Socioeconomic Development and Deforestation in the Cerrado biome, Brazil: spatial interactions and heterogeneity

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Abstract: This paper investigates the relationship between socioeconomic development and deforestation in the Cerrado biome, with special focus on the current Brazilian agricultural frontier, known as Matopiba. More specifically, we search for spatial interactions and heterogeneity as well as spatial clusters among the municipalities, using the exploratory analysis of spatial data (ESDA). Due to the large number of possible socioeconomic variables that may be related to deforestation decisions, we create a Socioeconomic Development Index (SDI) that synthesizes all possible influences using factorial analysis from multivariate statistics. We also grouped with cluster analysis municipalities with dissimilar deforestation and economic development patterns. The results show that biome's economic development and deforestation are spatially concentrated and heterogeneous. in addition to be negatively associated for the majority of Cerrado municipalities both in the spatial and cluster analysis, indicating that socioeconomic development may be an inhibitor of deforestation.

Keywords: Deforestation; Socioeconomic Development; Matopiba.

JEL Codes: Q01; Q56.

Resumo: Esse artigo investiga a relação entre desenvolvimento socioeconômico e desmatamento no bioma Cerrado, com foco especial na atual fronteira agrícola brasileira, conhecida como Matopiba. De forma específica, analisou-se a presença de interações e heterogeneidade espaciais, assim como a presença de *clusters* espaciais, utilizando análise exploratória de dados espaciais (AEDE). Devido a grande quantidade de variáveis socioeconômicas que influenciam a decisão de desmatamento, criou-se um Índice de Desenvolvimento Socioeconômico (IDS) para sintetizar as possíveis influencias por meio da análise fatorial. Também se agrupou, por meio da análise de agrupamentos, municípios com padrões dissimilares de desmatamento e desenvolvimento econômico. Os resultados indicam que o desenvolvimento econômico e o desmatamento estão espacialmente concentrados e heterogêneos, além de estarem negativamente associados na maioria dos municípios do Cerrado, tanto na análise de agrupamentos quanto na de *clusters* espaciais, indicando que o desenvolvimento socioeconômico pode ser um inibidor do desmatamento.

Palavras-Chave: Desmatamento; Desenvolvimento Socioeconômico; Matopiba.

Classificação JEL: Q01; Q56.

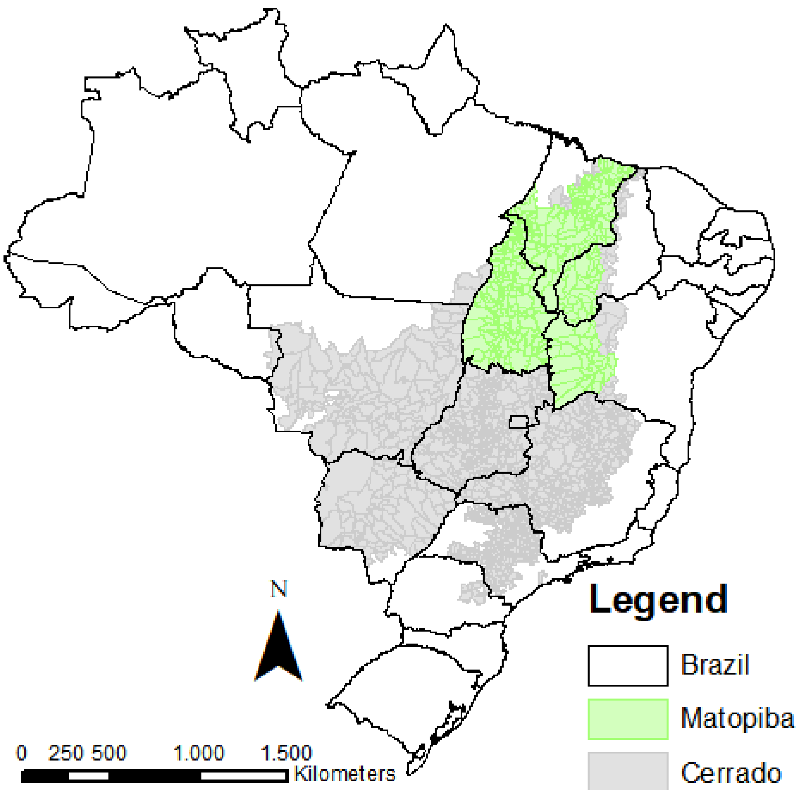
Área Temática 4: Geoprocessamento e análise espacial

1. Introduction

The Cerrado biome is the richest savanna in the world and is important to the balance of the global ecosystem. However, its intensive occupation, especially after the 1970 with the expansion of the Brazilian agricultural frontier, has caused serious damage to its environment, making it a hotspot of the world's biodiversity[1], with high endemism and threat of irreparable environmental losses (MYERS et al., 2000). The biome is located essentially in the central region of Brazil and occupy 25% of the national territory, with an area of approximately 2,039,243 km², covering 1,389 municipalities (IBAMA, 2010).

The current Cerrado deforestation occurs mainly due to the establishment of new frontiers for agricultural production. The Matopiba, composed by the states Maranhão, Tocantins, Piauí and Bahia, are the main region of the current Brazilian agricultural frontier, which is presenting rapid economic development (BOLFE et al, 2016; DIAS et al., 2016; NOOJIPADY et al., 2017; BRAGANÇA, 2018). In fact, there is an increase in the pressure for the opening of new agricultural areas in Brazil, due to the expansion of the agricultural frontier, especially in the Cerrado (GIBBS et al., 2015; BRAGANÇA, 2018; ARAÚJO et al. 2019). According to Araújo et al. (2019), agricultural frontier is a region dominated by natural vegetation that is facing intensive agriculture-related land occupation. In this context, recognizing the region's strategic importance for Brazilian agribusiness, the country's government issued Decree No. 8,447 on May 6, 2015, establishing an Agricultural Development Plan, which seeks to guide federal projects of agricultural and livestock activities specifically for the region (BRASIL, 2015). Figure 1 shows the Cerrado and the Matopiba location in Brazil.

Figure 1 –Cerrado and Matopiba Location in Brazil



Source: research data.

[1] 25 biologically rich areas in the world that have lost at least 70 % of their original habitat (MYERS et al., 2000).

Assunção and Bragança (2015) and Bragança (2018) argues that the recent land use change dynamics of Matopiba is part of a historical process thar reflects the agricultural frontier expansion in the Brazilian Cerrado, which began in the 1960s and 1970s. This expansion has been mainly due to the implementation of technologies adapted to local conditions, as the accommodation of soy cultivation in tropical areas for acid and poor soils, which allows an increase in productivity for the agricultural production (SPEHAR, 1994; KIIHL and CALVO, 2008; ASSUNÇÃO and BRAGANÇA, 2015; MUELLER and MUELLER, 2016).

