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Analysis of the Evolution of Deforestation in the Cerrado Biome in the State of Minas Gerais using the DETER System and Images from the Amazônia-1 Satellite

Análise da Evolução do Desmatamento no Bioma Cerrado do Estado de Minas Gerais Utilizando o Sistema DETER e Imagens do Satélite Amazônia-1

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Abstract: The Cerrado is considered the second largest biome in Brazil, covering an area of more than 200 thousand hectares distributed in thirteen states. This is an area of great importance for the biodiversity of Brazilian fauna and flora. However, the transformation of its vegetation to other land covers has been accelerated in recent years, mainly due to the need for new areas for agricultural production and for the formation of pastures. Since protection efforts are inferior in relation to other biomes, such as the Amazon, for example, inappropriate environmental interventions have been expanded. In the specific case of the state of Minas Gerais, the Cerrado biome occupies more than 50% of the territory and has been heavily impacted, mainly in municipalities in the northeast region of the state. Therefore, considering the vast territorial dimension of this biome and the complexity of actions for the effective maintenance of environmental protection, remote sensing resources have been an important tool to assist environmental agencies in inspection. In this context, the alerts issued by the DETER System are of great importance for identifying deforestation polygons. Likewise, the use of orbital images of adequate quality in terms of spatial and temporal resolution, such as those captured by sensors on board the Amazônia-1 satellite, makes this information available more quickly.

Keywords: **R**emote Sensing; Cerrado; Deforestation; Environmental inspection; Geoprocessing.

Resumo: O Cerrado é considerado o segundo maior bioma do Brasil, abrangendo uma área de mais de 200 mil hectares distribuídos em treze estados. Trata-se de área de grande importância para a biodiversidade da fauna e flora brasileira. No entanto, a transformação da sua vegetação para outras coberturas da terra tem sido acelerada nos últimos anos, principalmente devido à demanda por novas áreas para a produção agrícola e a formação de pastagens. Devido aos esforços de proteção serem inferiores em relação a outros biomas como a Amazônia, por exemplo, as intervenções ambientais têm sido ampliadas. No caso específico do estado de Minas Gerais, o bioma Cerrado ocupa mais de 50% do território e tem sido muito impactado, principalmente em municípios da região nordeste do Estado. Portanto, considerando a vasta dimensão territorial desse bioma e a complexidade das ações para manutenção efetiva da proteção ambiental, os recursos de sensoriamento remoto têm sido uma importante ferramenta para auxiliar os órgãos ambientais na fiscalização. Nesse contexto, os alertas emitidos pelo Sistema DETER são de grande importância para identificação dos polígonos de desmatamento. Da mesma forma, a utilização de imagens orbitais de qualidade adequada, em termos de resolução espacial e temporal como aquelas capturadas por sensores a bordo do satélite Amazônia-1, permite a disponibilização dessa informação com maior celeridade.

Palavras-chave: Sensoriamento Remoto; Cerrado; Desmatamento; Fiscalização ambiental; Geoprocessamento.

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1. Introduction

The Cerrado is considered the second largest biome in Brazil, with a total area of approximately 2,036,448 km² (IBF, 2020) that represents more than 200 million hectares, corresponding to approximately 22% of the entire territory. Its vegetation has three main physiognomies: forest formations, with the presence of tree species with continuous canopy or not; savannas, where trees and shrubs are scattered in a grassy stratum (without a continuous canopy) and grasslands, where herbaceous and shrubby species predominate, with an absence of trees (RIBEIRO; WALTER, 2008).

However, the transformation of Cerrado vegetation into other land covers in recent years has been very evident, especially in areas located in regions of agricultural expansion. According to Klink and Machado (2005), agriculture in the Cerrado is very financially profitable and its expansion takes place at an accelerated pace. In recent years, deforestation rates in this biome have historically been higher than those in the Amazon rainforest, and efforts to conserve the Cerrado are much lower, considering that only 2.2% of the Cerrado area is legally protected (KLINK; MACHADO, 2005).

Brazil is among the main world producers of agricultural commodities, which encourages the growing demand for new arable areas, especially those inserted in the Cerrado biome (MUELLER; MARTHA JÚNIOR, 2008), which may favor degradation and deforestation in this region.

According to Andrade *et al.* (2016), another important factor that favors degradation and deforestation is the fact that about 53 million hectares of the Cerrado are destined for cultivated pastures, corresponding to 55% of beef production in the country. From generated scenarios, it was found that about 80% of the degraded planted pasture area of the Cerrado biome is concentrated only in the states of Goiás, Mato Grosso, Mato Grosso do Sul and Minas Gerais (ANDRADE *et al.*, 2016). Particularly in the state of Minas Gerais, the Cerrado biome covers a total area of 54% of the territory, located in the central-western portion, and, as in other states, the vegetation is also highly vulnerable due to deforestation and forest fires.

