UNIVERSITY OF BRASILIA

CAMPUS OF PLANALTINA

Graduate Program in Environmental Sciences

Analysis and use of anthropization data of the Brazilian Cerrado

M. Sc. student: Ubirajara de Brito Cruz Júnior

Advisor: Antônio Felipe Couto Júnior

A thesis submitted to the faculty at the University of Brasília in partial fulfillment of the requirements for the degree of Master of Science in the Graduate Program in Environmental Sciences.

Area of Concentration: Structure, Dynamics and Environmental Conservation

Research Area: Environmental Modeling

Brasília-DF, Brazil

March, 2019

CAMPUS PLANALTINA

Programa de Pós-Graduação em Ciências Ambientais

Análise e uso de dados de antropização do Cerrado Brasileiro

Mestrando: Ubirajara de Brito Cruz Júnior

Orientador: Antônio Felipe Couto Júnior

Dissertação apresentada ao Programa de Pós-Graduação em Ciências Ambientais da Universidade de Brasília como parte dos requisitos para a obtenção do grau de Mestre em Ciências Ambientais.

Área de concentração: Estrutura, Dinâmica e Conservação Ambiental.

Linha de pesquisa: Modelagem Ambiental

Brasília-DF

Março, 2019

Ficha catalográfica elaborada automaticamente,
com os dados fornecidos pelo(a) autor(a)

dD288a

de Brito Cruz Júnior, Ubirajara
Analysis and use of anthropization data of the Brazilian Cerrado / Ubirajara de Brito Cruz Júnior; orientador Antônio Felipe Couto Júnior. -- Brasília, 2019.
34 p.

Dissertação (Mestrado - Mestrado em Ciências Ambientais)- Universidade de Brasília, 2019.

1. Land cover change. 2. tropical savanna. 3. data analysis. 4. environmental modeling. I. Felipe Couto Júnior, Antônio, orient. II. Título.

Acknowledgments

To my beloved wife Tathyana and our daughter Nina. To my parents, sisters and niece. To my supervisor Antônio and the members of the committee.

To my friends: Alexandre, Alisson, Bruno, Carol, Clara, Cristina, Dianne, Glauber, Iuri, Karlla, Lucas, Margareth, Marina, Patrícia and Pedro.

To the coordinators, employees and professors of the Post-Graduate Program in Environmental Sciences of UnB.

UBIRAJARA DE BRITO CRUZ JÚNIOR

Analysis and use of anthropization data of the Brazilian Cerrado

A thesis submitted to the faculty at the University of Brasília in partial fulfillment of the requirements for the degree of Master of Science in the Graduate Program in Environmental Sciences.

Approved by the Examination Committee:

Committee Chair (Thesis Advisor):____
Antônio Felipe Couto Júnior, Ph.D

Committee Member: ____
Edson Eyji Sano, Ph.D.

Committee Member: ____
Eraldo Aparecido Trondoli Matricardi, Ph.D.

Abstract

The human being has been appropriating of an increasing portion of the planet's resources, and consequently potentially undermining the capacity of the ecosystems to maintaining a safe operating space for humanity. Non-forest ecosystems (NFE) have been neglected in this anthropization process, although they encompass vast territories with high biodiversity levels as those observed in forests ecosystems. The Brazilian Cerrado is a hotspot of biodiversity and also the most threatened tropical savanna in the world with only 2.2% of the area protected. This biome has been intensively occupied in the last decades, which resulted in soil and ecosystem degradation and the spread of exotic species as significant threats. In this research, we intended to address land change models and the use of available dataset to support analysis to understand those changes better and to mitigate the negative impacts of human activities. In the first chapter, we analyzed three of those maps sources by investigating differences among them, based on extensive data preparation and programming to compose the comparison. Our study results can be used for researchers to better comprehension and choice between the anthropization maps available and used for techniques evaluation by projects that estimate or classify land cover and use. In chapter two, we demonstrated the use of anthropization data available for Cerrado, by focusing on the Federal District (FD) and by comparison relationship between anthropization and its impacts on water resources. In this chapter, we draw attention to the use of the anthropization mapping for solving real problems related to the land-use systems and water resources. Based on this methodological approach, we crossed from lower to higher spatial scale and from focus on datasets specificities to reality assessment through data use. We intended to assert it is crucial to keep producing and improving the land use and land cover classifications, and the available datasets have vast potential to make possible a variety of modeling and studies of the natural conversion and its impact on the Cerrado.

Keywords: Land cover change, tropical savanna, data analysis, environmental modeling

Resumo

Os seres humanos têm se apropriado de uma parcela crescente dos recursos do planeta e, potencialmente, minam a capacidade dos ecossistemas de manter um espaço operacional seguro para a humanidade. Os ecossistemas não-florestais (ENF) foram negligenciados neste processo de antropização, embora cubram grandes territórios e tenham níveis de biodiversidade comparáveis às florestas. O Cerrado brasileiro é um *hotspot* de biodiversidade e, possivelmente, a savana tropical mais ameaçada do mundo, com apenas 2,2% de área protegida. Este bioma tem sido intensamente ocupado nas últimas décadas, com a degradação do solo e dos ecossistemas e a disseminação de espécies exóticas como grandes ameaças. Nesta pesquisa, abordamos modelos de mudança de uso e cobertura da terra como apoio aos pesquisadores para compreender melhor essas mudanças e elaborar maneiras de reduzir o impacto negativo das atividades humanas. No primeiro capítulo, analisamos três principais fontes desses mapas, investigando as divergências entre elas, com extensa preparação de dados e programação para possibilitar a comparação. Os resultados deste estudo podem ser utilizados por pesquisadores para melhor compreensão e escolha entre as estimativas disponíveis de antropização e para avaliação de técnicas de classificação por projetos que estimam ou classificam a cobertura e uso da terra. No capítulo dois, demonstramos um uso dos dados de antropização disponíveis para o Cerrado, com foco no Distrito Federal (DF) e os efeitos da antropização nos recursos hídricos. Esta parte do estudo chama a atenção para o uso dos dados disponíveis para a solução de problemas reais, principalmente ligados a sistemas de uso da terra e recursos hídricos. Com essa abordagem, saímos da escala mais ampla com foco nas especificidades dos dados, para a mais detalhada, voltada para a avaliação da realidade ambiental através do uso de dados. Compreendemos que é crucial continuar produzindo e melhorando as classificações de uso e cobertura da terra, e que os dados disponíveis têm alto potencial para viabilizar uma variedade de modelagens e estudos sobre a conversão da cobertura natural e seu impacto no Cerrado.

Palavras-chave: Mudança da cobertura do solo, savana tropical, análise de dados, modelagem ambiental.

TABLE OF CONTENTS

CHAPTER 1 - CONTEXTUALIZATION

Land use is becoming a force of global importance that have enabled humans to appropriate of an increasing portion of the planet's resources, and, consequently can undermine the capacity of ecosystems to maintain food production, freshwater and forest resources (Foley et al., 2005). Land use changes probably have the most significant effect on terrestrial ecosystems, and, some models have predicted that most land use will continue to occur in tropical and temperate forests of South America. (Sala et al., 2000).

Although non-forest ecosystems (NFE) cover large parts of the country and have biodiversity levels comparable to forests, including biodiversity hotspots, they have not been appropriately considered for conservation (Myers et al., 2000; Overbeck et al., 2015). This is the case of the Brazilian Cerrado, a hotspot of biodiversity with endemic species that is considered the most threatened tropical savanna in the world (Myers et al., 2000; Silva and Bates, 2002).

This vast region has only 2.2% of its territory as a strictly protected area and has been intensively occupied during the last 40 years, with soil and ecosystem degradation and the spread of exotic species as the major threats (Klink and Machado, 2005). Cerrado has become an essential beef producing region, with the most substantial extent of pasturelands and approximately 50% of the Brazilian herd with a pronounced conversion of native vegetation into monoculture over the past 20 years (Lapola et al., 2014).

The most pronounced land use changes occurred while the Amazon Forest called the attention of the conservation agenda (Klink and Machado, 2005), becoming mandatory to extend conservation strategy to maintain biodiversity significantly, and could take the lead in the conservation of NFE world-wide (Overbeck et al., 2015).

Based on it, land change models can support researchers to understand these land cover changes better and to develop alternative approaches to reduce the negative impact of human activities on the Earth system at scales ranging from global to local (Camacho Olmedo et al., 2018).

Remote sensing datasets are the primary input for the study and modeling of the land use changes, and with the understanding of Cerrado anthropization is not different. For better understanding the Cerrado natural land cover conversion, we proposed two views of an essential source of information, the anthropization maps estimations.

In the first view, chapter two, we analyzed three of those maps sources by investigating a possible reason for the divergence between the maps. Our analysis was based on extensive data preparation and programming to make possible the whole and divided comparison. The results obtained can be used for researchers to better comprehension and choice between the estimations available, and used for techniques evaluation by projects that estimate or classify land cover and use.

