Land Use Efficiency or Vulnerable Population Exclusion? A Critical Examination of Land Consumption and Population Growth under the Agricultural Expansion Context in Brazil

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Abstract

The balance between urban population growth and land consumption is a primary challenge in achieving land use efficiency in Global South countries. A common urbanization trend in these nations involves the expansion of settlements on their periphery, which further exacerbates this challenge. This is the case in Brazil, and SDG 11.3.1 can provide a clearer insight into this spatial-demographic process. This target specifically quantifies the land consumption rates to population growth rates, and it was not successfully measured in Brazil. This study analyzes thirty years of land consumption and population growth patterns in fifty municipalities in the Amazon-Brazilian Savanna ecotone region – two crucial biomes for ecosystem balance and population subsistence in Brazil. The methodology was applied according to the 11.3.1 Indicator, aiming to quantify the Ratio of Land Consumption Rate to Population Growth Rate (LCRPGR). Official Census data was used to quantify the urban population, while ancillary spatial data and time series classification products of land use and cover change were used to quantify urban areas in the regions. The results showed an increasing population density trend with a significant regional disparity between the municipalities. From 2001 to 2021 the LCRPGR values ranged from 1.2 to 0.004, where values >1 indicate decreasing urban density, while values <1 indicate increasing urban density. Here, the socioeconomic and spatial inequality within these urban areas is analyzed considering the ecotone region's agricultural expansion context which also collaborates to an aligned analysis of the land-use efficiency concept.

Introduction

Globally, urbanization is a growing phenomenon. Today, 54 percent of the world's population lives in urban areas (United Nations 2019). This trend is predicted to continue, with urban inhabitants estimated to constitute 66 percent of the global population by 2050 (United Nations 2019; Kourtit, Nijkamp, and Partridge 2013; Satterthwaite 2000). In the Global South, Brazil's urbanization pattern stands out, considering that, despite being only 36 percent urban in 1950, the nation underwent a significant transformation. By 2018, 87 percent of its 211 million inhabitants resided in urban areas. This shift highlights Brazil's role as a significant contributor to the broader regional and global trends of urbanization (United Nations 2019).

The increase in urban residents raises several important questions. It must be considered whether these populations are adequately settled with access to basic services, and economic and social opportunities and whether their living conditions promote environmental sustainability. In the case of Brazil, urban development and expansion occur in a spatially asymmetric manner. They are deeply influenced by a variety of factors including the local and regional historical development, economic context, availability of natural resources, governmental policies, participation in the global capitalist trade market, and population migration patterns (Martine and McGranahan 2010). As a result, urban areas in Brazil show contrasting degrees of infrastructure and economic and social development. This leads to regions that are poorly connected to the urban center, having no easy access to basic services. Consequently, population spatial distribution tends to align with socio-economic status, with vulnerable populations often residing on the peripheries of these urban regions (Hogan 2005; Frederico 2012; Benachio 2018; Alves 2019).

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This increasing urban population and spatial inequality unfolding process is the scenario of the urban areas in the transition zone between two important Brazilian biomes: the Amazon and Cerrado (Brazilian Savanna), also known as the Amazon-Cerrado Ecotone region (ACE). The boundary region incorporating the ACE biomes constitutes the largest interface between tropical forests and savanna worldwide, with the Cerrado recognized as the most biodiverse savanna globally (Brando et al. 2013; Marengo, Jimenez, Espinoza, et al. 2022). However, despite its ecological importance, this region is facing intense pressure due to land-use changes driven by the expansion of agribusiness (Marengo, Jimenez, Espinoza, et al. 2022). Among the states within this region, Mato Grosso is an important contributor, being one of the major suppliers of agricultural commodities, including soybean and meat (Marengo, Jimenez, Espinoza, et al. 2022).

Agricultural expansion has been one of the main reasons for the increased environmental pressure on agricultural frontiers in Brazil and worldwide in recent years, being responsible for 40 percent of deforestation in tropical areas (Spiri 2022). This expansion is also connected to population growth in municipalities in the Legal Amazon region, which includes municipalities in the ACE region (Frederico 2012; Khan and Silva 2023). Studies have shown that there is a positive relationship between the increasing number of inhabitants in municipalities and increasing deforestation areas in the Legal Amazon region (Khan and Silva 2023). Agribusiness capital and technology-intensive monocultures have taken over these areas since the 1970s, replacing natural vegetation (mainly Amazon and Cerrado transition mixed vegetation), and traditional farming practices (carried out by rural communities and/or smallholder farms) (Cunha 2006; Pequeno and Frederico 2016). The growing need for services to sustain the productivity of the agricultural sector primarily drives the urbanization of the agricultural frontiers. Cities have become hubs for service offers and consumption for the agricultural sector, allowing its integration with the global exporting market. In essence, cities have transformed into the operational centers of modern agricultural production.