Considering the large area that the Cerrado represents, the use of remote sensing techniques and geotechnology resources to monitor the biome has been an important strategy for environmental monitoring and preservation. In this sense, it is convenient to mention several works related to the topic developed by Viana (2012) (use of ALOS-Palsar images), Barroso, Sano and Freitas (2018) (use of Remote Sensing and NDVI techniques), Maciel, Alves and Sant'Anna (2021) (which emphasizes the use of remote sensing satellite images in the analysis of processes of deforestation and regeneration of conservation units in the Ribeira Valley), Lewis et al. (2022) (Mapping native and non-native vegetation in the Brazilian Cerrado using freely available satellite products), Lopes, Nóbrega and Macedo (2022) (dealing with multitemporal analysis using sensing data through Landsat images), Maia *et al.* (2023) (study of recovery of areas degraded by fire in the Pantanal Region), Melo *et al.* (2024) (evaluated the dynamics of land use and occupation, analyzing essential factors, such as deforestation rates and regeneration of deforested areas over a multitemporal series of the last 31 years from1988 to 2019 in the Itapecuru River Hydrographic Basin by using geoprocessing tools through images available on the Mapbiomas collection 7.0 platform), Souza *et al.* (2025) (analyzed the multitemporal land use and land cover of the Iguape Bay Marine Extractive Reserve – Bahian Recôncavo), Tibangayuka and Mulungu (2025) (developed an analysis of spatiotemporal surface water variability and drought conditions using remote sensing indices in the Kagera River Sub-Basin, Tanzania, by using NDVI). However, traditionally research carried out in this field of environmental inspection and protection requires considerable financial costs. Thus, the present study intends to demonstrate the feasibility and pertinence of using freely available resources such as open programs known as FOSS (Free Open-Source Software), as demonstrated in GVSIG Asociación (2014), OSGeo (2019), Sousa *et al.* (2020), Graziuso et al. (2022), Ogli and Murodilov (2023), as well as the use of freely available geographically wide databases.

Given these brief considerations dealing with the degradations and risks that pressure the natural environments of the Cerrado, the proposal of this scientific work is justified for the development of a study related to the theme that is based on a systematic bibliographical review of several works in the literature dealing with the subject and that emphasizes the use of free and widely available tools and resources associated with remote sensing, databases and geoprocessing. The organization of the research work encompasses the definition of the study area, materials and methods (including the definition of deforestation polygons, environmental inspection points, obtaining free orbital remote sensing images, analysis by using geoprocessing tools), analysis of the results through a historical approach as well as comparative graphs and, finally, the concluding remarks.

2. Methodology

2.1 Study area selection

The Cerrado biome has its territorial coverage spread in the Brazilian states of Goiás, Tocantins, Federal District, Bahia, Ceará, Maranhão, Piauí, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Paraná, Rondônia and São Paulo. The present study limited the research of the Cerrado biome to the territory of the State of Minas Gerais, as shown in Figure 1.

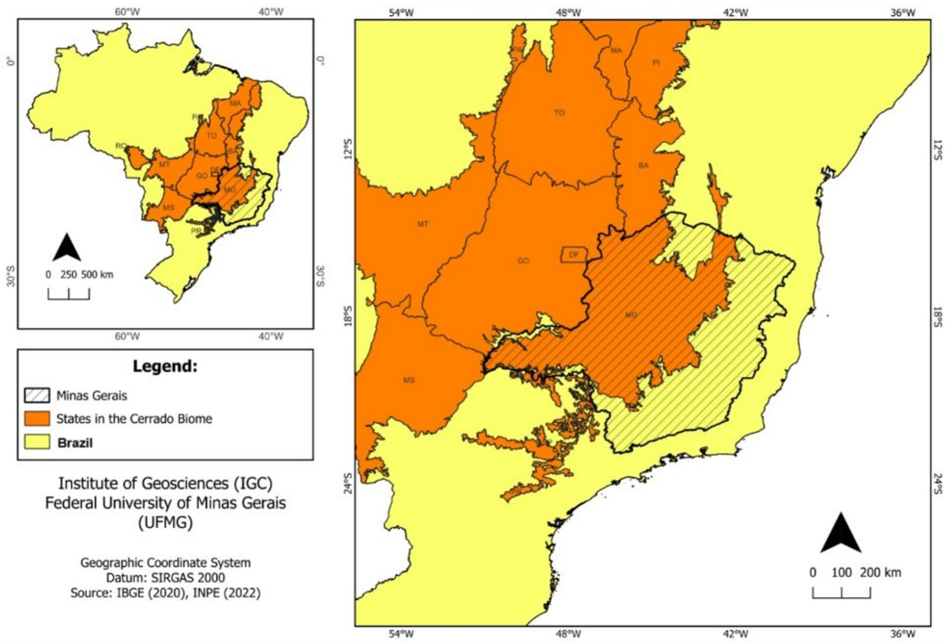


Figure 1 – Distribution of the Cerrado biome in the Brazilian states, with emphasis on Minas Gerais.
Source: Authors (2024).

2.2 Materials selection

2.2.1 Deforestation polygons

The deforestation polygons were extracted from the detections (vector contours) provided free of charge on the TerraBrasilis platform, made available by the National Institute for Space Research (INPE) through the Real Time Deforestation Detection System (DETER). Teures and Castilho (2011) and Diniz et al. (2015) present an exposition with more details about the data and characteristics of the System.

The DETER program was developed by INPE to generate evidence alerts regarding changes in vegetation cover. Initially intended only for application in the Amazon, the system uses images from the WFI sensor, carried on board the Sino-Brazilian Earth Resources Satellite (CBERS-4), with a spatial resolution of 64 meters and a three-day revisit rate, as explained by Almeida et al. (2022). Based on the use of panchromatic band images captured by the CBERS-4/PAN satellite, with a spatial resolution of 5 meters and using 5 to 15 ground control points, Akiyama *et al.* (2021) generated images with a very reliable positional accuracy, varying from 10 to 15 meters.