In the second view, chapter three, which indicate that land-cover change studies at higher resolution and larger scales (smaller area) are required to portrait more effectively the complexity of natural land cover conversion for better assessment of human impacts and environmental policy (Jepson, 2005), we demonstrate the use of anthropization dataset available for Cerrado. With a focus on the Federal District and the relation between anthropization and its impacts on water resources, this chapter draws the attention on the use of the dataset available for solving real problems, mostly related to land-use systems and water resources.

From the first part of the study to the second, we changed from lower to higher scale and from focus on datasets specificities to reality assessment through data use. Finally, we concluded that it is crucial to keep producing, improving and investigating the techniques and differences in the land use and land cover classifications. Furthermore, the available data has vast potential to make possible a variety of modeling and studies of the natural conversion and its impact on the Cerrado.

CHAPTER 2 - COMPARISON OF BRAZILIAN CERRADO ANTHROPIZATION ESTIMATIONS[1]

Abstract: Land-system changes should be understood as an expression of the anthropization process, and its representation has fundamental aspects related to time, space, model adherence, and computational approach. Those representations become even more challenging for the Brazilian Cerrado, the highest biodiversity tropical savanna in the world that has been marked by the agribusiness expansion. In this study, we assess three sources of anthropization datasets (TerraClass Cerrado, Prodes Cerrado, and Mapbiomas). We have divided the Cerrado biome into 121 Landsat scenes (path/row), generated Dice Similarity Coefficient (DSC) among those scenes, and estimated the spatial autocorrelation for each scene, and assessed the relationship between the two indicators. Scenes within low similarity were observed in the Northern Cerrado for all datasets and the eastern for the MapBiomas dataset. Prodes and TerraClass showed high similarity and similar spatial autocorrelation, due to the same applied segmentation methods in the classification processes. We observed that when segmentation was used in the classification process, it generated more aggregated pixel estimations and higher similarity between the sources. When segmentation was not applied, the pixels were more disaggregated and correlated to dissimilarities between the datasets. These study results raise questions about the suitability of the classification methods to map the anthropization process in the tropical region.

Keywords: Environmental assessment, human activities, tropical savanna, spatial autocorrelation, similarity

1An adapted version of this chapter, containing the main results and conclusions presented here, was submitted to the journal Applied Geography, in partial fulfillment of the requirements for the degree of Master of Science in the Graduate Program in Environmental Sciences.

2.1 Introduction

Land-system change is one of the planetary boundaries that maintain a safe operating space for humanity and affects the biogeochemical flows, freshwater use, climate change, and biosphere integrity (Steffen et al., 2015). These authors highlighted that land-system change is in a zone of uncertainty with increasing risk to safe operating space for humanity on Earth, considering the remaining amount of the tropical-temperate and boreal biomes. Global biodiversity scenarios predicted that land use is the primary driver of changes on biodiversity especially on tropical environments (Sala et al. 2000).

Land-use change, land management, and land degradation are responsible for must of human impacts on the environment and natural resources (Smith et al., 2016). Those anthropic processes have been grounded in the understanding of the basic concept of land use and land cover (LULC), that have usually been related, to human activities and the biophysical processes, respectively (Cihlar & Jansen, 2001).

The anthropization data representation has fundamental aspects regarding time, space, model adherence, and computational approach, as a pervasive framework associated with the new forms of understanding the environment (Pedrosa and Câmara, 2004).

Classification LULC datasets has been inspiring comparisons of: LULC simulated maps (Mas, Vega and Clarke, 2010; Dalposso et al.,2012; Carvalho de Lima et al., 2013; Sohl et al. 2016); of modeling and its implications for the assessment of biodiversity (Pérez-Vega and Ligmann-Zielinska, 2012); of spatial distribution of biomass (Houghton et al., 2001); and of land-use classification (Rozenstein and Karnieli, 2011).

The land-use classification becomes even more challenging in the Brazilian Cerrado, and a better understanding of available data should start by presenting major mapping initiatives. TerraClass Cerrado (BRASIL, 2015) is a project based on 121 Landsat-8 scenes, Operational Land Imager (OLI), acquired between July and August 2013. This classification used a segmentation algorithm considering threshold area 70 pixels (~ 6.25 hectares). To map land use and land cover changes in the Cerrado biome, this procedure was based on supervised and not supervised algorithms, and visual interpretation, which generated an 80.2% agreement index between the estimation and validation.

Prodes Cerrado is another public mapping initiative that applied semi-automatic techniques to map deforestation in the Cerrado biome validated visually by specialists, and it was based on methodology developed by Prodes (Amazon) using a segmentation algorithm (FUNCATE, 2018). This project estimates only the deforestation in 1:250.000 scale, biennial composition from 2000 to 2012, and annually from 2013 to 2017. The orbital data included 118 Landsat5/TM, Landsat7/ETM+, Landsat8/OLI scenes and 207 scenes of IRS2/LISS-III. Additionally, it was acquired satellite imagery from Google Earth and Google Earth Engine Time Capsule and used as auxiliary data.

MapBiomas Collection 3 included annual series from 1985 to 2017, produced by applying supervised classification pixel by pixel (MapBiomas, 2018). The random-forest classification used a feature space of 104 input variables, by including the original Landsat bands. Subsequently, the information was refined with spatial and temporal filters with a preliminary global accuracy of 0.75 and 0.80.

Those three mapping initiatives were based on remotely sensed data acquired by (Landsat) satellite, which show peculiarities on the representation of the anthropic activities in the Cerrado. Based on it, we aimed to assess similarities and differences between the three anthropization datasets (TerraClass Cerrado, Prodes Cerrado, and Mapbiomas). Also, this research investigates if the agreement of the sources is due to the similarity of the applied technique.

2.2 Material and Methods

Brazilian Cerrado is a tropical savanna that encompasses as more than 200 million hectares (Figure 1) and is considered a hotspot of biodiversity with high species richness and 44% of endemic plants (Klink and Machado, 2005; Sano et al. 2010). This biome includes 19 ecoregions that express spatial framework based on topography, vegetation, precipitation, and soil types (Sano et al., 2019). Despite the diversity, only 8% of the Cerrado biome is officially considered protected areas and, therefore, has been subjected to land-system change in the past 50 years (Klink and Machado, 2005).

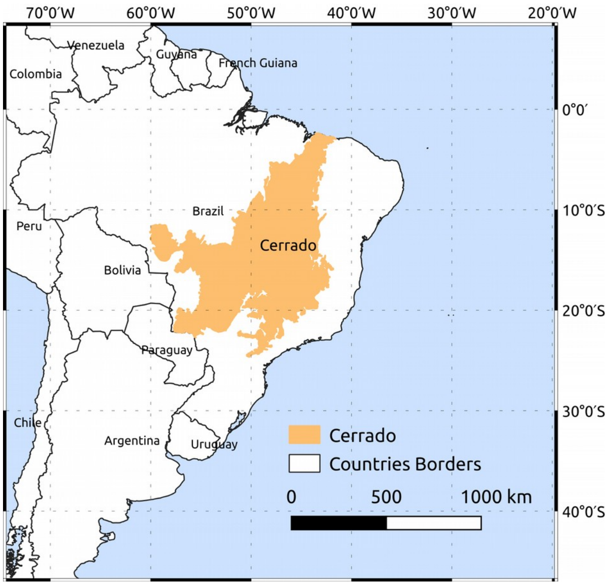

Figure 1 – Study area location - (Brazilian Cerrado) within Brazil.

We used TerraClass Cerrado, Prodes Cerrado, and Mapbiomas datasets to assess the estimation of anthropogenic activities in the Cerrado biome by considering Landsat images acquired in 2013. Reclassification and alignment of the images were previously conducted for the division of the Cerrado biome into 121 paths/row of Landsat scenes (Figure 3), which aimed to avoid misconception of a one-shot of entire map comparison among the datasets (Figure 2). It would drastically reduce the available data for further analysis otherwise.

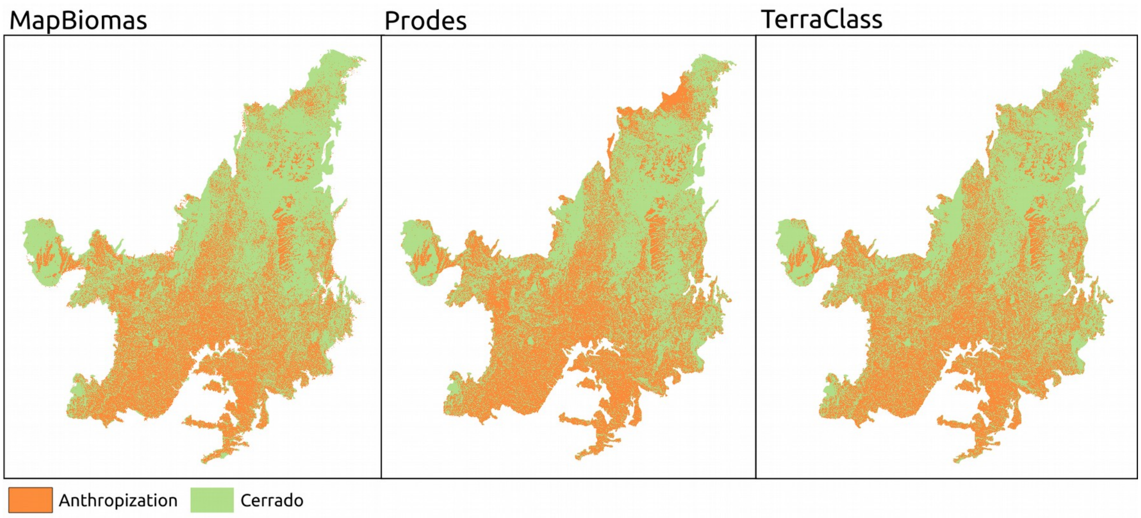

Figure 2 - Three reclassified estimations (MapBiomas, Prodes, and TerraClass) for anthropization of Cerrado in the temporal intersection of 2013.