As a result of such conjuncture, urban regions in the ACE region have central areas equipped with public systems such as hospitals, wastewater collection systems, public transportation, and a range of private services. Also, the city center tends to offer the most diverse set of employment opportunities. This dynamic leads to a pattern where economically disadvantaged citizens migrate to the periphery areas (Pequeno and Frederico 2016; Elias and Pequeno 2007; M. Santos 2003). These disadvantaged populations are involuntarily displaced from the rural areas, and central regions due to urban growth and property agricultural market pressures, which are often linked to the interests of the agricultural sector (Benachio 2018).

The present study will analyze thirty years of agricultural land consumption and population growth patterns in municipalities in the ACE region. For developing this analysis, the Sustainable Development Goal (SDG) "11.3.1 Indicator: Ratio of Land Consumption Rate to Population Growth Rate (LCRPGR)" was chosen. This indicator can provide a clearer insight into this spatial-demographic process, which has not been measured in Brazil. Hence, this analysis explores the concept of land-use efficiency, which relates to how effectively cities use land, with compact cities typically demonstrating higher efficiency due to adequate resource management and cost-effectiveness (United Nations Human Settlement Programme (UN-Habitat) 2018). This study is conducted within the ACE region's historical, social, economic, and environmental contexts. Therefore, this approach allows to correctly interpret the indicator with the unique local, regional, and global realities that the ACE region is part of. Tracking this SDG indicator can guide and assist policymakers and practitioners to better understand the spatial and demographic dynamic in the ACE region. At the same time, contextualized land use efficiency concepts can provide realistic and fine-tuned solutions.

Material and Methods

Study Area

The study area comprises 50 municipalities in the transition region between the Amazon and Cerrado biomes (ecotone region) in the Mato Grosso state (Fig. 1). Previous studies regarding the Amazon-Cerrado ecotone region were used as a reference to delimitate a transition zone of 100 kilometers around the official line dividing the Cerrado and Amazonia biomes according to the Brazilian Institute of Geography and Statistics (IBGE) (Marengo, Jimenez, Espinoza, et al. 2022; Maciel, Oliveira-Filho, and Eisenlohr 2016; Marques, Marimon-Junior, Marimon, et al. 2020; Instituto Brasileiro de Geografia e Estatística (IBGE) 2004).

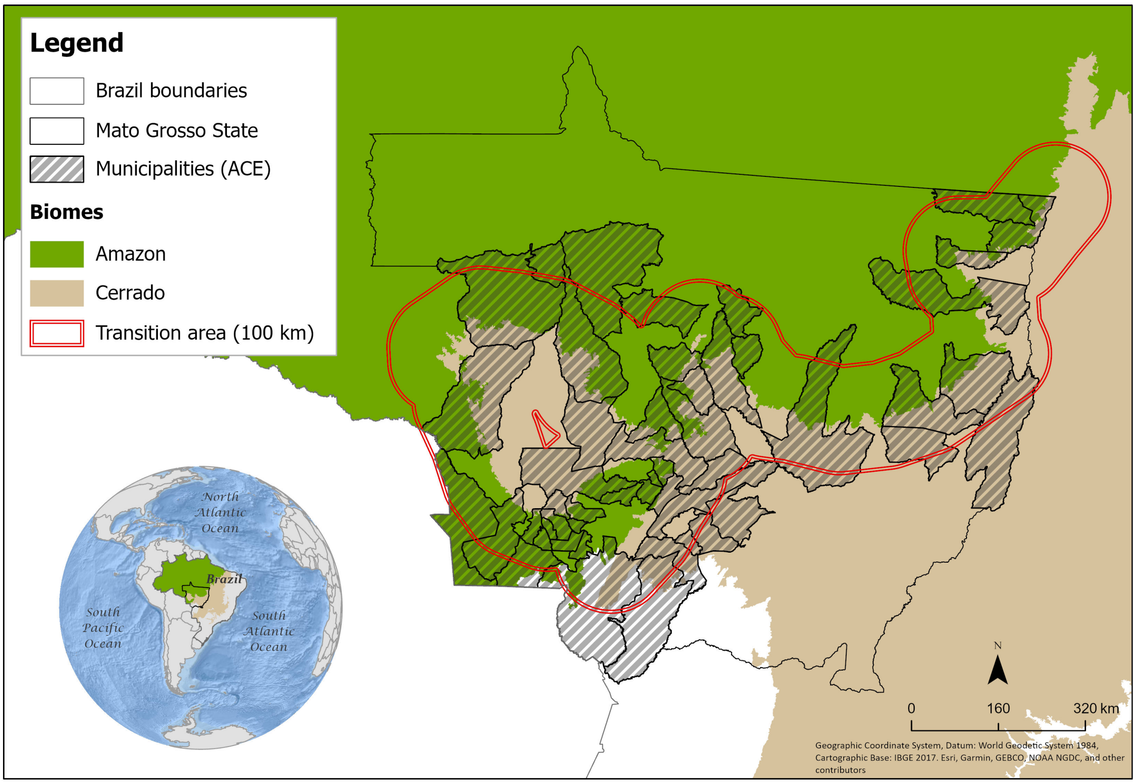

Figure 1: *The study area is composed of 50 municipalities within the ACE region in the Mato Grosso State (MT), in Brazil.*

The selection criteria for the municipalities included: being fully or partially located in the 100-kilometer transition zone buffer, being located entirely within the state of Mato Grosso, having demographic data available since 1991, and having spatial data available since 1991.

