

Spatial and temporal dynamics of land use and fire hotspots in the Municipality of Miranda-MS

Dinâmica espacial e temporal do uso da terra e dos focos de calor no município de Miranda-MS

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Abstract

The annual analysis of land use and fire hotspots is crucial for wildfire prevention and control strategies, providing key indicators of environmental impact. Several studies highlighted fire as a fundamental element in shaping the landscapes of the *Cerrado*, but frequent fires, combined with intensified land use, lead to a biodiversity loss. Land use and land cover data from MapBiomas were compiled, and fire hotspots from BDQueimadas were analyzed using QGIS and the R programming language. Although both land use/land cover (LULC) changes occur to a lesser extent, they are present throughout the municipality of Miranda, with more pronounced shifts in the NW. This region presents transitions from pasture to soybean plantations and other crops, along with a reduction in wetland areas. Regarding fire hotspots, the Pantanal biome recorded the highest numbers, with annual fluctuations influenced by both climatic and human factors. Fire hotspots were also observed in Indigenous lands, areas of the Serra da Bodoquena, the vicinity of the Pantanal do Rio Negro State Park Conservation Unit, and the SW portion of Miranda municipality. The analysis of fire hotspots reveals fire patterns and supports strategic planning to mitigate risks. The GIS software used provided effective visual analyses, essential to understand fire hotspot behavior and land use dynamics in Miranda, Mato Grosso do Sul State (MS).

Keywords:

Environmental analysis, Wildfires, Land use change, Miranda, Mato Grosso do Sul State.

Resumo

A análise anual do uso da terra e dos focos de calor é crucial para estratégias de prevenção e controle de incêndios florestais, fornecendo indicadores sobre impactos ambientais. Estudos destacam o fogo como elemento essencial na estruturação de paisagens do cerrado, mas os incêndios frequentes, associado a intensificação do uso da terra, resultam em perdas de biodiversidade. Foram compilados dados Mapbiomas de uso e cobertura da terra e analisados focos de calor BDQueimadas utilizando QGIS e linguagem de programação em R. As transformações na utilização e cobertura do solo, apesar de ocorrerem em menor proporção, ocorrem em toda a área do município de Miranda, com mais evidência na porção noroeste, áreas que estão em mudança nos padrões de uso, de pastagem para implantação de soja e outras culturas, bem como a diminuição de áreas pantanosas. Em relação aos focos de calor, áreas do bioma Pantanal registraram maior número, com flutuações anuais influenciadas por fatores climáticos e humanos. As terras indígenas e áreas da Serra da Bodoquena também apresentaram ocorrências de focos de calor durante o período analisado, assim como as proximidades da Unidade de Conservação do Parque Estadual do Pantanal do Rio Negro e a porção sudoeste do município de Miranda. A análise de focos de calor revela padrões de incêndios e permite planejamento para redução de riscos. Os softwares de SIG utilizados ofereceram análises visuais eficazes, fundamentais para compreender o comportamento dos focos de calor e do uso da terra em Miranda, MS.

Palavras-chave:

Análise Ambiental, Incêndios florestais, Mudança de uso do solo, Miranda-MS.

I. INTRODUCTION

The LULC (Land use/ Land Cover) analysis is an important tool to support planning, especially when seeking to reduce deforestation and forest fires that may occur due to changes in local economic matrices. The Geo-technologies have contributed significantly to understand the different classes of land use and land cover in Brazil. An example of that are the data made available by the MapBiomas project, which allows to identify land use classes, the area occupied by each class and the analysis of transitions between these classes over the years, when data is available.

Fitz (2008) defines geo-technologies as those new technologies linked to geosciences and related fields, which allowing significant advances to the development of research, planning actions, and in many other aspects related to the structure of the geographic space. According to Rosa (2011) geo-technologies are a set of technologies for collecting, processing, analyzing and information with a geographic reference. Geo-technologies are composed of hardware, software and people ware solutions that together constitute

powerful tools for decision-making. Most of the geo-technology applications are linked to municipal management, the environment, strategic business planning, agribusiness and utilities.

Among all the possibilities for applying geo-technologies, a special attention is given to studies for spatial-temporal analyses of land use and coverage, because its results, contribute to planning and formulation of public policies, highlighting probable environmental impacts (Souza et al., 2025).

Forest fragmentation, for example, is one of the consequences from the dynamics of LULC, which compromises the continuity of natural habitats, transforming forest formations into isolated patches due to deforestation. These areas can become environmentally unstable, and require a detailed analysis of the land occupation, as well as regional characteristics, to fully understand the process of landscape fragmentation and other direct impacts (Pinheiro et al., 2016).

The inclusion of LULC in natural resource development and planning strategies is vital to ensure sustainable human settlements. Since land use and land cover influence water conservation, erosion control and biodiversity, the occurring changes affect biodiversity loss, increased soil erosion and disruption of hydrological cycles, requiring immediate attention. Globally, 62% of land has been transformed from natural vegetation to agricultural and urban areas. The frequency and intensity of disturbances impact food security and ecosystem services in the area of its occurrence (Afuye et al., 2024).