A raster algebra and a similarity index estimation were conducted by using the three anthropization maps of the Cerrado, of each of the 121 Landsat scenes. Pixel by pixel comparison was applied to compare the land use maps (Power, Simms and White, 2001).

We used the Dice Similarity Coefficient (DSC) (Dice, 1945), to estimate similarity. This technique is a statistical analysis indicated for binary classification. For binary classified maps, any of so-called similarity or “matching” coefficients used in cluster analysis, can be applied and a commonly-used similarity or matching coefficient equivalent used for cluster analysis is Jaccard’s (Bonham-Carter, 1994). Mathematically, DSC is a semi-metric version of the Jaccard index and is defined as the total area where the patterns match (positive and negative) are divided by the total area.

For a more granular dissimilarity comparison, accordingly to the applied DSC, a map algebra subtraction between those two by two arranged maps was applied (Tomlinson, 1981). A modulation was inserted to keep the difference as 1, no matter if it was misleading from the first or the second map of the equation.

We used spatial autocorrelation to assess the segmentation approach and the convergence among the datasets. In this case, the indicator used was Moran’s I that is part of several statistical tests for overall clustering, that consider the null hypothesis is spatial randomness in the spatial distribution of data values (Haining, 2003).

2.3 Results

The divided data sources, in the absolute number of pixels without spatial approach (Figure 3), showed close medians, and similar counting, which indicates a convergence between TerraClass and MapBiomas datasets.

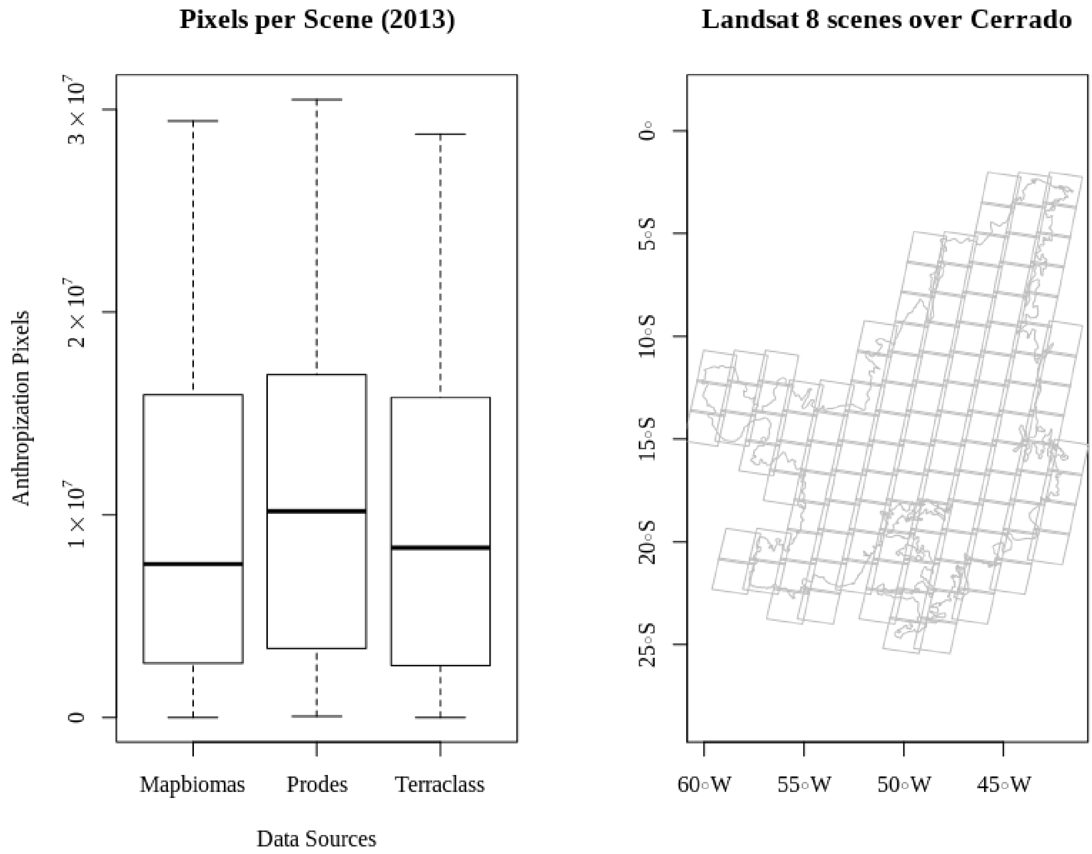

Figure 3 - Anthropization pixels counted per Landsat scene for each land use datasets and Landsat scenes used in this study (scatter plot) and the division of 121 scenes that overlap the Cerrado biome.

The comparisons show the convergence or divergence measured at two by two combinations (Figure 4). The results of the comparison between Prodes and TerraClass showed clear spatial convergence, even though the absolute numerical divergence was 9.81%. For the MapBiomas and TerraClass comparison, the divergence was more significant, and the absolute numerical divergence was 1.43%. For the MapBiomas and Prodes comparison, the numerical divergence was 11.39%, which was considered the highest when comparing two by two estimations, visually confirmed by the spatial analysis.

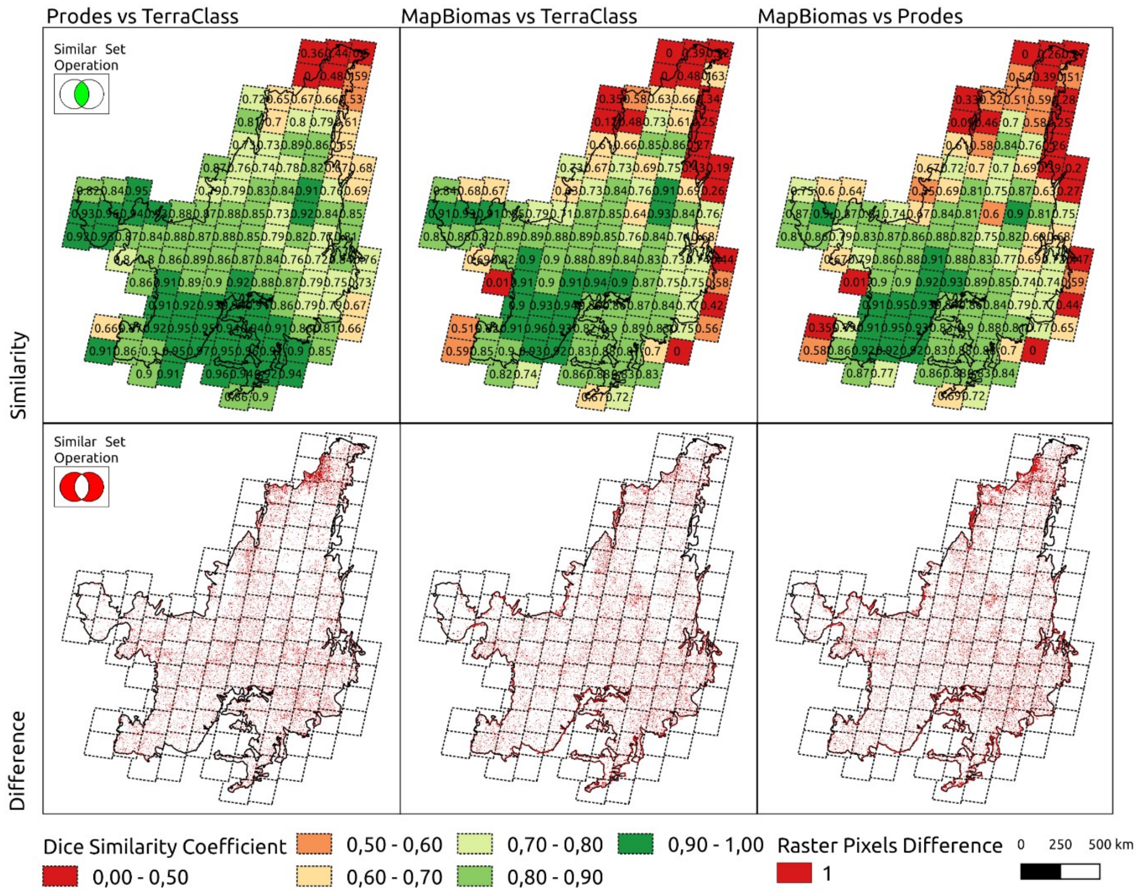

Figure 4 - Dice similarity coefficient (DSC) comparison and raster pixel difference calculated in combinations of 2 by 2 with the respective value (top) and the raster difference pixel by pixel (down).

