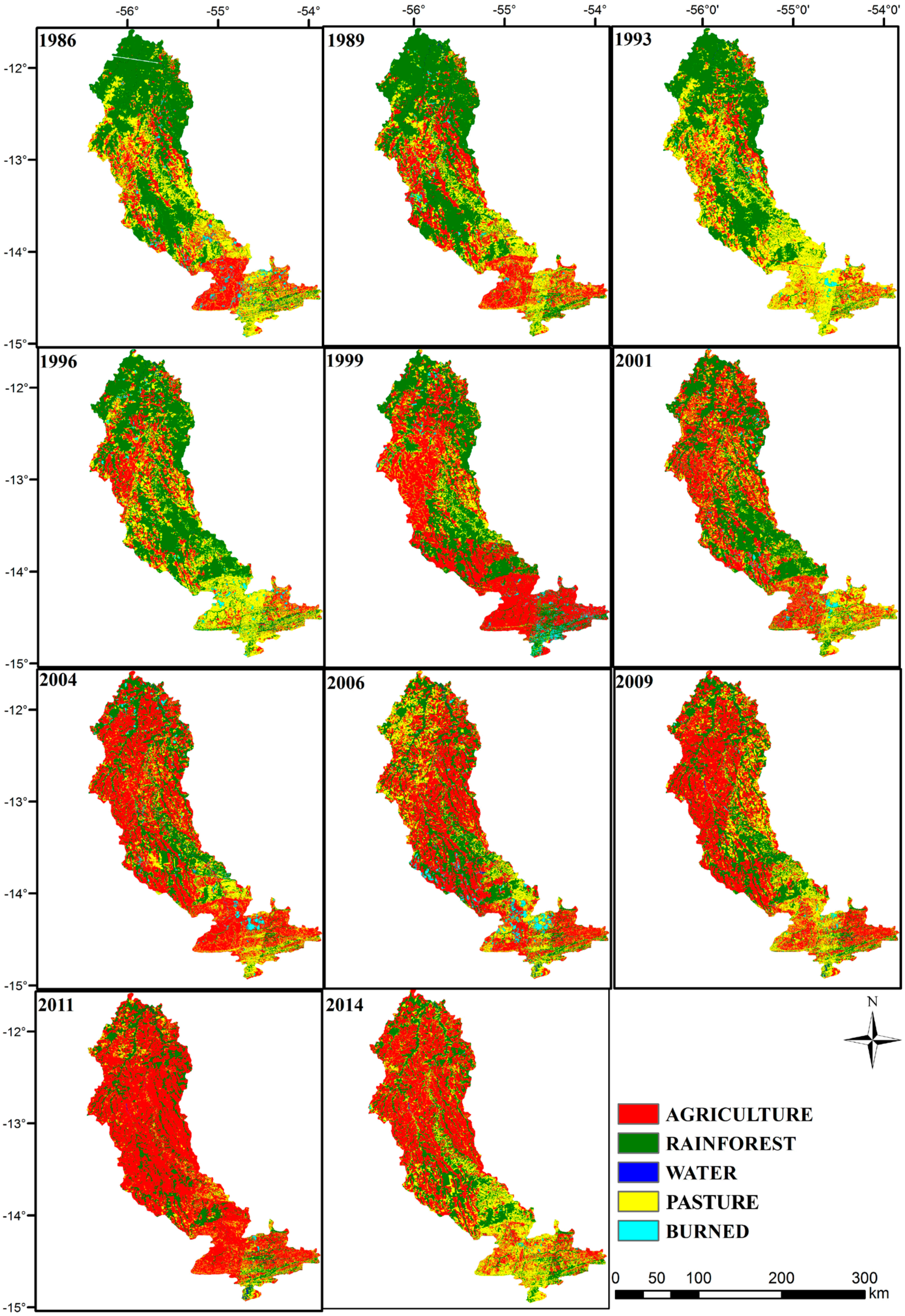

Figure 2. Maps of land use and cover change in the upper Teles Pires River basin, Brazil, from 1986 to 2014. This figure is in color in the electronic version.

highest value in 1993 (14,508.98 km²) and the lowest in 2011 (3,655.88 km²) (Figure 3), with a 37% coefficient of variation (CV) between 1986 and 2014.