A crucial element to be analyzed in land use and land cover changes is the use of fire. Fire is the agent that causes the greatest damage to forests worldwide (Soares et al., 2009). The analysis of the annual behavior of hot spots is important, as it contributes to some strategies for preventing and controlling forest fires, and also provides indications of potential environmental impacts in the area under study. Nascimento (2001) reports several studies which point to fire as a fundamental element in the structure of some *Cerrado* landscapes. Its effects can be observed, either by the rapid regrowth after the fire - attracting a varied contingent of herbivores in search of new forage - or by the germination of seeds that require this thermal shock to break its vegetative dormancy.

Nunes et al. (2023) warn that Brazilian biomes are faced to strong anthropogenic pressure, and that fire is very common, resulting in serious biodiversity losses. Correa et al. (2022) inform that forest fires are now behaving differently than in the past in terms of frequency, intensity, and areas affected.

Most fires are frequently caused by human action, for the preparation and maintenance of planted areas, new pasture, burning of residues, and elimination of pests and diseases. The use of fire in agroforestry activities and deforestation are the main causes identified for its' occurrence (Setzer et al., 2021; Brasil, 2023;

Nunes et al., 2023). Regarding its occurrence, forest fires and burnings outside protected areas are more frequent due to the widespread use of fire in rural activities (Patrana Mojica et al., 2024). In the Pantanal, nearly 98% of current forest fires were caused by human activities, whether accidental or criminal (Berlinck et al., 2022). Regarding natural influences on forest fires, Menezes et al. (2022) reinforce that, for example, lightning does not contribute to a high proportion of fires in the Pantanal, representing only 5% of fire scars. Coppola et al. (2023) do not rule out the influence of climate change in the Pantanal, where extreme drought and a propensity for fires will possibly be the region's 'new normal' in the coming years.

The use of fire for pasture management is a common and traditional practice in the Brazilian Pantanal, explained by Soriano et al. (2020). Its purpose is to increase the supply of forage for animals, especially during the dry season (August to September), and according to Nascimento (2001), they often occur by setting fire to large areas.

Controlled burning is permitted by law as a management tool in rural areas (Decree No. 2,661/1998). Although legally permitted, it is often neglected, carried out without authorization and without basic care, and loss of control can generate forest fires with incalculable consequences, giving rise to a series of negative impacts (Brasil, 2023).

According to Soriano et al. (2020), controlled fire depends much more on the weather conditions at the time of application from the management strategy, and on the large biomass volume, than on physical control through firebreaks and other tools. A fire can easily cross the boundaries of rivers, roads and firebreaks with strong winds, high temperatures and low relative humidity.

Hot spots are one of the indicators to monitor the behavior of forest fire. This data is available at the National Institute for Space Research (Brazil/INPE, 2024) in vector files of shape file points and tables in CSV (Comma-Separated Values) format. These data show temperatures above 46.85°C, such as hot spots in satellite images.

Souza et al. (2023) warn on limitations of hotspots: despite being one of the main tools for monitoring fires in Brazil, they can distort the real incidence of fires in certain locations. These authors explain that not all hotspots are fires, and that not all fires can be detected by sensors. However, according to Coelho and Deina (2023), the products derived from the analysis of hotspots can contribute to review and preparation of management plans for risk reduction, providing additionally subsidies for the spatial, statistical and temporal analysis of these occurrences and for studies of ecological, atmospheric and climate change effects.

In this context, the objective of this paper is to analyze changes in land use and land cover and the dynamics of hotspots in the municipality of Miranda-Mato Grosso do Sul State (Figure 1) between 2014 and 2022. This municipality is important for these studies because it shows a transition between the Pantanal and *Cerrado* and some indigenous villages, representing important areas of forest fragments. It is also a traditional area of agriculture and livestock farming, and its basic economy is a large production of irrigated rice. Other important economic activities are fishing and nature tourism (Leite; Carvalho, 2014).

Located in the Mato Grosso do Sul State, this municipality is part of the administrative micro-region Aquidauana and the meso-region *Pantanaís Sul-Mato Grossenses*. Geographically Miranda is located between S 19°35' - 20°40' and WGr 56°05' - 57°05', with an area of 5,478.83 km².

