

## LAND USE AND URBAN EXPANSION IN A BRAZILIAN HISTORIC CITY (TIRADENTES, MG): IMPLICATIONS FOR ENVIRONMENTAL PROTECTION

Uso da terra e expansão urbana em uma cidade histórica brasileira (Tiradentes, MG):  
implicações para a proteção ambiental

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Artigo recebido em junho/2025 e aceito em agosto/2025

### RESUMO

Nós analisamos os padrões de uso e ocupação do solo entre 2017 e 2023 na cidade histórica de Tiradentes (MG, Brasil), cuja formação teve início nos séculos XVIII, durante o ciclo do ouro no Brasil. A Teoria Geral dos Sistemas Aplicada à Geografia foi adotada para determinar os procedimentos metodológicos, os quais incluíram coleta de dados para o desenvolvimento da base cartográfica digital, trabalho de campo, pesquisa bibliográfica e análise da legislação municipal. O uso do solo para pastagem, principal categoria de uso da terra (cerca de 47%), apresentou redução constante em sua contribuição relativa ao longo do período estudado (de 48,5% para 45,5% entre 2017 e 2023). As áreas de vegetação natural apresentaram leve tendência de redução entre 2017 e 2020, mas vivenciaram um novo crescimento no período pandêmico e pós pandêmico, entre 2021 e 2023. Já as áreas urbanas apresentaram tendência de crescimento até 2022 (de 3,3% para 3,6%), marcado por uma desaceleração no período pandêmico, entre 2020 e 2022, e novo aumento na taxa de expansão entre 2022 e 2023 (de 3,6% para 3,9%). A expansão urbana concomitante à retração rural pode apontar para um crescimento periférico da cidade, cujo centro urbano já não oferece tantas oportunidades de expansão por concentrar elevada densidade de atrativos turísticos, como restaurantes, pousadas e lojas. A expansão periférica é marcada pela substituição de antigas propriedades rurais por empreendimentos imobiliários, como condomínios residenciais, pousadas e áreas de recreação, resultando em cenários de ocupação intensiva e crescente na periferia do município, na interface com áreas de proteção ambiental e de maior concentração de recursos hídricos. O mapeamento do uso e ocupação do solo permitiu a identificação e quantificação da

expansão urbana, entre outros elementos circundantes ao longo do tempo, podendo fornecer uma importante ferramenta de gestão e administração para a autoridade municipal na atualidade.

**Palavras-chave:** Urbanização; turismo; planejamento urbano; impactos ambientais; hidrografia.

## ABSTRACT

We analyzed land use and land cover patterns of the historic city of Tiradentes (Minas Gerais, Brazil) for the period between 2017 and 2023; the city's urban formation began in the 18th century during Brazil's gold cycle. The General Systems Theory Applied to Geography guided the methodological framework, which encompassed data collection for the development of a digital cartographic base, field surveys, bibliographic research, and analysis of municipal legislation. Pasture, the predominant land-use category with ~47% surface cover, consistently declined during the study period (from 48.5% in 2017 to 45.5% in 2023). Natural vegetation experienced a slight reduction from 2017 to 2020, followed by renewed growth during the pandemic and post-pandemic years (2021–2023). Urban areas showed an upward trend until 2022 (from 3.3% to 3.6%), marked by a deceleration between 2020 and 2022 and a subsequent increase in the expansion rate from 2022 to 2023 (from 3.6% to 3.9%). The simultaneous urban expansion and rural contraction suggest peripheral urban growth, as the historical center has limited capacity for expansion due to its high density of tourist-related infrastructure, including restaurants, inns, and retail stores. This peripheral expansion was characterized by the replacement of former rural properties with real estate developments such as residential condominiums, inns, and recreational facilities, resulting in intensified land occupation in peripheral areas, often adjacent to environmentally protected zones and regions with significant water resources. Land use and land cover mapping enabled the identification and quantification of urban expansion and other temporal-spatial dynamics, offering a valuable tool for contemporary municipal planning and governance.