The area occupied by the class "Burned" (Figure 5) was highly variable in size across the study period (CV 54.60%). Overall, an increase was observed between 1993 and 2006, followed by a significant drop in 2011, followed by another rise. The highest incidence of the class "Burned" occurred in 2006 when some 1009.37 km² (approximately 2.13% of the total area of the upper Teles Pires basin) was allocatable to this category.

Based on the rates of change in the classes (Puyravaud 2003; Beuchle *et al.* 2015) (Figure 6), significant changes

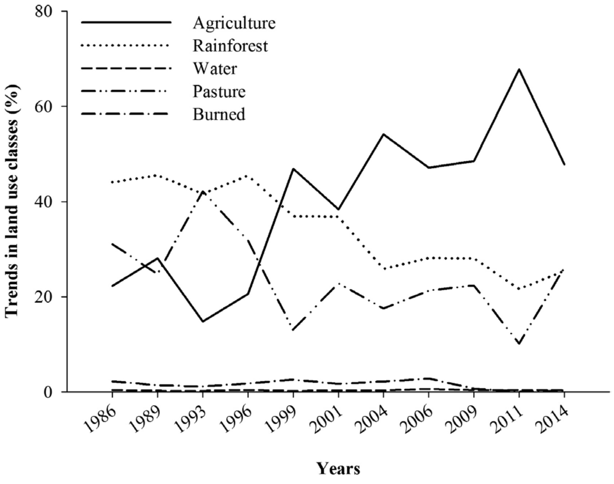

Figure 3. Trends in Agriculture, Rainforest, Water, Pasture and Burned land use classes in the upper Teles Pires River basin, Brazil, from 1986-2014.

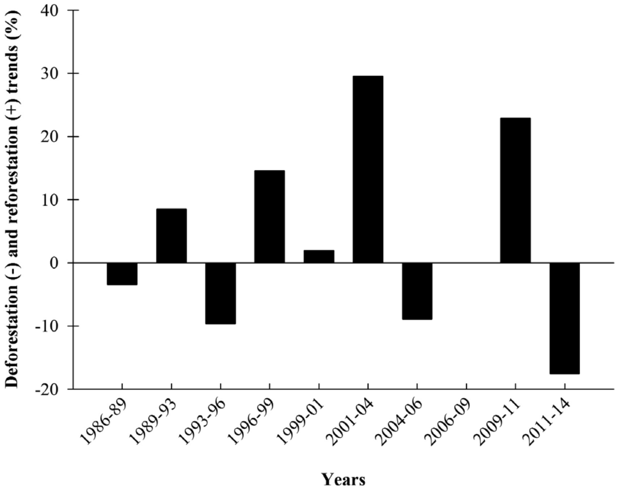

Figure 4. Deforestation (+) and reforestation (-) trends in the upper Teles Pires River basin, Brazil, from 1986-2014.

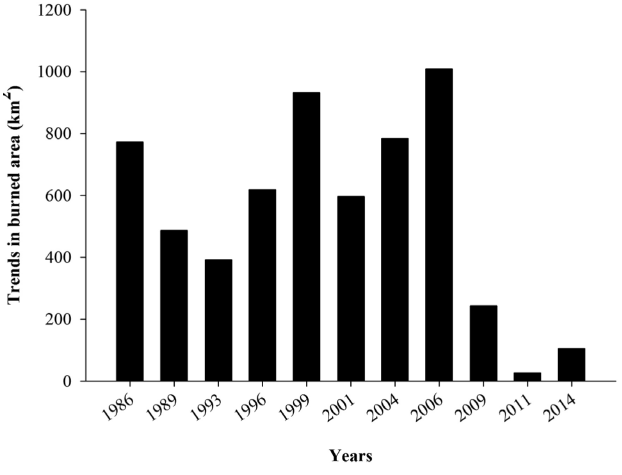

Figure 5. Trends in burned area extent in the upper Teles Pires River basin, Brazil, from 1986-2014.

were recorded in the class "Agriculture" between 1996 and 1999 (+ 27.47%), 2009 and 2011 (+ 18.19%), and 2011 and 2014 (-11.62%). Class "Pasture" showed significant variations in the periods 1996–1999 (-29.75%), 1999–2001 (+ 28.06%), 2009–2011 (-36.95%) and 2011–2014 (+ 31.42%). The highest variations in the class "Rainforest" were recorded between 2001 and 2004 (-11.80%), and 2009 and 2011 (-13.18%). However, the greatest increase for this class was recorded between 2011 and 2014 (+ 5.42%). The class "Burned" showed greatest variation in cover between 2006–2011 (-118.37%), and 2011–2014 (+ 45.77%).

