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# Spatiotemporal Analysis of an Urban Water-Supply Watershed
## Análise Espaço-Temporal de uma Bacia Hidrográfica de Abastecimento Urbano

Gustavo Facincani Dourado[1]; Jaíza Santos Motta[1], Antonio Conceição Paranhos Filho[1]; David Findlay Scott[2]; Sandra Garcia Gabas[1] & Edna Maria Facincani[1]

[1] *Universidade Federal de Mato Grosso do Sul, Faculdade de Engenharias, Arquitetura e Urbanismo e Geografia, Cidade Universitária, s/n, 79070-900 Campo Grande, MS, Brasil*
[2] *The University of British Columbia Okanagan, Department of Earth and Environmental Sciences, I. K. Barber School of Arts and Sciences, 3247, University Way, Kelowna, British Columbia, V1V 1V7, Canada*
*E-mails: gustavo.gfd@hotmail.com; ea.jsmotta@gmail.com; antonio.paranhos@pq.cnpq.br; david.scott@ubc.ca; sandra.gabas@gmail.com; edna.facincani@ufms.br*
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Resumo

O manejo sustentável dos recursos hídricos e da terra é atualmente uma das principais prioridades na agenda de muitos países ao redor do mundo, o que exige informações sobre as mudanças na cobertura da terra em bacias hidrográficas. Neste estudo, mapas de 1984, 1996, 2005 e 2016 foram desenvolvidos utilizando-se composições falsa-cor e o Índice de Vegetação por Diferença Normalizada (NDVI) para identificar as principais mudanças ocorridas na bacia do Córrego Guariroba. Essa bacia hidrográfica é uma Área de Proteção Ambiental desde 1995, quando se tornou a fonte de abastecimento urbana da capital do estado de Mato Grosso do Sul, Brasil. Para tanto, o software livre QGIS e imagens Landsat foram usados para determinar as mudanças no uso e ocupação da terra. Essas informações permitiram a discussão das possíveis pressões e consequências ambientais das mudanças nesses períodos. A bacia hidrográfica tem estado sob intensa atividade agropecuária, com a maior parte de sua superfície sendo ocupada por pastagens para a pecuária e silvicultura de eucalipto. Os resultados indicam que a influência direta das atividades humanas reduziu drasticamente a cobertura natural na área, com implicações para o cumprimento da legislação do Código Florestal. Os usos antrópicos da terra representam mais de 57% da cobertura total do solo em todos os anos, atingindo 79,70% em 2005. Em 2016, houve um aumento na recuperação da vegetação nativa, mas apesar desse incremento o uso humano da terra continua alto (74,09%). Parte do pequeno ganho de vegetação nativa deve-se aos planos de reflorestamento realizados a partir de 2010. A sedimentação do reservatório de água é visível em 2016, formando bancos de areia que se estendem por cerca de 700 m na porção distal do Córrego Guariroba. Os resultados deste estudo podem ser aplicados para uma possível revisão do plano de manejo da bacia, considerando-se a gestão de seus recursos hídricos integrados ao planejamento ambiental e ao desenvolvimento econômico. Esse tipo de análise pode auxiliar no processo de tomada de decisão de órgãos governamentais, de forma que as bacias utilizadas para o abastecimento de água apresentem restrições de uso da terra, devido ao risco de redução na quantidade e a qualidade da água.
**Palavras-chave**: Cobertura da terra; Landsat; Multitemporal; NDVI; QGIS

**Abstract**

Sustainable management of water and land resources is currently a top priority on the agenda of many countries around the world, which demands information on the land cover changes in watersheds. In this study, maps of 1984, 1996, 2005 and 2016 were developed using false-color composites and the Normalized Difference Vegetation Index (NDVI) to identify the main changes occurred in the Córrego Guariroba's stream catchment. This watershed is an Environmental Protection Area since 1995, when it became the urban water supply of the state's capital of Mato Grosso do Sul, Brazil. In order to do that, the open source software QGIS and Landsat imagery were used to determine the land use and land cover changes. This information allowed the discussion of the possible pressures and environmental consequences of the changes in these periods. The watershed has been under intense agriculture and livestock farming activities, with most of the land surface occupied by pasturelands for cattle ranching and eucalyptus forestry. Results indicate that the direct influence of human activities drastically reduced the natural cover in the area, with implication for the compliance of the Forest Code legislation. Anthropogenic land uses represent more than 57% of the total land cover in all years, reaching 79.70% in 2005. In 2016, there was an increase in native vegetation recovery, but despite this enhancement the human land use continues high (74.09%). Part of the small gain in native vegetation is due to reforestation plans carried out from 2010. The sedimentation of the water reservoir is visible in the 2016 image, forming sandbanks that extends for about 700 m in the distal portion of the Guariroba stream. The results of this study can be applied to a possible revision of the management plan of the watershed, considering the management of its water resources integrated to environmental planning and economic development. This type of analysis may aid in the decision-making process of governmental agencies, so that watersheds used for public water supply have restrictions of land use due to the risk of reducing the quantity and quality of water.
**Keywords**: Land cover; Landsat; Multi-temporal; NDVI; QGIS

## 1 Introduction

The Córrego Guariroba's stream catchment, located in the rural area of the municipality of Campo Grande - MS, is the main source of local urban water supply, even though it is 30 km away from the consumer center. This is mainly due to the low density of surface waterbodies with sufficient flow and quality to meet the city's demand, that increases the water treatment and distribution costs (Cavazzana *et al.,* 2012). Due to its importance for the water supply of about 50% of the local urban population (Batista *et al.,* 2017), which already exceeds 870,000 inhabitants (IBGE, 2017), the area has been the object of many studies.