However, the agricultural frontier expansion has led to a progressive depletion of the natural resources of the Cerrado, making this biome the second that suffered more changes due to anthropogenic actions in Brazil, after the Atlantic Forest. For example, between 2002 and 2010, the biome had 4% of its forest cleared, reaching 47,8% of total deforested area. Considering only 2010, the annual rate of deforestation was 0.3%, the highest for all biomes present in the Brazilian territory. In terms of extension, the deforestation in Cerrado also exceeds the cleared area of the Amazon rainforest. Nevertheless, the Cerrado biome have been overlooked when compared to the attention given to the Amazon region; conservation units protect only 7.44% of its territory, which has served to aggravate the intensive use of its natural resources (IBAMA, 2010; BEUCHLE et al., 2015).

According to Bolfe et al. (2016), Bragança (2018) and Araújo et al. (2019), the increase in the use of high-capacity land, combined with the adoption of productivity-enhancing technologies, has enabled the Matopiba to present significant increases in its production levels and consequently economic development. However, according to Garcia and Vieira Filho (2018), approximately 68% of the agricultural expansion in the region between 2002 and 2014 resulted from conversion of native areas. In fact, according to Noojipady et al. (2017), the Cerrado current deforestation has been located mainly in these sparsely occupied areas, as is the Matopiba case, due to new agricultural frontiers, especially for soybean cultivation. In 2017, for example, the region accounted for approximately 11% of the national soy production, a figure that may increase in the future as the agricultural frontier in expands (ZANIN and BACHA, 2017; ARAÚJO et al., 2019).

The existence of underutilized and/or not yet occupied land, together with the agricultural frontier expansion and economic growth of the Matopiba, may boost the deforestation process in the region in the following years. To make matters worse, Garcia and Vieira Filho (2018) point out that due to inadequate soil management, the region has approximately 9 million hectares with moderate and 591 thousand hectares with high degree desertification. It is also worth mentioning that the agricultural frontier expansion in Matopiba faces some natural challenges, especially at transitioning areas with the Caatinga biome. Silva et al. (2016) argues that a transition area normally presents diverse ecosystems, climatic conditions and lower natural fertility. For example, the soybean is not suitable in regions with annual average rainfall below 1000mm, which occur in Cerrado areas near the semi-arid. In other words, the annual average rainfall acts as a natural barrier for the agricultural frontier expansion, a scenario that could be reversed, however, with the development of new varieties of soy that supports rainfall between 1000 - 800 mm, a technological innovation that could boost deforestation along with agricultural production in Matopiba (ARAÚJO et al., 2019).

In this context, the present paper aims to verify if there is a relationship between economic development, - which is correlated with the increase in agricultural production (BRAGANÇA, 2018) - and the Cerrado biome deforestation, with a special focus on the Matopiba, due to the agricultural frontier expansion in the region. This paper has four sections, including this introduction. In the second, we have an overview on the agricultural frontier expansion in Cerrado, while in third section the methodology and the database are detailed. The results and discussion are in fourth section, followed by final considerations.

2. The Cerrado Biome and the Agricultural Frontier Expansion

The Cerrado biome is present in several Brazilian states, with distinct proportions: Goiás with 97%; Maranhão, 65%, Mato Grosso do Sul, 61%; Minas Gerais, 57%; and smaller portions in the states of Mato Grosso, 40%; Piauí, 37%; Sao Paulo, 33%; Bahia, 27%; Paraná, 2%; and Rondônia with 0.2% (IBAMA, 2010). The Matopiba demarcation was elaborated by the *Empresa Brasileira de Pesquisa Agropecuária (Embrapa),* having as its main criterion the presence of the Cerrado in the four states, as well as other socioeconomics elements, which resulted in 337 municipalities with an area of 73 million hectares. The state with the highest percentage in the region is Tocantins with 37.95% (139 municipalities), followed by Maranhão with 32.77% (135 municipalities), Bahia with 18.06% (30 municipalities) and Piauí with 11.21% (33 municipalities) (EMBRAPA, 2017).

The Brazilian government played an active role in the occupation and expansion of the agricultural frontier in the Cerrado, which began in the 1970, especially after the *II Plano Nacional de Desenvolvimento (PND)*. In practice, the incentive for the Cerrado occupation, especially the Central-West, was through the advancement of the Agricultural Frontier (BECKER, 2001). The basic instrument used was subsidized rural credit offer, combined with the implementation of an infrastructure that enabled the territory occupation, especially for the production of agricultural commodities. Such incentives resulted in rapid changes in land coverage and use in the region (ASSUNÇÃO and BRAGANÇA, 2015; BRAGANÇA, 2018). In addition, colonization projects that granted land rights and subsidies, associated with the construction of roads, allowed the displacement of farmers to the region, intensifying the territory occupation. The colonization projects lasted from 1940 to 1980, characterized by a considerable increase in the Cerrado population, especially in the Central-West region (ALSTON et al., 1996; JEPSON, 2006; SANTOS et al., 2012).

Soybean, originally cultivated in southern Brazil, is the main crop that led to the agricultural frontier expansion in the Cerrado, especially after the 1960s. Initially, soy cultivation was inadequate for the region due to the characteristics of the Central part of Brazil, which were overcome after Government investments in agricultural research aimed to adapt this crop to the tropical climate and soil of the region, which was naturally acidic and poor in nutrients (SPEHAR, 1994; KIIHL and CALVO, 2008; ASSUNÇÃO and BRAGANÇA, 2015; MUELLER and MUELLER, 2016; ARAÚJO et al., 2019). In the 1970s, the Brazilian Central-West accounted for approximately 5% of the national soybean production, which increase to more than 40% in the 1990s. The migration of soybean farmers from the South region of Brazil explains considerable proportion of this cultivation increase in the Cerrado, as well as in other regions of the country. In other words, there is an interconnection between the advance of soy in the Cerrado and the migration of farmers from the South region. In addition, the literature points to empirical evidences that this phenomenon is still underway, with Matopiba being the main attraction region in recent periods (ZANIN and BACHA, 2017)

Table 1 shows the distribution and percentage of each type of land use and cover in the Cerrado from 1985 to 2015. Pasture, agriculture and pasture/agriculture presented a joint growth in land use of 10% in the period, which highlights the importance that agriculture and livestock has in the Cerrado occupation. However, this fact increased the pressure to open new areas intended for agricultural production, reflected in a reduction of 11% in the native forest area in the biome, a value that is practically similar to the joint growth of agriculture and pasture. This fact corroborates the hypothesis that the main driver of deforestation in the Cerrado is the agricultural frontier expansion.

It is worth mentioning that the decline in the biome's native forests presented a faster pace between 1985 and 2005, concomitantly with significant growth in the area devoted to agriculture and pasture. After 2005, both reduce their respective rates, indicating a relative stabilization in the land use and cover in the Cerrado. In addition, between 1995 and 2005, the area growth rate devoted to agriculture and pasture are approximately 6%, while the reduction in native forests are 5%. On the other hand, in the period of 2005 and 2015, agriculture and pasture grew 1%, with native forests also declining by 1%. This dynamic indicates a possible connection between changes in land use and deforestation, given its negative correlation.