The "Similarity per Scene" boxplot (Figure 5) enhanced the spatial results and indicated that the most prominent similarities are observed when comparing Prodes and TerraClass, followed by MapBiomas and TerraClass, and last by MapBiomas and Prodes datasets (Figure 5). The most significant differences were observed between the two comparisons conducted against the MapBiomas datasets.

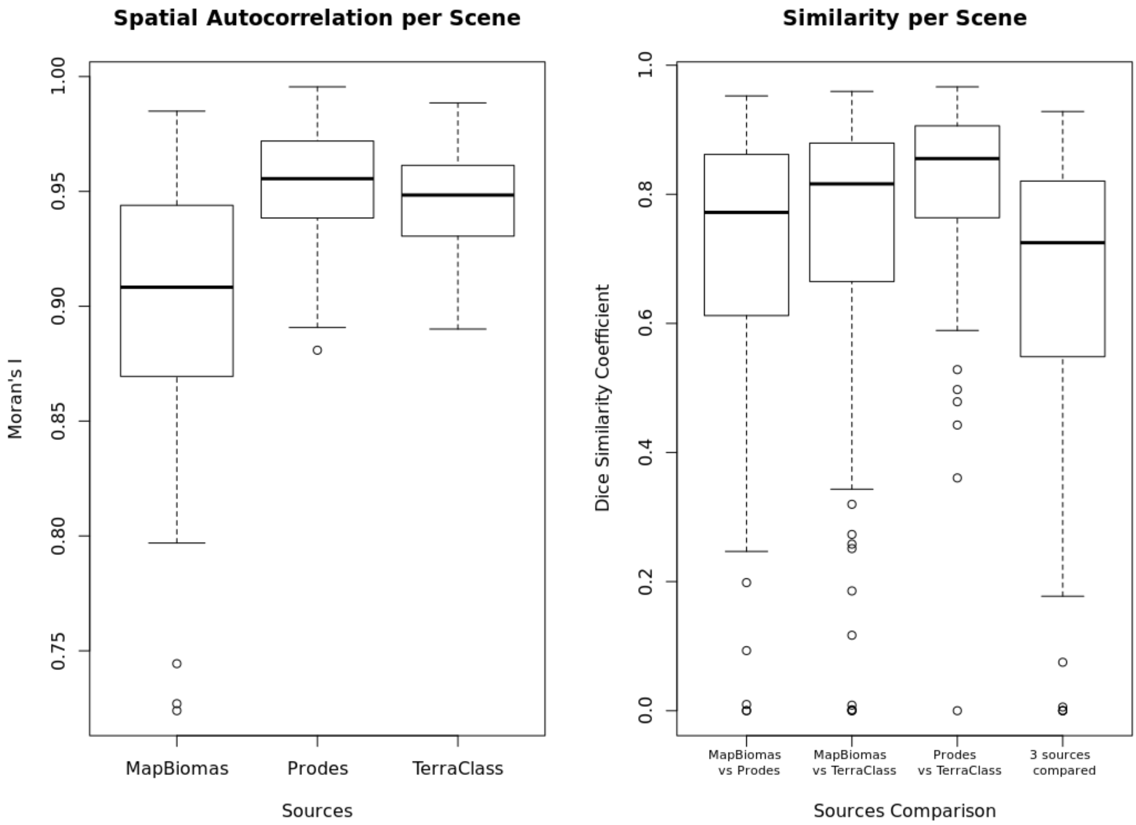

Figure 5 -Spatial autocorrelation of the sources using Moran's I and similarity between the data sources using DSC calculated for each Landsat scene. Prodes and TerraClass showed higher medians and low spreading for spatial autocorrelations compared to MapBiomas. Prodes and TerraClass showed a higher similarity.

For the spatial autocorrelations measured on each data source, almost all the Landsat scenes showed values higher than 0.80 (Figure 6). The spatial autocorrelation showed that MapBiomas scenes were by far sparser, with lower median and lower overall values, if compared to Prodes and TerraClass. Prodes data source showed the most significant values of Moran's I, followed by TerraClass dataset. These last two datasets showed more similarities and very closer spatial autocorrelations. Therefore, the last estimated results were based on the possible relationship between the spatial autocorrelation and the marked similarities.

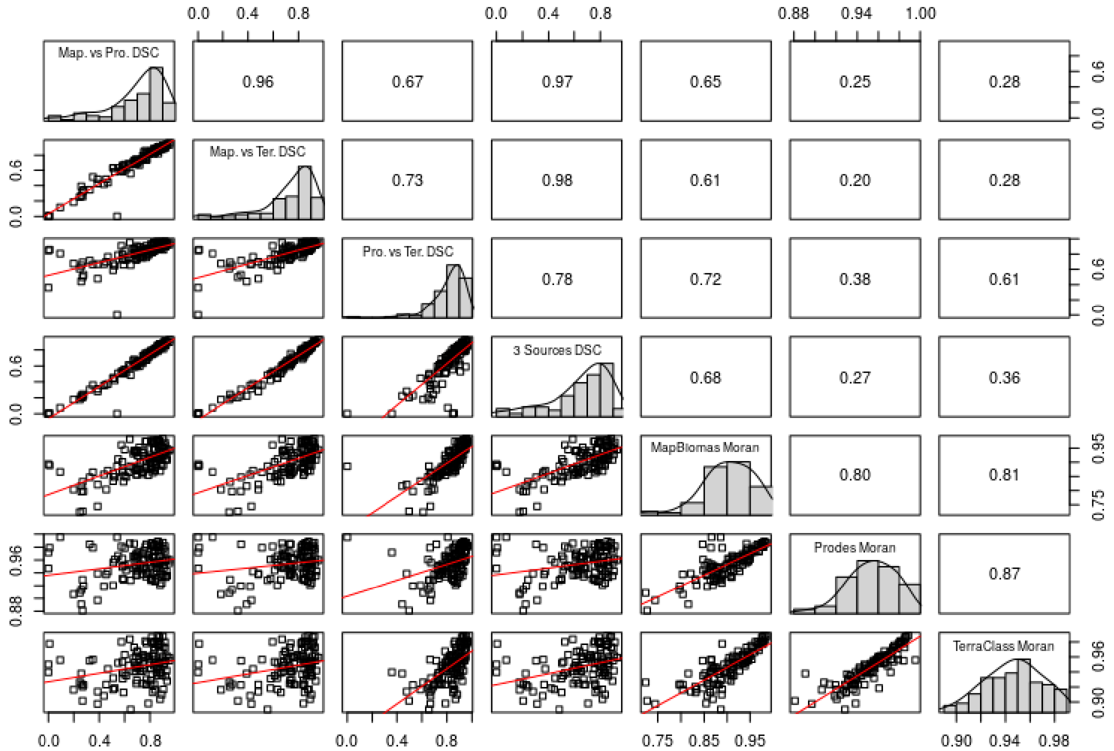

Figure 6 - Scatter plot of matrices (SPLOM), with bivariate, scatter plots using a linear fit below the diagonal, histograms of calculated similarities and spatial autocorrelations on the diagonal, and the Pearson correlation above the diagonal.

2.4 Discussion

In Figure 6 the two representations above and below the diagonal can be understood as two views of the same aspect, the correlation between the column and the line of each box. The diagonal histograms represent another possible visualization of the boxplots. The correlations are calculated between the DSC and Moran's I calculated for the sources for each Landsat Scene.

Analyzing the relationship between DSC values by using the central column from its half up, it was observed that the correlation presented from "Prodes vs. TerraClass DSC" and "3 Sources DSC" was the lowest with 0.78, compared with the other two with MapBiomas presence (0.98 and 0.97). This result is consistent with the results; MapBiomas dataset is responsible for the highest difference between the data sources. Some of the correlations on the Scatter Plot Matrices (SPLOM) were rejected, which included: the correlation among the Moran's I values; a correlation between some Moran's I of a source and DSC without the same source, Prodes Moran and MapBiomas/TerraClass DSC. For the compatible correlations, none of the measured Moran's I on the TerraClass or Prodes estimations expressed more importance than the

Moran's I value of MapBiomas dataset for the similarity comparisons.

The high values of spatial autocorrelation of Prodes and TerraClass datasets are likely due to the lack of influence on the similarities. For the MapBiomas dataset analysis, we did not observe it. By comparing the MapBiomas Moran to the "3 sources DSC" and the other two either, the values encountered was above 0.61 (positive correlation), which indicate that the sparse pixels are influencing the dissimilarity. In other words, when the spatial autocorrelation values of MapBiomas dataset became larger, greater similarity between MapBiomas and the other sources was observed. As opposed to it the values observed for the correlations between Prodes and TerraClass Moran and the DSC values were all below 0.61 or even smaller.