Freshwater catchments for water-supply purposes, such as the Córrego Guariroba stream, require efficient and well-balanced planning, which minimizes the negative impacts of certain types of land use and land cover (LULC) on water resources, particularly on the quality and quantity of water captured and retained in the soil, or available in rivers, lakes or dams (Meneses *et al.,* 2017). However, the research carried out in the Guariroba basin has been focused on management planning (Campo Grande, 2008), the estimation of soil loss due to water erosion (Rodrigues *et al.,* 2009), watershed delimitation (Alves-Sobrinho *et al.,* 2010), concentration time (Almeida *et al.,* 2014), erosion modeling (Anache *et al.,* 2015), good agricultural practices (WWF-Brasil, 2015), hydrochemistry of groundwater and surface water (Leite *et al.,* 2016), water resources potential (Lastoria *et al.,* 2017) and the vulnerability of the unconfined aquifer (Batista *et al*., 2017).

Sustainable management of water and land resources is currently a top priority on the agenda of many countries around the world, which demands information on the changes in land cover (LC) occurring in watersheds, as these changes influence the hydrological cycle (Desta *et al.,* 2017). In this context, a specific study on the anthropogenic changes in LULC in the Guariroba catchment is justified, as the region is an Environmental Protection Area (APA) since 1995 (WWF-Brasil, 2015). Its conservation is important due to the consequences of the LC dynamics on water supply of the state's capital of Mato Grosso do Sul (MS). This requires an accurate estimation of present and past dynamics of LULC and its possible consequences, which can be easily, quickly, accurately and inexpensively carried out with the advent and development of integrated geospatial techniques that combine the use of Remote Sensing (RS) and Geographic Information Systems (GIS) (Rawat & Kumar, 2015).

Several RS indices have been developed and widely used for precise and consistent environmental monitoring, planning and development purposes, such as the Normalized Difference Vegetation Index (NDVI) (Rouse *et al.,* 1974; Ceccato *et al.,* 2002; Lillesand *et al.,* 2008; Sinha *et al.,* 2015, Aburas *et al.,* 2017). NDVI has been the most used method in LC classification and land use (LU) change studies, and one of the most used indicators to detect changes on the land surface caused by anthropogenic activity (Aburas *et al.,* 2017). As the index can be used in the analysis of vegetation cover and spatiotemporal changes (Thakkar *et al.,* 2014), it was adopted in this paper.

Although the implantation of the water abstraction and adduction system to the urban area occurred in 1985 (Campo Grande, 2012), the Guariroba Reservoir was already built in 1984. In the present study, Landsat imagery of 1984, 1996, 2005 and 2016 were processed and analyzed in the open source software QGIS. In this way, the images demonstrate the changes that occurred since the Córrego Guariroba's stream damming. The LULC data were collected considering the following aspects: the detection of changes, the identification of the nature of the observed changes and their possible consequences, and the determination of the area of each LC class.

## 2 Material and Methods
### 2.1 Study Area

The study area corresponds to the Córrego Guariroba's stream catchment area, located in the northwest portion of the municipality of Campo Grande - MS, between 20° 28' and 20° 43' South latitude and 54° 29' and 54° 11' West longitude (Figure 1), occupying an area of approximately 36,200 ha (Almeida *et al.,* 2014). The area has a concrete gravity dam, constructed in the early 80's, creating a reservoir on the upstream side of the dam with a volume of approximately 4 million m$^3$ in a 53 hectares area, which is operated by a private concessionaire, the Águas Guariroba company (WWF-Brasil, 2015).

The wet season occurs between October and March, and the dry season is well-marked between May and September (Campo Grande, 2008). Soils are derived mainly from sandstones forming a relatively flat terrain; they have a strong limitation to intensive agricultural use, mainly due to the extensive and continuous sandy areas and the low water retention capacity (Batista et al., 2017), presenting the maximum agronomic potential use under artificial pastures and commercial forests, especially eucalyptus (Campo Grande, 2008). The typical vegetation is the Cerrado, the Brazilian savannah, with a closed to open canopy of deciduous and semi-deciduous forests, closed or open shrubland and natural grasslands (Beuchle *et al*., 2015). Gallery and riparian forests are extensively found in the area, many times associated with shrub-herbaceous and grassy wetlands with palms and palm swamps (Campo Grande, 2008). There have been found 42 springs in this region, which in most cases flow from the unconfined aquifer by gravitational force, occurring in wetlands, which are in advanced environmental degradation status, what portrays the basin in general, under silting conditions, soil fertility loss and impairment of water quantity and quality (WWF-Brasil, 2015).