For index accuracy, the Kappa and Global Accuracy rates showed values above 80% for the years studied, with the lowest value occurring in 2011 (84%) and highest (99%) in 2004 (Table 2).

Producer and user accuracies (Table 3) were persistently high, ranging from 59% to 100% (the lower value being for the "Agriculture" class in 2011), and 68 to 100% (the lower value being for the "Water" class in 2011), respectively.

The omission error varied between 0 and 32%, the highest error occurring in the "Water" class in 2011. This implies that about 32% of the points that needed to be classified as water did not correspond to the category in reality, and therefore were omitted. When comparing the classes, the commission error was significantly higher for the "Agriculture" class (40.58%) during 2011 (Table 4).

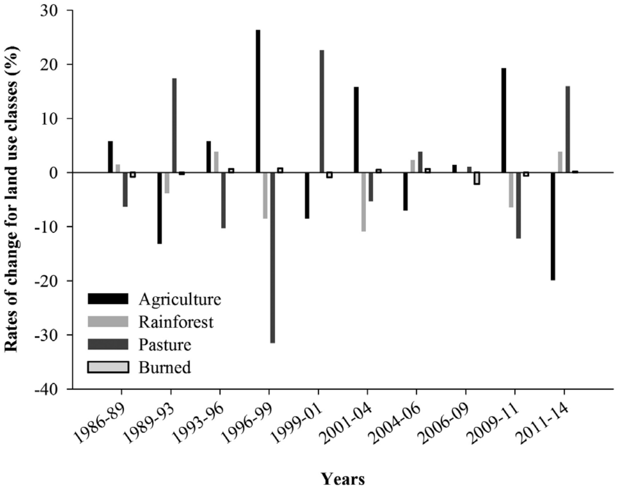

Figure 6. Rates of change for land use classes in the upper Teles Pires River basin, Brazil, from 1986-2014.

Table 2. Kappa and overall accuracy indexes for supervised classification in the upper Teles Pires River basin, Brazil, from 1986-2014.

	1986	1989	1993	1996	1999	2001	2004	2006	2009	2011	2014
Kappa	0,89	0,98	0,97	0,97	0,93	0,91	0,99	0,95	0,93	0,84	0,94
Overall Accuracy	0,89	0,98	0,97	0,97	0,93	0,91	0,99	0,95	0,93	0,84	0,94

Table 3. Producer (Pro) and user (Usu) accuracy indexes for supervised classification in the upper Teles Pires River basin, Brazil, from 1986-2014.

Year	Agriculture		Rainforest		Water		Pasture		Burned	
	Usu	Pro	Usu	Pro	Usu	Pro	Usu	Pro	Usu	Pro
1986	100	77,69	99,00	89,19	79,00	98,75	83,00	97,65	89,00	93,68
1989	100	97,09	100	96,15	99,01	97,09	95,05	100	96,00	100
1993	100	97,03	100	100	100	90,00	90,91	99,01	96,19	100
1996	96	97,96	100	93,52	100	99,02	97,03	95,15	98,02	100
1999	100	90,91	83,17	94,38	90,00	83,33	92,00	100	99,00	97,06
2001	99,01	86,21	99,00	91,67	89,00	100	94,00	98,95	95,10	97,00
2004	98,00	100	98,02	99,00	100	100	100	97,09	100	100
2006	95,05	88,07	100	97,09	95.05	100	91,00	94,79	94,06	95,96
2009	100	90,91	100	87,72	78,38	98,86	89,00	100	98,02	89,19
2011	100	59,41	92,00	92,00	68,00	100	83,00	98,81	79,00	100
2014	100	89,19	100	96,15	96,04	92,38	99,00	99,00	78,00	97,50

Table 4. Omission (O) and commission (Co) errors for supervised classification in the upper Teles Pires River basin, Brazil, from 1986-2014.

