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SPATIOTEMPORAL VARIABILITY IN FIRE FOCI DETECTION IN THE STATE OF MATO GROSSO, BRAZIL

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Resumo

Variabilidade espacial e temporal na detecção de focos de queima no estado do Mato Grosso, Brasil. A queima da vegetação constitui uma das principais fontes de emissão de gases do efeito estufa na atmosfera. O monitoramento da variabilidade espaço-temporal de focos de queima por satélites ambientais pode ser utilizado no desenvolvimento estratégico de prevenção ao fogo. Os objetivos deste estudo foram analisar a variabilidade espaço-temporal na detecção de focos de queima no estado de Mato Grosso e determinar as variáveis correlacionadas com a detecção a nível municipal. Para tal, foram coletados dados de focos de queima dos satélites AQUA e Suomi-NPP (S-NPP) que foram quantificados por município e correlacionados com 11 variáveis independentes. A média anual de focos foi de 38.646 pelo satélite AQUA (2003 a 2023), e de 127.992 pelo S-NPP (2013 a 2023). Durante o período de sobreposição, o S-NPP detectou 4,7 vezes mais do que o AQUA. Apesar da diferença, ambos os dados apresentaram correlação significativa. Setembro foi o mês com maior registro de focos. Colniza foi o município com o maior número de detecções, enquanto Itanhangá e Nova Nazaré registraram a maior densidade de focos pelos satélites AQUA e S-NPP, respectivamente. Dos 141 municípios, 133 foram classificados com incidência de fogo extrema ou muito alta. O desflorestamento da vegetação primária foi a variável que apresentou maior correlação com a densidade municipal de focos de queima. Os resultados podem servir para o desenvolvimento de políticas públicas voltadas à redução de incêndios e queimadas no estado.
Palavras-chave: Incêndios florestais; sensoriamento remoto; conservação da natureza.

Abstract

Biomass burning of vegetation is one of the primary anthropogenic sources of greenhouse gas emissions into the atmosphere. Monitoring spatiotemporal variability of wildland fire occurrence by environmental satellites is a method that can be used in the development of fire prevention strategies. The objectives of this study were to analyze the spatiotemporal variability in fire foci detection in the state of Mato Grosso and to determine the variables associated with fire detection at municipal level. Data from AQUA and Suomi-NPP (S-NPP) satellites were quantified by municipality and correlated with 11 independent variables. Mean annual number of fire foci detected was 38,646 by AQUA based on data from 2003-2023, and 127,992 by S-NPP from 2013-2023. During the overlap period, S-NPP detected 4.7 times more foci than AQUA. Despite the difference, both datasets were significantly correlated. Most fire foci were detected in September. Colniza was the municipality with the highest number of detections, while Itanhangá and Nova Nazaré registered the highest fire foci density by the AQUA and S-NPP satellites respectively. Of the 141 municipalities, 133 were classified as having extreme or very high fire incidence. Primary deforested area was the variable that presented the highest correlation with municipal fire density. The findings of this study may serve as a foundation for developing public policies aimed at reducing the occurrence of wildland fires in Mato Grosso.
Keywords: Wildland fires; remote sensing; nature conservation.

INTRODUCTION

Wildland fires exert multifaceted impacts on forest ecosystems, leading to alterations in vegetation structure, loss of biodiversity, and the release of greenhouse gases such as carbon dioxide, which contribute to the intensification of the current global climate change scenario (GAJENDIRAN *et al.*, 2023). Measuring the global impact of wildland fires on greenhouse gas emissions has become increasingly important. To date, 2024 had the highest combined land–ocean temperature anomaly (1.46 °C above the pre-industrial average) solidifying its position as the warmest year since at least 1850 (NOAA, 2025). Brazil's climate data also underscores a significant warming trend, with 2024 marking the hottest year on record: 25.02°C, which is 0.79°C above the 1991–2020 average (INMET, 2025). This warming is contributing to more frequent and severe climate-related disasters, including droughts, floods and storms, highlighting the urgent need for comprehensive climate adaptation and mitigation strategies.

The use of satellite remote sensing for wildland fire detection represents a critical approach for monitoring fire activity, particularly in remote or inaccessible areas. In Brazil, the *Centro de Previsão de Tempo e Estudos*