Governmental incentives for conservation practices have been implemented, since 2010 in the watershed, such as the Manancial Vivo Program,

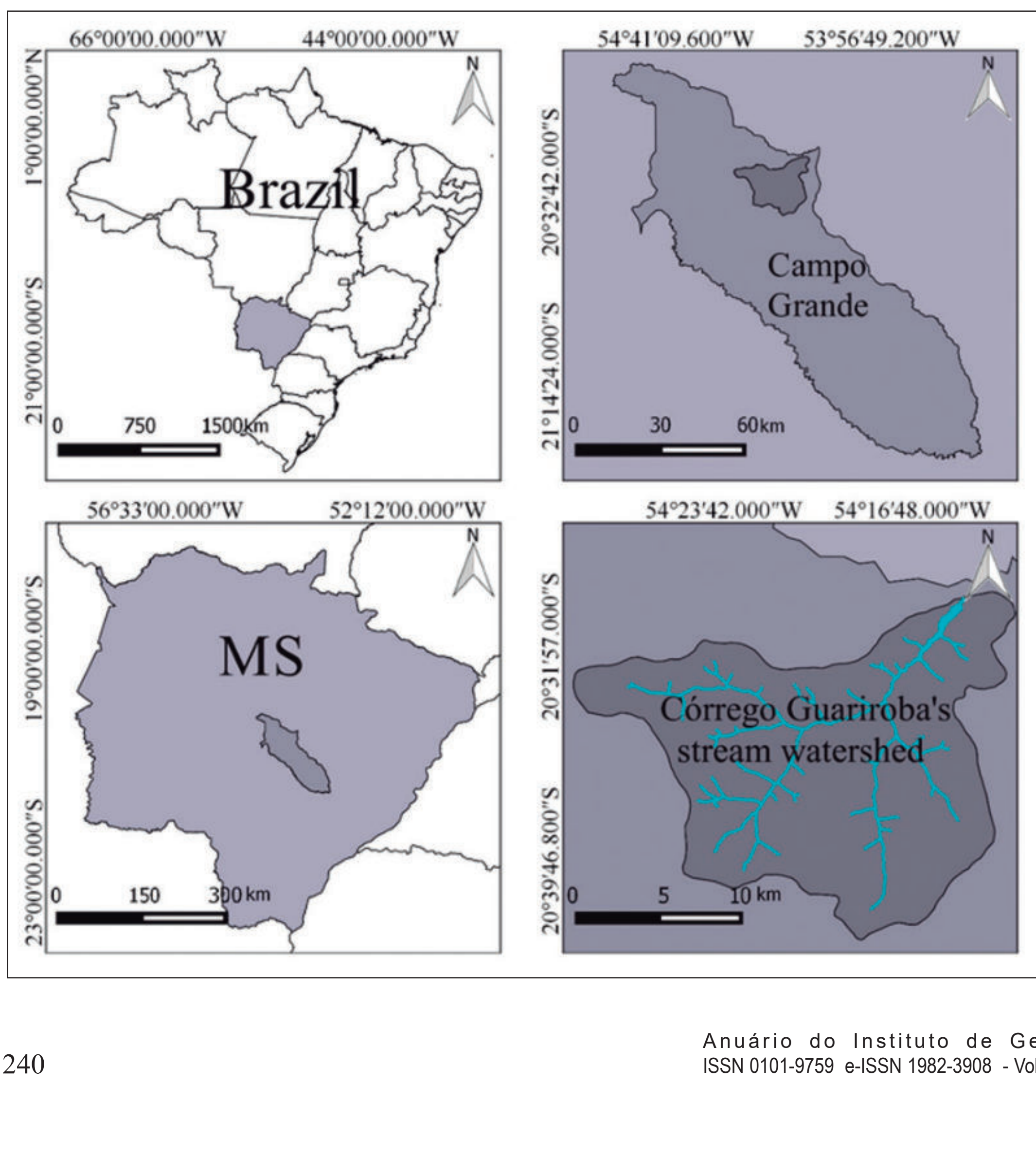


Figure 1
Location map of the study area.

which aims to restore the water potential and to control the diffuse pollution in the rural environment, which is part of the Produtor de Água Program of the Agência Nacional de Águas (ANA), executed by the Secretaria Municipal do Meio Ambiente e Gestão Urbana (Semadur) (Batista et al., 2017). In addition, the Água Brasil Program, a partnership amongst WWF-Brasil, Fundação Banco do Brasil, Ministério do Meio Ambiente and Agência Nacional de Águas, works on ecological restoration, soil conservation, development of forest-livestock-crop integration systems, and implementation of good agricultural practices (WWF-Brasil, 2015).