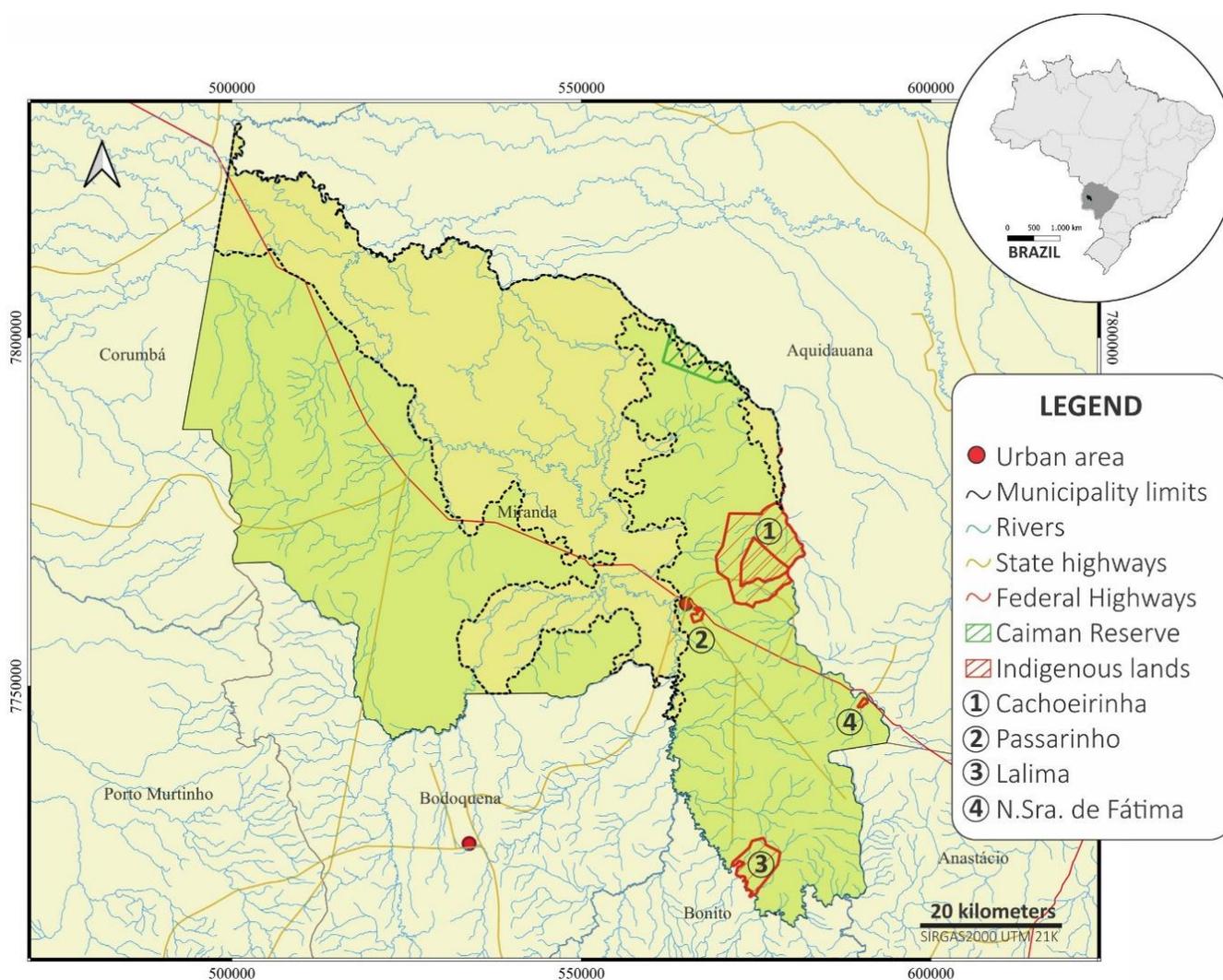


Figure 1 – Localization, Indigenous Lands, Forest Reserves and biomes in the Miranda Municipality, Mato Grosso do Sul State.

II. MATERIALS AND METHODS

Analysis of land use land cover changes

The analysis of land use and land cover was made according to the flowchart at Figure 2, using data provided by the Mapbiomas Collection 8 project with maps in GeoTiff format. Data for years 2014 and 2022 were analyzed. They were imported into the QGIS software together with the municipal limits (IBGE, 2019) to define the area of interest. Data for each class analyzed were calculated and tabulated (r.report function) to determine its area occupied in km².

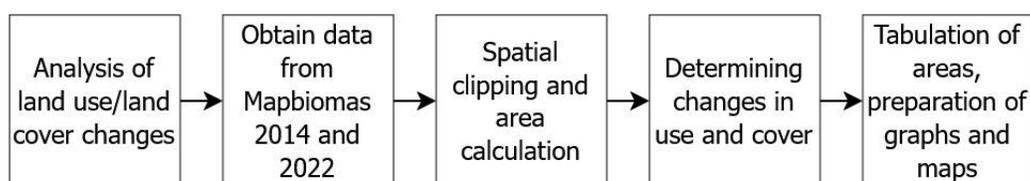


Figure 2 – Methodology flowchart for the analysis of land use land cover.

Applying the cross classification function of QGIS SCP (Semi-Automatic Classification Plugin) plugin to the maps from 2014 and 2022, it was possible to verify the changes in the land use and land cover categories. A table and map was created, indicating whether there were changes or not in the thematic classes of land use and land cover applying the aforementioned function. This table was analyzed in the software R (R CORE TEAM, 2023) and RStudio (POSIT TEAM, 2024). The libraries ggplot2 (Wickham, 2016), readxl (Wickham; Bryan, 2023) and dplyr (Wickham et al., 2023) were used. With the creation of a script, it was possible to filter the data, group and calculate the areas and develop a Sankey diagram, highlighting the changes in land use and cover (OpenLand package by Exavier & Zeilhofer, 2021).

Analysis of hotspots

The hotspot data (Figure 3) used in this study were obtained from the fire monitoring system of the National Institute for Space Research (INPE), accessing the BDQueimadas website. The data were in vector format (shapefile) and in table (CSV). Data from the AQUA_M-T reference satellite were considered. These data were filtered for the Miranda municipality, Mato Grosso do Sul State, and for the period 2014 to 2023.