Since June 2022, the deforestation polygons of the DETER system have also started to be carried out based on image data from the Amazônia-1 satellite, as approached in scientific works, such as Barbosa, Ferreira and Júnior (2023) and Silva and Loureiro (2023). More than 180 polygons analyzed in these studies were collected by the new sensor on board the Amazônia-1. The imaging device uses a WPI camera (Wide Field Imaging Camera) to capture images at six levels and is considered the first satellite with 3-axis stabilization fully developed in Brazil.

2.2.2 Environmental inspection points

Data referring to environmental inspections were collected directly on the IDESISEMA platform, made available on the Internet by the Minas Gerais Secretary of State for the Environment (SEMAD-MG).

2.2.3 Remote sensing orbital images

The orbital images are generated by the Amazônia-1 satellite and were extracted in raster data format directly from the INPE image catalog page. The images used in the study are Level L4, with high processing quality, already available in orthorectified form, with essential radiometric corrections and geometric system corrections based on terrain control points and digital terrain model (INPE, 2021). These types of images were also recently used in studies carried out by Barbosa, Ferreira and Júnior (2023) and Silva and Loureiro (2023).

2.2.4 Analysis and geoprocessing

Spatial data in vector and raster formats were processed using tools from the QGIS program version "3.16.5 Hannover" (QGIS, 2021). Graphs and analysis were obtained using the Microsoft Excel 365 (2021) program.

2.3 Methods

2.3.1 Proceedings

The study delimited a five-year time frame for analyzing the evolution of deforestation in the Cerrado biome of Minas Gerais, comprising the years 2018, 2019, 2020, 2021 and 2022. This period coincides with the availability of existing information on the Spatial Data Infrastructure platform (IDESISEMA). Figure 2 presents a general outline of the procedures for obtaining the intended results in this study.

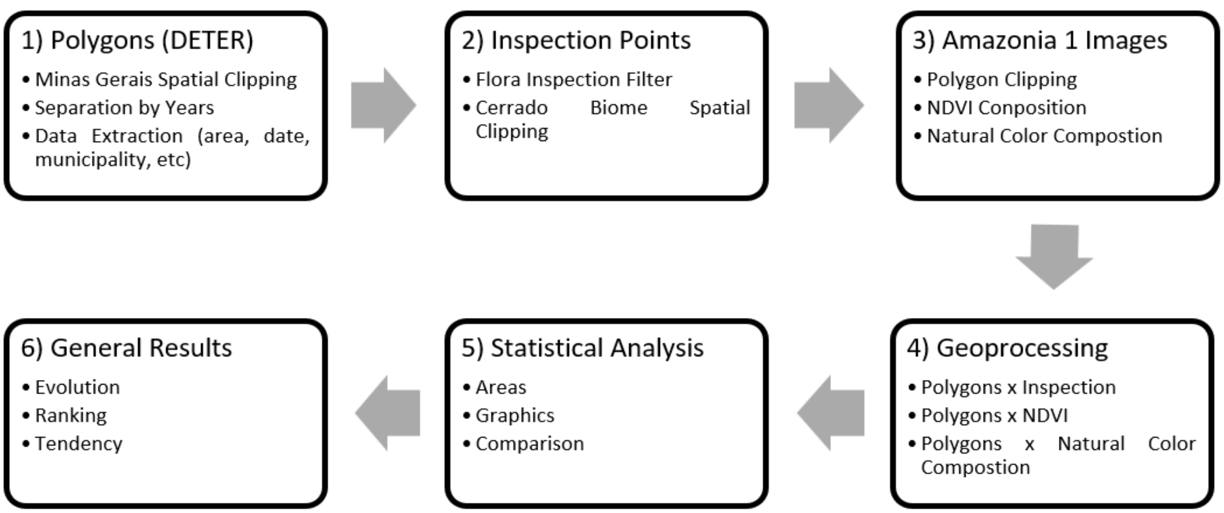


Figure 2 – General outline of the methodology.
Source: Authors (2024).

2.3.2 DETER polygons and inspection points

The alert polygons generated by DETER and the inspection points for the period 2018 to 2022, in the Cerrado vegetation in Minas Gerais, were extracted and cut as shown in Figures 3 and 4.