**Keywords:** Urbanization; tourism; environmental impacts; urban planning; hydrography.

## 1. INTRODUCTION

Urbanization, throughout history, has been a complex phenomenon, reflecting the dynamic interaction between societies and geographical space (Lefebvre, 2008). From the initial ordering of territory to the subsequent development of urban planning, cities have evolved, adopting unique forms, functions, and characteristics (Carlos, 2009; Carlos, 2020). This historical journey from ancient villages to modern metropolises reveals a physical transformation and the incessant search for solutions that reconcile human needs with environmental demands. With urban progress, societal evolution has led to refinement in organizational forms, initially concentrated on territorial ordering. This progression later evolved into territorial planning (Costa, 2023; Santos, 2004). Thus, urban development reveals not only a physical transformation of the occupied landscape but also a complex adaptation to social demands, reflecting the constant pursuit of more efficient and balanced urban structures. Given the various demands permeating urban space, planning becomes imperative to adapt and improve the urban environment, simultaneously seeking environmental protection and

improvements in quality of life. In the Brazilian Federal Constitution, urban policy, although allocated in the "Economic Order", is essentially social (Santos, 2004; Fantin *et al.*, 2009).

During urban growth, inadequate occupation of urban space, implying a disordered growth process, frequently results in serious urban problems such as environmental impacts and occupation of areas susceptible to natural disasters (Fantin *et al.*, 2009; Santos, 2015). To address such urban challenges in the Brazilian territory, the City Statute was enacted by Law No. 10,257 on July 10th, 2001, and serves as a fundamental guideline for implementing and developing national urban policies, including planning and management. Planning and management are distinct yet complementary concepts; the former is related to the future, predicting and simulating the evolution of events and their implications, while the latter is related to the present, managing situations according to immediate resources and needs (Fitz, 2008; Souza, 2015). The City Statute establishes general guidelines that guarantee the right to a sustainable city, understood as the right to urban land, housing, environmental sanitation, urban infrastructure, transport, public services, work, and leisure for present and future generations (Carvalho Filho, 2011; Brazil, 2018). The City Statute was made available to municipalities as an innovative urban planning and management tool, introducing diverse urban instruments for territory intervention.

The City Statute enabled municipalities to develop and implement a master plan, compulsory parceling and building, progressive property tax over time, expropriation with payment in bonds, special urban usucapion, special use concession for housing purposes, surface rights, preemptive rights, onerous grant of the right to build, consortium urban operations, transfer of the right to build, neighborhood impact study, and democratic city management (Carvalho Filho, 2011; Brazil, 2018). However, the effectiveness of these practices can be compromised by the lack of cartographic data, environmental protection measures, and information for both public agency professionals and the population. Geoinformation infrastructure is crucial to implementing the instruments of the City Statute, avoiding gaps between legal and social effectiveness (Almeida *et al.*, 2009; Carvalho Filho, 2011). Thus, through cartographic data, geoinformation supports public policies for territorial planning and management, analyzing disasters from a geographical perspective. Moreover, by providing information on patterns of land use and occupation, geoinformation allows for the identification of vulnerable areas and areas of increased potential for environmental stress, such as areas of enhanced erosion risk, water pollution, and deforestation (Fantin *et al.*, 2009; Rockett *et al.*, 2014).

The historic city of Tiradentes, located in the Campo das Vertentes region in Minas Gerais (Brazil), has undergone disordered urban expansion, which resulted in impacts on natural resources, including water resources (Cruz, 2016) despite the implementation of a Municipality Master Plan in