Data Collection and Preprocessing

Demographic Data

The population data were obtained from the official government agency, the Brazilian Institute of Geography and Statistics (IBGE), through the Automatic Recovery System (Sistema IBGE de Recuperação Automática) - SIDRA. The SIDRA database is a comprehensive source of socioeconomic and demographic data about Brazil, containing extensive information about various aspects of the Brazilian population, geography, economy, and social topics.

SIDRA includes not only census data but also information from diverse demographic surveys conducted by IBGE. In the context of this study, SIDRA was used to gather urban population data across the municipalities in the ACE region for the years 1991, 2000, and 2010. This data was then used to analyze and compare the population growth rates over these periods and allowed the estimation of urban population data for the years 2001, 2011, and 2021. The dataset used to carry out this study was "Table 200 - Resident population, by sex, situation, and age groups - Sample - General Characteristics of the Population". Here, the urban population was selected for the municipalities in the respective years under analysis. This is the main input data for calculating the urban population growth over the three decades.

Spatial Data

The spatial data were obtained through Google Earth Engine (GEE) API using the Jupyter Lab interface. The dataset used to calculate urban areas through the years under analysis was the Mapbiomas Land Use and Cover Collection (MapBiomas 2022). The MapBiomas Project offers precise data on land cover classification every year, with a resolution of 30 meters. This level of detail enables accurate representation and analysis of land cover and land use patterns across Brazil on different scales.

The correspondent urban classification in the ACE municipalities over the years 1991, 2001, 2011, and 2021 were selected and the total urban area was calculated for each year. This is the main input data for calculating the land consumption rate over the same period.

SDG Indicator 11.3.1

The indicator under consideration in this study is the Ratio of the Land consumption Rate to the Population Growth Rate (LCRPGR). For a better understanding of this indicator, a clear definition of two key components is needed: population growth and land consumption rates.

Population Growth Rate (PGR) refers to the change in population over a specific period of time, usually one year. It reflects the number of births and deaths during a period and the number of people migrating to and from the focus area. In SDG 11.3.1, this is computed at the area defined as urban/city. The PGR is calculated by comparing the population size at a past point in time with the population size at the current or in a considered final period of time, considering the difference between the years under analysis (United Nations Human Settlement Programme (UN-Habitat) 2018).

Mathematically, it's often represented as follows in Equation 1:

$$PGR = \frac{\ln\left(\frac{Pop_{t+n}}{Pop_t}\right)}{y} \tag{1}$$

Where:

- LN is the natural logarithm value;
- Pop_t is the total population in the past/initial year;
- Pop_{t+n} is the total population in the current/final year;
- y is the number of years between the two measurement periods.

The Land Consumption Rate (LCR) is the other crucial component of the 11.3.1 indicator. In this context, land consumption refers to the conversion of land from non-urban to urban uses, marking its uptake by urban development. Accordingly, the land consumption rate usually represents the annual rate of change in land occupation by a city or urban area, denoted as a percentage of the city's total land area at the beginning of that period. The result is the measure of the pace at which urban land area expands over time (United Nations Human Settlement Programme (UN-Habitat) 2018).

$$LCR = \frac{V_{\text{present}} - V_{\text{past}}}{V_{\text{past}}} \cdot \frac{1}{t} \tag{2}$$

Where:

- V_{present} is the total urban area in the current year;
- V_{past} is the total urban area in the past year;
- t is the number of years between V_{present} and V_{past} (or the length in years of the period considered).

And finally, the Land Consumption Rate per Population Growth Rate (LCRPGR) is calculated as follows in Equation 3:

$$LCRPGR = \frac{LCR}{PGR} \tag{3}$$

In the LCRPGR values >1 indicate decreasing urban density, while values <1 indicate increasing urban density. In the UN methodology proposal, PGR is calculated as a log, while LCR is not. Generally, the logarithmic method is used for calculating population growth rates over multiple periods because it correctly accounts for the compounding effect. In the context of population growth, the compounding effect refers to the phenomenon where the population grows not exclusively from the original (or principal) amount but also from the growth it has accumulated over the years (David-Barrett 2019; Preston, Heuveline, and Guillot 2001). On the other hand, the UN methodology uses the linear method for calculating the land consumption rate (LCR). To use consistent methods when directly comparing or combining different metrics such as LCR and PGR, here it was adopted the linear method for both to ensure the proper comparison between them (Equation 4).

$$PGR = \frac{\left(\frac{Pop_{t+n}}{Pop_t}\right)}{y} \tag{4}$$

The linear method was chosen for calculating both the PGR and LCR due to its consistency and comparative utility. However, it's important to acknowledge the existence of a compounding effect — each period's population is dependent on the prior period's, accounting for any growth or decline — and the linear method offers clear advantages when dealing with this data. Given the complex and varied nature of the data, and the aim to track actual change over time rather than hypothesize a constant rate of change, the linear method simplifies understanding of temporal changes in land consumption change and population growth patterns.