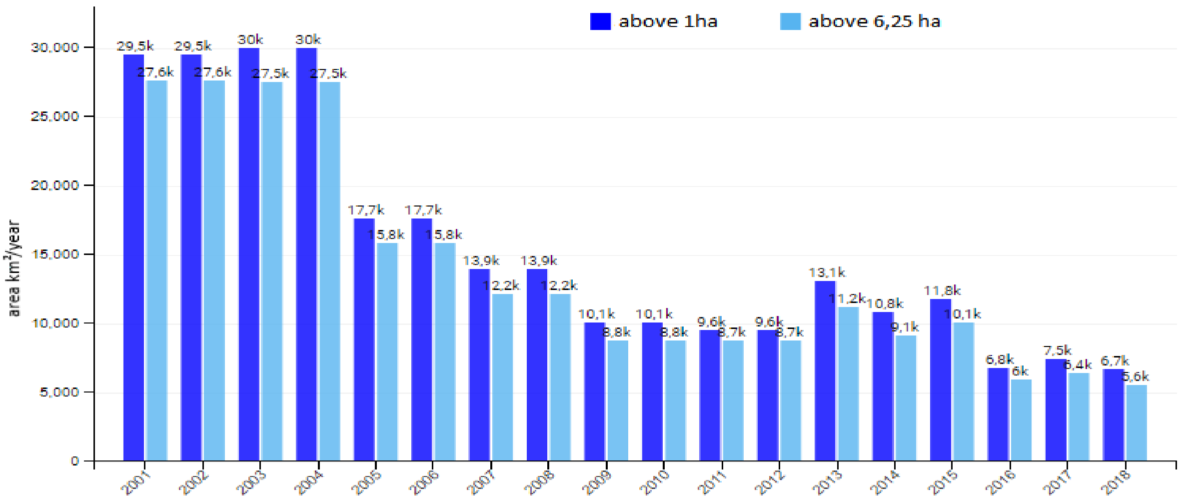
Table 1 - Land use and cover in the Cerrado from 1985 to 2015.

Class	1985		1995		2005		2015	
	Hectares	(%)	Hectares	(%)	Hectares	(%)	Hectares	(%)
Forest	112.736.620,67	0,56	103.397.324,69	0,51	94.372.623,95	0,46	92.163.330,48	0,45
Pasture	36.999.133,48	0,18	49.501.478,93	0,24	52.993.574,51	0,26	48.784.659,34	0,24
Agriculture	5.370.055,78	0,03	8.964.408,84	0,04	15.440.277,94	0,08	23.429.564,97	0,12
Pasture/Agricult*	22.297.905,12	0,11	14.734.388,63	0,07	13.820.613,12	0,07	13.162.889,26	0,06
Forestry	515.637,12	0,00	1.087.997,60	0,01	995.899,44	0,00	2.355.195,93	0,01
Water	1.189.881,00	0,01	1.217.313,33	0,01	1.535.092,89	0,01	1.568.446,22	0,01
Others	23.854.356,94	0,12	24.060.678,08	0,12	23.805.508,26	0,12	21.499.503,92	0,11
Total	202.963.590,11		202.963.590,11		202.963.590,11		202.963.590,11	

Source: Mapbiomas (2019). *Note:* * This corresponds to land use between agriculture and/or pasture that are not precisely identified. Its value declines over the period due to the improvement of the satellite images and methods.

To check how this scenario translated into actual deforestation, Figure 2 shows the annual deforestation in the Cerrado between 2001 and 2017 in area per km². We can note that in the period prior to 2005, the cleared area presented a rate of approximately 30,000 km² per year, while in the later period the deforestation decreased considerably, reaching a level of less than 7,000 km² in 2018. In addition, deforestation occurred predominantly in areas larger than 6.25 hectares, which could be due to the agricultural frontier expansion that occurred mainly in large agricultural properties. (BOLFE et al., 2016; ZANIN and BACHA, 2017).

Figure 2 – Cerrado deforestation between 2001 and 2018.



Source: TerraBrasilis – Cerrado (2019).

Despite this deacceleration, according to Soares-Filho et al. (2014) and Noojipady et al. (2017), changes in the Brazilian Forest Code (FC) legislation in 2012 may induce more deforestation in the Cerrado biome, especially in Matopiba, due to the no longer mandatory protection of 'hill top' areas in rural properties. In addition, the Forest Code established minimum amounts of reserves in private properties, with 35% for the Cerrado portion belonging to the Legal Amazon and only 20% for the rest of the biome, which are smaller than the current reserves in many rural properties of the region. For comparison purposes, rural properties located in the Amazonian biome should have 80% in legal reserves, a considerably higher value. In other words, the legislation itself can become an environmental degradation vector in the Cerrado biome.

In addition, the Soy Moratorium (SoyM), an industry effort to reduce deforestation in Amazon stemming from soy production after 2006, despite being successful in its goal, may have cause spillover effects on the Cerrado biome. This effort consisted of restrictions on market access to soybeans cultivated in recently deforested areas. However, the SoyM, along with the FC, led to an increased in the area cultivated in other regions, such as the Cerrado. This is an important spillover effect from the Amazon region leading the deforestation of Cerrado due the smaller restrictions applied to this region, in a 'cross-biome leakage' (MACEDO et al., 2012; GIBBS et al., 2015; NOOJIPADY et al., 2017).

In fact, Noojipady et al. (2017) points out that the soybean restriction in Amazonia, associated with SoyM and FC, is the reason why the growth of this crop is concentrated in the Cerrado, with a considerable part occurring due to forest areas reduction in rural properties. To illustrate this phenomenon, according to Gibbs et al. (2015), among the 14.2 million unprotected forest suitable for soybean cultivation in the Cerrado, approximately 2 million hectares can be deforested legally under the FC. In addition, about 23% of the soybean expansion in the biome between 2007 and 2013 occurred in forest areas, a figure that reaches 40% when considered Matopiba.

According to Bragança (2018), the agriculture expansion in the Cerrado has been also reallocating the rural organization of the region, with cropland inducing a decrease in cattle ranching. Barona et al. (2010), Arima et al. (2011), Macedo et al. (2012) and Richards et al. (2012) found evidence that this process is also occurring in the Legal Amazon. The authors argue that the increase in soybean production in Amazon, as well as in the Cerrado, has induced the advance of cattle raising to agricultural frontiers and, consequently, causing deforestation. In addition, we can mention Barona et al. (2010), Andrade de Sá et al. (2013) and Jusys (2017), who found evidence that an increase in sugarcane production for biodiesel production in the state of São Paulo, and to a lesser extent in other regions, also shifted livestock towards the agricultural frontiers, together with other non-fuel crops. In fact, Freitas Júnior and Barros (2018) confirms this advancement to the agricultural frontiers in Amazon and Cerrado, which presented a considerable higher cattle herd growth in the 1990-2015 period, when compared to others Brazilian regions. Therefore, changes in land use in the Cerrado impact not only this region, but also indirectly, and possibly the deforestation, in the Amazon.