Climáticos (CPTEC), from the *Instituto Nacional de Pesquisas Espaciais* (INPE), is responsible for generating and disseminating fire occurrence data based on environmental satellite imagery. Currently, INPE receives imagery from ten satellites equipped with optical sensors operating in the mid-infrared spectrum (~4 μm), including NOAA-18, NOAA-19, METOP-B, METOP-C, TERRA, AQUA, Suomi-NPP, NOAA-20, GOES-13, and MSG-3 (INPE, 2025). Among these, data from the AQUA satellite (afternoon passage), obtained via the MODIS sensor and processed with the "Collection 6" algorithm, has been used as reference since 2002. This long-term dataset supports the generation of consistent time series and enables trend analysis for fire activity (INPE, 2025). With AQUA nearing the end of its operational life, the transition to a new reference sensor has become necessary. According INPE (2025) the Suomi-NPP satellite (afternoon passage), equipped with the VIIRS sensor, will serve as reference data succeeding the AQUA. Both MODIS and VIIRS provide observations twice daily (morning and afternoon), and their similar overpass times allow for continuity in sampling the diurnal cycle of fire activity (INPE, 2025). In comparison to MODIS, VIIRS offers enhanced spatial resolution (375 m versus 1 km), which significantly improves the detection of smaller fire events.

Although satellite-based remote sensing is a fundamental tool for wildland fire detection, it is subject to inherent limitations that may lead to detection errors, particularly omissions (false negatives) and, to a lesser extent, commissions (false positives). Omission errors are more prevalent in data derived from the MODIS sensor when compared to the VIIRS sensor due to the coarser spatial resolution of MODIS (WHITE, 2019). Nonetheless, omission errors can affect all satellite sensors used in fire detection mostly when fires ignite and extinguish between satellite overpasses, under dense cloud cover, in surface fires beneath closed forest canopies, or along terrain features such as mountainsides oriented away from the satellite's line of sight (INPE, 2025). Daytime commission errors are comparatively rare and are typically associated with high-reflectance surfaces, such as industrial rooftops or areas affected by sun glint, which may trigger false fire detections (SCHROEDER; GIGLIO, 2017). These false positives generally account for less than 1.2% of active fire detections in VIIRS data and approximately 1.0% in MODIS (SCHROEDER; GIGLIO, 2017).

Wildland fires in the state of Mato Grosso demonstrate distinct spatiotemporal dynamics, which are strongly influenced by the region's patterns of agricultural and livestock expansion. In the Amazon biome, fire activity is primarily associated with deforestation practices, whereas in the Cerrado biome, the recurrent use of fire remains a common component of traditional agricultural land management (White, 2024). The Pantanal region, when comparing with the Cerrado, is more sensitive and vulnerable to extreme fire events, especially during periods of severe drought. A notable example occurred in 2020, when wildfires affected more than 30% of the Pantanal's total area, resulting in unprecedented ecological damage (Silva et al., 2021b). Since the implementation of satellite-based wildland fire monitoring in Brazil, Mato Grosso is the second-ranked state in terms of fire detections, surpassed only by Pará (INPE, 2025).

Given this scenario of high fire incidence and environmental heterogeneity, analyzing the spatiotemporal patterns of fire occurrence and understanding the factors influencing fire detection are essential for improving the interpretation of fire dynamics in the region and for supporting the development of effective fire prevention and mitigation strategies. Therefore, this study aims to analyze the spatiotemporal variability of fire detections in the state of Mato Grosso using data from the AQUA and Suomi-NPP (S-NPP) satellites, to assess the similarity and correlation between these datasets, and to identify the independent variables associated with fire detection at the municipal level.

MATERIAL AND METHODS

Characterization of the study area

The state of Mato Grosso, located in the Central-West region of Brazil, covers an area of approximately 903,357 km², accounting for about 10.6% of the national territory. It is the third-largest Brazilian state in terms of land area. Colniza is the largest of the 141 municipalities, with an area of 27,946 km², while São Pedro da Cipa is the smallest with 344 km² (IBGE, 2025). In 2022 the total population in the state was 3,658,649 corresponding to an average population density of 4.05 inhabitants per km² (IBGE, 2022).

The predominant climate in the northern and western regions is the tropical monsoon (Am), characterized by a high annual average temperature exceeding 24°C and heavy rainfall (approximately 2,000 mm annually). In the eastern and southern regions, the tropical savanna climate (Aw) prevails, marked by summer rains and a dry winter, with average temperatures around 23°C in the plateau areas. Precipitation is also high in this climate, exceeding an annual average of 1,500 mm (KOTTEK et al., 2006).

The state hosts three major Brazilian biomes: the Amazon Rainforest, the Cerrado (Brazilian savanna), and the Pantanal (the world's largest tropical wetland). Approximately 53% of the state's territory falls within the Legal Amazon (IBGE, 2020). The northern portion of the state is characterized by dense ombrophilous and seasonal forests, typical of the Amazon biome. Central Mato Grosso is dominated by the Cerrado, which features savanna-like vegetation including grasses, shrubs, and fire-adapted trees (MAPBIOMAS, 2024a). The southwestern region is occupied by the Pantanal, an extensive floodplain that exhibits a mosaic of riparian, savanna, and aquatic vegetation, shaped by complex hydrological dynamics and biogeographical interactions with the Amazon and Atlantic Forest (JUNK *et al.*, 2006).