Data Analysis

The calculation of urban areas for each municipality was performed through retrieved classified pixels from Mapbiomas Collection images in the years 1991, 2001, 2011, and 2021. The following procedure was applying the LCR formula. In sequence, the demographic data of the urban population was obtained for each municipality through the SIDRA database. The available demographic census data were regarding 1991, 2000, and 2010 years. Aiming to have the population data in the same corresponding years of LCR calculations, first, it was calculated the urban population growth rates between 1991-2000 and 2000-2010 using a linear formula of population growth rate (Equation 5).

$$PGR_{t_1}^{t_2} = \frac{Pop_{t_2} - Pop_{t_1}}{t_2 - t_1} \tag{5}$$

Where:

- $PGR_{t_1}^{t_2}$ is the annual population growth rate from year t_1 to year t_2;
- Pop_{t_2} is the total population size in year t_2;
- Pop_{t_1} is the total population size in year t_1;
- $t_2 - t_1$ is the number of years between the two measurement periods.

In sequence, the urban populations for the years 2001, 2011, and 2021 were projected as shown in Equation 6 by using the annual population growth rate previously calculated (Equation 5).

$$Pop_{t_2} = Pop_{t_1} + PGR_{t_1}^{t_2} \cdot (t_2 - t_1) \tag{6}$$

Where:

- Pop_{t_2} is the projected total population size in year t_2;
- Pop_{t_1} is the total population size in year t_1;
- $PGR_{t_1}^{t_2}$ is the annual population growth rate from year t_1 to year t_2;
- $t_2 - t_1$ is the number of years between the two measurement periods.

For each municipality and respective year analyzed, the LCR and PGR were calculated. The next steps involved applying the LCRPGR formula and presenting the results through maps and graphs, which will be shown and discussed in the following sections.

Results

From 2001 to 2021, the population growth and urban expansion rates in the analyzed municipalities have transformed significantly. The median annual population growth rate (PGR) slowed down, going from 12.4 percent in 2001 to 11.2 percent in 2021. The annual median land consumption rate (LCR), which indicates urbanization trends, also decreased, dropping from 1.88 percent in 2001 to 1.23 percent in 2021. Urbanization slowed down faster than population growth, as seen in the decrease of the median LCRPGR from 16.2 percent in 2001 to 10.5 percent in 2021. This means that less urban land is being used per unit of population growth, which suggests an increase in population density. To analyze the central tendency and variability of the PGR, LCR, and LCRPGR data, statistical measurements such as mean, median, standard deviation, and percentiles were used (Tab. 1). The standard deviations for PGR, LCR, and LCRPGR decreased over the study period, indicating that these rates are becoming more similar across municipalities. The spatial patterns of the LCRPGR for the years 2001, 2011, and 2021 are shown in sequence (Fig. 2, Fig. 3, Fig. 4).

In 2001, the LCRPGR had a mean value of around 0.229. This indicates that a population increase by one person was associated with 22.9 percent of a unit of land being consumed. It's worth highlighting that this was significantly higher than the subsequent years of 2011 and 2021, indicating a greater change

Summary of statistical measures for the Population Growth Rate (PGR), Land Consumption Rate (LCR), and LCR times PGR (LCRPGR) in the years 2001, 2011, and 2021.

	PGR 2001	LCR 2001	LCRPGR 2001	PGR 2011	LCR 2011	LCRPGR 2011	PGR 2021	LCR 2021	LCRPGR 2021
MEAN	0.165	0.032	0.229	0.124	0.016	0.129	0.114	0.015	0.123
MEDIAN	0.124	0.019	0.162	0.115	0.012	0.098	0.112	0.012	0.105
STD	0.122	0.038	0.274	0.036	0.015	0.11	0.018	0.01	0.078
0.25 percentile	0.102	0.01	0.082	0.105	0.007	0.059	0.105	0.007	0.071
0.5 percentile	0.124	0.019	0.162	0.115	0.012	0.098	0.112	0.012	0.105
0.75 percentile	0.176	0.04	0.232	0.135	0.02	0.154	0.126	0.02	0.173