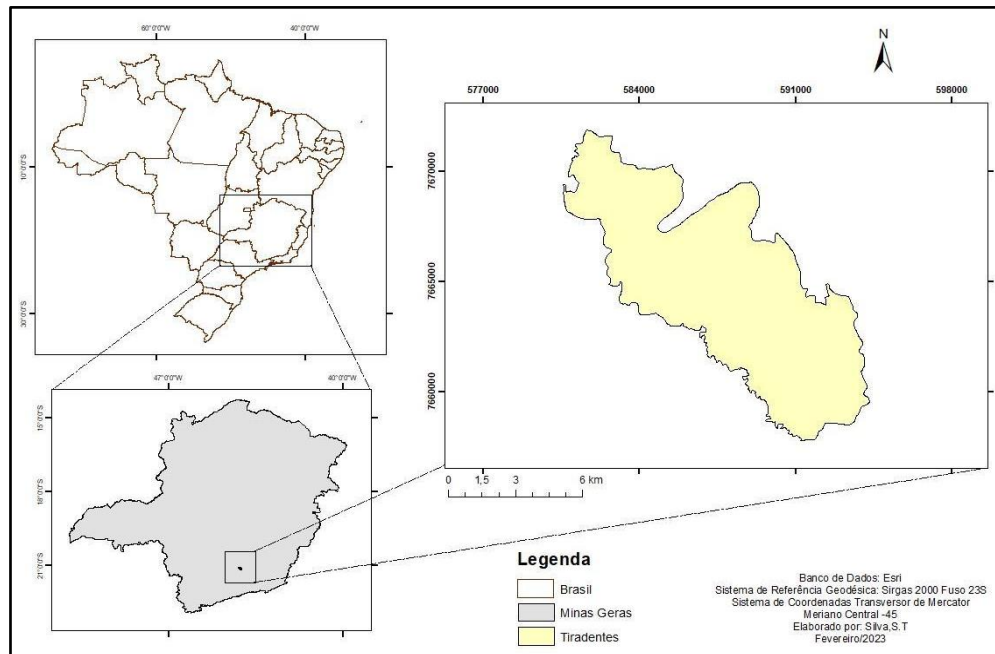
2015, aimed at regulating urban growth. Following the same pattern observed for other important historic cities in Minas Gerais, urbanization in Tiradentes started during the Gold Mining Cycle and was marked by its typical architecture (Rocha *et al.*, 2020; Cruz, 2016). During the 19th and 20th centuries, the region underwent a profound social and economic transformation, though it has preserved its valuable historical and cultural patrimony (Campos, 2006). In recent decades, tourism has emerged as a key component of the local economy, catalyzing conservation initiatives and further stimulating urban development (Cruz, 2016). Over the past 30 years, Tiradentes has become a favorite destination for gastronomic and cultural festivals, besides other thematic events, such as markets, music concerts, and cultural exhibitions throughout the year. According to current data from the Municipal Tourism Office, the number of annual events and festivals in Tiradentes has more than doubled in the last 20 years. As a result, this city with ~7,700 inhabitants receives 2 to 3 times its population as tourists during some months of the year, causing several urban problems, such as water and electric power supply failures, irregular waste deposition, including on public places and local natural resources, sanitation problems, and visual and noise pollution.

Moreover, the massive tourism development of the city in the last decades has allowed for real estate speculation and produced a pattern of peripheral expansion towards rural and natural preserved areas, whereby lower-income inhabitants are forced to migrate towards the city peripheral boundaries (Neves, 2013), including areas of geological or flood risk, and leaving the center for tourism facilities, such as restaurants, hotels, and commercial buildings. Moreover, infrastructure deficiencies caused by tourism-mediated increased demands, e.g., regarding water and energy supply, sanitation, and waste disposal, contribute to increasing environmental impacts, including soil and water pollution. This urban development scenario, driven by massive tourism, is transforming rural and natural surrounding areas in urbanized areas and compromising the health of urban natural resources, making this historical city ideal for analyzing planning and the emergence of applicable urban policies. However, for planning to be effectively implemented, current information on land use and land occupation patterns should be available to allow understanding current and future urban expansion scenarios and mitigate environmental impacts accordingly.

Here, we present an assessment of land use and cover patterns for Tiradentes between 2017 and 2023, focusing on environmental pressures on natural and agricultural areas and water resources. We show an apparent increase in urban areas concomitant with a reduction in pasture areas, resulting from the expansion of urban areas towards surrounding rural areas, especially during the post-pandemic years of 2022 and 2023. Concomitantly, a small increase in water bodies occurred from 2021 onward, represented mostly by small water supply and fishery ponds.

## 2. STUDY AREA

Tiradentes is a historical and highly touristic city in the Brazilian federal state of Minas Gerais, within the microregion of São João del-Rei and the mesoregion Campo das Vertentes. It encompasses a micro basin with a total area of 83.047 km<sup>2</sup> and an estimated population of 7,744 inhabitants (IBGE, 2022) (Figures 1 and 2).



**Figure 1** - Location of Tiradentes in the state of Minas Gerais, Brazil.



**Figure 2.** Tourists in the historic center of Tiradentes (left). Gastronomic festival in Tiradentes (right).

**Credits:** Nereu Jr.

The region's climate shows marked seasonal variation, characterized by mild dry winters and hot, rainy summers (Köppen-Geiger Cwa – humid subtropical climate; Veloso; Góes-Filho, 1982).



Rainfall patterns are driven by various air masses and interactions with convergence zones and cyclonic systems (Moreira, 1999). Noteworthy in the region is the Santo Antônio stream, popularly known as Ribeirão Santo Antônio or "Ribeiro," whose waters cross natural landscapes, agricultural areas, and urban spaces. The Santo Antônio stream basin is located at the transition between the Cerrado and Atlantic Forest biomes and exhibits Montane Semideciduous Seasonal Forests, primarily in the riparian forest of the stream and protected areas of the basin (Velooso *et al.*, 1991; IBGE, 2012).