2.5 Conclusions

The differences among the land use datasets can be related to the segmentation technique applied by each data source, which generates more aggregated pixels estimations. The estimation with a pixel by pixel technique showed a significant positive correlation with the similarities of the data sources, higher than the other techniques based on segmentation.

The data source that did not apply segmentation techniques, (as in MapBiomas case), showed sparse and lower values of spatial autocorrelation when compared to the other two – TerraClass and Prodes datasets. The lower spatial autocorrelation of MapBiomas was more significantly correlated with the dissimilarities. The other two higher autocorrelation values for TerraClass and Prodes showed that this aspect of the data was not affecting the divergence between the data sources.

We understand that the relationship between the sparse pixels and the classification divergences could be better analyzed with others more refined statistical approach. By using the same classification approach, a correlation between the absolute numerical differences by pixel and the dissimilarities can be calculated and compared with the spatial autocorrelation. It should be considered before a final conclusion about the source of the observed divergences.

Future studies should better explore the spatial autocorrelation in the biophysical limits as well as investigate the use of Neural Networks and Deep Learning for anthropization classifications based on past estimations since some of those networks apply the segmentation approach.

CHAPTER 3 - SUSCEPTIBILITY TO ANTHROPIZATION AND LAND COVER CHANGE EFFECTS ON HYDROLOGY REGIME OF HEADWATER WATERSHEDS IN THE BRAZILIAN CERRADO

Abstract: The rapid natural conversion of Brazilian Cerrado threatens biodiversity by increasing fragmentation, invasive species, soil erosion, water pollution, and land degradation. This land use process is even worse in the Federal District (FD), a location of springs of three large hydrologic regions: Tocantins, São Francisco, and Paraná. The study intended: to model the anthropization susceptibility in the Federal District (FD) and to assess the anthropization effect in the hydrologic regime of selected paired watershed. We used the dataset provided by the Conservation and Sustainable Use of Biological Diversity Project (PROBIO) for 2002 to 2008 to generate the map of susceptibility to anthropization, and the anthropization map for 2009 and 2011 provided by Project of Deforestation Monitoring of Brazilian Biomes by Satellite (PMDBBS). We used the elevation, slope, distance from rivers, and distance from roads as explanatory spatial variables to model the anthropization in the FD using the Dinamica EGO software and selected those two watersheds by considering the map of mean probability of susceptibility and consecutive anthropization. The hydrological regime assessment was based on the variance analysis on the watershed discharges, and statistical hypothesis tests to evaluate the relevance of the hydrological regime change in the affected Ribeirão Engenho das Lajes (REL) watershed in contrast to the neighboring Ribeirão Ponte Alta (RPA) watershed that suffered almost none anthropization from 2009 to 2011. We concluded that the anthropization susceptibility model could assist the prediction of land cover changes that affect the basin hydrological regime. This approach demonstrates the potential of the modeling to the assessments of the Cerrado hydrology and should be considered in environmental planning and public policies creation.

Keywords: Land-system change, deforestation, tropical savanna, hydrology, variance change

3.1 Introduction

The Cerrado occupies about 200 million hectares in central South America, which is considered the largest, most abundant, and the most threatened tropical savanna in the world, ranked among the most critical terrestrial biodiversity hotspots in the world, and sharing ecological transition zones with rainforest, semi-arid region, wetland, and coastal forest (Silva and Bates, 2002; Myers et al., 2000). Topography, vegetation, precipitation, and soil of Cerrado reflect the environmental heterogeneity within the biome, according to the whole division of 19 ecoregions (Sano et al., 2019).

However, the rapid natural conversion of the Cerrado threatens biodiversity with fragmentation, loss of biodiversity, invasive species, soil erosion, water pollution, and land degradation (Klink and Machado, 2005). According to species-by-species assessments using a continuous model, 397 threatened endemic plant species are in extinction risk, causing potential changing to the ecosystems and their capacity to provide services to local and regional communities (Strassburg et a., 2017).

By considering the water resources, the Cerrado also spans three of the largest basins in South America (Tocantins, São Francisco, and Paraná), which altogether contribute to 43% of Brazil's surface water (Strassburg et al., 2017). Headwater watershed of those three hydrographic regions flow from the territory of the Federal District (FD), the Brazilian District Capital, and has lost about 60% of natural cover (Brasil, 2015). Land use intensification is likely to severely limit the Cerrado's future regarding production and ecosystem stability but lacking the understanding of the interaction between terrestrial and aquatic systems (Hunke et al., 2015). Stream carbon and nutrient concentrations were significantly higher in catchments where the native vegetation was replaced which is widely reported as a consequence of deforestation (Nobrega et al., 2018).

The understanding of Cerrado land cover change requires higher resolution and larger scales (greater details) to represent more effectively the complexity of land conversion into crop fields and to better assess human impacts and environmental policy (Jepson, 2005). This study aimed: to model the anthropization susceptibility in the Federal District (FD), and to assess the effect of this susceptibility in the hydrological regime of study watersheds. We observed that land cover changes affect the hydrological system by generating high variance in discharge, and by increasing the interval between maximum and minimum average discharge (Hewlett, 1983).

3.2 Material and Methods

3.2.1 Study area

The Federal District (FD) encompasses 5,738 km2 in Central Brazil where is located headwater of three basins: Tocantins (north), São Francisco (east) and Paraná (center and southwest) in the core area of Cerrado (Figure 1). A total of 41% of the FD Territory has been deforested, and pasture lands occupy more than 16% of it by 2013 (Brasil, 2015). Most of the native vegetation is spatially located within protected areas due to the high anthropogenic pressure of the agribusiness activities.

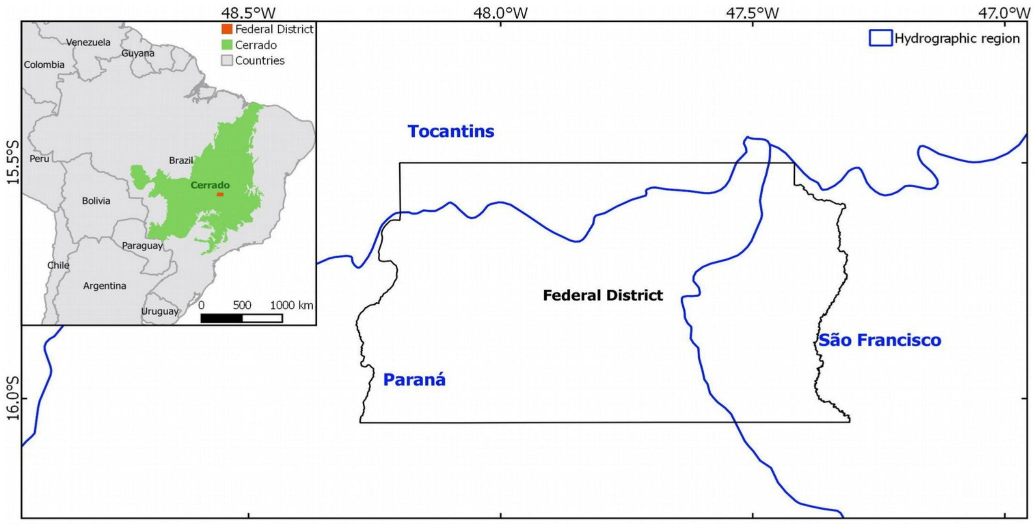

Figure 1 – Study Area (Federal District - FD) location within the country of Brazil. Details of the hydrographic regions (blue lines): Tocantins, São Francisco, and Paraná.

3.2.2 Land cover maps

We used the PROBIO dataset as deforestation estimative, which is one of the most disseminated datasets of deforestation and anthropization for the Cerrado region, with 90% accuracy by considering natural/anthropic classification only. The PROBIO dataset includes deforestation in 2002 and 2008, and it was extended to 2009 and 2011 by Project for Deforestation Monitoring of Brazilian Biomes by Satellite (PMDBBS, 2011, 2015).

3.2.3 Explanatory variables

We used elevation, slope, distance from rivers, and distance from roads as explanatory variables, known as determinant maps (Figure 2), to model the anthropization within the FD, because of their excellent accuracy to model the occupation in the Cerrado (Espírito-Santo et al., 2016). Elevation dataset was acquired from the Shuttle Radar Topographic Mission (SRTM), with 30 meters spatial resolution, provided by the USGS and it was used as input to estimate the slope. For the study area, we used hydrography and roads vector datasets at national scale acquired from the Brazilian Institute of Geography and Statistics (IBGE), and they were used as input to conduct the distance analysis.