### 2.2 Data Acquisition and Processing

The images were collected in the dry season, what guarantees a better differentiation between the phytophysiognomies avoiding incoherent responses caused by phenological changes. All images were acquired from the Earth Explorer page (http://earthexplorer.usgs.gov), which belongs to the United States Geological Survey (USGS) website. The Landsat data were used because they are georeferenced, orthorectified and atmospherically corrected to surface reflectance by the USGS, with low absolute radiometric calibration uncertainties (Sulla-Menashe *et al*., 2016). The Landsat 5 images were processed by the Ecosystem Disturbance Adaptive Processing System (LEDAPS) and the Landsat 8 image was processed by the Landsat 8 Surface Reflectance (L8RS) system (Landsat 8 Product Guide) (Zhu *et al*., 2016). Topographic effects were taken as negligible as the local relief is mostly flat.

For this study, satellite images were selected from the Path 224 Row 74 with no cloud cover on the study site. The images used are: Landsat 5 Thematic Mapper (TM sensor), of September 4, 1984, August 20, 1996 and August 13, 2005 (Earth Explorer, 2000a; 2000b; 2000c) and the Landsat 8 Operational Land Imager (OLI sensor), of September 28, 2016 (Earth Explorer, 2015).

The software QGIS, version 2.10 (QGIS Development Team, 2016), was used to analyze and process the satellite images for mapping. All data were exported to QGIS and re-projected into the WGS84 cartographic system - Universal Transverse Mercator Projection (UTM) 22 S (EPSG: 32722), when necessary. In addition, Google Earth Pro (Google, 2015) was used as an auxiliary tool in the LC identification process.

### 2.3 Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI), created by Rouse *et al*. (1974), is defined as an indicator of the balance between energy received and emitted by terrestrial objects (Aburas *et al*., 2017), being the best index used as a numerical indicator of vegetation greenery, since it indicates the chlorophyll amount and the green cover fraction (Ihuoma & Madramootoo, 2017). The NDVI can be calculated using the equation 1:

$$NDVI = (NIR - R) / (NIR + R) \tag{1}$$

where: NIR is the reflectance in the near-infrared band (Landsat TM Band 4 or Landsat OLI Band 5); R is the reflectance in the red band (Landsat TM Band 3 or Landsat OLI Band 4). The index varies from -1 to +1. In the present study, the values found for NDVI vary between 0.915 and -0.476. In which, the greater the phytomass amount and the vegetation density, the greater the chlorophyll amount and the higher the NDVI response (Ponzoni *et al.,* 2015).

### 2.4 Land Use and Land Cover Classification

Landsat false-color composites (RGB NIR-SWIR1-Red) for TM and OLI sensors at each date were interpreted after the LC classification of Paranhos Filho *et al.* (2006) and Gamarra *et al.* (2016) for the classes of LC found in the Cerrado. In order to separate soil cover classes, the false-color composites and the NDVI of each studied year were used. During the process of identification of the land surface, Google Earth was used as a reference for the validation of this classification. The watershed was differentiated into five classes on the bases of the NDVI values. The delineated classes were: Water, Bare Soil, Grassland, Open Cerrado, Closed Cerrado and Forest Formation, in which the vegetation was divided according to their phytomass quantity.

By recognizing the LC types according to their spectral signatures in the false-color composite and the reading of the NDVI values, it was possible to adjust the NDVI response intervals appropriately for all classes of each image. The classification took into account the individually classified images, not making comparisons between the pixels of the images. Thus, the difference of the areas of vegetation coverage was calculated in order to verify variations in vegetation cover. To produce the LU classification map of 2016, the data of the LC map of 2016 was divided into only two classes, in which the portions used for the development of farming activities were classified as areas under anthropogenic change. Forest fragments, Areas of Permanent Preservation (APPs), Legal Reserves and other areas with original or recovered natural vegetation, were defined as native vegetation.

## 3 Results and Discussion
### 3.1 Land Use and Land Cover Classification

The NDVI intervals determined by the pixel reading of each class identified on the false-color composite can be found separately on Table 1. The minimum and maximum values vary as the images are from different years. Figure 2 shows the result of the classification for each Landsat image, producing LC maps.

After the LC classification, the area occupied by each class of all classified images was calculated for tabulation (Table 2).

In 1984, only small areas considered as Forest Formation are found, possibly due to the selective deforestation, fires and the impact caused by cattle grazing and trampling caused by the expansion of livestock farming. Some of the socio-economic activities already existed when the urban water supply was established in the area. These practices probably led to the decrease in tree density in this year, by converting woodlands to more open savannah formations mostly mapped as Closed Cerrado. There was a forest degradation although the carrying capacity may support the native forest ecosystems in some areas, as it can be seen in the posterior years when recovery in vegetation can be found. There are several Bare Soil areas, characterized by burned spots, including in APPs, which can be seen in the false-color composite, possibly for the expansion of agricultural boundaries what can be explained by the geometric shapes of the bare areas (Figure 2).

According to Table 2, between 1984 and 1996, there was an increase in Open Cerrado, caused by the deforestation in denser vegetation areas (Closed Cerrado) and the regeneration in Grassland and Bare Soil areas. There was also an increase in the Forest Formation class, which is more likely to be due to the natural regeneration of the vegetation than to reforestation activities.