The stream has significant historical and touristic importance. The diversity of natural, agricultural, and urban environments in Tiradentes suggests that environmental complexity is crucial for understanding the interactions between the local population and natural resources.

In Tiradentes, increasing and disordered tourism-mediated urban growth, especially since the '90s, in the proximity of areas designated for permanent preservation, significantly impacts municipal urban planning and management, emphasizing the critical need for monitoring urban growth patterns through recent cartographic data as an essential measure to formulate plausible solutions to current environmental challenges (Brazil, 2018; Rolnik, 2002). The conflict between development and environmental and historical preservation demands crucial adjustments to ensure a sustainable future evolution of Tiradentes. Hence, an integrated approach emerges as imperative to guarantee the long-term sustainability of this historically significant city.

### 3. MATERIAL AND METHODS

We adopted the General Systems Theory applied to Geography, which proposes an integrated analysis of the environment and its social components. The distinction between the physical and the human geographic environment is emphasized, highlighting the association between the social and environmental aspects, focusing on anthropogenic actions as determining factors in modifying natural elements (Limberger, 2006; Von Bertalanffy, 2008). Geoprocessing techniques were employed to understand the land use and cover in Tiradentes in light of increasing urban sprawl. Field visits were conducted at the beginning and end of the data acquisition step to identify land use classes within the municipality and to validate the results obtained from processing digital databases provided by the State Environmental and Water Resources System of Minas Gerais (IDE-SISEMA).

IDE-SISEMA, an extension of the State Environmental System of Minas Gerais, was chosen due to the reliability of its geospatial data, which allows for an accurate understanding of the characteristics and distribution of land use in the region, providing robust support for decisions on environmental monitoring, territorial planning, and impact assessment. Each spatial unit is represented by an integer-valued pixel. A vector layer delimiting the municipality of Tiradentes was used to clip the area of interest within the raster layer, allowing the identification of land use and

cover classes: vegetation, pasture, mixed use (areas where vegetation and pasture are indistinguishable), urban areas, and water bodies. Data on land use from 2017 to 2023 were collected and organized in shapefile format within the Geographic Information System (GIS) environment ArcGIS 10.5 (modules ArcMap, ArcCatalog, and ArcToolBox). Within this environment, the database was projected to the geocentric reference system for the Americas, Sirgas 2000, zone 23S. Pixels were reclassified and grouped by land use class, and the resulting data were quantified to calculate class densities and compare changes across the studied years. Subsequently, land use and cover of different classes were calculated in terms of the municipality's absolute (km<sup>2</sup>) and relative (%) surface cover. The overlay of the raster land use layer with the municipal boundary vector layer enabled precise clipping and facilitated temporal change analysis. Final map layouts were also produced in ArcGIS 10.5 to ensure consistency between analytical procedures and cartographic outputs.