Table 1: *Summary of the key statistical measures for the Population Growth Rate (PGR), Land Consumption Rate (LCR), and LCR times PGR (LCRPGR) across the geographical areas under study in the years 2001, 2011, and 2021. Each column in the table corresponds to a specific metric (PGR, LCR, LCRPGR) for a specific year (2001, 2011, 2021). Each row represents a different statistical measure calculated for the data. The 'mean' represents the average value of the metric across all geographical areas under study. The 'median' is the midpoint value when the metric's data is organized in ascending order. The 'std' is the standard deviation of the metric, indicating the extent of deviation or dispersion of values from the mean. '0.25 percentile', '0.5 percentile', and '0.75 percentile' respectively denote the 25th, 50th (which is identical to the median), and 75th percentiles of the data. These percentiles illustrate the value below which a specific percentage of the data falls.*

per growth rate during that year. There is a significant difference in the LCRPGR for 2001, as evidenced by the standard deviation of 0.274. This indicates that certain areas had a greater increase or decrease in LCRPGR compared to others (Fig. 2). The mean value being higher than the median (0.162) further confirms this and suggests that there were specific regions with exceptionally high LCRPGR values that influenced the overall mean value.

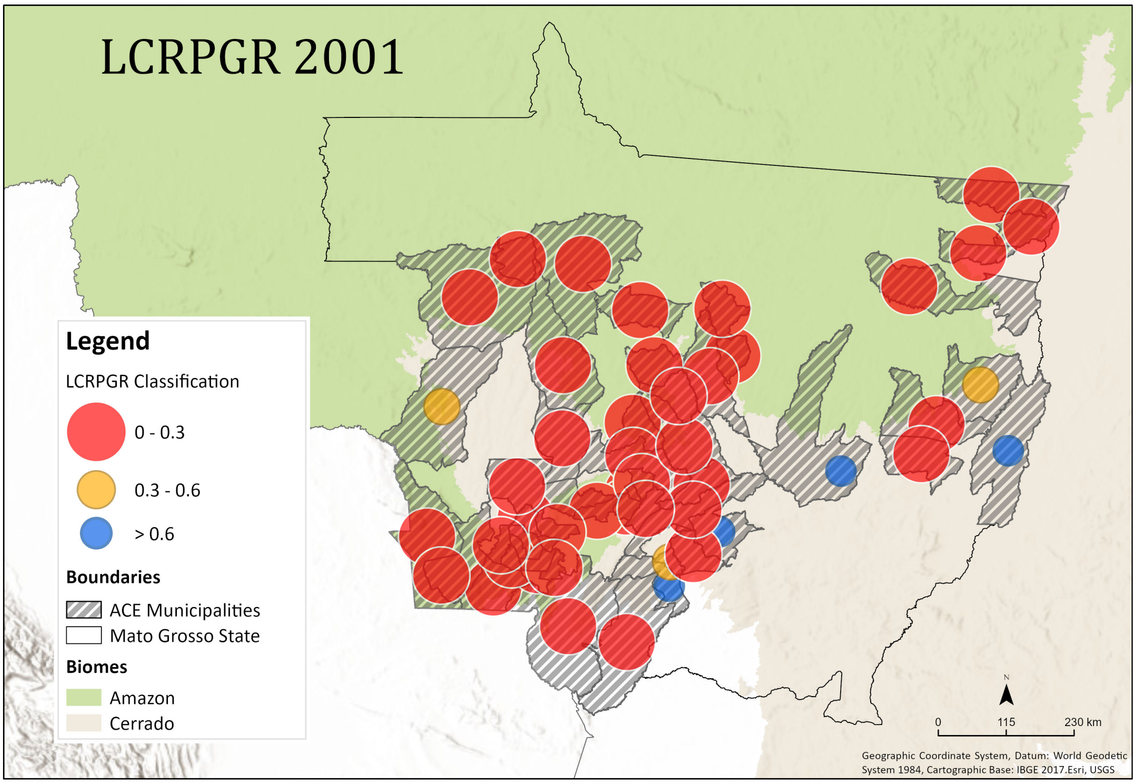

Figure 2: *The figure displays LCRPGR values for 50 municipalities in 2001. The values are classified into three categories: red for values up to 0.3, yellow for values greater than 0.3 but less than or equal to 0.6, and blue for values above 0.6.*

In 2011, the average LCRPGR was 0.129. This suggests that for every additional person in the population, 12.9 percent of a unit of land was consumed on average. However, there's a significant spread in these values as indicated by the standard deviation of 0.11, showing that land consumption rates varied between different areas (Fig. 3). The median LCRPGR value, 0.098, being lower than the mean suggests that there were some areas with particularly high land consumption rates per unit of population growth, which increased the average.