Mato Grosso is one of Brazil's most dynamic states, with agribusiness, especially soybeans, corn, cotton, and cattle, driving both national and global markets (IBGE, 2022). This sector dominates the state's GDP, supported by favorable climate and soils. However, its growth has often come at the expense of native vegetation in the Amazon and Cerrado, resulting in high deforestation rates (MAPBIOMAS, 2024a).

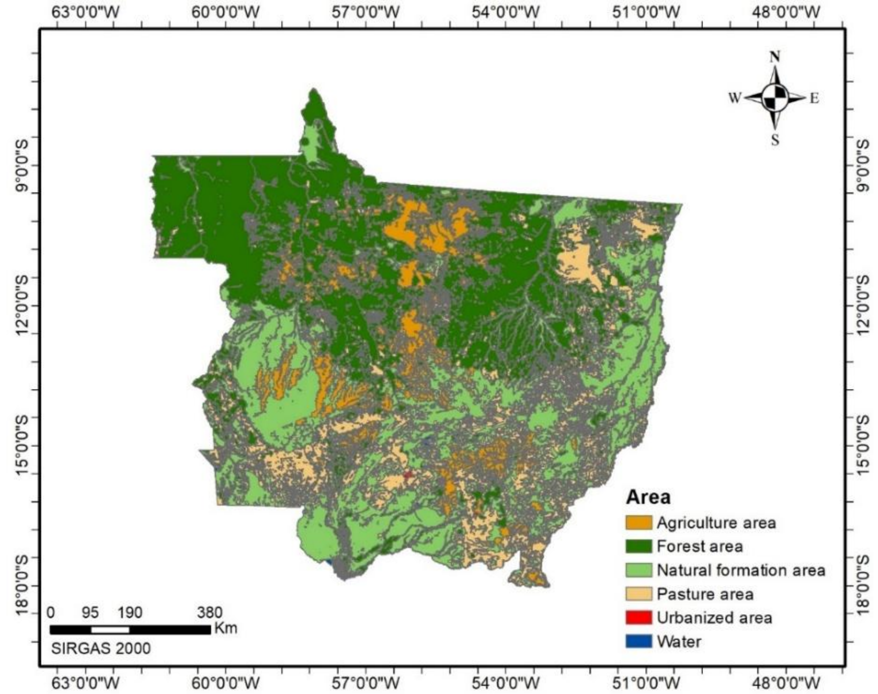

Figure 1. Spatial distribution of land use and land cover classes in the state of Mato Grosso, based on IBGE mapping derived from satellite imagery acquired in 2014. Credit: B. White. Data Source: IBGE (2020).
Figura 1. Distribuição das diferentes coberturas de solo no estado do Mato Grosso baseando-se em mapeamentos da cobertura do solo derivados de imagens de satélite obtidas em 2014. Elaboração: B. White. Dados: IBGE (2020).

Data collection

Records of fire foci in the state of Mato Grosso were obtained from the Queimadas Program (INPE, 2025), based on 21 years of data from the AQUA satellite (afternoon passage) - 01 Jan 2003 to 31 Dec 2023, and 11 years of S-NPP - 01 Jan 2013 to 31 Dec 2023. The values were quantified by municipality, grouped by month and year.

The following independent variables that may have influenced the number of fire foci were quantified for each municipality: mean annual temperature; mean annual rainfall; population size; mean area of forest (including natural and planted forests, and mangroves); mean area of non-forest natural formations (including wetlands, grasslands, apicum and other non-forest formations); mean urbanized area; mean agriculture area; mean pasture area; mean primary vegetation deforestation area; mean secondary vegetation deforestation area; and mean fire scars area. These variables were used due to the availability of historical data and due to the fact that previous studies have already indicated that they can influence wildland fire occurrence (WHITE 2018; WHITE 2020).

The mean forest, non-forest natural formation, urbanized, agriculture, pasture, deforested (primary and secondary), and fire scars areas from each municipality were obtained based on annual data from 2003-2023 (MAPBIOMAS, 2024a). Such data were divided by the municipality area to avoid the positive influence of the municipality size in the wildland fire detection during the Pearson's correlation matrix analysis. The data available by MAPBIOMAS are annual and based on images from the Landsat satellite with 30m resolution. For each year, a mosaic is created that covers Brazil, representing the behavior of each pixel according to the number of available observations, varying from 0 to 23 observations per year (MAPBIOMAS, 2024b).

Mean annual temperature and mean annual rainfall were obtained from CLIMATE-DATA (2024), which is based on data from the European Centre for Medium-Range Weather Forecasts (ECMWF) collected from 1991 to 2023. Population and municipality size were obtained from IBGE (2022).