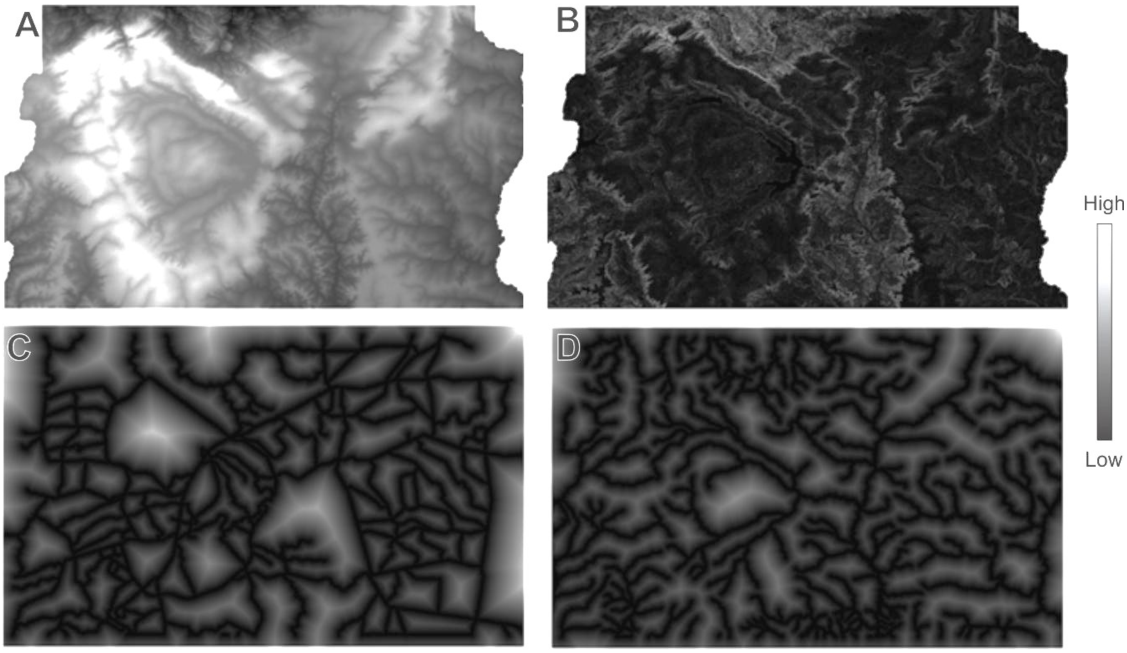

Figure 2 – Determinant maps to model the anthropization of Federal District (FD): Elevation (A), Slope (B), Distance from roads (C) and Distance from rivers (D). The values of the determinant maps area expressed in a gradient from white (high values) to black (low values).

3.2.4 Anthropization susceptibility modeling

The Dinamica Ego software uses a quantification of land transition probability based on the Weights of Evidence (WoE) method to generate the land use probability maps or anthropization susceptibility map. This method is based on a Bayesian inference that estimates the probabilities (a posteriori) to occur a deforestation event given a spatial pattern of evidence (Ferreira et al., 2012).

The WoE method consists of three tasks: determination of evidence weight ranges; transforming the continuous variables into categorical ones, determination of weights coefficients; to select the variables that influence the dynamics of land use transitions, creating local probabilities of differences and correlation report; and to provide information about the spatial association between two variables and its probable elimination necessity (Monteiro Junior *et al.*, 2018).

The WoE method, as a better alternative to descriptive and more generalist static methods as logistic regression, presents more flexibility in modeling the relationship between the probability of change and the drivers, which is independently calculated. For this reason, the spatial association between the explanatory variables should be investigated by using a set of correlation tests to measure the Cramer's coefficients, contingency coefficient, and joint information uncertainty (Gago-Silva, Ray and Lehmann, 2017).

In this analysis we compared the anthropization from PMDBBS from 2009 to 2011 with susceptibility to anthropization map provided by PROBIO for 2002 and 2008, to assess the adherence of susceptibility to anthropization.

3.2.5 Watershed hydrological regime change assessment

Based on the susceptibility to anthropization map available, we selected watersheds with a high probability of being anthropized in 2008 that was converted from natural in the following years. We considered the probability mean map by using Jenkins breaks in the susceptibility to anthropization values to the selection. Subsequently, we compared the hydrological regimes of the paired watershed by assuming the same climate conditions and by using discharge (m3.s-1) data from the Environmental Sanitation Company of the Federal District (CAESB, Portuguese). We performed a variance change analysis in the subbasins discharge by using the R changepoint library to detect a broken temporal pattern. After that, we performed Student's t-test to ensure the relevance of the detected hydrological regime change.

3.3 Results and Discussion

3.3.1 Anthropization susceptibility modeling

Based on the results of the anthropization model, we observed predominantly high anthropization susceptibility in northern and southern FD territory, (Tocantins and Paraná Hydrographic Region, respectively), and low susceptibility in eastern São Francisco Hydrographic Region (Figure 3). High susceptibility was observed in the surroundings of three protected areas: Brasilia National Park (BNP), Águas Emendadas Ecological Station (AEES), and Gama e Cabeça de Veado Environmental Preservation Area (GCVEPA).

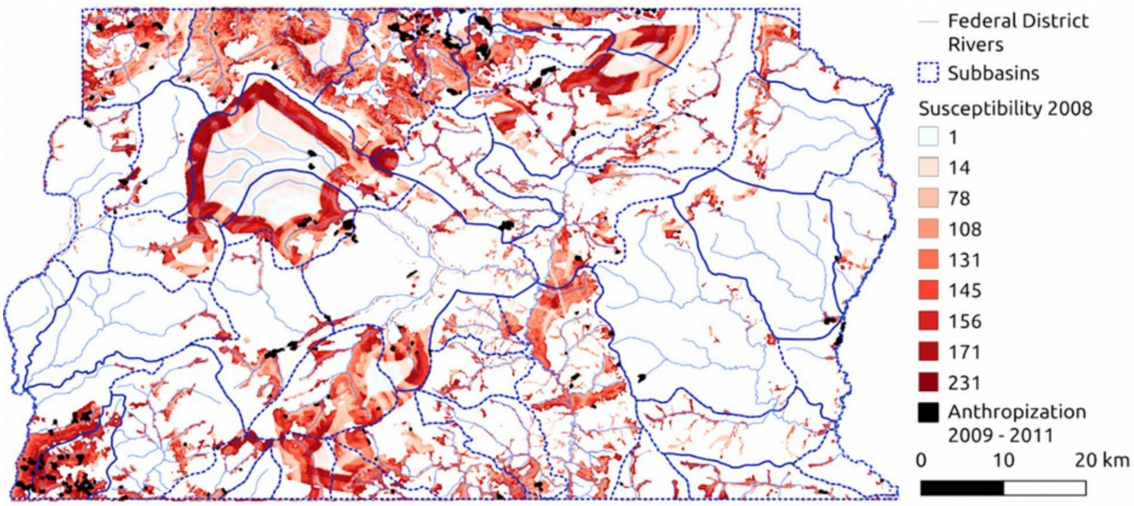

Figure 3 - Susceptibility to anthropization int the Federal District (FD) for 2008 (1 (low) to 254 (high) probability) by considering the PROBIO dataset for 2002 and 2008 and anthropization occurred from 2009 to 2011 and adherence of susceptibility to anthropization occurred from 2009 to 2011 (black spots). There were included the FD subbasins (dotted dark blue lines) and hydrology (light blue lines).

The anthropization occurred between 2009 and 2011 followed the probability raised by the susceptibility model and was higher in northern and southwestern FD (Figure 3, black spots). In the same period, has occurred anthropization within and around the BNP and GCVEPA, and both are protected areas.

3.3.2 Assessment of hydrological regime change of a subbasin

By comparing the mean probability of anthropization for each watershed in 2008 and the effective anthropization in the subsequent years, we observed that the highest anthropization occurred in the Ribeirão Engenho das Lajes (REL) (Figure 4). The results evidenced there was no relevant anthropization in the adjacent Ribeirão Ponte Alta subbasin (RPA) in the same period from 2009 to 2011, which allow a comparative analysis between the basins (REL and RPA).

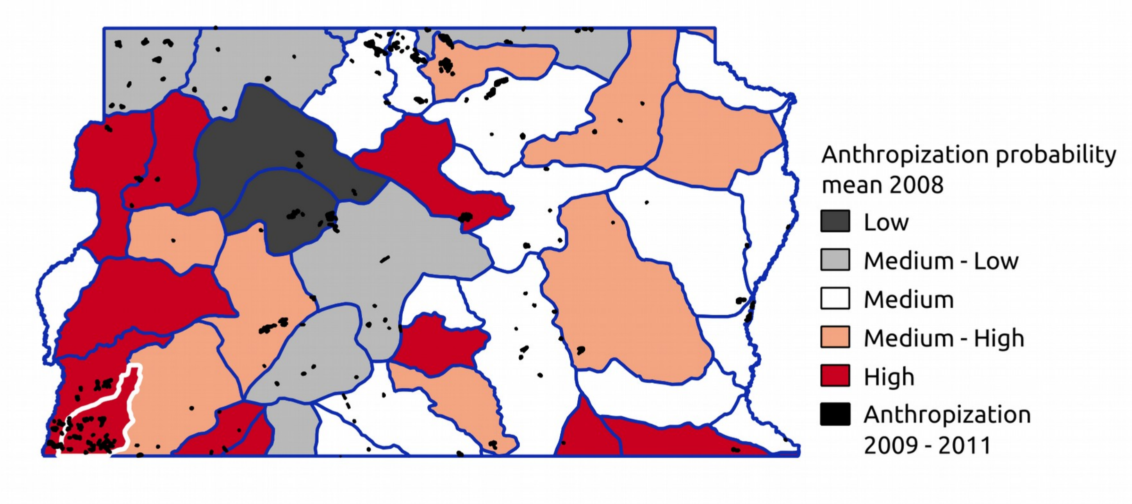

Figure 4 - Mean anthropization probability for the Federal District (FD) in 2008 (1 (low) to 254 (high)) with Jenkins breaks, based on the PROBIO dataset from 2002 to 2008 and anthropization occurred from 2009 to 2001 (black spots). The Ribeirão Engenho das Lajes watershed is highlighted (white line) as the highest anthropization occurred between 2009 and 2011.