#### 4. RESULTS AND DISCUSSION

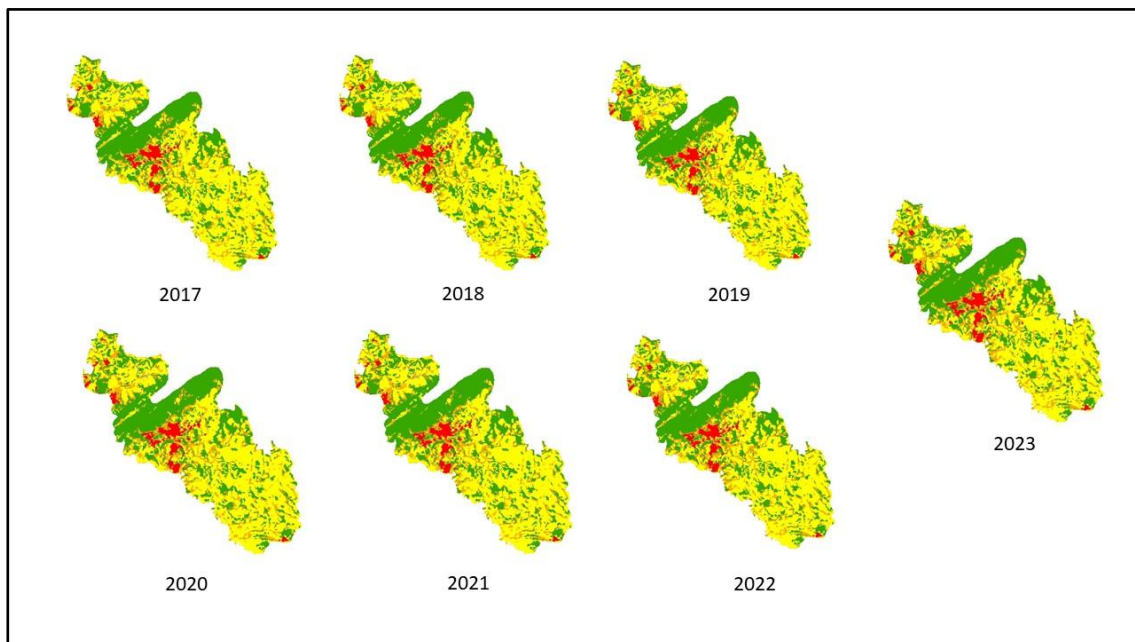
Our results show four main land-use categories in Tiradentes: pasture, naturally vegetated areas, urban areas, and water bodies, distributed throughout the municipality's ~83 km<sup>2</sup> (Table 1, Figure 3). Other land use categories were grouped into a "mosaic" category, which includes cover types indistinguishable between natural and pasture landscapes. Between 2017 and 2023, Tiradentes experienced significant territorial transformations, marked by several challenges and opportunities for municipal sustainable planning. As a result, pasture areas reduced from 48.5% in 2017 to 45.5% in 2023, corresponding to a reduction of approximately 2.5 km<sup>2</sup> (Table 1). This decrease in pasture areas remained more or less constant between 2017 and 2021 but showed an acceleration in 2022 and 2023. On the other hand, urban areas increased from 3.3% in 2017 to 3.5% in 2019, followed by a stagnation period between 2020 and 2022 during the COVID pandemic (Table 1). From 2022 to 2023, urban growth accelerated again, with urban area increasing by approximately 0.26 km<sup>2</sup> in only one year (reaching a total relative contribution of 3,9% in 2023).

**Table 1:** Temporal analysis of land use coverture in Tiradentes (MG, Brazil). Land use classes are represented in terms of absolute surface coverage (Km<sup>2</sup>) and relative coverage (%) over a seven-year period.

Land-use category	2017 km <sup>2</sup> (%)	2018 km <sup>2</sup> (%)	2019 km <sup>2</sup> (%)	2020 km <sup>2</sup> (%)	2021 km <sup>2</sup> (%)	2022 km <sup>2</sup> (%)	2023 km <sup>2</sup> (%)
<b>Natural vegetated areas</b>	28.16 (33.9)	28.24 (34.0)	28.14 (33.8)	27.93 (33.6)	28.27 (34.0)	28.24 (34.0)	28.45 (34.3)
<b>Pasture</b>	40.28 (48.5)	40.01 (48.3)	39.50 (47.6)	39.22 (47.2)	39.17 (47.2)	38.60 (46.5)	37.79 (45.5)

<b>Urban areas</b>	2.76 (3.3)	2.83 (3.4)	2.92 (3.5)	2.96 (3.6)	3.00 (3.6)	3.00 (3.6)	3.26 (3.9)
<b>Water bodies</b>	0.05 (0.1)	0.06 (0.1)	0.07 (0.1)	0.06 (0.1)	0.07 (0.1)	0.11 (0.1)	0.17 (0.2)
<b>Mosaic of Land use</b>	11.79 (14.2)	11.85 (14.3)	12.42 (15.0)	12.87 (15.5)	12.53 (15.1)	13.09 (15.8)	13.37 (16.1)
<b>Total</b>	83.05 (100)	83.05 (100)	83.05 (100)	83.05 (100)	83.05 (100)	83.05 (100)	83.05 (100)

Considering a total increase of around 0.5 km<sup>2</sup> in urban areas from 2017 to 2023 (Figure 4), the increase between 2022 and 2023 represented more than half of the total urban expansion observed in the investigated period. This recent acceleration in urban expansion deserves attention and should be accompanied by political strategies to minimize future social and environmental impacts.