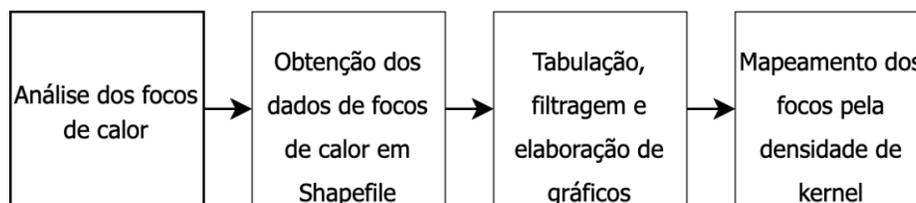


Figure 3 – Methodology flowchart for the analysis of hotspots.

The hotspots, organized in a vector file of points, were imported into the QGIS software (QGIS DEVELOPMENT TEAM, 2024), where they were re-projected to the UTM coordinate system, time zone 21S, Datum Sirgas 2000. Using this software, the Heat Map function (Kernel Density Estimation) was applied, creating a density raster (heat map) considering a kernel density estimation. The results allow the visualization of the hotspots. The maximum radius of 10 km was established for this analysis, so the concentration of hotspots represents their number within a 10 km radius.

The R software (R Core Team, 2023) and the RStudio development environment (Posit team, 2024) were used to analyze the tabulated data, filtering them per year and biome, based on the development of a script which acted on the hotspot table. The libraries ggplot2 (Wickham, 2016), readxl (Wickham; Bryan, 2023) and dplyr (Wickham et al., 2023) were also used.

Furthermore, to analyze the spatial behavior of the hotspots, it was decided to observe them within the limits of the municipality, its borders, its biomes, its conservation units and indigenous lands. These data were obtained from the IBGE website (2024) in vector format and superimposed on the heat maps.

III. RESULTS AND DISCUSSION

Land use and land cover

Analyzing Figure 4 and data in Table 1, which provides data on land use and land cover, one verifies that, in this municipality, mining occupies small areas near the Agaxi stream, east of Miranda, coinciding with the municipal limits of Aquidauana. Additionally, forestry areas were found in the eastern portion of the municipality, close to BR-262 highway, in the direction of Aquidauana-Miranda. The forestry class had a significant reduction of 39% in the occupied area between 2014 and 2022.

The urban area of Miranda city increased 5.7% during the period analyzed. On the other hand, the “Other Non-Vegetated Areas” class grew considerably, from 1,477 km² in 2014 to 4,945 km² in 2022.

Table 1 – Land use / land cover classes and respective areas.

Thematic class	2014 Area (km ²)	2022 Area (Km ²)
Mining	0,010	0,685

Forestry	4,876	2,962
Urban area	4,367	4,618
Other Non-Vegetated Areas	1,477	4,945
River, Lake	42,609	33,340
Flooded field and marshy area	247,985	49,684
Soybean plantation	30,169	106,637
Other temporary cultures	89,138	121,995
Mosaic of uses	444,603	509,758
Open field formation	438,905	559,540
Savanna formation	1.014,593	1.058,099
Pasture	1.541,989	1.422,256
Forest formation	1.606,486	1.596,792

The areas of water bodies and marshes (such as rivers, lakes, flooded fields and marshy areas) suffered a significant 71.43% reduction of its areas, notably in the NW portion of the municipality. The reduction from each of these classes has various impacts, but, generally such a significant decrease affects negatively the biodiversity and the quality of local ecosystems. These areas are replaced by native fields or planted pastures which, if not properly managed, are fuel for forest fires. The MapBiomass Project (2024) has already warned that Mato Grosso do Sul was the State with the greatest absolute and proportional loss of water surfaces in the historical series analyzed, with a reduction of 57%.

The decline in rainfall recorded in recent decades has significantly reduced the water availability to maintaining the extensive floodable areas, a characteristic of the Pantanal. This scenario has driven changes in land use, promoting the expansion of grassland formations to replace aquatic environments, which highlights an ongoing ecological transition process in the biome (Marques et al., 2024).

According to data from IBGE (2022), the municipality's agricultural sector, regarding the annual crops, does not present a characteristic of a productive diversification. However, the area destined for plantations more than doubled between 2014 and 2022. In 2014, the area planted or destined for harvest was 77.94 km², increasing to 157.36 km² in 2022. The agricultural sector is ranked as the third most important economic sector, accounting for 24.16% of the total.