We assessed the effect of anthropization of paired watershed from the Parana hydrographic region, in the southwest region of the FD (Figure 5) by using discharge data. In a first look, the discharge average of Ribeirão Engenho das Lajes (Figure 5 A) showed changes between 2010 and 2014. Previously, showed less discharge oscillating values when compared with the same period of the Ribeirão Ponte Alta (Figure 5 B).

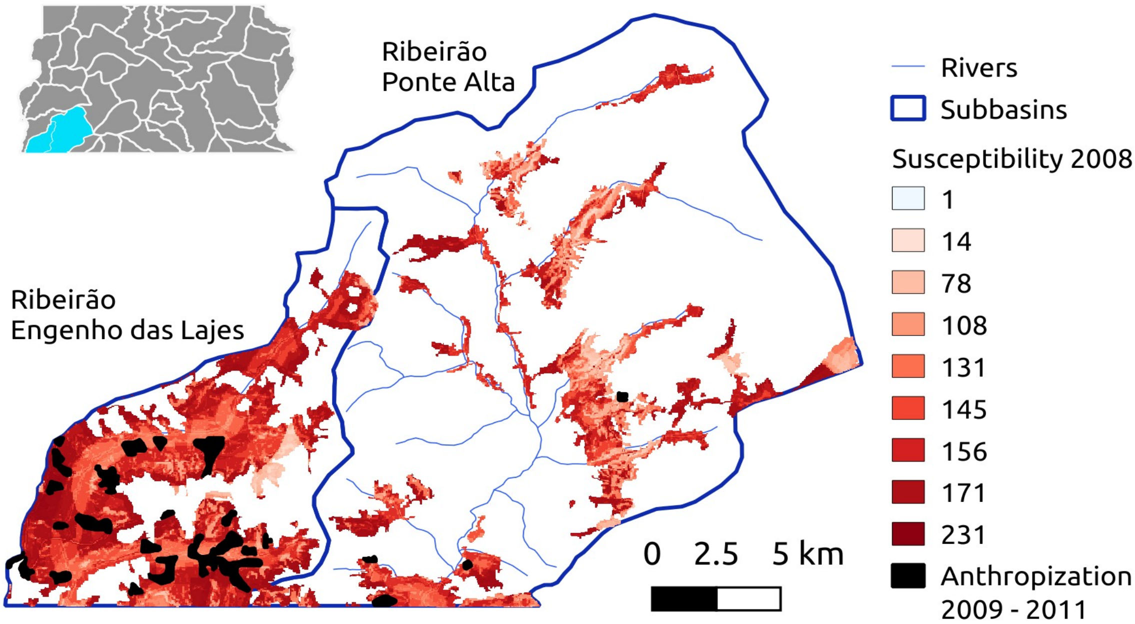

Figure 5 - Model of susceptibility to anthropization for the Ribeirão Engenho das Lajes and Ribeirão Ponte Alta for 2008, by considering the PROBIO dataset from 2002 to

2008, and anthropization occurred from 2009 to 2001, which show the adherence of the mapped susceptibility with the consecutive anthropization (black spots).

The variance change analysis indicated a broken temporal pattern in the REL series and not for RPA (Figure 5 C and D). From the change points of REL, the paired Student's t-test between the two first sections (Figure 5 E) confirmed the hydrological regime change (p-value=0.026) of the period prior to September 2010 (first change point) showed a statistically significant change up to November 2013 (second change point), by considering 95% confidence level and p-value > 0.05. For example, we calculated the average (red line) of RPA in the complete period (Figure 5 F), by assuming that since there was no change point for this subbasin and the hydrological regime was assumed as not altered, as opposite to REL.

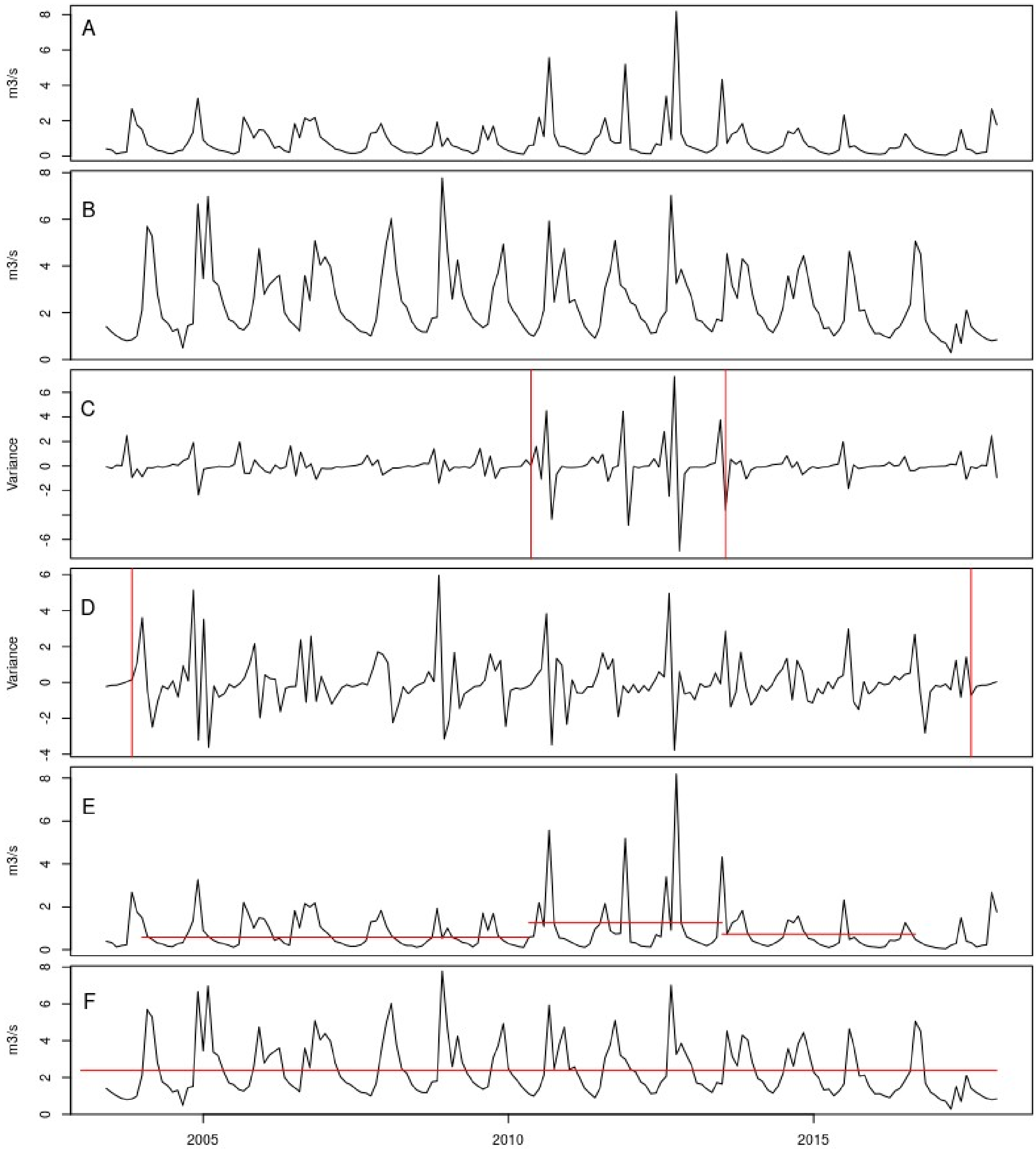

Figure 6 – Average discharge (m^3.s^{-1}) for Ribeirão Engenho das Lajes (A) and Ribeirão Ponte Alta (B), Variance change for Ribeirão Engenho das Lajes (C) and Ribeirão Ponte Alta (D), Average discharge change (m^3.s^{-1}) for Ribeirão Engenho das Lajes (E) and Ribeirão Ponte Alta (F).

3.4. Conclusions

Based on the previously mentioned environmental importance of the Cerrado biome and the land use conversion pressure observed in the study area, our research indicates that susceptibility to anthropization modeling represents a viable map solution to assist the prediction of impact in the discharge of subbasins. The use of elevation, slope, distance to roads and distance to rivers were suitable determinants maps to generate susceptibility to anthropization model with Dinamica EGO for FD.