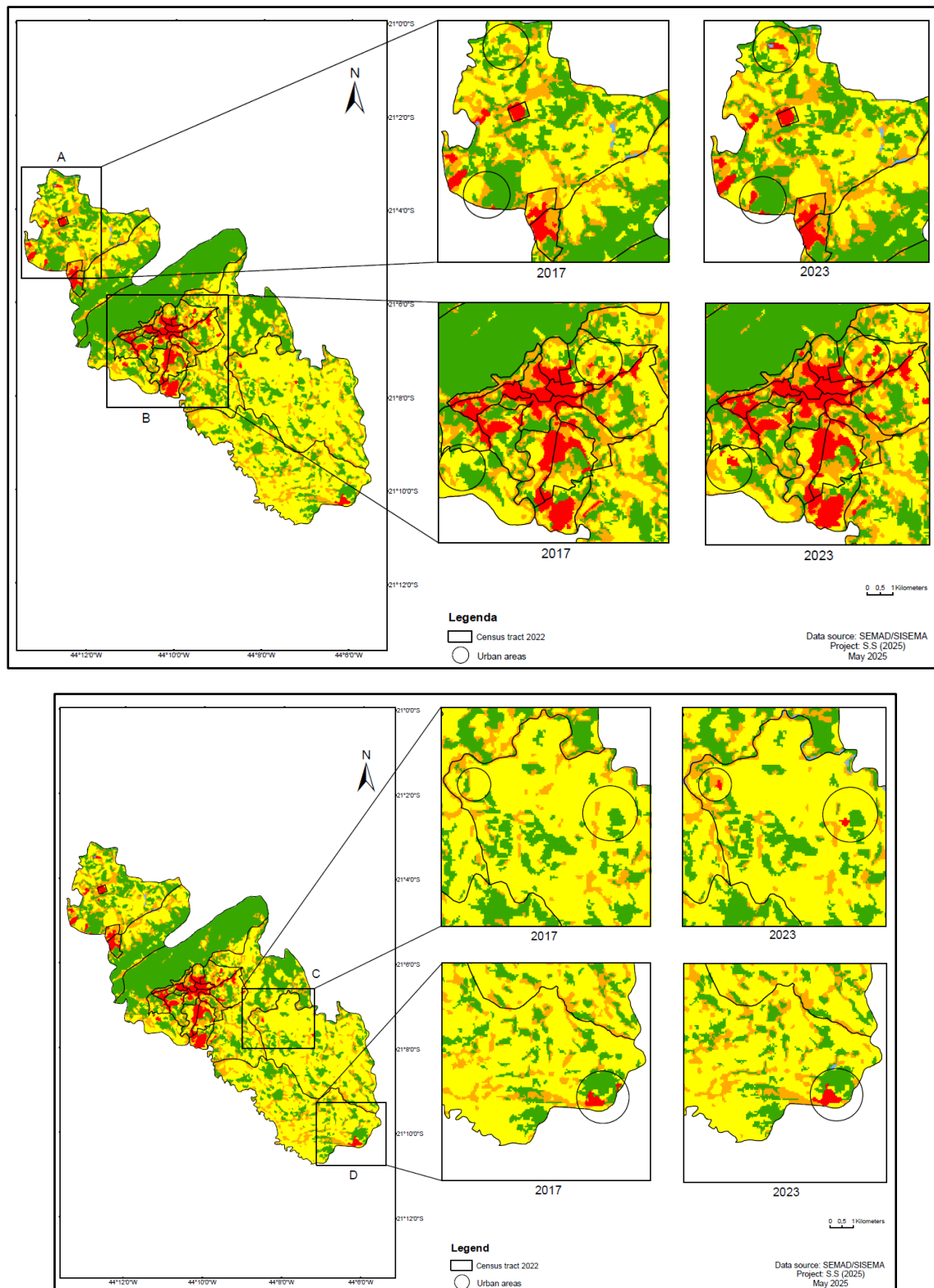


**Figure 3** - Land use evolution between 2017 and 2023 in Tiradentes. Red: urban areas; Yellow: Pasture; Green: naturally vegetated areas; Orange: Mosaic of land use.

As revealed by the data, the process of replacing pasture landscapes with urban areas reflects the expansion of commercial and residential establishments and real estate speculation. This phenomenon is closely linked to recent urban transformations that raised the standard of living in the municipality, attracting investors and tourists from the main economic hubs of the Southeastern region of Brazil, including São Paulo and Rio de Janeiro. The analysis also revealed that urban expansion occurred at a relatively low rate between 2017 and 2021 but saw a significant increase in 2022 and, especially, 2023, likely due to the end of economic and mobility restrictions imposed by the COVID-19 pandemic. The urban expansion in Tiradentes occurred along the central axis of the city but is also observed in peripheral areas and more distant neighborhoods (Figure 4). Peripheral



growth is driven by real estate development, which transforms pastureland, such as former farms, into residential areas for the construction of gated communities, and has become a major kind of urban development in the peripheral areas of Tiradentes and other cities in the region.