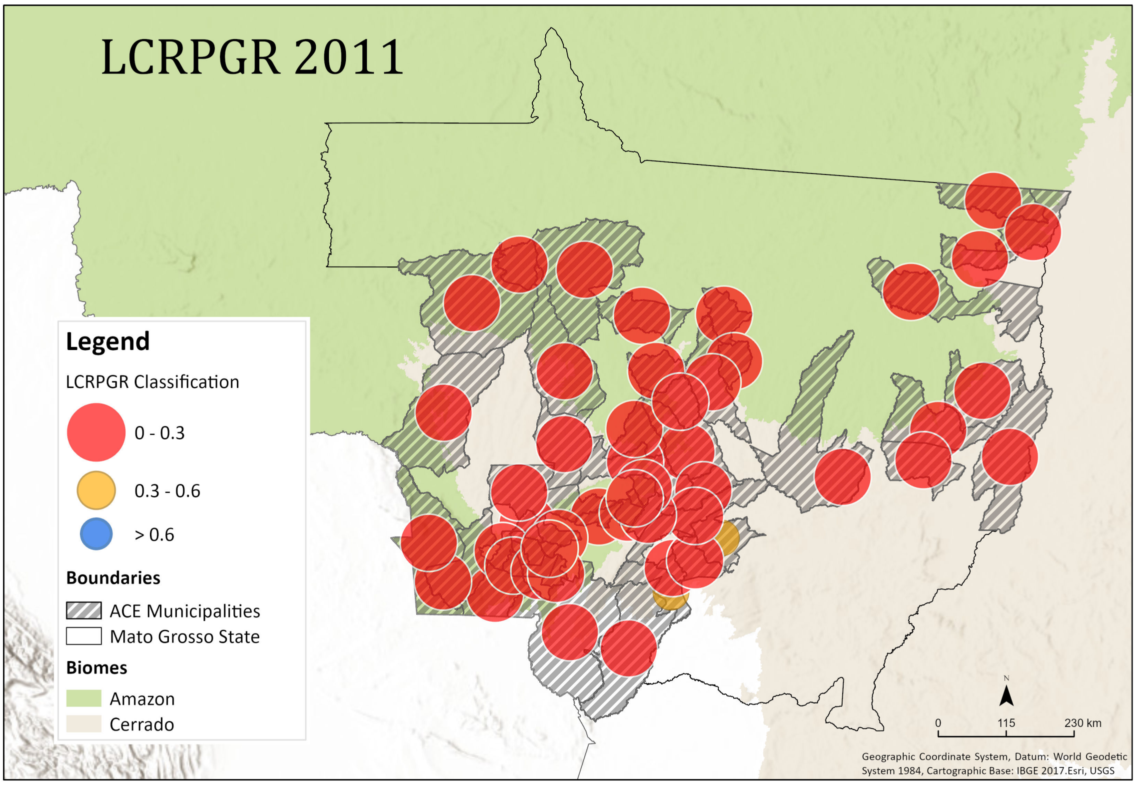

Figure 3: *The figure displays LCRPGR values for 50 municipalities in 2011. The values are classified into three categories: red for values up to 0.3, yellow for values greater than 0.3 but less than or equal to 0.6, and blue for values above 0.6.*