In area terms, the state that presented greater deforestation of Cerrado is Sao Paulo, with about 90% of the total. Then, Mato Grosso do Sul with 75.87%, Federal District, 70.63%, Paraná, 70%, Goiás, 65.11%, Minas Gerais, 56.84%, Mato Grosso, 42.83%, Bahia, 36.45%, Tocantins, 26.4%, Maranhão, 22.85, Piauí, 15.1%, and, finally, Rondônia with 2.88% (IBAMA, 2010). Although the states belonging to the Matopiba are those with the smallest area deforested, the current Cerrado deforestation has been located mainly in these unoccupied areas due to the establishment of new agricultural frontiers (ARAÚJO et al., 2019). To reinforce this, Table 2 brings the ten municipalities that presented the largest deforested areas in the Cerrado in 2010. We can note that all are located in states belonging to Matopiba.

In this context, the Brazilian Government has been adopting measures to combat and inhibit the deforestation of Cerrado. In 2009, it released the *Plano de Ação para Prevenção e Controle do Desmatamento e das Queimadas no Bioma Cerrado (PCCerrado)*, which aims to reduce continuously and permanently the deforestation, forest fires and wildfires in the biome. In 2014, the second phase of the plan was launched for guiding actions to be taken, in addition to ratifying the importance of the natural resources' conservation. An essential element of the plan is the *Política Nacional de Mudanças Climáticas*, Law nº 12.187/2009, which seeks the reduction of greenhouse gas emissions in the atmosphere and reduce at least 40% of the deforestation in the biome. The Brazilian government also launched a program to monitor deforestation annually in the Cerrado, using Landsat satellite-derived spatial data (ARAÚJO et al., 2019).

Table 2 – Cerrado municipalities that presented greater deforestation in 2010.

Municipality	State	Suppression (km2)	Area (%)
Baixa Grande do Ribeiro	PI	394,29	5,05%
Uruçuí	PI	203,48	2,41%
Formosa do Rio Preto	BA	143,92	0,89%
São Desidério	BA	119,85	0,81%
Mateiros	TO	93,06	0,97%
Barreiras	BA	88,39	1,12%
Balsas	MA	85,24	0,65%
Santa Quitéria	MA	73,88	3,85%
Codó	MA	69,91	1,60%
Riachão das Neves	BA	68,81	1,18%

Source: IBAMA (2010)

Considering the Matopiba region, its intensive occupation for agricultural production begins in the 1980 and is still underway, which occurs due to the existence of many underutilized lands, which adopt low productivity production techniques. The region owns conditions that facilitate the occupation process as good climate for agriculture, flat land that enables the adoption of land productivity enhancing machinery, cheap labor, easy-to-fix soils and low-price land. In addition, we have many areas where native forests of the Cerrado prevail, which could be incorporate into the most dynamic areas of Matopiba, as the agricultural frontier advances. (BATISTELLA and VALLADARES, 2009; BOLFE et al., 2016; DIAS et al., 2016; NOOJIPADY et al., 2017; BRAGANÇA, 2018; ARAÚJO et al., 2019).

In terms of population, the Matopiba has about 6 million inhabitants, and 35% resides in the rural area, considerably above the Brazilian average of 15.3%. Among the region states, the most populous is the Maranhão with 57.6% of the total, followed by Tocantins with 25.30%, Bahia with 12.72% and 4.75% in Piauí (IBGE, 2010). In relation to the region's income, it presented a per capita value of only 40% compared to the Brazilian average, ie, R$8,000 against R$19.878,00 for Brazil. However, if considered only Tocantins and Bahia, the percentage would go up to approximately 60%, indicating a per capita income spatial heterogeneity between the regions that comprise the Matopiba (BOLFE et. al, 2016).

3. Methodology

3.1 Factorial and Cluster analysis

The factorial analysis, used to create the Socioeconomic Development Index (SDI), is an instrument that aims to summarize p variables, which are correlated with each other, in a number of k variables (with $k < p$,). Here, we used specifically, the Principal Components (PC) approach and the orthogonal rotation known as Varimax criterion by Kaiser (1958). Finally, we used two measures to check the sample quality: i) Kaiser-Meyer-Olkin (KMO) that is appropriate when $KMO > 0{,}8$ and the ii) *Bartlett* sphericity test, which presents a chi-squared distribution with $\frac{1}{2}p(p-1)$ degrees of freedom. So the farther away from one are the eigenvalues ($\hat{\lambda}_i = 1$), higher is T, indicating suitability. The factorials scores obtained indicates whether a particular factor contribute positively or negatively. From them, we calculated the Socioeconomic Development Index (SDI) with

$$SDI_m = \sum_{j=1}^{k} \frac{\lambda_j}{tr(P_{nxn})} F_{jm} \tag{1}$$

where, SDI_m is the municipality m index; λ_j is the j-th root characteristic of correlation matrix; k is the number of factors chosen; F_{jm} is the factorial load of the municipality from factor j; $tr(P_{nxn})$ is the correlation matrix P_{nxn} trace. We also restricted the values from 0 to 100, with

$$\overline{SDI_m} = \frac{(SDI_m - SDI_{min})}{(SDI_{max} - SDI_{min})} \times 100 \tag{2}$$

SDI_{min} is the smallest index found in (4) and SDI_{max} is the largest.

For cluster analysis, we use the Euclidean distance and the hierarchical technique, that consists of a grouping method that starts with as many groups as elements, $n = m$. From there, each sample element is grouped up to the limit that $n = 1$. The final choice of the number of groups are based on the Dendrogram, that shows all the agglomerations carried out of $n = m$ until $n = 1$. We also used the *Complete Linkage Method* to define the clusters, which is defined by the elements that are "less similar" to each other, so clusters will be grouped according to the largest distance between them.

3.2 Exploratory Spatial Data Analysis (ESDA)

The ESDA capture effects of spatial dependence and heterogeneity, association patterns (spatial clusters) and indicate how the data are distributed. The Moran's I are a statistics that seeks to capture the degree of spatial correlation between a variable across regions. Mathematically,

$$I_t = \left(\frac{n}{S_0}\right)\left(\frac{z_t' W z_t}{z_t' z_t}\right) \quad t = 1, \dots n \tag{3}$$

where n is the number of regions, S_0 is a value equal to the sum of all elements of matrix W, z is the normalized value of the variable of interest, Wz_t is the mean value of the normalized variable in neighbors according to W. However, the Moran's I statistic only capture global autocorrelation, not identifying association at a local level. In this context, we use the LISA (Local Indicator of Spatial Association) statistic, which are capable to capture local spatial autocorrelation and clusters,

$$I_i = z_i \sum_{j-1}^{J} w_{ij} z_j \tag{4}$$

z_i represents the variable of interest of the standardized region i, w_{ij} is the spatial weighting matrix element (W) and z_j is the value of the variable of interest in the standardized region j. We can also compute a correlation indicator in the context of two variables with

$$I^{yx} = \frac{n}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j (x_i - \bar{x}) w (y_i - \overline{y)}}{\sum_i (x_i - \bar{x})^2} \tag{5}$$

which is the Moran's I in the context of two variables.