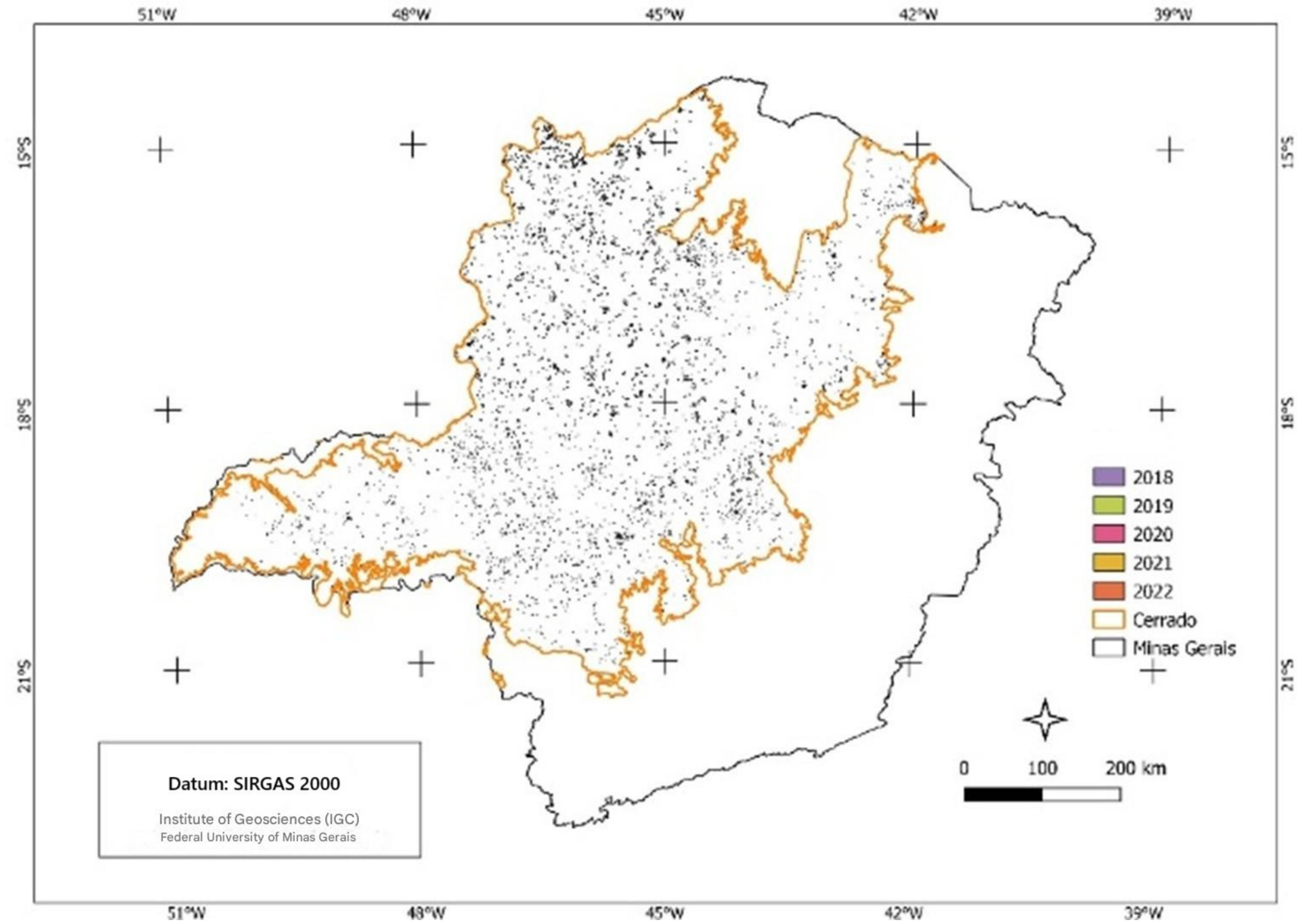
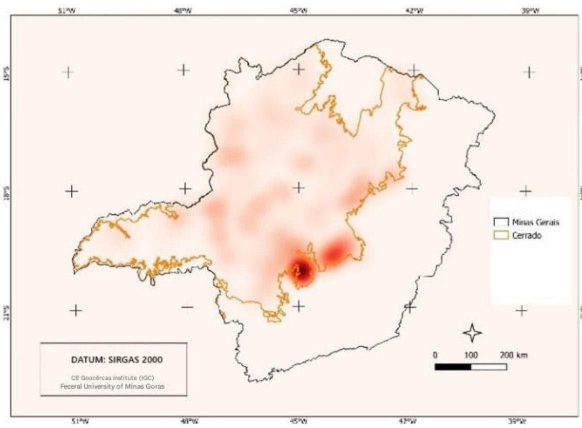
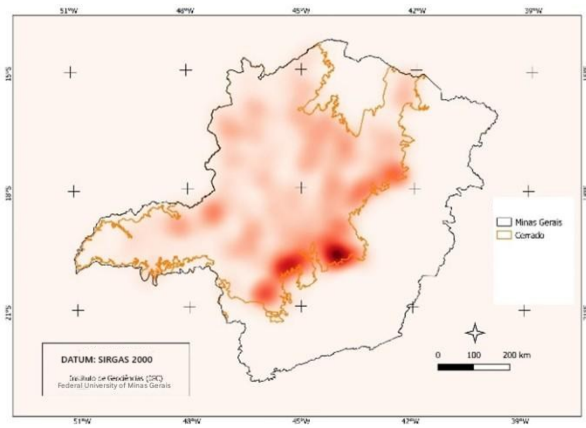


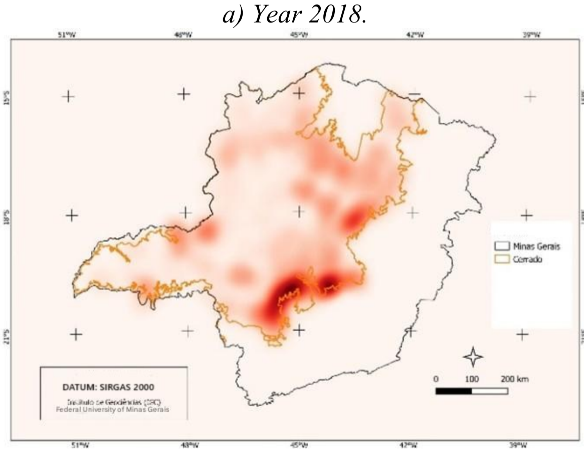
Figure 3 – DETER polygons (2018 to 2022).
Source: Authors (2024).