Fire foci incidence classification

The municipalities were grouped according to the classification used by White (2020) into six fire incidence classes, based on the number of fire foci detected per area by the AQUA satellite during a period of one year (Table 1).

Table 1. Classification of fire foci density detected by AQUA satellite (afternoon passage) over one year according to White (2020).

Tabela 1. Classificação da densidade de focos de queima detectados pelo satélite AQUA (passagem da tarde) durante o período de um ano de acordo com a classificação de White (2020).

Frequency class	Number of fire foci detected per year	Density of fire foci
Very Low	None or one fire focus for an area > 600 km^2	< 0.0017 fire foci km^{-2} year^{-1}
Low	One fire focus for an area > 300 and ≤ 600 km^2	> 0.0033 and ≤ 0.0017 fire foci km^{-2} year^{-1}
Average	One fire focus for an area > 150 and ≤ 300 km^2	> 0.0067 and ≤ 0.0033 fire foci km^{-2} year^{-1}
High	One fire focus for an area > 75 and ≤ 150 km^2	> 0.0133 and ≤ 0.0067 fire foci km^{-2} year^{-1}
Very High	One fire focus for an area > 25 and ≤ 75 km^2	> 0.04 and ≤ 0.0133 fire foci km^{-2} year^{-1}
Extreme	One fire focus for an area ≤ 25 km^2	≥ 0.04 fire foci km^{-2} year^{-1}

Data analysis

Trends in annual fire foci were assessed using linear regression, while correlations between AQUA and S-NPP satellites (2013–2023) were tested with Pearson’s correlation. The influence of independent variables on municipal fire foci density was evaluated through a Pearson correlation matrix, considering only AQUA data for its longer time series. Monthly fire foci (2003–2023) were compared using ANOVA, since data presented normal distribution and homogeneity of variance, followed by the Tukey-Kramer test to identify significant differences.

RESULTS

A total of 811,570 fire foci were detected by the AQUA satellite from 2003 to 2023, and 1,407,915 were detected by S-NPP from 2013 to 2023, resulting in annual means of 38,646 and 127,992 foci for AQUA and S-NPP, respectively. Fire foci were detected in all 141 municipalities. São José do Povo had the lowest number and Colniza the highest for both satellites. Proportionally to their area, Itanhangá and Nova Nazaré were the two municipalities with the highest density of fire foci according AQUA and S-NPP satellites respectively. The linear regression of the annual number of fire foci over time indicated a significant downtrend from 2003 to 2023 for the AQUA satellite data (r^2 = 0.40; $p < 0.01$). Considering only the data for the overlap period (2013-2023), no significant trend was observed for any of the satellites (Figure 2).

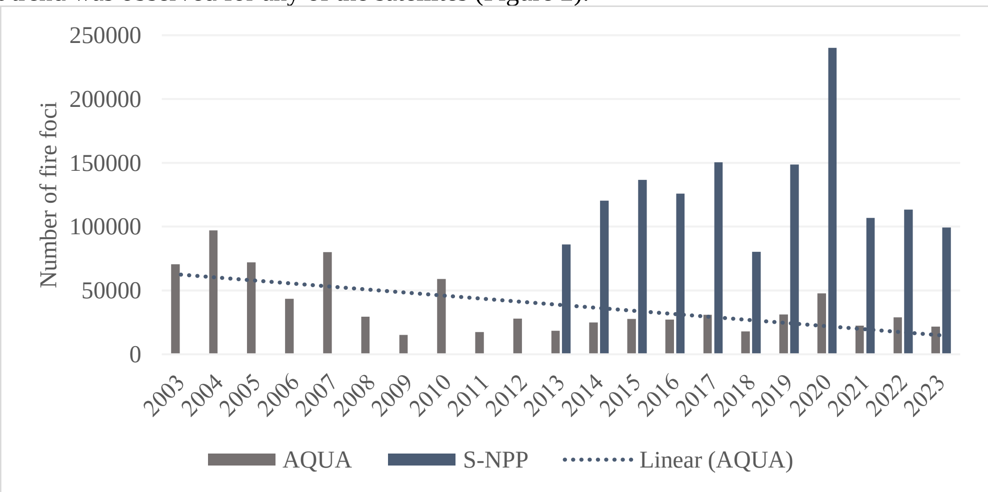

Figure 2. Yearly number of fire foci detected in Mato Grosso state (Brazil) by the AQUA (2003-2023) and S-NPP (2012-2023) satellites. The dashed line indicates the regression line of AQUA detections over time, indicating a significant downward trend.

Figura 2. Focos de queima detectados em Mato Grosso, agrupados de acordo com o ano, pelos satélites AQUA (2003-2023) e S-NPP (2013-2023). A linha pontilhada representa a linha de tendência dos valores obtidos pelo satélite AQUA, indicando uma tendência de queda durante o período avaliado.