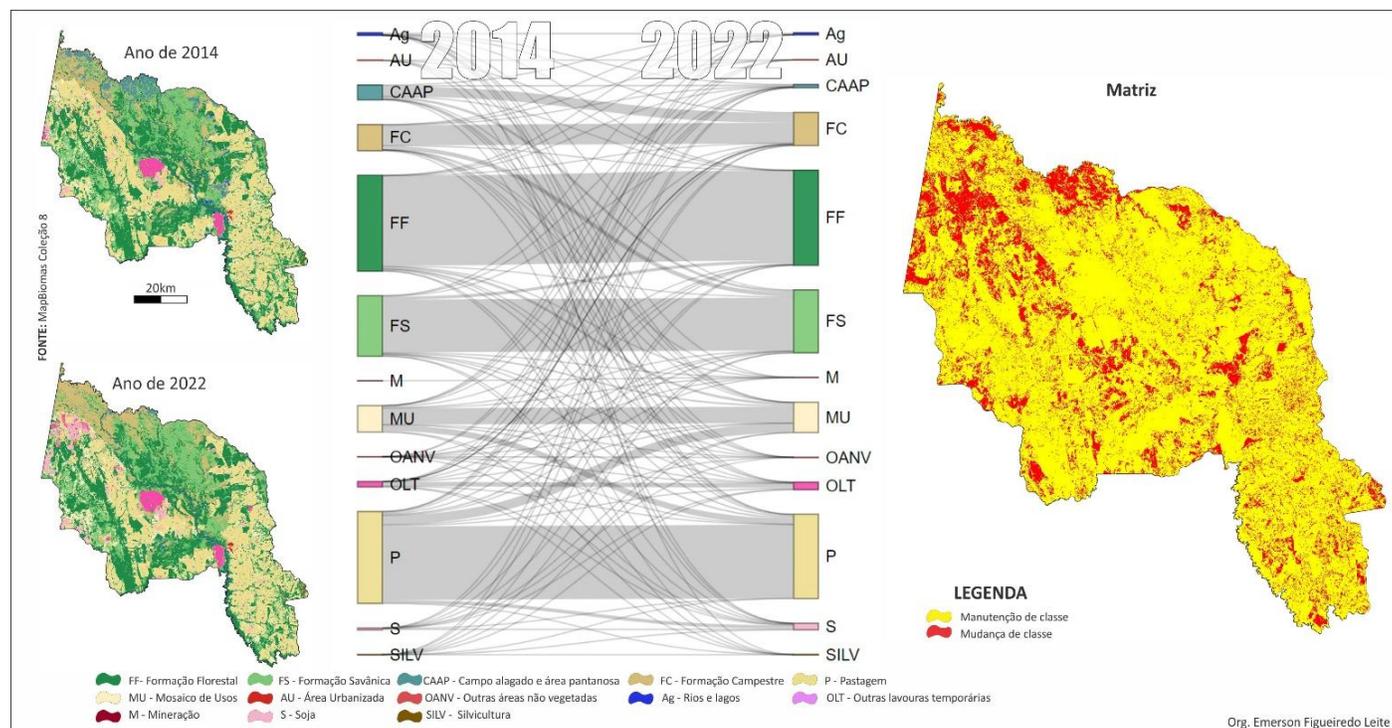


Figure 4 – Land use / land change matrix for Miranda municipality, Mato Grosso do Sul State.

According to data from IBGE (2022), some significant changes were observed in the agricultural crops of the Miranda municipality. The traditional rice crop, cultivated through with irrigation technique, lost its space during the period analyzed: the area destined for cultivation was reduced from 45.2 ha in 2014 to 28 ha in 2022. The corn cultivation did not show a solid dynamic, presenting important fluctuations; the area planted was 71 ha in 2018 decreased to 20.40 ha in 2022. The main agricultural highlight of this municipality was soybeans, which began to stand out in 2012 with 19.75 ha, reaching its peak in 2018 with 133.03 ha, decreasing later to 101.41 ha.

Soybean plantations and other temporary crops also showed considerable changes, as shown in Figure 4. The areas intended for soybean cultivation increased significantly by 253.46%. Furthermore, other temporary crops and the mosaic of uses increased by 18.32%, totaling 631.753 km².