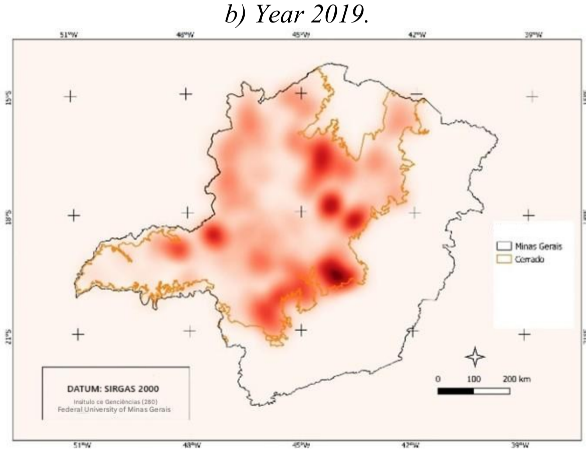
a) Year 2018.



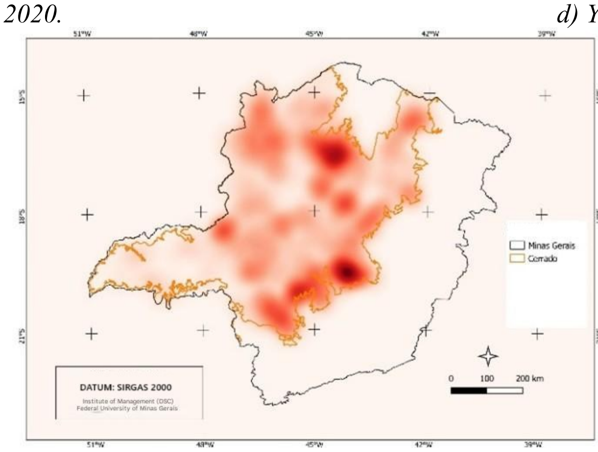
b) Year 2019.



c) Year 2020.



d) Year 2021.



e) Year 2022.

Figure 4 – Inspection Points – Heat map (2018 to 2022).
Source: Authors (2024).

2.3.3 NDVI composition

The NDVI (Normalized Difference Vegetation Index) is an index that highlights the spectral response of vegetation and is calculated by the difference between the near-infrared spectrum band and the red spectrum band, divided by the sum of both bands, allowing a normalized response. This index is widely used to demonstrate the difference between vegetation strata (underwater stress, life cycle stage, etc.) and other cover elements such as exposed soil. Its value ranges from -1 to 1 and the higher it is, the better the spectral response representing the vegetative vigor and photosynthetic activity of the plants. Different research studies involving NDVI applications are developed in the works of Pereira and Tavares Júnior (2017), Barroso, Sano and Freitas (2018), Moraes et al. (2018), Cambraia Filho, Brites and Souza Bias (2020), Mabunda et al. (2021), Silva Júnior et al (2021), Herrmann, Nascimento and Freitas (2022), Maia et al. (2023).

The NDVI raster data was obtained through arithmetic operations performed with the infrared and red bands of the Amazonia-1 satellite images, as shown in Equation 1:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \quad (1)$$

Considering that the information of interest derived from the images depict polygons of vegetation suppression in an area of the Cerrado biome producing a consequent increase in soil exposure, a representation in NDVI composition was performed to highlight the affected areas as shown in Figure 5.