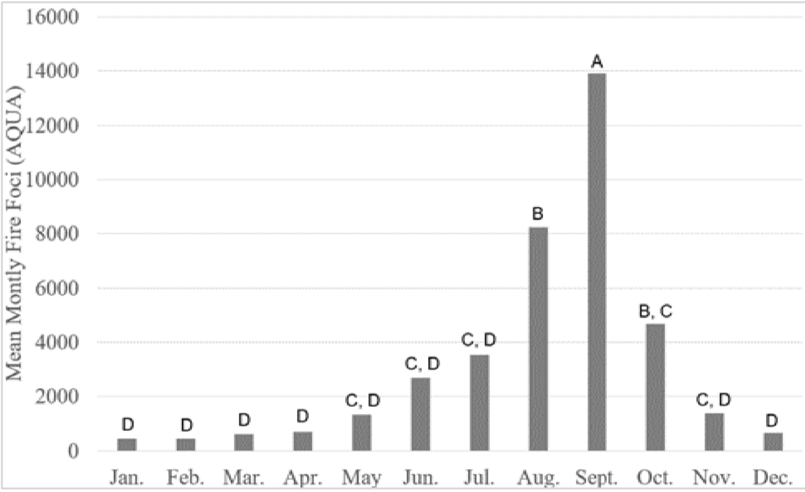

Figure 3. Mean monthly number of fire foci detected by the AQUA satellite for the period 2003-2023. Different letters indicate significant differences between the mean monthly values according Tukey-Kramer test.
Figura 3. Média mensal de focos de queima detectados pelo satélite AQUA no período de 2003 a 2023. Letras diferentes indicam diferença significativa entre os valores médios mensais, de acordo com o teste de Tukey-Kramer.

During the AQUA and S-NPP overlap period (2013-2023), S-NPP detected 4.7 times more fire foci than AQUA (Table 2). Despite this difference, AQUA and S-NPP yearly fire foci data for all the state were significantly correlated during their overlap period ($r = 0.98$; $p < 0.001$).

Table 2. Total, mean and standard deviation of the yearly number of fire foci detected in Mato Grosso state (Brazil) by the AQUA and S-NPP satellites. AQUA data are shown for its total active period and for its overlap period with S-NPP.
Tabela 2. Total, média e desvio-padrão do número anual de focos de queima detectados em Mato Grosso pelos satélites AQUA e S-NPP. Os dados do AQUA são apresentados para todo o seu período ativo e para o período de sobreposição com o S-NPP.

Satellite	**AQUA**		**S-NPP**
Period	2003-2023	2013-2023	2013-2023
Total	811,570	299,615	1,407,915
Mean ± standard deviation	38,646 ± 23,452	27,238 ± 8,187	127,992 ± 43,761

Classifying the total number of fire foci according to the months of the year in which they were registered and using the ANOVA test, it was observed significant differences between the months ($F= 27.04$; $p < 0.001$). Using the Tukey-Kramer test to compare the monthly means, it was possible to define 4 different groups, with the highest numbers of fire foci in September (Figure 3).

Using the AQUA data to classify the wildland fire incidence intensity according White (2020), 52 municipalities were classified as having extreme incidence of wildland fires, 81 had very high incidence and eight high. No municipalities were classified in the medium, low or very low categories (Table 3). The majority of municipalities with the highest densities of fire foci were located in the north portion of the state (Figure 4).