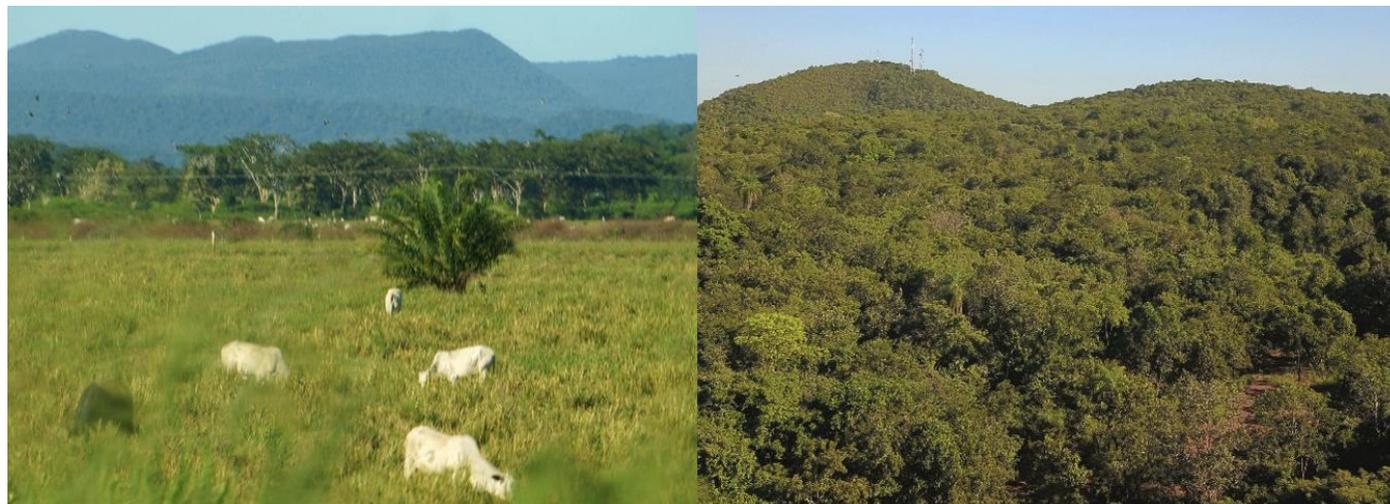


Figure 5 – Land use / land cover and forest fragments in Miranda municipality – Mato Grosso do Sul State.

According to data from MapBiomias (2024), pasture areas (Figure 5, left) were reduced by 119,733 km², representing 7.76% of the previously occupied area. Forest remnants decreased 9,694 km², while savanna areas increased 43,506 km².

Ribeiro and Bourscheidt (2024) warn that changes in the reduction of forest areas impact directly the loss of environmental services, such as the deficit in the maintenance of biodiversity, reduction of carbon stocks and threats to the soil.

The maintenance of forest areas (Figure 5) can be observed along watercourses and in residual relief of *Serra da Bodoquena*. This analysis reflects the consolidation of land use and land cover in the municipality and can be useful to understand how the landscape has evolved over this period. The livestock sector represents an important sector in Miranda's economy: it is the largest employer in the agricultural sector. According to Caged (2023) (General Register of Employed and Unemployed Persons), from the 642 formal jobs in agriculture in 2023, 513 (79.9%) were related to the livestock sector. The municipality concentrates 1.69% of the State's cattle herd, with a total of 315,361 head in 2021.

The applied change matrix is an important tool to assess changes in land cover over time. According to the data found, 81% of the area from land use and land cover classes did not change, while 19% showed changes for the type of thematic class between 2014 and 2022. It was verified that these changes occurred in the western and northwestern portions of the municipality, and they are due to the expansion of agricultural activities and the reduction of marshy areas, respectively.

Hotspots

Climate change, with the intensification of extreme events, caused changes in the rainfall regime at the Pantanal biome in the last five years, resulting in longer drought periods. In this context, those fire events recorded in the region are the result of the combination of human action and drought conditions, exacerbated by reduced rainfall (Freitas et al., 2023).

In the period analyzed, which covered the years 2014 to 2023, totaling 10 years, Miranda suffered 1,669 hotspots recorded by the INPE monitoring system, BDQueimadas, listed on Table 2 and Figure 7 and presented in the hotspot intensity maps on Figure 6.

Table 2 – Total hotspots during the years analyzed.

Ano	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Total	66	103	50	43	2	554	131	394	55	271

Source: INPE, BDQueimadas (2024).

Analyzing the period from 2014 to 2016, one observes that the hotspots were concentrated in the northwestern portion of the municipality, mainly in transition areas between the Pantanal and *Cerrado* biomes, totaling 264 hotspots. Setzer et al. (2021) reported that, frequently in Brazil, fire occurs in regions of biome transition and during the dry season and periods of prolonged drought.