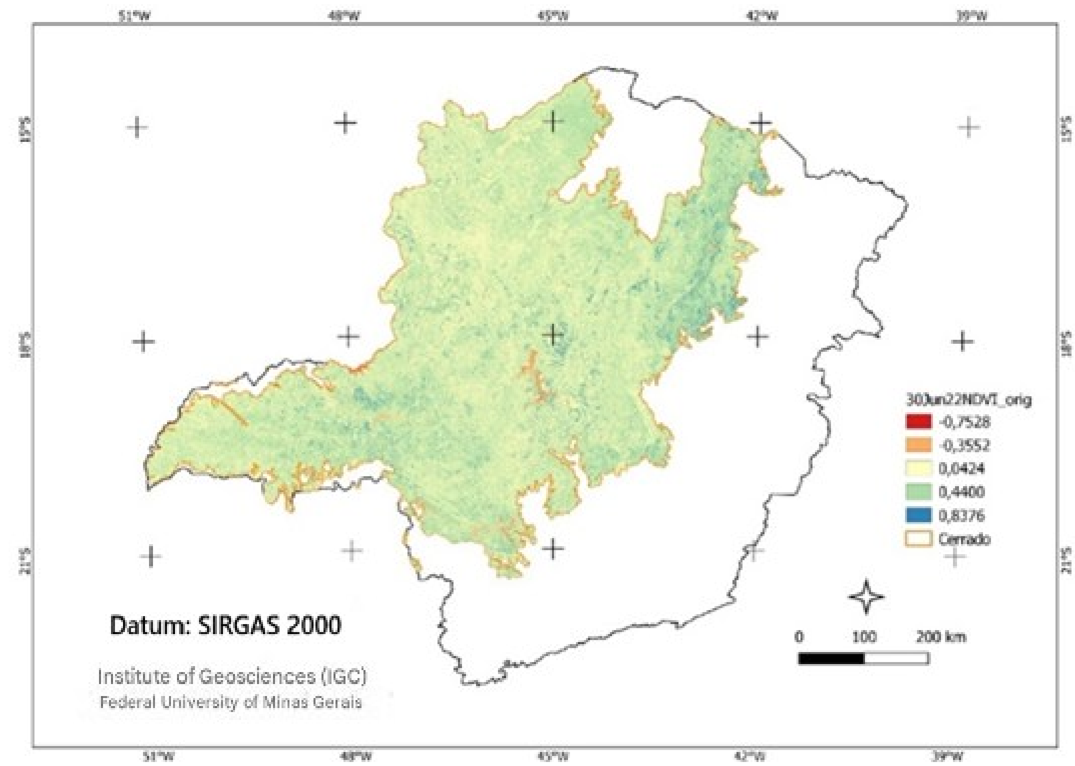


Figure 5 – NDVI composition (false color enhancement) with Amazônia-1 satellite image.
Source: Authors (2024).

3. Results

The maps generated allowed a quantitative analysis of the evolution of deforestation in the Cerrado biome in the State of Minas Gerais, between the years 2018 and 2022, as shown in Table 1. In total, 6,100 deforestation polygons were detected in the period, which corresponds to a combined area of 1,607.02 hectares (ha), with an average of 0.26 hectares per detection.

Table 1 – Deforestations detected by the DETER system in the Cerrado of Minas Gerais (2018-2022).

Year	Detections	Area (ha)	Average (ha)	Minimum (ha)	Municipality	Maximum (ha)	Municipality
2018	2243	441.42	0.20	6.67×10^{-5}	Luz	4.23	Buritizeiro
2019	1484	350.32	0.24	1.67×10^{-7}	Formoso	7.91	João Pinheiro
2020	861	236.69	0.27	2.15×10^{-7}	Felixlândia	7.34	Bonito de Minas
2021	904	321.60	0.36	1.19×10^{-5}	Itapecerica	8.55	Senador Modestino Gonçalves
2022	608	256.96	0.42	2.21×10^{-4}	Araçuaí	7.16	Formoso
Total	6.100	1,606.02	0.26	-	-	-	-

Source: Authors (2024).

In 2018, the highest number of deforestations occurred totaling an area of 441.42 ha (a total of 2,243 detection polygons), compared to 350.32 ha in 2019 (1,484 detections), 236.69 ha in 2020 (861 detections), 321.60 ha in 2021 (904 detections) and 256.96 ha in 2022 (608 detections). This allows us to state that there was a significant reduction in the number of environmental interventions over the period, with an increase only in the period 2020 to 2021. About the size of the polygons, it was found that the largest area (8.55 ha) was detected in the municipality of Senador Modestino Gonçalves, in 2021, while the smallest (2.15 x 10-7 ha) occurred in Felixlândia, in 2020.

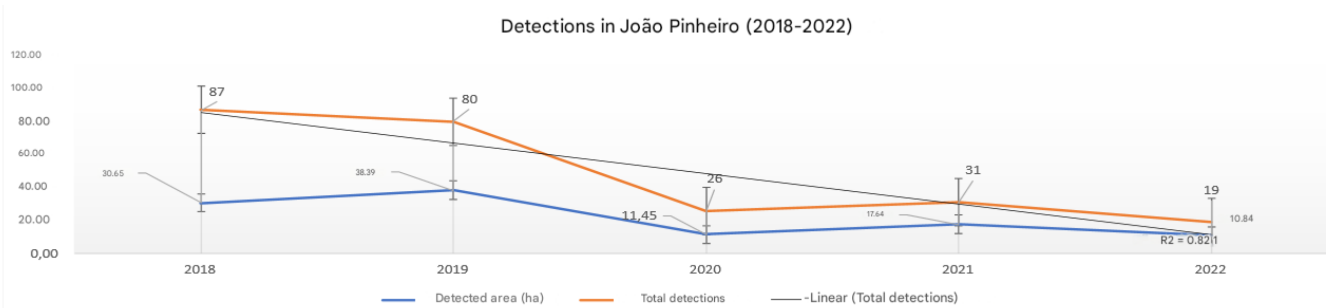
To evaluate the municipalities with the largest number of polygons and deforested areas over the period from 2018 to 2022, the first four were ranked, as shown in Table 2. It is noted that the municipality of João Pinheiro had the highest total number of detections (243) and also the largest total deforested area corresponding to 108.96 ha.

Table 2 – Municipalities with larger areas and findings of detections (2018-2022).

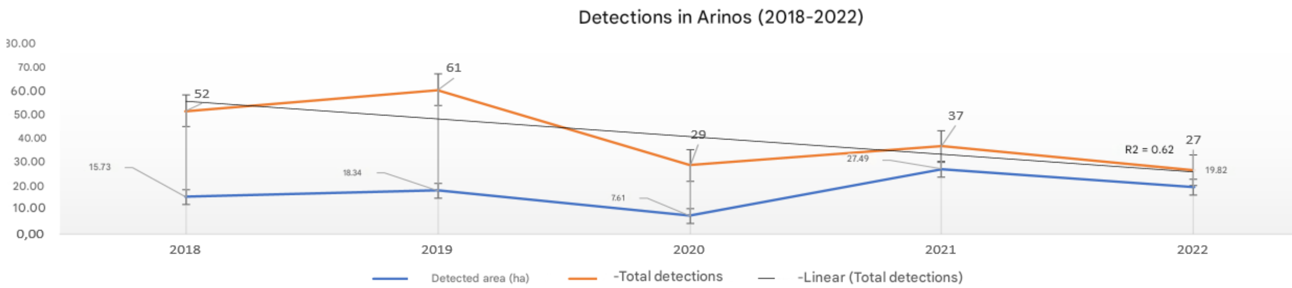
Ranking	Municipalities	Total area (ha)	Detections	Average (ha)
1º	João Pinheiro	108.96	243	0.45
2º	Arinos	88.99	206	0.43
3º	Buritizeiro	79.85	180	0.44
4º	Formoso	73.65	161	0.46
	Total	351.45	790	1.78

Source: Authors (2024).