**Figure 4** - Detailed view of urban growth between 2017 and 2023 in four selected areas of Tiradentes (A: districts of Águas Santas and César de Pina; B: City central area; C: District of Caixa d'Água da Esperança; D: District of Elvas). Circles represent areas with urban growth in the period.

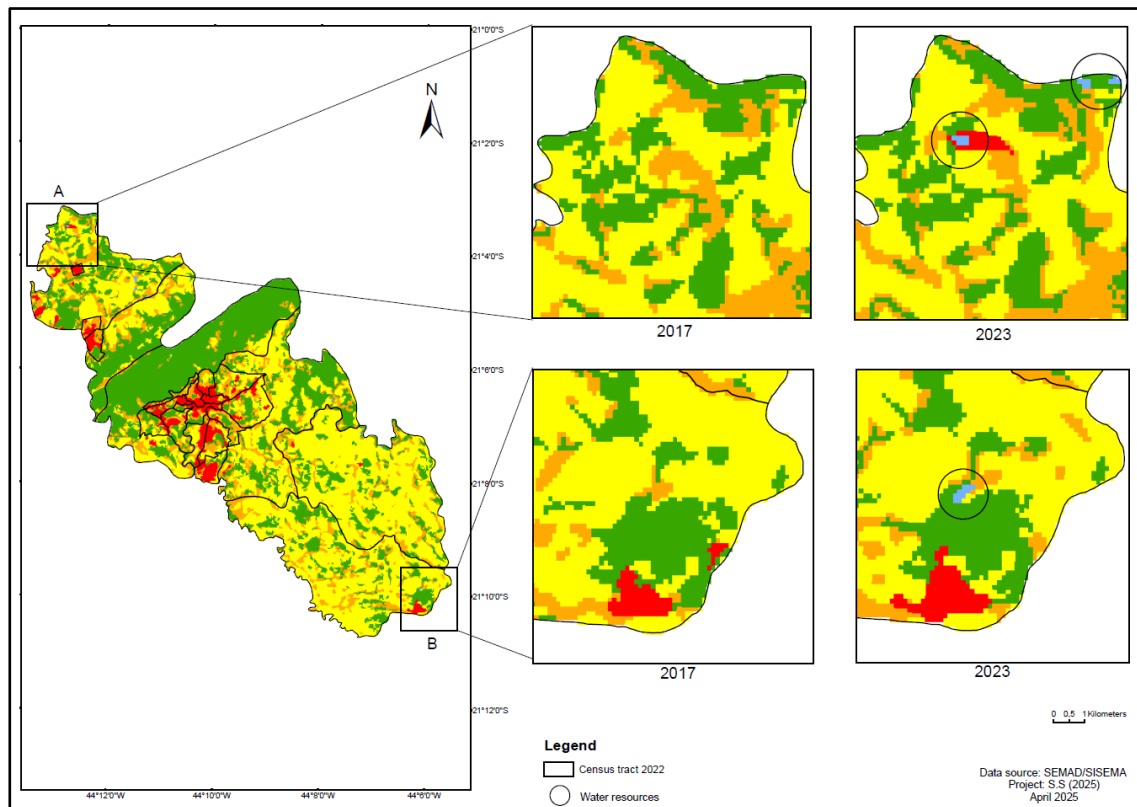
The growth of the city, driven by increasing tourism and the concentration of people during events and festivals, has led to the proliferation of commercial establishments such as bars, stores, and inns towards the city center, which encompasses the main channel of the Santo Antônio stream, the main watercourse of Tiradentes. As a result, this historically significant stream is increasingly impacted by solid waste and commercial effluents. In the city's commercial center, untreated sewage is directly discharged into the Santo Antônio stream (Figure 5), causing serious environmental issues. Despite a revitalization project carried out by the municipal administration in 2016, the lack of regular maintenance of the waste collection pipes installed along the stream banks has led to structural damage, undermining the primary objective of the project: to eliminate the direct discharge into the main channel. Recent surveys revealed significant urban impacts on the main sections of the Santo Antônio stream, including increased eutrophication and visual and odor pollution caused by waste disposed into the main channel (unpublished data). Similar results were observed in the Pacu stream, whose main channel runs through an urban expansion area of the city and flows into the Santo Antônio stream. Eutrophication of the city's urban streams is not the only change observed in Tiradentes' water resources over the years.