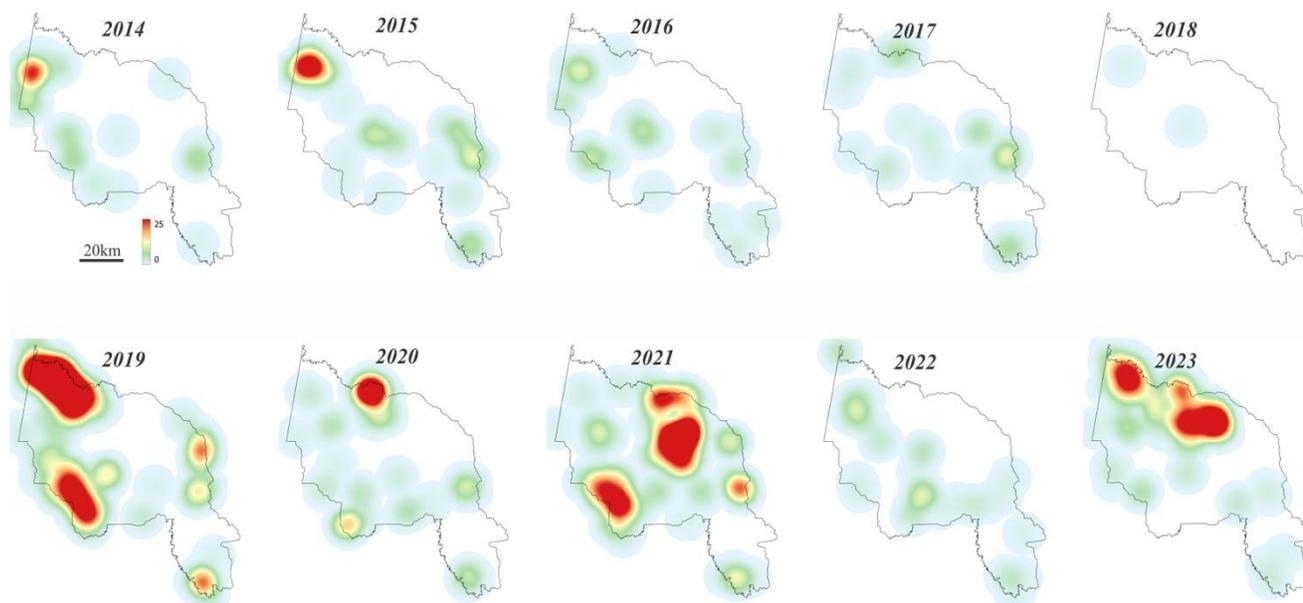


Figure 6 – Density of yearly hotspots for Miranda municipality, considering a radius of 10 km.

At 2019, there was a significant increase (Figure 7) of hotspots, with a total of 554 outbreaks, representing an increase of 110% compared to the last four years analyzed. During this period, the outbreaks

remained concentrated in the NW and SW portions, in the *Cerrado* areas of *Serra da Bodoquena* region, a representative area of Forest Savannah remnants.

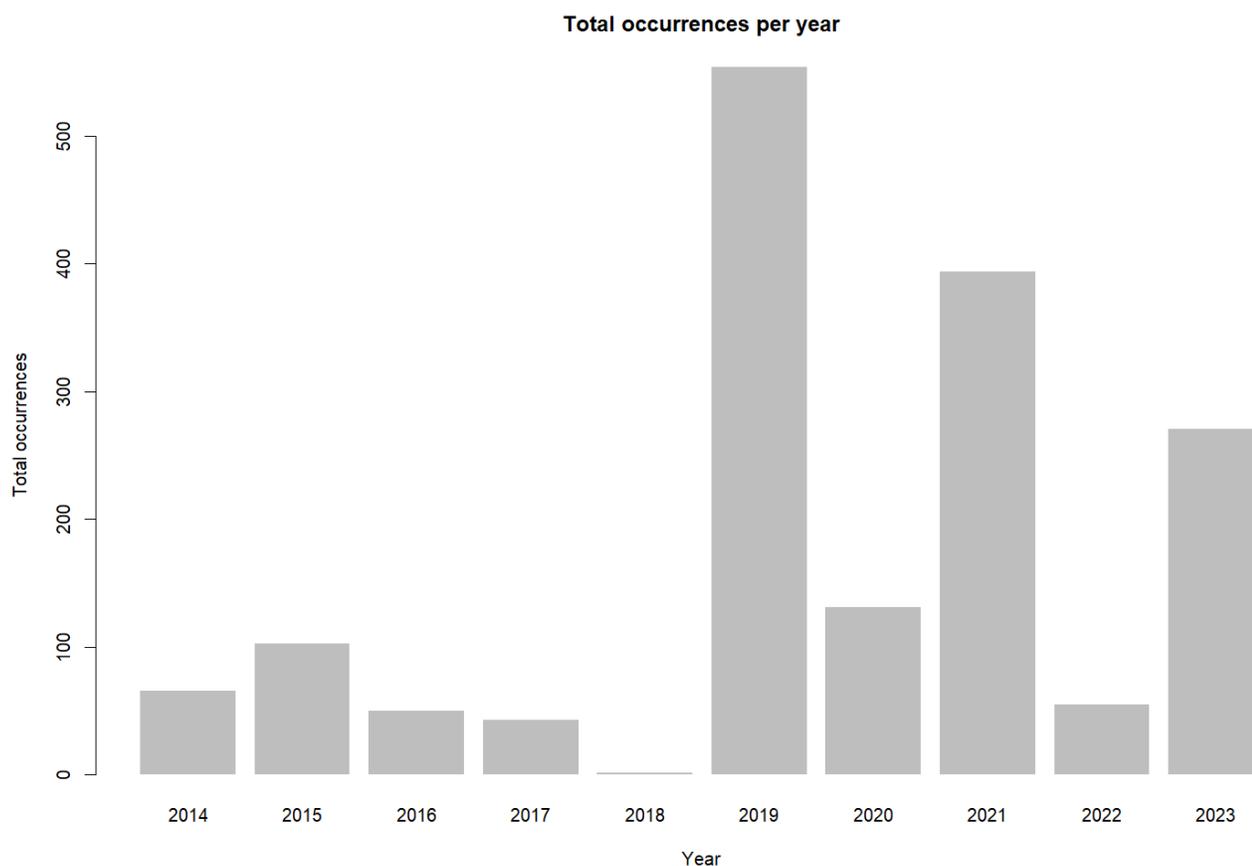


Figure 7 – Annual heat spot occurrences in Miranda municipality.

Moreira et al. (2021) inform that among the reasons why fire broke out more intensely in 2019 are the low rainfall rate typical for the dry season and the anthropogenic actions of agricultural producers in the region. Berlinck et al. (2022) warn that the Pantanal has suffered an extreme drought since 2019, with a decrease in the amount of water in floodplains and rivers, resulting in extremely dry soil and vegetation, increasing the risk of forest fires. Furthermore, according to Souza (2023), there is a positive relationship between above-average fire in the Pantanal biome and the increase of vapor pressure deficit and as a consequence, the reduction of soil moisture and precipitation in the Pantanal and adjacent biomes. This represents a strong indication of a relationship with the climate change.