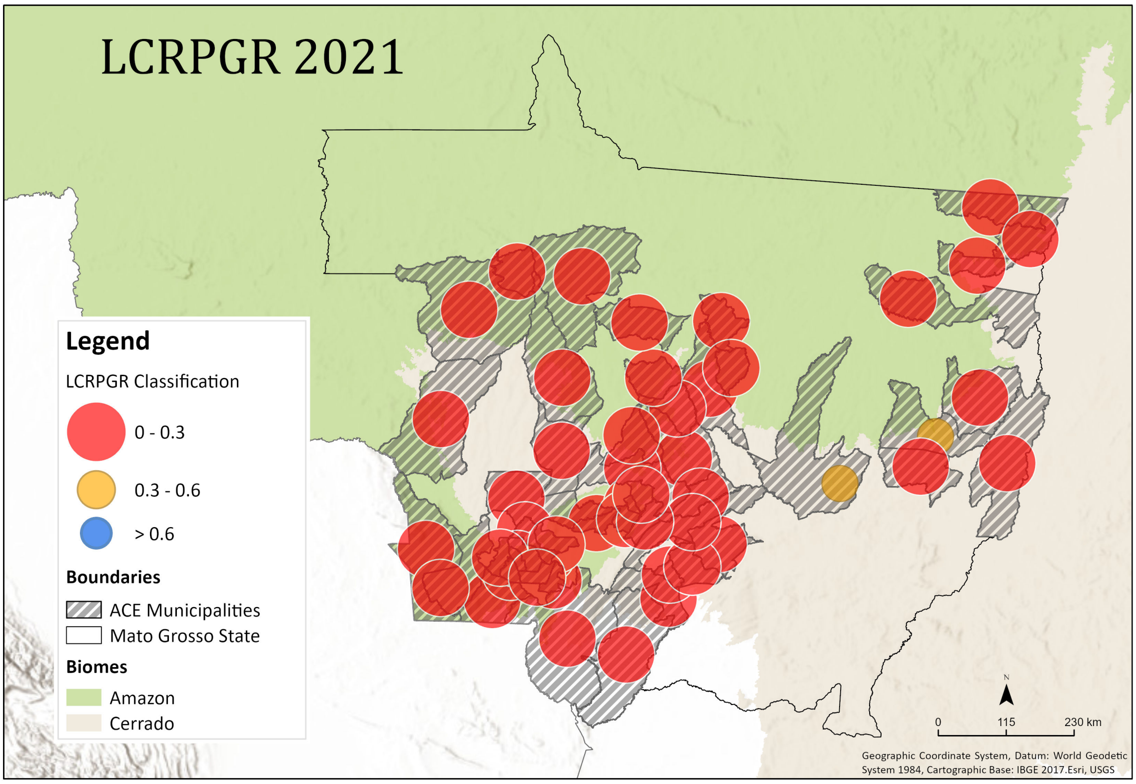

Figure 4: *The figure displays LCRPGR values for 50 municipalities in 2021. The values are classified into three categories: red for values up to 0.3, yellow for values greater than 0.3 but less than or equal to 0.6, and blue for values above 0.6.*

In 2021, the LCRPGR had a mean value of around 0.123. This means that when the population increases by one person, on average, 12.3 percent of a unit of land was consumed. Based on the data, the median value of LCRPGR is 0.105, which is slightly lower than the mean value. This indicates that there is an uneven distribution, meaning that some municipalities have higher LCRPGR values than others. Despite the disparity in values and spatial distribution, most municipalities in 2021 fell between the range of 0-3.0 on the LCRPGR scale (red class), which suggests that fewer urban areas were being consumed per unit of population. (Fig. 4)

Discussion

Agricultural Expansion and Urban Density

As previously mentioned, the ACE region is an important agricultural area that has been transitioning from natural regions into agricultural systems and pastures for several decades. In Mato Grosso state where the ACE is located, originally 41 percent (362,500 km2, an area larger than Italy) was covered by forests, and 62 percent of the original cover has been consumed for various purposes such as cattle farming, agriculture, timber logging, hydroelectric power, and sugarcane ethanol production (Marques, Marimon-Junior, Marimon, et al. 2020; Brando et al. 2013; Alencar et al. 2004; Marengo, Jimenez, Espinoza, et al. 2022).

Given this context, agricultural production, specifically the growth of agribusiness, is a leading factor in the urbanization of certain municipalities. As agribusiness expands, it stimulates the development of new cities and urban areas called "agribusiness cities", which are primarily designed to support the needs of modern agriculture (Elias and Pequeno 2007). Therefore, the narrative of these urban areas cannot be separated from the narrative of the agricultural sector that drives their growth. The economic, social, and spatial areas of these cities are significantly shaped by the demands and dynamics of agribusiness, making it an essential framework for understanding their evolution (Elias and Pequeno 2007; A. E. Santos 2018).

By tracking the LCRPGR from 2001 to 2021 in this work, it was possible to note a trend that confirms the increasing urban density in the studied areas. The two-decade span from 2001 to 2021 demonstrates significant shifts in urban density within the studied municipalities, as evidenced by changes in the LCRPGR. From 2001 to 2011, a considerable reduction in the mean LCRPGR was observed, falling from 0.229 to 0.129, marking a nearly 44 percent decline. This reduction reflects a substantial decrease in land consumption corresponding to each unit increase in population, thereby suggesting changes in land use patterns and a rise in urban density. In the decade following, from 2011 to 2021, a more marginal decline in the mean LCRPGR was noted, with a drop from 0.129 to 0.123, a reduction of approximately 4.7 percent. Despite this latter decrease appearing less drastic, it is indicative of a continued trend towards increased urban density, as municipalities sustain a pattern of accommodating more individuals per land unit. This consistent decrease in LCRPGR over the past 20 years demonstrates that municipalities are increasing their urban density and changing their land consumption patterns per capita.

It is worth noting that over the years, there has been a decrease in the standard deviation of LCRPGR, from 0.274 in 2001 to 0.110 in 2011, and further down to 0.078 in 2021. This indicates a decreasing difference in urban density patterns among municipalities. However, there are still significant variations, indicating that the increase in urban density has not been the same across all municipalities. The varying levels of urban density and development among different municipalities can be attributed to the differing urbanization processes that agribusiness cities have undergone (Cunha 2006). These cities have received varying levels of investment from both private and governmental sectors, and have developed urban infrastructure that corresponds with their importance in the agricultural sector and production requirements. (Cunha 2006; A. E. Santos 2018; Camargo et al. 2017)

Examining the demographic patterns of agribusiness cities, it's also important to consider the process by which they gained their populations. The ACR region includes cities created specifically to support agribusiness, as well as cities that were incorporated into the agricultural frontier. These different types of cities experienced different population dynamic processes. Cities created to meet the demands of agriculture received migrants to make up their urban population, while other cities experienced various forms of migration, such as rural exodus or migration from nearby and distant cities (Cunha 2006; A. E. Santos 2018; Camargo et al. 2017; Lombardi and Carmo 2020).