In accordance with Table 2, between 1996 and 2005, there was a loss of 5,028.7 ha of total native vegetation (Open and Closed Cerrado and Forest Formation), of which about 4,940 ha became Grassland. The Bare Soil area increased three times in this same period probably due to the pasture degradation. Figure 2 shows the trend of environmental degradation caused by the deforestation, generally causing the suppression of natural vegetation even in the riparian zones, characterized as APPs.

| Land cover classes | Range of NDVI values | | | |
|---|---|---|---|---|
| | 1984 | 1996 | 2005 | 2016 |
| Water | -1 to 0.059 | -1 to -0.031 | -1 to -0.015 | -1 to 0.090 |
| Bare Soil | 0.059 to 0.175 | -0.031 to 0.040 | -0.015 to 0.050 | 0.090 to 0.190 |
| Grassland | 0.175 to 0.350 | 0.040 to 0.290 | 0.050 to 0.285 | 0.190 to 0.490 |
| Open Cerrado | 0.350 to 0.385 | 0.290 to 0.350 | 0.285 to 0.360 | 0.490 to 0.600 |
| Closed Cerrado | 0.385 to 0.510 | 0.350 to 0.440 | 0.360 to 0.440 | 0.600 to 0.740 |
| Forest Formation | 0.510 to 1 | 0.440 to 1 | 0.440 to 1 | 0.740 to 1 |

Table 1 Intervals of NDVI responses for all classes of the studied years.

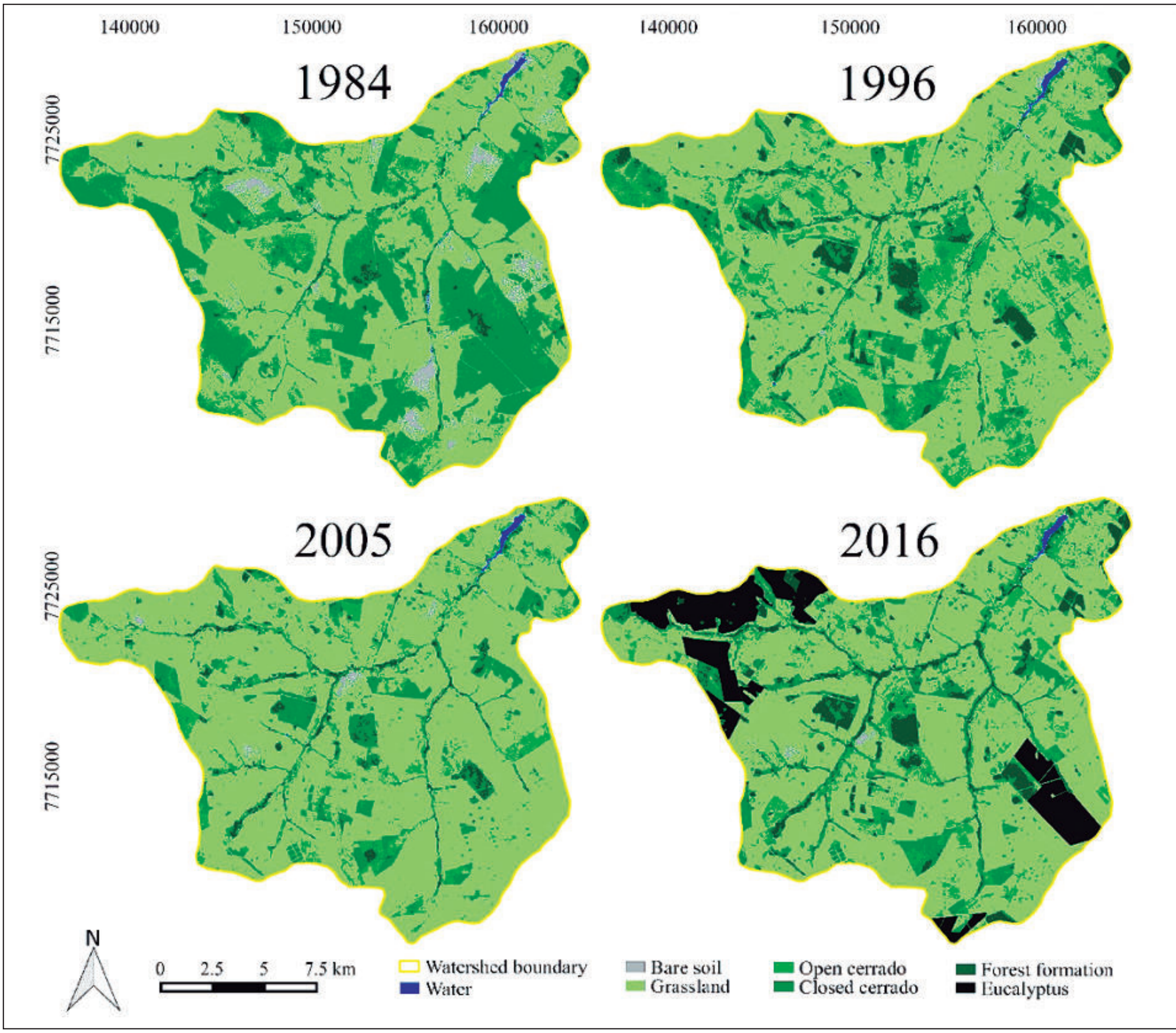

Figure 2 Land cover classification map for the catchment for each Landsat imagery (Original boundary from: Campo Grande, 1995).