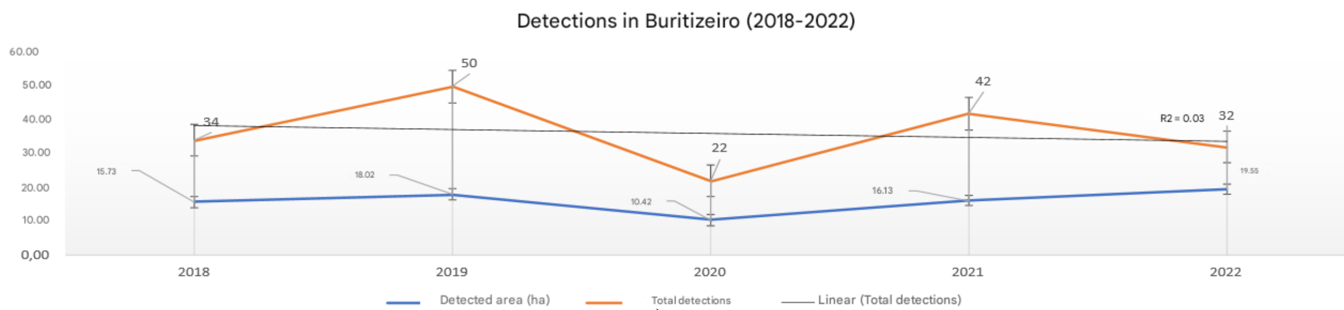
Based in the results, Figures 6(a), 6(b), 6(c) and 6(d) were constructed to demonstrate the evolution of deforestation in each of these municipalities. Despite having the highest accumulated value in the period 2018 to 2022, the total number of detections and the area detected in the municipality of João Pinheiro (1a) show a downward trend (R2 = 0.82). Likewise, despite a slight increase between the 2018-2019 and 2020-2021 biennia, a decrease was also observed in the municipality of Arinos (1b) (R2 = 0.62). In the municipality of Buritizeiro (6c), despite the accumulated increase in the deforested area, there was a maintenance in the number of detections (R2 = 0.03). In the municipality of Formoso (6d), although it has only 161 detections, a progressive increase was observed in the same period, both in the accumulated area and in the number of detections ($R^2 = 0.41$), which corroborates the information that the average hectare deforested is proportionally higher (0.46 ha/detection).



a)



b)



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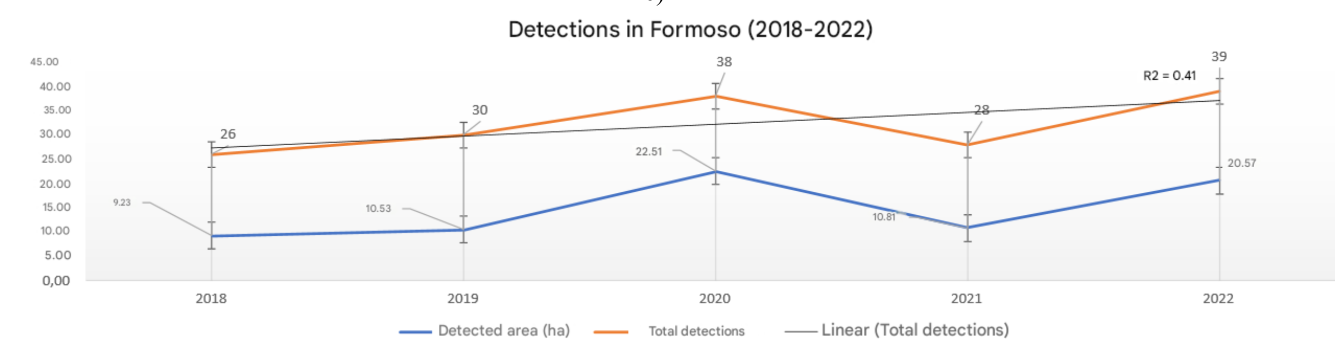

d)

Figure 6 – Evolution of deforestation in municipalities in the Cerrado of Minas Gerais based on the polygons detected by the DETER system (2018-2022).
Source: Authors (2024).

Since June 2022, the deforestation polygons of the DETER system have also been detected based on data from the Amazônia-1 satellite, in addition to the continued use of the CBERS-4 satellite. In view of this, an area located in the municipality of João Pinheiro, monitored by both satellites, was chosen for comparison, as shown in Figure 7. The analysis showed that despite the registration of small failures in the overlapping of detections in given instances, there is in fact an excellent correspondence between the deforested areas and the detected polygons. For this procedure, a high-resolution image obtained from the Global Forest Watch website was used, which allowed demonstrations of the great potential of using data from the new sensor.