3.3 Data and Descriptive Statistics

The deforestation and forest cover in the Cerrado comes from the *Projeto de Monitoramento do Desmatamento por Satélite (PRODES),* an official monitoring system carried out by the *Instituto Nacional de Pesquisas Espaciais (INPE).* We used 2010 as a reference for the variables due to the wide availability of data related to socioeconomic development of the municipalities from the Demographic Census and the Altas of Human Development. Table 3 reports the descriptive statistics, for Matopiba and for the Non-Matopiba municipalities of the Cerrado. We can notice considerable differences between the variables. Deforestation is four times larger in Matopiba the region has approximately 60% of remaining forest cover, twice compared to the rest of the Cerrado while Matopiba has half of the socioeconomic development.

Table 3 – Descriptive statistics.

Variable	Mean		Standard Deviation		Minimum		Maximum	
	Non-Matop.	Matopiba	Non-Matop.	Matopiba	Non-Matop.	Matopiba	Non-Matop.	Matopiba
DEFOREST	4.167042	16.14699	8.506893	26.3755	0	0	103.53	227.34
SDI	50.33009	26.87199	13.49983	12.8613	0.05	0	100	74.34
FOREST.COVER	0.3018216	0.602651	0.2014908	0.1997072	0.01	0.04	0.97	0.98

Source: research results. *Note:* Non-Matop. refers to 1,060 municipalities, excluding those in Matopiba (337).

Finally, the variables that compose the index are in Table 4, which comes from IBGE's Demographic Census and the Altas of Human Development, try to capture many dimensions of socioeconomic development.

Table 4 – Variables used in the factorial analysis model and their respective sources.

Variables		Source
Income_pc	Per capita income	ATLAS
Higher_education	Population with higher education (%)	IBGE
HDI_E	HDI_E – Human Develop. Index - Educational Dimension	ATLAS
HDI_L	HDI_L – Human Develop. Index – Life Expectancy Dimension	ATLAS
Labor_market	Formalization of the labor market (%)	ATLAS
Fertility_rate	Fertility rate	ATLAS
Child_mortality	Child mortality	ATLAS
Illiterate_pop	Illiterate population (%)	ATLAS
Primary_school	Population (over 18 years) without elementary school (%)	IBGE
Gini	Gini coefficient	ATLAS
Extremely_poor	Proportion of extremely poor people	ATLAS
Electricity	Population in households with electricity (%)	ATLAS

Source: research data.

4. Results and Discussion

The factorial analysis allowed the extraction of two factors with characteristic roots larger than one ($\lambda_i \geq 1$). The Table 5 shows the factors obtained, after the Varimax orthogonal rotation, with their respective characteristic roots, and the explained and accumulated variance. The two factors explain approximately 78.51% of the twelve variables variance, indicating that they managed to summarize them relatively well. According to Hair et al. (2009), a cumulative variance greater than 60% is satisfactory in social sciences. Therefore, the factors obtained represent, in fact, the Cerrado socioeconomic development.

Table 5 – Characteristic root, variance explained by factor and accumulated variance.

Factor	Characteristic root	Variance explained by the factor (%)	Cumulative variance (%)
F1	7.049	54.22	54.22
F2	3.157	24.29	78.51

Source: research data.

The Kaiser-Meyer-Olkin (KMO) test presented a value of 0,9072, meaning that the sample have a sufficiently high correlation for factorial analyses. The Bartlett's sphericity test also is statistically significant[2], rejecting the null hypothesis that the correlation matrix is equal to the identity matrix. Therefore, we can support that the sample is suitable for the method. Table 6 reports the factorial loads of each factor and variable uniqueness.

Factor 1 (F1) is related to nine variables, with a positive relation with five, and negative with four. Among the positive ones: Income_pc, per capita income; Higher_education, population with higher education (%); HDI_E, Human Development Index - Educational Dimension; HDI_L, Human Development Index – Life Expectancy Dimension; Labor_market. The variables mentioned are related to economic and social development, and the higher values, more the municipality is characterized as a locality that provides good material and social conditions for its population. The variables related negatively to Factor 1 are: Fertility_rate; Child_mortality; Illiterate_pop, Illiterate population (%); Primary_school, Population (over 18 years) without elementary school (%). High values for these variables are related to underdeveloped localities, justifying the inverse impact. Therefore, we called Factor 1, by capturing economic and social characteristics the *Indicator of Socioeconomic Development*.

Table 6 – Factorial loadings and commonality

Variables	Factorial loadings		Uniqueness
	F1	F2	
Income_pc	**0.9262**	-0.1750	0.1116
Higher_education	**0.9043**	0.0220	0.1817
HDI_E	**0.8168**	-0.3605	0.2029
HDI_L	**0.7907**	-0.4167	0.2012
Labor_market	**0.7468**	-0.4438	0.2453
Fertility_rate	**-0.5881**	0.5036	0.4005
Child_mortality	**-0.7354**	0.5465	0.2429
Illiterate_pop	**-0.8074**	0.4780	0.1197
Primary_school	**-0.8898**	0.2193	0.1601
Gini	-0.0833	**0.9029**	0.1777
Extremely_poor	-0.6249	**0.6498**	0.1230
Electricity	0.3260	**-0.6843**	0.4254

Source: research data.