In 2020, 131 outbreaks were recorded, with the highest concentration in the northern limits of the municipality, close to the border with Aquidauana, and in the vicinity of the Cachoeirinha Indigenous Land. In

the following year, 2021, 394 outbreaks occurred, concentrated in the central-northern portion, in areas of the Pantanal biome, and in the SW portion, in areas of *Cerrado* in the *Serra da Bodoquena* region.

In 2022, there was a decrease to 55 records in the number of fires, located in the central region of the municipality where livestock farming is the predominant economic activity, followed by an increase in records in 2023, with 271 fires concentrated in the northern and northwestern portions, comprising areas of the Pantanal biome. Considering the biomes, the Pantanal was the one that presented the largest number of fires compared to the *Cerrado*, with 961 and 708 fires respectively.

Nunes et al. (2023) examined the effects of climatic variables on fire outbreaks in three biomes in the Mato Grosso do Sul State during 1999-2021. These authors showed that the relationship between fire outbreaks and climatic variables was not linear, and that most of the fires occurred in the Pantanal (wetlands), followed by the *Cerrado* and Atlantic Forest (semi-deciduous forest). The results indicated that trends in land use and land cover have changed over the years, showing a strong correlation between fire and agriculture. The high probability of fire indicates that the expansion of agricultural areas with the conversion of natural biomes, impacts several natural ecosystems, transforming land use and land cover. This land conversion is promoting more fires every year Marques et al. (2021) reinforce this statement emphasizing that fires have been influenced by human actions, mainly resulting from pastures and agricultural activities, notably their advance and influence in the *Cerrado*/Pantanal agricultural frontier region.

In fact, in the *Cerrado*, the land structure based on large properties opened space for deforestation, and the practice of burning, because it does not represent costs, has been most frequently used. Without efficient monitoring, uncontrolled fires reach other vegetation complexes, spreading over several hectares (Nascimento, 2001). Setzer et al. (2021) warn on the importance of these biomes for the climate, due to carbon storage, original vegetation cover and because they are sources of water.

The Cachoeirinha and Lalima indigenous lands presented hot spots throughout the analyzed period, except for 2018, when only 2 hot spots were recorded in the municipality. The same occurred in area of *Serra da Bodoquena*, close to the Conservation Unit *Parque Estadual do Pantanal do Rio Negro* and at the SW portion of Miranda municipality.

Regarding indigenous lands, Santa Rosa et al. (2019), when analyzing the recurrence of hot spots in the *Cerrado* biome (2002-2017), found a low recurrence of active fires in federal conservation units and indigenous lands where the majority, although some of these areas showed a high recurrence.

The speed and efficiency to detect and monitor these fires are essential for their location and control, avoiding more drastic consequences for the Pantanal ecosystem. The use of computational resources, combined with Geographic Information Systems, has greatly facilitated the prediction and fighting against fires (Soriano et al., 2020).

Considering the probability of recurrent and out-of-control forest fires, Berlinck et al. (2022) suggest that fire prevention policies and best management practices must be included for any use in the Pantanal. These authors emphasize the need for (A) continuous monitoring for early detection of fire risks and events; (B) the installation of fire brigades in strategic locations in the region with continuous action; (C) community education programs focused on the appropriate use of fire for management purposes, (D) effective application of fire use policies and (E) implementation of a wildlife conservation plan.

IV. CONCLUSIONS

Changes in land use and land cover, although occurring to a lesser extent (19%), were observed throughout the municipality, with stronger evidence in the western and northwestern portions, sectors that are undergoing a shift from livestock farming to soybeans and other crops, as well as a reduction in marshy areas. These changes have significant relevance for the environment and the sustainable development of the municipality. Monitoring these trends and implementing appropriate management strategies is essential to balance urban growth, environmental preservation, and agricultural production.

Regarding the dynamics of hotspots in the municipality of Miranda, the results indicate that fire is present in a greater or lesser proportion of hotspots in the area studied. In conclusion, areas of the Pantanal biome recorded a significantly higher number of hotspots when compared to the *Cerrado*. Indigenous lands and areas of the *Serra da Bodoquena* also showed occurrences of hotspots during the period analyzed, as well as in the vicinity of the Conservation Unit *Parque Estadual Pantanal do Rio Negro* State Park and the SW portion of the Miranda municipality.

The data reveal a significant variation in hotspots over the years. A strong increase was observed in 2019, with 554 hotspots, followed by a decrease in 2020 and 2022. However, in 2023, there was a substantial increase again, with 271 hotspots. This pattern suggests an annual fluctuation in hotspots, influenced by several factors, such as weather conditions and human activities.

These data are essential for identifying the fire behavior patterns. Analysis using GIS software provided a clear and efficient view through maps and graphs, revealing modifications of hotspots and changes in land use and cover in the municipality of Miranda, MS.

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