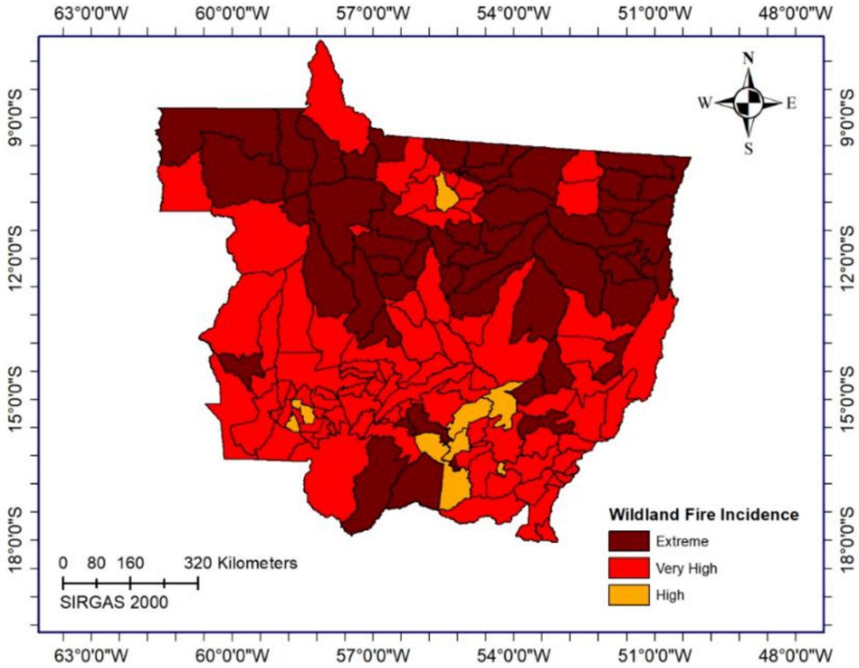

Figure 4. Classification of the 141 municipalities of Mato Grosso state (Brazil) according to their fire foci density based on the number of fire foci detected by the AQUA satellite (afternoon passage) during the period 2003-2023.

Figura 4. Classificação dos 141 municípios do estado de Mato Grosso de acordo com a densidade de focos de queima com base no número de focos detectados pelo AQUA (passagem da tarde) durante o período 2003-2023.

Table 3. Top 20 Mato Grosso municipalities with higher fire foci (FF) density from 2003 to 2023 based on data from AQUA satellite, afternoon passage. Classification of fire foci density according to White (2020).

Tabela 3. Lista dos 20 municípios do Mato Grosso com maior densidade de focos de queima para o período de 2003 a 2023 segundo dados do satélite AQUA (passagem da tarde). Classificação da densidade conforme White (2020).

Rank	Municipality	Mean annual number of FF	Density (FF km^{-2} $year^{-1}$)	Classification
1	Itanhangá	396,57	0,1368	Extreme
2	Alto Boa Vista	256,62	0,1145	Extreme
3	Nova Nazaré	446,71	0,1106	Extreme
4	Confresa	628,71	0,1084	Extreme
5	Santo Antônio do Leste	334,29	0,0982	Extreme
6	Nova Bandeirantes	941,52	0,0981	Extreme
7	União do Sul	427,10	0,0932	Extreme
8	Campinápolis	550,52	0,0920	Extreme
9	Santa Carmem	353,62	0,0917	Extreme
10	Juruena	249,52	0,0898	Extreme
11	Serra Nova Dourada	127,38	0,0849	Extreme
12	Vera	235,33	0,0797	Extreme

Rank	Municipality	Mean annual number of FF	Density (FF km^{-2} year^{-1})	Classification
13	Paranaíta	379,48	0,0791	Extreme
14	Cláudia	303,67	0,0789	Extreme
15	Santa Terezinha	508,57	0,0786	Extreme
16	Luciara	322,81	0,0761	Extreme
17	Nova Ubiratã	947,43	0,0758	Extreme
18	Colniza	2086,76	0,0747	Extreme
19	Cotriguaçu	698,43	0,0741	Extreme
20	Vila Rica	546,05	0,0735	Extreme

According to the Pearson correlation matrix, the percentage of the municipalities area that undergo primary deforestation was the variable with the highest correlation with fire foci density in the Mato Grosso municipalities, followed, respectively, by the variables: fire scars, rainfall amount and temperature. Forest area, non-forest natural formations area, agriculture area, urbanized area, pasture area, secondary deforested area and population did not correlate significantly with AQUA municipalities fire foci density (Table 4).

Table 4. Pearson correlation matrix of all variables potentially related to fire foci (FF) density in the municipalities of Mato Grosso (Brazil). Correlation coefficients in bold are significant at $p < 0.01$.
Tabela 4. Matriz de correlação de Pearson entre as variáveis avaliadas neste estudo que poderiam exercer influência na densidade municipal de focos de queima no estado de Mato Grosso. Valores em negrito são significantes ($p < 0.01$).

Variable	FF Density (AQUA)	Forest	Non-forest	Pasture	Agric.	Urb.	Prim. defor.	Sec. defor.	Fire scars	Temp.	Rain	Pop.
FF Density (AQUA)	**1,00**	0,02	-0,08	-0,22	-0,04	0,00	**0,74**	-0,21	**0,47**	**0,30**	**0,37**	-0,02
Forest		**1,00**	**0,91**	**0,70**	**0,34**	0,00	0,11	-0,04	-0,05	-0,05	0,09	-0,03
Non-forest			**1,00**	**0,76**	**0,31**	0,00	-0,07	0,02	0,12	0,02	-0,09	-0,04
Pasture				**1,00**	0,07	0,05	-0,06	**0,31**	-0,15	0,04	-0,18	-0,04
Agriculture					**1,00**	0,04	-0,05	-0,20	-0,20	**-0,37**	-0,05	0,08
Urbanized						**1,00**	0,07	**0,28**	-0,08	0,07	-0,11	**0,78**
Primary deforested							**1,00**	0,04	0,10	0,18	**0,30**	0,02
Secondary deforested								**1,00**	-0,08	0,12	**-0,40**	0,21
Fire scars									**1,00**	**0,44**	0,01	-0,04
Temp.										**1,00**	-0,02	0,06
Rainfall											**1,00**	-0,09
Population												**1,00**

Note: mean forest, non-forest natural formation, pasture, agriculture, urbanized, primary and secondary deforested, and fire scars areas from each municipality were divided by its corresponding municipality size to avoid the inherent positive influence of the municipality size in fire foci detection.