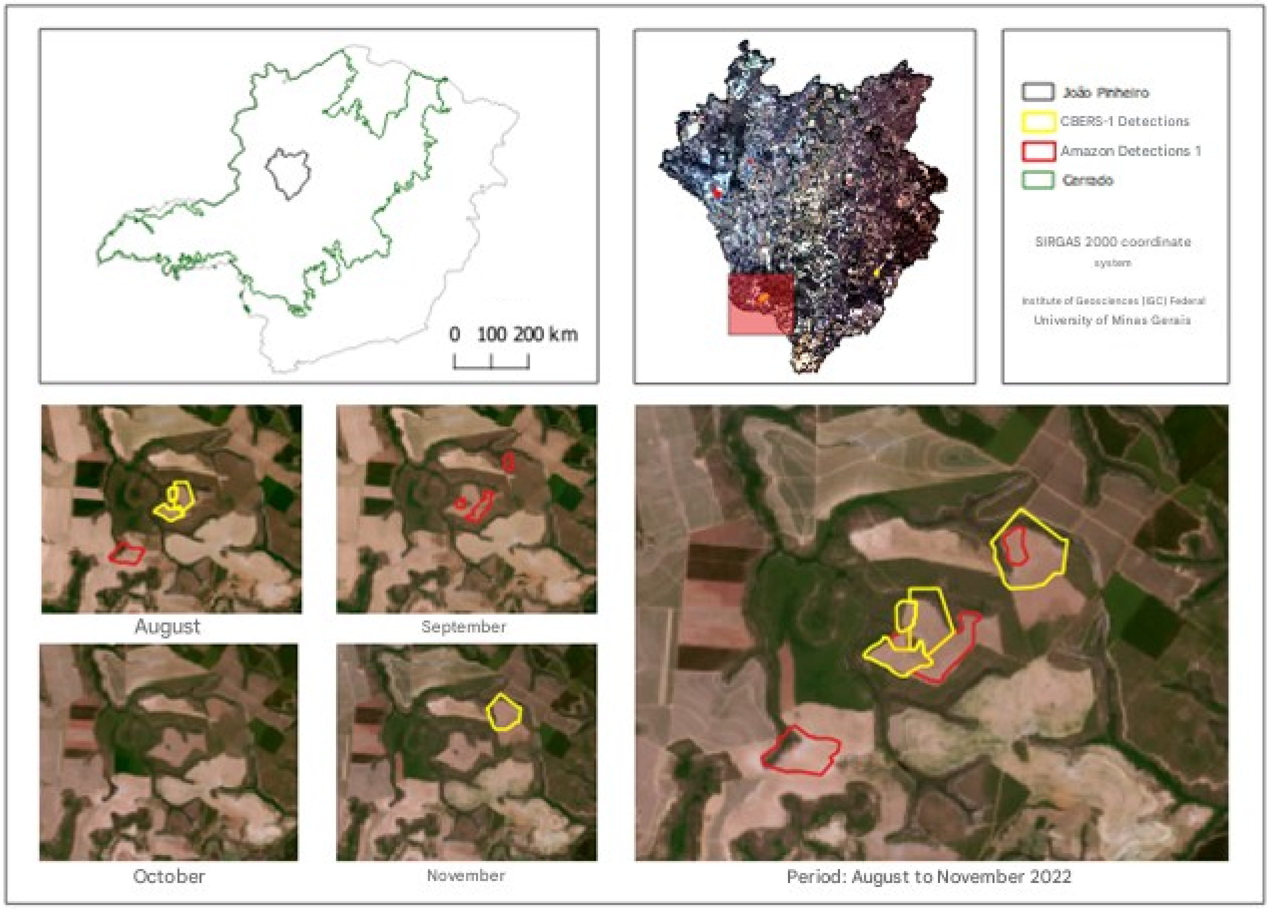

Figure 7 – Polygons detected in the municipality of João Pinheiro (August to November – 2022). Source: Authors (2025).

4. Conclusion

The use of remote sensing orbital images in the evaluation of environmental interventions has been an important strategy for optimizing planning and for a quick response from environmental inspection agencies against environmental violators. The present study showed that the spatial and temporal resolution of the images are of crucial importance for these types of analyses, so that a shorter interval for making images available results in a more effective response against environmental offenders.

In this context, the use of images recently made available by sensors carried on board the Brazilian satellite Amazônia-1, launched in 2021, must be considered as an innovative methodology, as demonstrated in its use in the present work. In the future, with the generation of a robust temporal collection and a greater number of images from this sensor, new studies may be carried out resulting in significant cost reduction, as the images are made available free of charge. In addition to this aspect of the research, it is important to encourage the use of free programs, such as QGIS and its freely available applications, which were also successfully used in this research work.

The polygons made available by the DETER system demonstrated great relevance for the monitoring and planning of environmental inspection actions. The maps generated as a result confirmed that there was no significant increase in deforestation in the Cerrado and, at the same time, there was no significant overload in inspection actions, which could be concentrated in other critical regions of increasing priorities.

The results of the study indicate that it is very important to recommend a previous analysis of the maps generated from the DETER polygons, mainly in the Cerrado biome, to enable a more effective and faster assessment for the identification and inspection of deforested areas. These aspects enable greater planning effectiveness for preventive actions, as well as for actions to combat environmental violations.

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