Table 2 Total area occupied by each land cover class, in the Córrego Guariroba catchment.

| Land cover classes | Area in Hectares and Percentage | | | | |
|---|---|---|---|---|---|
| | 1984 | 1996 | 2005 | 2016 | Change between 1984 and 2016 |
| Water | 87.1 (0.24%) | 99.2 (0.27%) | 92.7 (0.26%) | 78.8 (0.22%) | -8.3 (-9.53%) |
| Bare Soil | 1,024.6 (2.83%) | 49.1 (0.14%) | 144.5 (0.40%) | 74.9 (0.21%) | -949.7 (-7.31%) |
| Grassland | 20,700.5 (57.12%) | 23,944.2 (66.07%) | 28,884.1 (79.70%) | 23,429.4 (64.21%) | +2,729.0 (+13,18%) |
| Open Cerrado | 4,077.9 (11.25%) | 6,436.6 (17.76%) | 3,166.6 (8.74%) | 4,271.9 (10.54%) | +194.0 (+4,76%) |
| Closed Cerrado | 9,870.8 (27,23%) | 3,753.1 (10.35%) | 3,003.2 (8.28%) | 3,839.1 (8.41%) | -6,031.7 (-61.10%) |
| Forest Formation | 482.1 (1.33%) | 1,960.7 (5.41%) | 951.9 (2.62%) | 962.8 (6.53%) | +480.7 (+99,71%) |
| Eucalyptus | - | - | - | 3,585.7 (9.88%) | +3,585.7(+9.88%) |

The increasingly fragmented vegetation had given space to managed pastures, demonstrating the intense modification suffered by the region over the years. Table 2 shows the LC change in percentage, where it can be seen that the Grassland class already occupied more than half of the total catchment area in 1984. Several Grassland areas are degraded in many parts of the watershed in all study years, as the watershed has a carrying capacity with agricultural suitability for pasture, forestry or integrated systems in less than half of its area (WWF-Brasil, 2015).

Nevertheless, the areas currently used by man for cattle raising (64.21%) and eucalyptus cultivation (9.88%) occupy 74.09% of the total area. According to Batista *et al.* (2017), the area occupied by pasturelands reached 82.68% in 2007, when eucalyptus started occupying 1.80% of the catchment area (totaling 84.48% for anthropogenic use), and also accounted for 74.34 % and 6.10% of the catchment area (80.44% of the total area) in 2013, respectively.

The Brazilian Forest Code establishes the protection of the riparian zone, even though, these areas previously covered by forest have been replaced by agricultural land, causing the reduction and isolation of forest fragments, usually associated with waterbodies. With regard to compliance with the actual Forest Code in relation to the endorsement of 20% of rural properties areas as Legal Reserves, it should be noted that it was not possible to specify the situation of each rural property. However, the information obtained through the satellite images indicates that many properties do not comply with the law.

Areas occupied by native vegetation in 1984 were 39.81%, which became 33.52% in 1996, and 19.64% in 2005, not even remaining the 20% of Legal Reserve vegetation in the region during this period, as determined by law (Provisional Measure No 2,166-67/2001). In 2016, there is a small improvement in the areas occupied by the Cerrado, especially in the APPs, due to the reforestation promoted by the conservation, preservation and recovery programs in the APA of the Córrego Guariroba stream, effective as of 2010, not embraced initially by all landowners but employed in many properties.

In 2016, eucalyptus plantations were found in different stages of growth in the area, presenting confusing responses with other spectral classes. They were differentiated however with the assistance of Google Earth, separating them to be counted apart from natural vegetation.

Between 2005 and 2016, there was a reduction of 5454.7 ha (15.49% of the catchment) in Grassland areas, of which 3585.7 ha (9.88%) were occupied by Eucalyptus, in addition to the increase of 1952.1 ha in native shrub-woody vegetation, mainly in the Open Cerrado class. In addition, portions of the Open Cerrado class can still be used for cattle grazing as cattle ranchers may still use areas with more open vegetation in the Cerrado.

According to Pagiola *et al.,* (2013), the progressive replacement of natural vegetation by cultivated pastures, associated to certain situations in which livestock and soil management are not compatible with the local carrying capacity, has generated significant erosion and silting processes in this watershed. In 2016 there was the lowest water coverage, according to Table 2 (0.22%), which is possibly caused by the sedimentation of approximately 700 m in the distal part of the Córrego Guariroba stream, which is visible in the satellite images. Most of this portion was not recognized by NDVI as Water (Figure 2), due to the presence of sandbanks formed by the accumulation of sediments between 2005 and 2016.