Year	Agriculture		Rainforest		Water		Pasture		Burned	
	O	Co	O	Co	O	Co	O	Co	O	Co
1986	22,31	0,00	10,81	1,00	1,25	21,00	3,53	18,00	6,32	11,00
1989	2,91	0,00	3,85	0,00	2,91	0,99	0,00	4,95	0,00	4,00
1993	2,97	0,00	0,00	0,00	10,00	0,00	0,99	9,09	0,00	3,81
1996	2,04	4,00	6,48	0,00	0,98	0,00	4,85	2,97	0,00	1,98
1999	9,09	0,00	5,62	16,83	16,67	10,00	0,00	8,00	2,94	1,00
2001	13,79	0,99	8,33	1,00	0,00	11,00	1,05	6,00	3,00	4,90
2004	0,00	2,00	1,00	1,98	0,00	0,00	2,91	0,00	0,00	0,00
2006	4,59	4,95	2,91	0,00	0,00	4,95	5,21	9,00	4,04	5,94
2009	9,09	0,00	12,28	0,00	1,14	21,62	0,00	11,00	10,81	1,98
2011	40,59	0,00	8,00	8,00	0,00	32,00	1,19	17,00	0,00	21,00
2014	10,81	0,00	3,85	0,00	7,62	3,96	1,00	1,00	2,50	22,00

DISCUSSION

The classes with the greatest coverage in 1986 were "Rainforest" and "Agriculture", covering 44.06% and 22.22% of the basin, respectively. These two classes showed the highest variation among the studied classes, ranging from 7,655.84 km² to 17,179.55 km² and from 15,149.65 km² to 9,133.645 km², respectively for "Agriculture" and "Rainforest". The "Rainforest" cover class had the lowest levels of tonal variation, which resulted in less overlap with other classes. This fact may be explained by the lower level of spectral dissimilarity between forest cover across the basin. Since the transition zone between Amazon and Cerrado biomes is characterized by areas of both rainforest and seasonal forest, they may present similar spectral signatures. Studying the structure and classification of seasonal forests and ecotone areas in the state of Tocantins, Haidar *et al.* (2003) also found similar characteristics between forest cover.

Significant areas with annual crops in stages of vegetative development were not identified, and this nonappearance was linked to the time of year at which imaging occurred, which coincided with the post-harvest period of crops in the basin under study. Therefore, in some areas vegetative growth of the annual crop might have been mistaken for some degree of pasture degradation. Nascimento *et al.* (2006) reported a similar issue in their image ratings during an assessment of the efficiency of digital analysis and image processing for identification of the extent of degradation of various grasslands in an area within the Rainforest Zone of Minas Gerais state, Brazil.

Vegetation cover in the basin was observed to have experienced continuous change over the analysed years, resulting from anthropogenic activities in the open areas exploited for agriculture, a situation also reported by Pessoa *et al.* (2013) in their spatiotemporal analysis of vegetation cover and land use of the Middle Paraguay River Basin in the south region of Mato Grosso. Although several fragment size classes were recorded in this study, all were suppressed due to their small representative areas. This also occurred in the study by Pereira *et al.* (2014) when analysing spatiotemporal evolution of land use in the Ribeirão Piancó hydrographic basin, in Goiás State, Brazil.

It is worth mentioning that deforestation must be appreciated as a complex phenomenon that does not result from a single factor (Vasconcellos and New 2004). Indirectly, and when bearing in mind the agricultural expansion process in the upper Teles Pires basin, it appears that post-deforestation land was mainly used for livestock (Walker *et al.* 2013), which supports the fact that between 1986 and 1996 the class "Pasture" showed greatest expansion. With the boost of agriculture in the Cerrado due to the Program for the Modernization of the Agricultural Tractor Fleet and Related Accessories and Harvesters (Moderfrota) launched in 2000, grazing areas were transformed into agricultural land, implying that the shift of rainforest to livestock pasture was one of the major reasons for the deforestation process. This was because the cost involved in converting pasture to agriculture was less than the expense involved in opening up a new area via active deforestation (Brandão *et al.* 2006). Driven by favorable crop prices, deforested areas are first used mainly for livestock, then converted to areas of agricultural production (annual crops), and, under a scenario of favorable prices of agriculture commodities, and then, finally, to soybean production (Morton *et al.* 2006). Other studies have also suggested that agriculture and pasture expansion are among the main causes of deforestation in Amazon and Cerrado biomes (Barone *et al.* 2010; Gibbs *et al.* 2015; Almeida *et al.* 2016).