**Figure 5** - Santo Antônio stream in Tiradentes. Sewage collection at the stream margins was implemented in 2016 to minimize direct discharge into the stream (A). Sewage discharge into the stream in 2025, 9 years after a municipal “revitalization” project (B).

Although only covering a small percentage of the municipality's area, water bodies have increased from 0.1 to 0.2% between 2017 and 2023 (Table 1; Figure 6). However, most of this increase occurred from 2021 onward, when their absolute area more than doubled relative to their area between 2017 and 2020. Most of this increase in water bodies is likely due to an increase in small ponds built for domestic water supply and fish production (Figure 6). Fishponds have proliferated in the whole southeastern region of Brazil in the last few years for recreational and economic purposes (ANDRIOTA et al., 2019). Such commercial establishments work as catch-and-pay fishing (“pesque-pagues”). In the implementation phase, ponds are excavated in rural areas and supplied with water

through permanent connections with adjacent streams. At the ponds' outlet, water contaminated with organic matter and fish excretion products is redirected to the same stream, leading to eutrophication and the introduction of exotic species (Rosa *et al.*, 2013).



**Figure 6.** Detailed view of water resources between 2017 and 2023 in two selected districts of Tiradentes (A: district of César de Pina; B: District of Elvas). Circles represent areas with new water resources in the period.

Regarding municipal laws, the Master Plan, as well as Supplementary Law No. 05, both established in 2015, aimed to set guidelines for urban land division and occupation in the municipality, respecting the right to housing, economic development, and the sustainability and preservation of natural, cultural, and historical assets. These documents define the zones where urban expansion is permitted within the municipality, establish their characteristics, and address the need for compliance with current legislation. Especially in the center areas of Tiradentes, architecture and buildings are strongly regulated by the National Institute of Historic and Artistic Heritage (IPHAN). However, in rural or natural areas, urbanization is less regulated. Both documents mention the necessity of approval by IPHAN and the competent environmental agencies, as well as the possibility of approval by the municipality in case of public interest.

## 5. CONCLUSIONS

Our study showed an ongoing process of urbanization in Tiradentes in the last 7 years, basically through the conversion of peripheral rural areas into urban areas, with consequences for environmental protection and water resources deterioration. Sustainable urban planning is necessary to avoid further development within the riparian buffer zones of streams in the municipality's historic core, as well as peripheral urban expansion towards the Serra de São José, a partially protected natural forest and Cerrado savannah area known for its rich biodiversity, scenic beauty, and historical significance. Consequently, municipal decision-makers must move beyond broad statements of intent and adopt concrete instruments that shape sustainable growth. Three priorities stand out for Tiradentes:

1. Enforceable zoning tied to ecological thresholds. Urban expansion should be regulated by clearly delineated ecological corridors and minimum riparian buffer widths, with fines and mandatory remediation for infractions. A public, map-based platform could make boundaries transparent and enable real-time monitoring.

2. Heritage-compatible densification of neighborhoods outside the historic core. Rather than allowing sprawl into rural and hillside areas, the city could relieve pressure by permitting small-scale infill and vertical additions that meet IPHAN guidelines. Coupled with incentives for adaptive reuse of vacant structures, this would reduce the demand to build on sensitive land while keeping the town's architectural identity intact.

3. Tourism-linked environmental compensation. Because tourism is the primary driver of land-use change, hotels and short-stay developments should contribute to a municipal environmental fund. Revenues would finance riparian restoration along urban streams and strengthen the protection of the Serra de São José foothills, creating a feedback loop in which the sector safeguards the landscapes it markets.

Together, these measures could transform the current legislation—from largely declarative texts—into a pragmatic framework that aligns urban growth, heritage preservation, and ecosystem integrity. Without such targeted action, Tiradentes risks repeating the uncoordinated expansion patterns already visible on its outskirts, undermining its cultural appeal and the natural assets that sustain local livelihoods.

## ACKNOWLEDGMENTS

The Graduate Program in Geography and colleagues of the Laboratory of Applied Limnology (Federal University of São João del-Rei) are acknowledged for technical and logistical support. S.T.S.

received a fellowship from the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG).

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