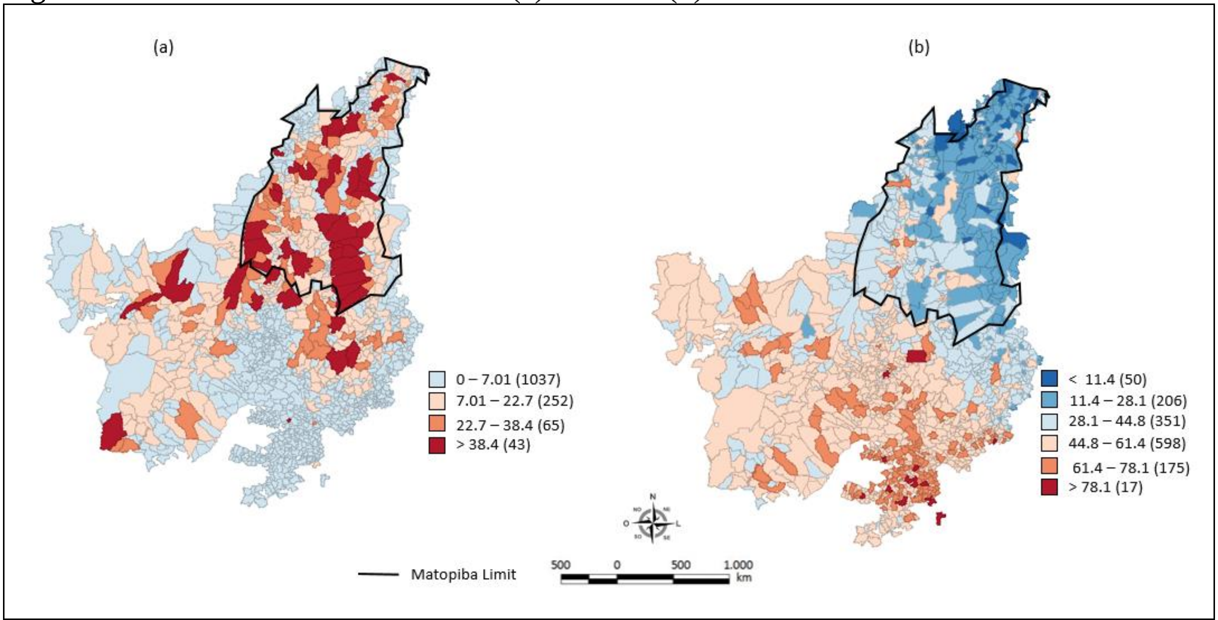
Factor 2 is related to three variables, two with a positive impact: Gini, Gini coefficient, and, Extremely_poor, proportion of extremely poor people. The one with negative impact is Electricity, Population in households with electricity (%). Therefore, Factor 2 is negatively related with the economic and social development of municipalities. We called Factor 2 as *Indicator of Socioeconomic Underdevelopment;* municipalities with a high value for this indicator, present lower development. Finally, we built the SDI with the factorial scores of each municipality.

The Figure 3 shows the spatial distribution of deforestation (Figure a) and the SDI (Figure b). We note that municipalities with high cleared area (Figure a) are concentrated in three parts of Matopiba, in western Bahia, the central area of the region and in the northern part

[2] Chi-square: 2.4310,139; Degrees of freedom: 66; p-valor: 0,000

of Maranhão. Araújo et al. (2019) argue that these regions, especially the first two, have undergone an intense modernization of their agricultural activity, especially in soy cultivation, resulting in significant increases in its production and yield after 2000s, a fact that is linked to the region's deforestation.

Figure 3 - Distribution of deforestation (a) and SDI (b) in Cerrado.

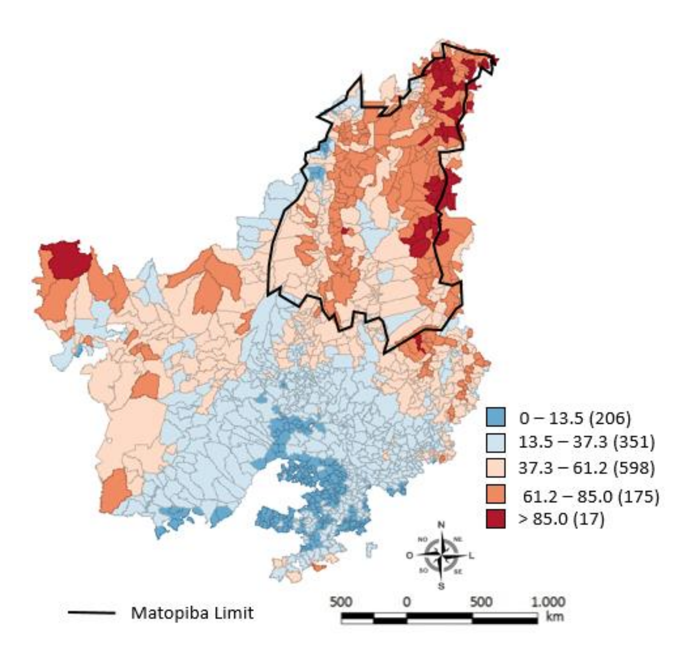


Source: research data.

We can also identify, although with less intensity, regions of Mato Grosso and Mato Grosso do Sul states that have deforested significant parts of their natural area. The cultivation of soybeans and cattle raising are advancing on both states, a fact that may have resulted in deforestation of their native forests (FREITAS JÚNIOR and BARROS, 2018; ARAÚJO et al., 2019). On the other hand, municipalities with low deforestation are located mainly in the states of São Paulo, Paraná and parts of Minas Gerais and Goiás. However, according to Mapbiomas (2019), these states cleared most of their forest areas, a fact that can explain their relative lower deforestation. Considering the SDI (Figure b), the Cerrado is divided into two areas with different development levels; municipalities with high socioeconomic development are located essentially in the states of São Paulo and in southern regions of Minas Gerais. On the other hand, underdeveloped municipalities are located mainly in the Matopiba region, as well as parts of northern Minas Gerais. These corroborate Bolfe et al. (2016) and Bragança (2018), which characterized Matopiba as a region with lower socioeconomic development compared to the other parts of Cerrado. Despite this, the authors emphasize that, due to the advancement of the agricultural frontier, the region has presented higher economic growth rates, a fact that has diminished the disparities.

A possible explanation for the deforestation and development spatial distributions may be the occupation and colonization process of Cerrado. The developed regions, which matches those with lower deforestation, are concentrated in parts of the Central-West and Southeast. These were the first to receive the migratory waves in the 1940s, encouraged by the concessions of land rights, subsidies and the construction of a basic infrastructure, especially roads (ALSTON et al., 1996; JEPSON, 2006; SANTOS et al., 2012). According to Zanin and Bacha (2017), this phenomenon is still underway, with Matopiba being the main migratory destination in Cerrado after 2000s.To check this fact, Figure 4 reports, in percentage terms, the forest remnants of the Cerrado biome. In fact, most of the municipalities with more than 60% of their territory covered by forest areas are located in Matopiba or adjacent regions, which may relate to the migratory waves in Cerrado. In addition, considerable parts of Matopiba are concentrated in a transitional area to the Caatinga biome and, according to Silva et al. (2016), it normally presents diverse ecosystems, climatic conditions and lower natural fertility. Araújo et al. (2019) argues that soybean cultivation, the main driver of Matopiba occupation, is suitable only in areas with annual average rainfall above 1000mm, which does not occur in areas near the semi-arid. The future of agricultural expansion in this region depends on the development of new varieties of soy that supports rainfall between 1000 - 800 mm and, if this occurs, we can expect profound land use changes with reductions in forest cover.

Figure 4 – Distribution of the remaining forest cover (%) in Cerrado.



Source: research data.

The concentration of deforestation and development is visible in Figure 3, indicating the existence of spatial patterns, which may result in spatial autocorrelation and heterogeneity. To verify this hypothesis, Table 7 presents the Moran's I statistic for these variables, according to several spatial matrices' conventions. We confirm the existence of spatial interactions for both variables, since all values are positive and statistically significant regardless of the convention adopted, indicating that deforestation and / or SDI are spatially concentrated. Theoretically, spatial concentration may result from spatial spillovers, resulting from productive links and from human and physical capital concentration.