DISCUSSION

Although wildfires are uncommon in well-preserved areas of the Amazon biome, primarily due to the high humidity maintained by intact forest ecosystems (RIBEIRO *et al.*, 2021), this study found a high incidence of wildland fires across all municipalities of Mato Grosso, including those within the Amazon biome, which covers approximately 53% of the state's territory. This pattern is largely attributed to ongoing deforestation, primarily driven by agricultural expansion in the northern region. In such regions, slash-and-burn practices are commonly used to convert rainforest into farmland (White, 2018; Ribeiro et al., 2021). Between 2003 and 2023, an estimated 6,565,687 hectares of forest were converted mostly into agricultural and pasture lands (MAPBIOMAS, 2024a).

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However, deforestation alone does not fully explain the occurrence of wildfires in the Amazon. Fire dynamics in the region are influenced by a combination of factors, including forest fragmentation, edge effects, accumulation of dry biomass, and climatic variability, particularly during periods of severe drought associated with phenomena such as El Niño (BERENGUER *et al*., 2021; White, 2018).

The annual number of fire foci detected by the AQUA satellite from 2003 to 2023 exhibited a significant downward trend. However, no significant trend was observed when considering only the period from 2013 to 2023, based on data from both the AQUA and S-NPP satellites. The decline in fire activity during the early 2000s can be attributed to the implementation of comprehensive government policies aimed at curbing illegal deforestation. These included improved monitoring and enforcement mechanisms, supply chain interventions, and the expansion of protected areas, which collectively led to a reduction of approximately 70% in the deforestation rate across the Brazilian Amazon (BRANDO *et al.*, 2020). In contrast, over the past decade, this trend has weakened due to a combination of increasing economic pressures from cattle ranching and agricultural expansion and a decline in the effectiveness of environmental governance. This includes reduced enforcement capacity, lower rates of environmental fines, and institutional weakening of environmental agencies, which have limited the control of illegal deforestation activities (ABESSA *et al.*, 2019). This shift, together with the increasing frequency of extreme climate events, has impeded further reductions in wildland fire occurrences and, in some areas, has even led to a rise in fire activity (INPE, 2025; MAPBIOMAS, 2024a; WHITE, 2018). In 2020, for example, the Mato Grosso Pantanal biome experienced the most severe wildfires on record, with over 4.5 million hectares burned—approximately 30% of the entire biome (SILVA *et al*., 2021b; MAPBIOMAS, 2024a). These fires were fueled by an extreme drought, linked to climate anomalies, and also by the use of fire for land clearing in surrounding areas (TEODORO *et al*., 2022).

The comparison of detected fire foci between the AQUA and S-NPP satellites demonstrates that the VIIRS sensor consistently identifies more fire foci than the MODIS sensor, as expected. Beside the difference in their spatial resolution, differences between AQUA and S-NPP fire records are due to variation in their spectral bands. Despite having similar spectral bands covering visible and infrared wavelengths, they slightly differ in width, sensitivity, and position within the electromagnetic spectrum, affecting fire detection capability (SCHROEDER; GIGLIO, 2017). The 4.7 S-NPP/AQUA ratio found in this work was similar to those reported in other studies worldwide. For instance, in a study case in Northeast Asia, the ratio was 6.1 (FU *et al.*, 2020). In the state of Pará, Brazil, the ratio was 4.5 (WHITE, 2024). Despite these differences in detection rates, all studies reviewed concluded that the datasets from both satellites are significantly correlated, thus supporting the integration of data from both sources (e.g., FU *et al.*, 2020; WHITE, 2024).

The concentration of fire foci in August, September, and October follows the pattern observed across most of South America (WHITE, 2019). All South American countries located south of the equator, except Chile, experience peak fire foci detections between August and November. This seasonal trend is primarily attributed to reduced rainfall during the Southern Hemisphere's winter, which leaves vegetation drier and more susceptible to burning (WHITE, 2019). In addition to this seasonal pattern, previous studies have shown that interannual variability in fire occurrence in the Amazon is influenced by large-scale climate phenomena such as the El Niño–Southern Oscillation (ENSO), which can intensify drought conditions and increase fire susceptibility during certain years (BERENGUER *et al*., 2021). However, this effect was not explicitly evaluated in the present study.