In 2016, taking into account the 20% of Legal Reserve area determined by law in the approximately 36,200 ha area, it can be estimated that the area occupied by Cerrado should represent something close to 7,240 hectares. The total Cerrado (Open and Closed Cerrado and Forest Formation) covers 25.48% (9,073.8 ha) of the catchment area. The remaining area (1,833.8 ha) demonstrates that the native vegetation cover is not enough to comprehend the APPs, as in 2008 these areas accounted for 3,918.8 ha (Campo Grande, 2008), and this number has grown after the implementation of reforestation activities with governmental incentives in 2010. Since then, the existing improvement in LC characterized by the recovery of native vegetation, is in most cases limited to waterway surroundings.

As a result, although in 2016 the areas occupied by Cerrado have increased by 5.84% in relation to 2005, the restoration is still not satisfactory, since the APPs alone needed to have 1,035 hectares restored (WWF-Brasil, 2015). This shows that neither the APP nor the Legal Reserve amounts are satisfactory; although not ideal, the data show that there was an improvement from 2005 to 2016. The LU classification for 2016 (Figure 3) shows the separation between areas under human-induced changes and native vegetation.

### 3.2 Anthropogenic Pressures and their Consequences

Understanding the LULC changes and the pressures under which they have occurred is the key to understand their consequences over the natural resources, affecting the landscape. The changes have been interrelated with the regional economy, political cycles, environmental and cultural characteristics of the area. Since there has been a growing trend of grazing areas in the past, and in afforestation using commercial eucalyptus monocultures nowadays, due to the regional economic demand. The expansion of cultivated eucalyptus is associated with the implantation or expansion of pulp and steel industries in the state (Batista *et al*., 2017). The lack of regulations and changes in land policies can also be drivers of such shifts in LULC.

Cattle grazing and trampling can promote the creation of bare patches in meadows and that increasing cattle numbers might degrade grasslands (Sica *et al.,* 2016). Overgrazing may lead to changes in surface rigidity, organic matter content and soil structure may affect the infiltration rate and hydraulic conductivity in a catchment (Yan *et al*., 2013). The land degradation and erosion processes impact water resources due to the increase in surface runoff and a more significant deposition of sediments toward the Guariroba Reservoir, which might accelerate the silting-up process, reducing its storage capacity. As stated by Campo Grande (2012), only between 2007 and 2011, siltation reduced 9.2% of the 3,843,975.78 m³ of the reservoir capacity.

The predominance of sandy soils may explain the low resistance of the surface against erosion, favoring significant soil loss and high sediment production in the basin (Anache *et al.,* 2015). The

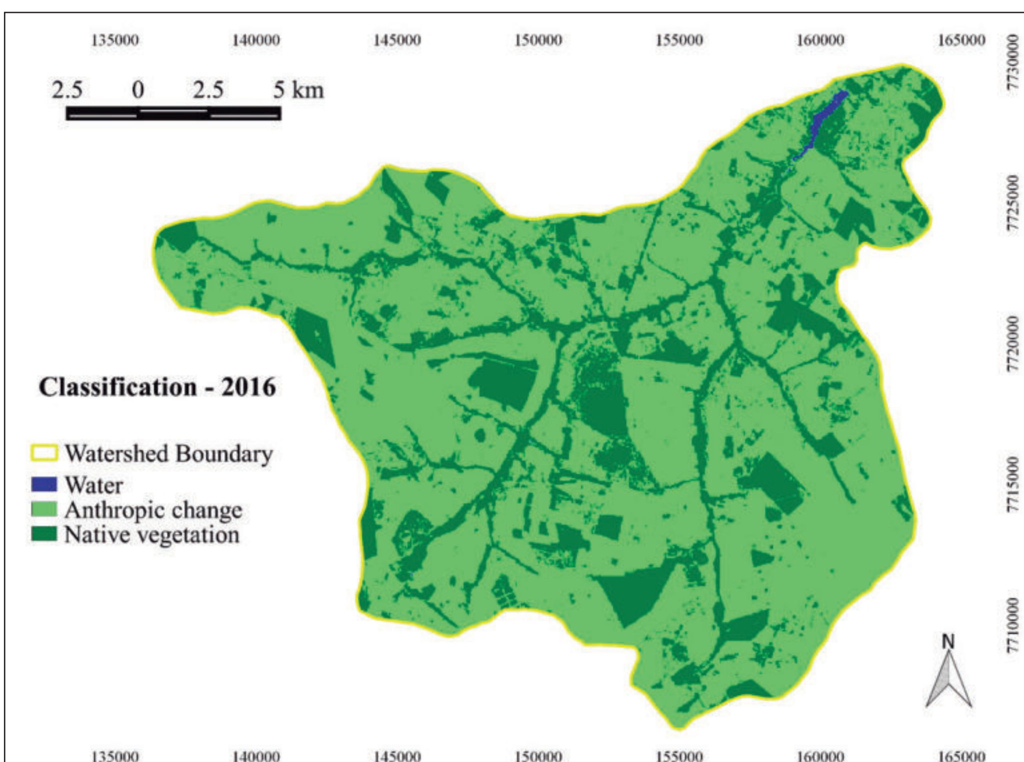


Figure 3 Land use classification map for the catchment in 2016 (Original boundary from: Campo Grande, 1995).

sediment accumulation in waterbodies has already been reported to significantly affect the vegetation of wetlands in the watershed (Campo Grande, 2008). Besides that, nutrients, pesticides and fertilizers can also be carried with the sediments, leading to water contamination (Moraes *et al*., 2017), affecting the structure and functioning of aquatic ecosystems, besides causing serious economic consequences, such as the higher cost of water treatment (Taniwaki *et al*., 2017).