Spatial Inequalities and Vulnerable Population

Cities that focus on agribusiness have distinct groups in their migrant populations (Pequeno and Frederico 2016; M. Santos 2003; A. E. Santos 2018). Wealthy migrants influence the development of urban infrastructure through their consumption habits, while migrants from rural or economically disadvantaged areas frequently end up living in peripheral areas with limited access to urban facilities and struggling to find stable employment. The agribusiness cities illustrate significant socio-economic disparities that shape their urban landscape and structure (Alves 2019; Pequeno and Frederico 2016).

A significant attraction can be observed in urban areas bordering agricultural expansion regions, drawing various economic sectors and waves of migrants seeking professional opportunities. However, these prospects are often interfered with by the high level of specialization in the job market and the use of machinery that reduces the need for labor. This leads to disputes over ownership and the value of urban land, which is privately owned by a limited number of economic agents, including those from the agribusiness sector. These agents reinvest their capital into urban spaces, leading to the exclusion of lower-income populations to access urban space and infrastructure (Frederico 2012; Pequeno and Frederico 2016). This scenario is common in cities with a strong influence from agribusiness, where real estate speculation becomes a major concern. In these cities, urban land owned by a select group of owners is commercialized based on market forces rather than public planning policies, fueling real estate speculation and directing the dynamics of expansion (Hogan 2005; Alves 2019; Pequeno and Frederico 2016).

This study showed that in the ACR there was a significant increase in population in 2001, as indicated by the high PGR. However, the decline towards 2021 suggests that demographic changes have stabilized over time. Additionally, the LCR decreased from 2001 to 2021, indicating a slowing down of urban land consumption. This could be due to various factors, such as the use of advanced mechanized agricultural practices reducing labor demand and changes in the real estate market. The decrease in LCRPGR from 2001 to 2021 suggests that there is less urban space either accessible or being utilized by the city's inhabitants. However, the considerable standard deviation associated with the LCRPGR points towards a significant variability among municipalities, thereby reflecting the complex narrative of socio-spatial segregation as well as local and regional disparities.

Thus, this consideration of LCR, PGR, and LCRPGR underscores the multifaceted dynamics within urban areas in the agricultural expansion region, offering a quantitative framework to further comprehend the socio-spatial transformations and challenges produced by the agribusiness sector. It is also crucial to remember that a decrease in LCRPGR doesn't necessarily signify efficient land use. It could also reflect socio-spatial inequalities, wherein disadvantaged populations are relegated to peripheral areas while affluent populations consolidate their holdings within urban centers.

The Land Use-Efficiency Concept is crucial in assessing the LCRPGR indicator, as it emphasizes the importance of compact and resourceful cities. This approach promotes reduced energy consumption, better waste management, and the benefits of agglomeration economies. By calculating the LCRPGR, policymakers can anticipate public service needs, identify growth areas, and guide sustainable urban development in a strategic manner (United Nations Human Settlement Programme (UN-Habitat) 2018).

It is important to evaluate Land Use-Efficiency and LCRPGR while considering local, regional, economic, and demographic factors. Only relying on LCRPGR can hide urban disparities, as seen in the ACE region. An interdisciplinary approach to LCRPGR values can help determine the actual local and regional conditions, leading to better resource management and the development of public policies.

Conclusions

It's important to pay attention to the impact of agricultural expansion on urban and population dynamics in Brazil, particularly in the Amazon and Cerrado biomes which are constantly threatened by deforestation and environmental damage. This leads to urban density and unequal spatial distribution in the cities located in these areas. This study emphasizes the importance of understanding the local and regional context in order to gain a better understanding of urban development trends. The data provided shows that there are significant variations in LCRPGR values over time, reflecting different dynamics in population growth and land consumption rates under the context of agricultural expansion. The results also indicate that different municipalities in the same region experienced distinct patterns of urban growth and land use. These findings can be used to support sustainable urban planning by bringing together environmental, social, and demographic data for a more comprehensive discussion on how to build sustainable cities in the agricultural frontier.

Data and Methodology Notes: It is important to note that the data used for this analysis cover a period of 30 years, starting from 1991 and ending in 2021. This extended timeline is necessary once the LCR, PGR, and LCRPGR calculations require previous information on land use and population to determine the rate of change. Therefore, the data's initial reference points are from 1991, which allows to calculate the changes observed from 2001 to 2021. Although the discussions and visualizations center on changes seen from 2001 to 2021, they are based on a more comprehensive 30-year dataset.

All the data and methodology of this work are published and available at GitHub repository: <URL>. Currently, the Indicator 11.3.1 has not been calculated in Brazil. This paper seeks to highlight the existence of reliable data and automated methods that can be utilized to achieve this goal.

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