The spatial distribution of fire foci across Mato Grosso's municipalities reveals a critical need for fire prevention measures across the entire state, as all municipalities were classified within the extreme, very high, or high fire incidence categories. Comparing with another bordering states as in Amazonas, for example, none of the municipalities were classified in the extreme fire risk category during the period from 2003 to 2016 (WHITE, 2018). However, in Pará, another state that is greatly affected by deforestation, based on data from 2003 to 2023, 90% of the municipalities were classified into the extreme, very high and high classes (WHITE, 2024). The high frequency of wildland fires in Mato Grosso exacerbates vegetation dryness, increasing flammability and reinforcing a feedback loop that contributes to global warming.

Using the Pearson correlation matrix, it was found that the municipalities that had: a higher proportion of their primary vegetation area deforested; a higher proportion of their area with fire scars; and with higher mean annual rainfall and temperature, presented higher fire foci density. The link between primary vegetation deforestation and fire foci density occurs because the clearing of humid forests generally starts by cutting down the vegetation, since the standing forest is too humid to burn, followed by burning and clearing a few weeks later, when the vegetation has lost enough humidity (BRANDO *et al*. 2020). In studies conducted in other Brazilian states covered by humid tropical forests such as Amazonas and Pará, for example, it was also found that deforestation was the better variable to explain fire foci density (WHITE, 2018; WHITE 2024).

Just as a significant correlation between primary deforestation and fire foci density was anticipated, a positive and significant correlation between fire foci density and fire scars was also expected, since fire scars represent areas that have burned. Nevertheless, the correlation between primary deforestation and fire foci density was stronger than that between fire foci density and fire scars. As already explained, in the Cerrado and, mainly, Amazonas biomes, a large portion of native forest deforestation is carried out using fire, mainly to clear areas for pasture or agriculture. Thus, fire hotspots spatially coincide with deforested areas, but they do not always result in detectable burn scars (e.g., controlled fires, partial burns, or fires following partial vegetation removal) (SILVA *et al.*, 2021a). This fact may explain why fire scars had a less strong correlation with fire foci density than primary deforestation.

It was also observed that municipalities with higher rainfall and temperature also exhibited higher fire foci density. The positive correlation between temperature and fire foci density is widely understood, as higher temperatures accelerate fuel drying, making vegetation more susceptible to burning. However, the positive correlation between rainfall amount and fire foci density is counterintuitive, since increased rainfall typically raises vegetation moisture content, reducing flammability (WHITE, 2018; WHITE, 2024). Explaining this paradox requires analyzing land cover and the spatial distribution of rainfall across Mato Grosso. The northern region of Mato Grosso, located within the Amazon biome, receives higher average annual precipitation compared to southern areas (CLIMATE-DATA, 2024). This wetter climate sustains extensive native forest cover, which is subject to significant deforestation pressure, as confirmed by spatial monitoring data in this study. Given that deforestation often involves slash-and-burn practices, these patterns align with broader Amazonian trends where forest-rich, high-precipitation areas face intensified clearing and more fire activity.

Given the environmental consequences of climate change, it is crucial to adopt strategies aimed at reducing the incidence of wildland fires in order to limit related greenhouse gas emissions. In Mato Grosso, preventing wildfires requires strict enforcement of penalties for illegal burning, alongside consistent environmental education initiatives. Raising awareness of the forest's role in climate regulation, biodiversity conservation, and the sustainable future of Amazonian agriculture is essential. Strategically creating conservation areas near agricultural frontiers can therefore be an effective approach to curb further deforestation and fire expansion.

CONCLUSIONS

- Despite the number of fire foci in the state of Mato Grosso exhibited a declining trend from 2003 to 2023, in the last decade this decline has plateaued. As a result, Mato Grosso remains one of the Brazilian states with the highest fire foci detection.
- During the overlap years of AQUA and S-NPP satellite data (2013-2023), S-NPP detected 4.7 times more fire foci than AQUA, yet the data from both satellites were significantly correlated.
- The highest fire foci detection occurred in September highlighting the need for fire prevention and mitigation efforts, mostly during this month.
- The majority of municipalities in Mato Grosso, particularly those situated in the north region, exhibited an extremely high incidence of fire foci. According the correlation matrix, primary deforestation, fire scars, rainfall and temperature were the variables potentially associated with municipal fire foci density.
- Some limitations should be considered when interpreting the results. The use of Pearson correlation allows the identification of linear associations between variables but does not imply causal relationships. Also, fire detection data derived from satellite sensors are subject to inherent limitations, including omission and commission errors.
- Strategies such as expanding protected areas, increasing monitoring and enforcement by environmental authorities, and promoting environmental education programs could reduce wildland fire activity in Mato Grosso, thus mitigating global climate change.

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