Replacing pasturelands by eucalyptus plantations may be beneficial in terms of soil protection (Nasta *et al.,* 2017), as eucalyptus presents larger canopy coverage, supporting soil stability in relation to degraded pastures. Reichert *et al.,* (2017) mentions that even though eucalyptus has a greater evapotranspiration rate than degraded grasslands, it can benefit the land with a greater rainfall interception and lower stormflow, providing a better soil structure and greater ground cover, reducing soil degradation by erosion. The authors defend that an increase in water production is also possible, due to a greater water infiltration and retention into the soil, and increased groundwater recharge.

However, the water consumption depends on the species, age and management (Reichert *et al.,* 2017), the position of the plantations in relation to their proximity to waterbodies and local climatic characteristics (Vital, 2007). Therefore, a generalized conclusion on this subject is impossible and studies are needed to better understand the hydrological effects of eucalyptus in the watershed. The favorable climate and the short rotation time of these plantations represent an economic advantage, but this cannot be the only factor to be taken into account.

A large portion of the eucalyptus forests has been planted close to headwater streams, putting at risk the local water resources, as they may cause negative impacts in the hydrological cycle. Plans for the expansion of eucalyptus should aim to occupy areas previously used for managed pasture, which are already impacted, rather than areas with native vegetation (Fernandes *et al.,* 2016). The plantation should be avoided in areas where the water table level is shallower, such as in the northeastern part of the watershed and waterway surroundings (Batista *et al*., 2017).

The major changes expected to happen in the watershed due to the implementation of the public programs for conservation and preservation were the increase in native vegetation cover, reduction of soil erosion and rehabilitation of degraded lands. The satellite images show a little gain in vegetation cover, mainly in APPs along the watercourses. The recovery of degraded pasturelands, by the way it has been carried out, seems to be difficult with the alternative option of being replaced by eucalyptus under an adequate management plan. The soil erosion reduction does not seem to be effective since the sandbanks in the distal part of the Córrego Guariroba stream have enlarged in recent years.

The management plan for this Environmental Protection Area, elaborated in 2008, characterizes a first step towards planning of human activities in this watershed. Nevertheless, there is a need for the revision of the management plan of the APA, as it has been developed based on the knowledge acquired years ago. The development of agricultural activities without a rigorous planning have led to the degradation of the environmental resources due to the attempt to have agricultural production in areas in which the soil cannot afford the human demand. Therefore, future studies are needed to better understand how each LULC type influences these resources to achieve more effective and exact means of conducting watershed management programs and predicting their hydrological consequences.

## 4 Conclusion

The Córrego Guariroba's stream catchment has been under agricultural activities that have caused the continuous LULC change mainly for cattle grazing, and lately eucalyptus plantation. By mapping different classes of LC using Landsat images of 1984, 1996, 2005 and LU of 2016 the changes on the land surface and the pressures that have promoted them were identified.

The maps showed the direct influence of human activities (cattle ranching and lately eucalyptus plantation) on natural covers (Cerrado, the Brazilian savannah), causing a drastic reduction in their surface area. That was caused by the expansion of agricultural frontiers that was already occurring since before the study period, representing a significant change in the landscape caused by the degradation and fragmentation of the native vegetation, especially in the period 1996–2005. The results showed the first 21-year period presented frequent and severe anthropogenic interventions in the environment.

The results highlight how the human-induced change in the watershed represent more than 57% of the total LC in all years, reaching 79.70% in 2005. While in the last 11-year period the analysis shows a small improvement in LC, which is characterized by the recovery of native vegetation. Despite this enhancement, the human-induced use continues high (74.09%), in 2016. Part of the small gain in native vegetation is due to reforestation plans carried out from 2010, which seems to be mostly restricted to APPs limited to waterways surroundings. Although the application of the governmental programs has brought some initial positive outcomes, the results show that in general there is a lack of areas occupied by APPs and Legal Reserves, as required by the Forest Code.

The results obtained in this study provided a significant tool for a better understanding of the spatiotemporal LC dynamics in the Córrego Guariroba's stream catchment. Consequently, the general man-made changes need to be constantly identified in order to obtain the best available information to support decision-making processes for the development of sustainable activities in this significant area. This methodology can be applied to other regions to provide important information monitoring the land surface for the development of improved watershed management strategies.

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