The reduction in deforestation observed after the 1999-2006 peaks reflects the dramatic decrease in deforestation resulting from the Soy Moratorium (SoyM) (Gibbs et al. 2015) (see Figure 4). After SoyM, deforestation associated with soy production had, at least up until 2014, dropped dramatically (Gibbs *et al.* 2015).

The class "Burned" is fundamentally related to favorable weather conditions and human activities. Burning is often justified by the direct initial conversion of rainforest land to pasture as, after a few years, pasture land drops in quality, and thus the operation of repeated fire cycles is frequently considered to be a "good" management practice in such regions (Alves *et al*. 2003). Assessing the biomass burning areas, Cardozo *et al*. (2016) identified a similar trend in Rondônia State between 2000 and 2011. The dynamics of this land management practice also explains the burning trends observed in the current study.

In their study of the role of agricultural prices and government policies in the recent deforestation in the Legal Amazon, Ferreira and Coelho (2015) reported a significant decrease in the rainforest area, most obvious from 2001, and proposed that deforestation results from an increase in the prices of agricultural products, especially soybean, which reached its highest value in 2004. These authors also emphasized that more consistent and focused command and control policies, such as field inspections, economic embargos and credit restriction on farmers who were noncompliant with environmental laws, played an important role in decreasing deforestation, especially in Mato Grosso, an opinion shared by Almeida *et al*. (2016), Aubertin (2015) and Sayer and Cassman (2013).

Although correlation does not explain possible causal relations, it did reveal the dissimilarity between the class pairs of "Agriculture" vs "Pasture", and "Agriculture" vs "Rainforest". A study of the dynamics of land use in a watershed in the state of Rio Grande do Sul between 1964 and 2005, reported similar results, with a drop in the area covered by native rainforest and an increase in the classes corresponding to agriculture (Lopes *et al*. 2010).

According to our Kappa statistic values, the classification performance level in the current study can be classed as 'excellent' (Landis and Koch 1977). Consequently, the methodology used to analyze the dynamics of land use and occupation in the upper Teles Pires River basin was appropriate, and could make a viable contribution towards a clearer understanding of this subject in the agricultural border region between the Amazon and Cerrado biomes in the state of Mato Grosso. Additionally, producer and user accuracies were persistently high, indicating that this mapping unit possessed a high number of accurately classified points in the digital map (producer), and the probability that the unit shown on the map actually matched the ground reality was high (user). Finally, the significantly higher value of the commission error for "Agriculture" class (40.58%) during 2011 may be explained by the contribution of pixels of all classes that were similar to the spectral results of the "Agriculture" class (i.e., "contamination" by the same pixel form in different classes).

CONCLUSIONS

In this study the spatial and temporal dynamics of land use and cover of the Upper Teles Pires River basin, in the Cerrado/Amazon transition zone, were evaluated for the period 1986-2014, and the wide expansion of the agricultural area and data paucity were considered. Forest cover in the upper Teles Pires basin has suffered intense anthropization during the study period, and represented the class with the greatest percent reduction in area. The expansion of new areas, primarily for pasture and later agriculture (which increased 25.53% between 1986 and 2014), was the main driver in forest clearing in the upper Teles Pires basin. The GIS and remote sensing techniques used in this study in the supervised classification allow a better understanding of how the landscape cover has changed. Furthermore, this approach provided a rapid and economical way to observe and measure the dynamics of land use and cover change in the basin, which is of critical importance for policy- and decision-makers in the planning of natural resource management in this crucial agriculture frontier. Accuracy indices in this study were above 0.84 for all the years studied for the Kappa index and overall accuracy, and could therefore be rated excellent on the Landis and Koch scale. Producer and user accuracy rates were high, with the minimum values being 59.4% and 68%, respectively, both values having been recorded in 2011. Omission and commission errors ranged from 0 to 32% and from 0 to 40.5%, respectively, with the classes "Water" and "Agriculture" showing highest error values in 2011. Further studies addressing land use and cover changes, climate change scenarios and water resources availability are in progress and will serve to support improved agricultural and natural resource management in the region.

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