Through the adherence of the susceptibility mapped using Conservation and Sustainable Use of Biological Diversity Project (PROBIO) dataset (2002 to 2008) with the consecutive anthropization from Project to Monitor Deforestation of Brazilian Biomes by Satellite (PMDBBS) dataset for 2009 to 2011, it was possible to detect a threatened sub-basin that had its hydrological regime altered.

Another highlight of the work was the paired watershed discharge analysis with no conventional created treatment and no treatment laboratory. With the given anthropization and no anthropization in the adjacent watershed, the relevance of the statistical test results testified the theoretical variance change in the discharge series.

A more formal method for selection and better separation of interest watershed are understanding as a lack in this study and should be better analyzed in other initiatives. Nevertheless, we believe that this approach demonstrates the potential to the assessments of the impacts of deforestation in the Cerrado and should also be considered in environmental planning and public policies creation.

CHAPTER 4 – CONCLUDING REMARKS

In this study, by using a view from lower to a higher scale and moving from a dataset analysis to a directly environmental assess, we evidenced the usability and possible evolutions related to the remote sensing land cover classification.

The chapter two by analysing and recognizing the quality of the assessed Cerrado Biome anthropization land cover classifications initiates a discussion about the possible influence of the computer techniques chosen in the very beginning of this type of process. The chapter three represents an innovative use of the type of data analyzed in the previous chapter by suggesting the specific WoE approach for modeling anthropization and its relationship with the average rivers discharges.

Our central consideration on the field of land cover classification, specifically related to the anthropization of natural covers, is about the analysis and modeling possibilities that can be made by cruising old and recently discovered computational techniques. This consideration takes into account both, the assessment of the available datasets and the uses of data itself to stimulate innovative approaches in the use and analysis of land cover anthropization data, or even in other tropical areas.

REFERENCES

Bonham-Carter, G. F. Geographic Information Systems for Geoscientists: Modelling with GIS. Pergamon Press. 1994.

Brasil. Ministério de Meio Ambiente. Mapeamento do Uso e Cobertura do Cerrado: Projeto TerraClass Cerrado 2013. 2015. Available on: http://www.dpi.inpe.br/tccerrado/Metodologia_TCCerrado_2013.pdf

Camacho Olmedo, M. T., Mas, J. F., and Paegelow, M. Geomatic Approaches for Modeling Land Change Scenarios. 2018.

Carvalho de Lima, T., Guilen-Lima, C. M., and Oliveira, M. S. DINAMICA EGO e Land Change Modeler para simulação de desmatamento na Amazonia brasileira: análise comparativa XVI Simpósio Brasileiro de Sensoriamento Remoto - SBSR. 2013

Cihlar, J., and Jansen, L. J. M. From Land Cover to Land Use : A Methodology for Efficient Land Use Mapping over Large Areas. The Professional Geographer, v. 53, n. 2, p. 16, 2001.

Dalposso, G. H., Uribe-Opazo, M. A. *et al.* Comparison measures of maps generated by geostatistical methods. Engenharia Agrícola, 2012.

Dice, L. R. Measures of the Amount of Ecologic Association Between Species Author (s): Lee R . Dice Reviewed work (s): Published by : Ecological Society of America Stable URL : http://www.jstor.org/stable/1932409 . v. 26, n. 3, p. 297–302, 1945.

Ferreira, M. E., Ferreira, L., Miziara F. *et al.* Modeling landscape dynamics in the central Brazilian savanna biome: future scenarios and perspectives for conservation. Journal of Land Use Science iFirst, p. 1–19, 2012.

Foley, J. A., Defries, R. *et al.* Global Consequences of Land Use. v. 570, 2005.

Funcate: Fundação de Ciência, Aplicações e Tecnologia Espaciais. Metodologia da detecção do desmatamento no bioma Cerrado: Mapeamento de Áreas Antropizadas com Imagens de Média Resolução Espacial. 2018, Available on: http://www.obt.inpe.br/cerrado/report_funcate_metodologia_mapeamento_bioma_cerrado.pdf.

Gago-Silva A., Ray, N., and Lehmann, A. Spatial Dynamic Modelling of Future Scenarios of Land Use Change in Vaud and Valais, Western Switzerland. ISPRS International Journal of Geo-Information, 2017.

Haining, R. Spatial Data Analysis: Theory and Practice. Cambridge Universty Press. 2003.

Hewlett, J. D. Principles of Forest Hydrology. University of Georgia Press. v. 64. 1983

Houghton, R. A., Lawrence, J. *et al.* The spatial distribution of forest biomass in the Brazilian Amazon: a comparison of estimates. Global Change Biology, v. 7, p. 731–746, 2001.

Hunke, P., Mueller, B. *et al.* The Brazilian Cerrado : assessment of water and soil degradation in catchments under intensive agricultural use. v. 1180, n. November 2014, p. 1154–1180, 2015.

Jepson, W. A disappearing biome? Reconsidering land-cover change in the Brazilian savanna. v. 171, n. 2, p. 99–111, 2005.

Klink, C. A. and Machado, R. B. Conservation of the Brazilian Cerrado. Conservation Biology, v. 19, n. 3, p. 707–713, 2005.

Lapola, D. M., Martinelli, L. *et al.* Pervasive transition of the Brazilian land-use system. Nature Publishing Group, v. 4, n. 1, p. 27–35, 2014.

Mapbiomas. MapBiomas General “Handbook” - Algorithm Theoretical Basis Document (ATBD) Collection 3 Version 1.0, 2018. Disponível em: <https://storage.googleapis.com/mapbiomas/base-de-dados/metodologia/colecao-3_0/1-ATBD-Collection-3-version-1.pdf>

Mas, J.-F.; Vega, A. P.; Clarke, K. Assessing simulated land use/cover maps using similarity and fragmentation indices. ASPRS 2010 Annual Conference. 2010

Monteiro, J. J., Silva, E. *et al.* Dynamical spatial modeling to simulate the forest scenario in Brazilian dry forest landscapes. Geology, Ecology, and Landscapes, 2018.

Myers, N., Mittermeier, R. *et al.* Biodiversity hotspots for conservation priorities. Nature, v. 403, n. 6772, p. 853–8, 2000.

Nóbrega, R. L. B., Guzha, A. *et al.* Science of the Total Environment Impacts of land-use and land-cover change on stream hydrochemistry in the Cerrado and Amazon biomes. Science of the Total Environment, v. 635, p. 259–274, 2018.

Overbeck, G. E., Eduardo, V. *et al.* Conservation in Brazil needs to include non-forest ecosystems. p. 1455–1460, 2015.

Pedrosa, B. M. and Câmara, G. Cap 8 - Modelagem Dinâmica. *In*: Análise Espacial de Dados Geográficos. Embrapa. 2004.

Pérez-Vega, A.; Mas, J. and Ligmann-Zielinska, A. Environmental Modelling & Software Comparing two approaches to land use / cover change modeling and their implications for the assessment of biodiversity loss in a deciduous tropical forest. Environmental Modelling and Software, v. 29, n. 1, p. 11–23, 2012.

Power, C.; Simms, A. and White, R. Hierarchical fuzzy pattern matching for the regional comparison of land use maps. International Journal of Geographical Information Science, 2001.

Rozenstein, O. and Karnieli, A. Comparison of methods for land-use classification incorporating remote sensing and gis input. Applied Geography, v.31, n2, p. 533-544, 2011.

Sala, O. E., Chapin III, F. S. *et al.* Global Biodiversity Scenarios for the Year 2100. Science, v. 287, n. March, p. 1770–1774, 2000.

Sano, E. E. Rosa, R. *et al.* Land cover mapping of the tropical savanna region in Brazil. Environ Monit Assess, v. 166, p. 113–124, 2010.

Sano, E. E., Rodrigues, A. A. *et al.* Cerrado ecoregions: A spatial framework to assess and prioritize Brazilian savanna environmental diversity for conservation. Journal of Environmental Management, 2019.

Silva, J. M. C. DA and Bates, J. Biogeographic Patterns and Conservation in the South American Cerrado : A Tropical Savanna Hotspot. v. 52, n. 3, 2002.

Espírito-Santo, M. M., Leite, M. E. *et al.* Understanding patterns of land-cover change in the Brazilian Cerrado from 2000 to 2015. Philosophical Transactions of The Royal Society B Biological Science. August, 2016.

Smith, P., House, J., *et al.* Global change pressures on soils from land use and management. Global Change Biology, v. 22, n. 3, p. 1008–1028, 2016.

Sohl, T. L., Wimerly, M. C. *et al.* Divergent projections of future land use in the United States arising from different models and scenarios. Ecological Modelling, v. 337, p. 281–297, 2016.

Steffen, W., Richardson, J. K. *et al.* Planetary boundaries: Guiding human development on a changing planet. Science, v. 348, 2015.

Strassburg, B. N., Brooks, T. *et al.* Moment of truth for the Cerrado. Nature Ecology & Evolution, Vol. 1, No. 4., 2017.

Tomlinson, C. D. Geographic Information Systems and Cartographic Modeling. Prentice-Hall. 1981.