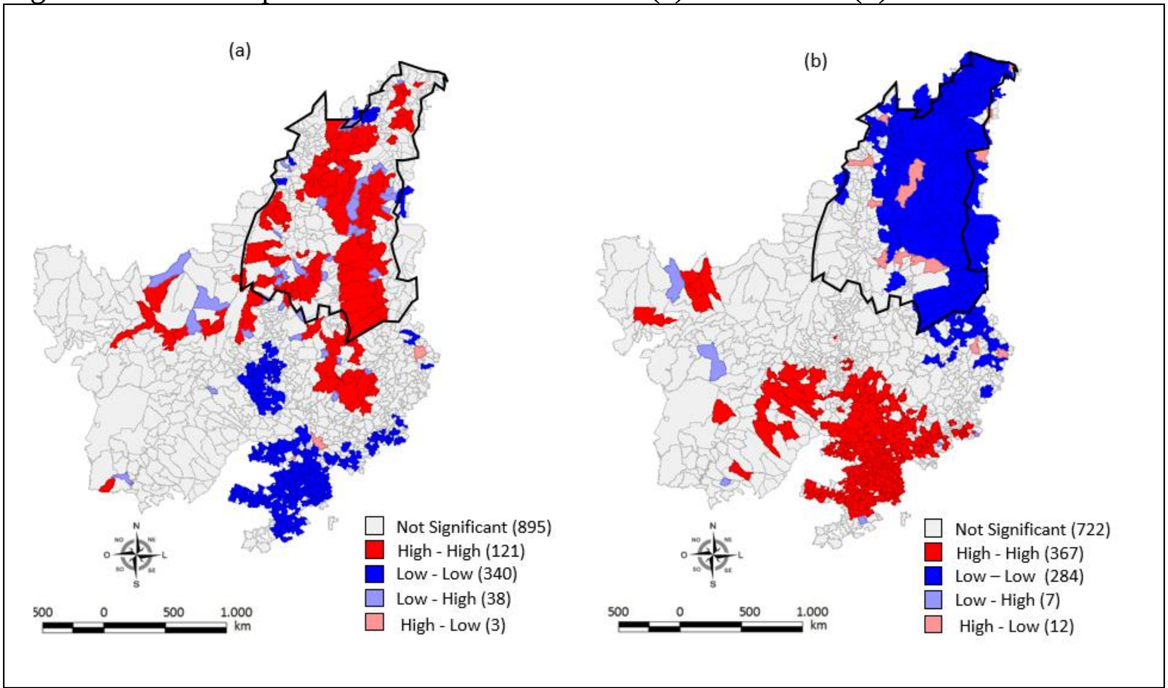
Table 7 **-** Moran's I for deforestation and for SDI in the Cerrado.

	Weights Matrix					
	Queen	Rook	Three neigh.	Five neigh.	Seven neigh.	Ten neigh.
Deforestation	0.31*	**0.32***	0.26*	0.22*	0.25*	0.21*
SDI	0.54*	0.54*	**0.56***	0.55*	0.55*	0.56*

Source: research data. *Note*: * Level of significance of 1%.

Figure 5 shows the LISA maps of spatial clusters for deforestation and SDI. We have two significant clusters for deforestation (Figure a) in the Cerrado region, one Low-Low and another High-High. The low deforestation cluster is located in the Southeast, composed by municipalities of the states of Sao Paulo and parts of Minas Gerais and Goiás. The high deforestation clusters, on the other hand, are concentrated especially in Matopiba, in two autocorrelated blocks: one in western Bahia and the other in the central part of the region. In addition, we have some extensions of these clusters, especially in west of Tocantins and Northwest of Minas Gerais. One important aspect is that the spatial clusters identified for the deforestation rate are not located in the same regions as the clusters for the socioeconomic development. The Matopiba, for example, presents a spatial concentration for deforestation at the same time that is a region with low SDI, while the opposite occurs for the Southeast region. This fact is in line with this paper's hypothesis, that there is a negative relation between deforestation and socioeconomic development. However, as we observed in Figure 4, the forests availability in the municipality may also be one an important responsible for this phenomenon.

Figure 5 – LISA map for deforestation in Cerrado (a) and for SDI (b).



Source: research data. *Note*: Empirical pseudo-significance based on 99,999 random permutations.

Table 7 presents the univariate Moran's I for the variables as well as its bivariate Moran's I in relation to deforestation. The purpose of bivariate statistics is to check whether some specific attributes of neighboring municipalities are autocorrelated spatially with deforestation. We can notice that spatial autocorrelation, in both univariate and bivariate Moran's I, changes when the Cerrado is divided into the Matopiba and Non-Matopiba. This relationship means that we have different spatial patterns according to the region considered, a fact that corroborates the previous descriptive analysis. For example, the relationship between deforestation and socioeconomic development variable is negative and significant in the municipalities located at the Non-Matopiba region while in Matopiba there are no significant spatial relation. This phenomenon indicates spatial heterogeneity within the Cerrado biome.

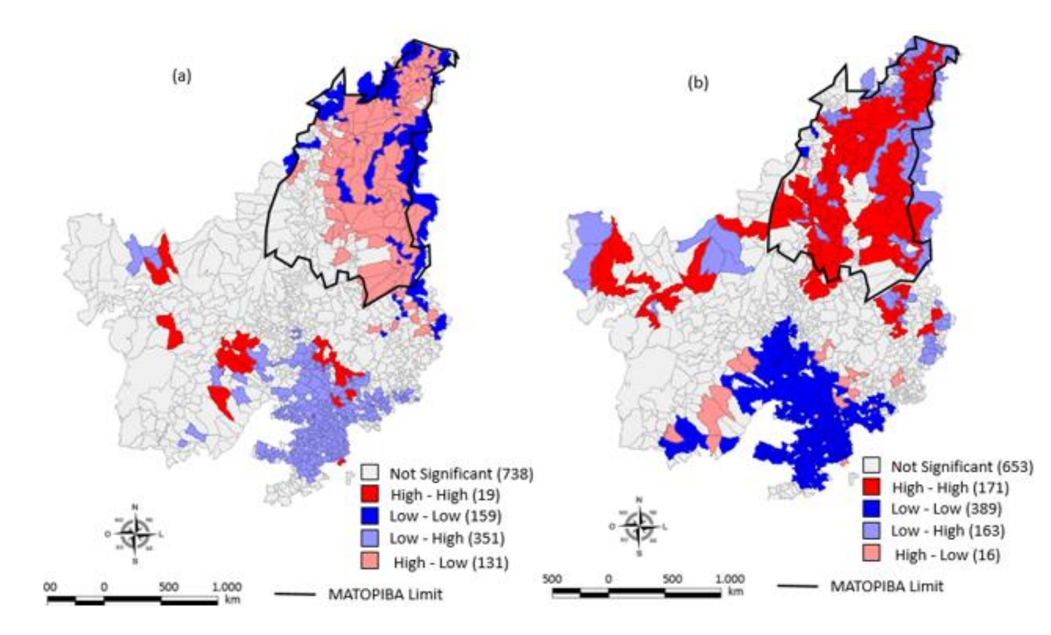
Table 8 - Univariate and bivariate Moran's I.

Variable	Cerrado		Matopiba		Non-Matopiba	
	Univariate	Bivariate	Univariate	Bivariate	Univariate	Bivariate
DEFOREST	0.3976*	-	0.3176*	-	0.3791*	-
SDI	0.7726*	-0.2484*	0.5651*	**0.0020**	0.6839*	-0.1699*
FOREST.COVER	0.8657*	0.2780*	0.7701*	**0.0597**	0.8671*	0.2511*

Source: research data. *Note*: Empirical pseudo-significance based on 99,999 random permutations; * significance of 1%.

Seeking to break the bivariate relationship locally, Figure 6 reports the local bivariate LISA for the deforestation in relation to the SDI (a) and forest cover (b). As expected, the low-high (LH) and high-low (HL) spatial clusters, in figure (a), showed a greater number of significant municipalities, compared to low-low (LL) and high-high (HH): 73.03% against 26.93%, respectively. In summary, the bivariate spatial cluster presents: (i) an inverse relationship between the variables; (ii) or a low value for both. In the first case (i), the relationship is in line with the hypothesis that high deforestation is associated with low socioeconomic development (and vice versa). In figure (b), on the other hand, 75,77% of the bivariate relationship between deforestation and forest cover are low-low (LL) or high-high (HH), indicating a positive spatial relationship. In addition, we can note a clear spatial pattern: the majority of the HH clusters occurs in the Matopiba, the current agricultural frontier in Cerrado, and the LL clusters are mostly in the southern part, which has less remaining forest areas. In this context, developed municipalities may deforest less because they do not have much remaining forest area to do it.

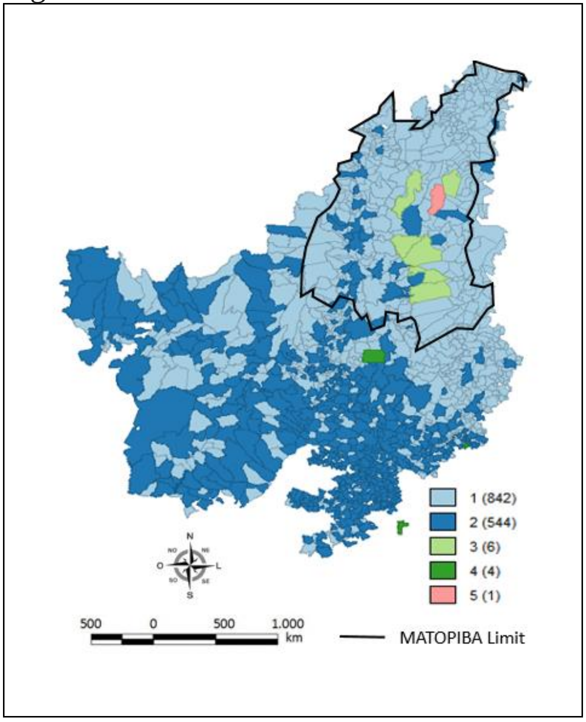
Figure 6 – Bivariate LISA map for Deforestation and SDI (a); Forest Cover (b) in Cerrado.



Source: research data.

However, it is worth mentioning that spatial clusters are significant only when they assume a certain spatial pattern, with municipalities necessarily having to be neighbors of each other. In cluster analysis, on the other hand, the neighborhood relation is not necessary; two municipalities may be located on opposite sides of the Cerrado, but still belong to the same cluster. According to Mingote (2005), the multivariate technique groups information according to some criterion, not disregarding information as in the spatial context. In this paper, we used the Complete Linkage Method, which classifies the clusters according to a criterion of dissimilarity, that is, it groups municipalities with high socioeconomic development and low deforestation (and vice versa). We used clusters analysis as a complementary methodology, once this technique is able to capture relationships that the ESDA cannot. In this paper, we selected five clusters, which are in Figure 7. Two groups captured most of the Cerrado municipalities; the largest one is Cluster 1 that has 842 municipalities (60.27% of the total) while the second, the Cluster 2, has 544 municipalities (38.94% of the total). Therefore, both has approximately 99.21% of the total, which represents the great majority of the municipalities belonging to the Cerrado biome.

Figure 7 – Clusters distribution.



Source: research data.

To better verify the characteristics of each Cluster, Table 9 shows the mean value for deforestation and the Socioeconomic Development Indicator (SDI) in each group as well as for all the biome. Cluster 1 presented a below-average value for SDI and, at the same time, above-average value for deforestation rate. The Cluster 2 presented an inverse figure, having high socioeconomic development and low deforestation. Therefore, high deforestation is linked to municipalities with low socioeconomic development (and vice versa), corroborating this paper’s hypothesis.

Table 9 – Deforestation and SDI mean for the five clusters

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cerrado
Deforestation	4,78	2,41	122,32	1,20	394,29	4,63
SDI	24,36	45,83	29,98	91,30	15,24	32,93
Municipalities	842	544	6	4	1	1397

Source: research data.

In any case, Cluster 3 and 5 have municipalities with deforestation rates considerably above the region average and lower levels of socioeconomic development. These municipalities are mainly located in Matopiba, especially western Bahia, possibly indicating the environmental impacts of the agricultural frontier expansion in the region. In fact, according to Araújo et al.

(2019), the western Bahia have undergone an intense modernization of their agricultural activity, especially of soy, which resulted in forest conversions and land use changes. On the other hand, municipalities with high development and low rates of deforestation compose Cluster 4.

In summary, both spatial and clusters analysis indicate the presence of spatial patterns and heterogeneity in Cerrado, specifically with low socioeconomic development relating to higher deforestation rates.

3.6 Final considerations

The main purpose of this paper was to investigate the relationship between socioeconomic development and deforestation in the Cerrado biome, with a special focus on the current Brazilian agricultural frontier, known as Matopiba. For socioeconomic development, we created a Socioeconomic Development Index with factorial analysis from multivariate statistics. The ESDA and cluster analyses techniques pointed to a spatial concentration and heterogeneity for deforestation and socioeconomic development in Cerrado. Specifically, there are two heterogeneous regions on Cerrado, which we can highlight the Matopiba region that presents different characteristics when compared to the remaining municipalities in Cerrado.

In this context, agricultural and environmental policies have to consider this spatial concentration and heterogeneity, since these spatial effects may induce different policies outcomes for each region. Therefore, any actions have to take into account possible mixed results, especially for Matopiba since it is at the beginning of its occupation and agricultural expansion process, differently from many Cerrado regions, that initiated it decades ago and are already consolidated, both economically and environmentally. Therefore, these empirical evidences can help to identify the deforestation different stages, possible outcomes and to construct focused agricultural and environmental policies that consider heterogeneous characteristics along with spillovers and heterogeneity effects.

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