Anuário do Instituto de Geociências
Universidade Federal do Rio de Janeiro
https://revistas.ufrj.br/index.php/aigeo/

ISSN 0101-9759
e-ISSN 1982-3908

ENVIRONMENTAL SCIENCES

Spatial-Temporal Distribution of Hot Spots in the Municipality of Nova Timboteua, Pará, Brazil

Distribuição Espaço-Temporal dos Focos de Calor no Município de Nova Timboteua, Pará, Brasil

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Abstract

Remote sensing is a tool that enables monitoring forest fires in extensive territories because it allows locating more and less vulnerable regions using satellites, reducing the costs and time for the perception of hot spots. Thus, the objective of this study was to evaluate the distribution of hot spots in the municipality of Nova Timboteua, Pa between the years 2015 and 2020. For this we used data from the National Institute for Space Research (INPE) burns program that was processed in spreadsheets, where graphs were produced, and in QGIS 3.28.1, which generated the Kernel density map using the function of Kartic estimation. In the municipality, 1,026 hot spots were recorded in the studied period, with higher occurrences observed in the years 2015 (250) and 2017 (215), periods with average rainfall below 200 mm. In addition, a seasonal variation of hot spots was observed in the municipality, where the months of November and December are the months that presented the highest number of hot spots. The southwestern and northeastern regions of the municipality were the ones that registered the highest number of hot spots, except for the year 2018. Furthermore, the hot spots were concentrated in PA-324 and PA-242. Thus, it is noted that the hot spots occur more frequently in periods of lower rainfall and that the northeastern and southeastern regions of the municipality are the most vulnerable to the occurrence of hot spots.

Keywords: Kernel density; Forest monitoring; Forest fire

Resumo

O sensoriamento remoto é uma ferramenta que viabiliza o monitoramento de incêndios florestais em territórios extensos, pois permiti localizar regiões mais e menos vulneráveis utilizando satélites, o que diminui os custos e o tempo para percepção de focos de calor. Com isso, o objetivo do presente estudo foi avaliar a distribuição dos focos de calor no município de Nova Timboteua, Pa entre os anos de 2015 a 2020. Para isso foi utilizado dados do programa queimadas do Instituto Nacional de Pesquisas Espaciais (INPE) que foram processados em planilhas eletrônicas, onde foram produzidos gráficos, e no QGIS 3.28.1, o qual foi gerado o mapa de densidade de Kernel utilizando a função de estimativa Quártica. No município foram registrados 1.026 focos de calor no período estudado, sendo observadas maiores ocorrências nos anos de 2015 (250) e 2017 (215), períodos com média de precipitação pluviométrica abaixo de 200 mm. Além disso, foi observada uma variação sazonal dos focos de calor no município, onde os meses de novembro e dezembro são os que apresentaram maior quantidade de focos de calor. As regiões sudoeste e nordeste do município foram as que registraram a maior quantidade de focos de calor, exceto para o ano de 2018. Ademais, os focos de calor se concentraram nas proximidades da PA-324 e da PA-242. Com isso, nota-se que os focos ocorrem com maior frequência em períodos de menor precipitação pluviométrica e que as regiões nordeste e sudeste do município são os mais vulneráveis para ocorrência de focos de calor.

Palavras-chave: Densidade de kernel; Monitoramento florestal; Incêndio florestal

Received: 25 June 2023; Accepted: 24 October 2024

1 Introduction

The process of demographic occupation in the states that comprise the Amazon region had the objective of making the region productive, so colonization projects were created with the aim of economically integrating the region with the rest of the country. The opening of roads and national and international investments made exploring larger areas and attracting rural producers to the region possible. (Nunes 2018). However, intensive occupation, especially from the 1970's onwards, is associated with increased deforestation and hot spots, as fires are mechanisms widely used in Brazilian agriculture (Lopes et al. 2017).

Shifting agriculture, which uses the slash-and-burn technique, is still widely used in the state of Pará due to the low cost and rapid release of nutrients to the soil. However, its sustainability has been contested, as the use of the technique releases greenhouse effect gases (GEG) that can cause forest fires, and if there is no control over the fire, in the long term it degrades the soil (Gonçalves et al. 2012; Rego & Kato 2017). In addition, fires release pollutants such as carbon monoxide (CO) that can harm people's health, especially those most susceptible (Gonçalveis et al. 2012). The intensification of occurrences of hot spots in recent years, in addition to being related to changes in land use caused by human activity, is also associated with meteorological conditions (Da Silva Júnior et al. 2021). Weather events, such as El Niño, increase the occurrence of hot spots and the risk of fire in Pará (Nascimento & Senna 2020).

The large territorial area of the state of Pará makes it difficult to monitor and combat forest fires. With this, remote sensing is a fundamental tool to control the state's fires. The spatial analysis increases efficiency in the planning of actions to prevent and combat forest fires, as it allows locating the regions that are most and least vulnerable to fires. (Jesus et al. 2020). Thus, it reduces the time and costs of monitoring in large territories (Lopes et al. 2017). Geoprocessing through Kernel interpolation is a tool that allows analyzing the distribution of outbreaks in an area, locating the points with the highest density by delimiting the radius of influence of a focus, estimating the number of overlapping events, grouping them, and assigning a pixel value greater than this region (Carneiro & Albuquerque 2019). Being an efficient tool to evaluate the spatial distribution of hot spots (Menezes et al. 2019). Thus, the use of geoprocessing and remote sensing tools contributes to signaling and formulating public policies aimed at controlling and combating hot spots (Lopes et al. 2017).

The National Institute for Space Research (INPE), through the Queimadas program, has an open database on hot spots observed by satellites such as Noaa, Terra, and Aqua. The program provides daily data on outbreaks that occur in America, Africa, and Europe (National Institute for Space Research [INPE], 2022). According to Cristovão & Rayol (2021), the variables provided by INPE, such as the number and location of hot spots, are essential to understanding the dynamics of fire use and support space-time studies about hot spots.

The municipality of Nova Timboteua was created by decree law with territory originating from the dismemberment of Igarapé-açu (Pará, 1944). Agriculture has been standing out in the economy of the municipality, being a fundamental part of its gross domestic product (GDP), whereas cassava production stands out in the municipality's agriculture, producing about 15 thousand tons in 2021 (IBGE 2022).

Therefore, when considering that remote sensing is a fundamental tool to monitor hot spots in large or isolated areas and that it contributes to formulating policies aimed at preventing and combating forest fires, for the present study, the following hypotheses were raised: 1st the distribution does not follow a pattern over the years studied; 2nd the highest occurrences of hot spots are in the driest months; 3rd the hot spots will be concentrated near roads and communities. Thus, the work aims to evaluate the distribution of hot spots in the municipality of Nova Timboteua, PA, between the years 2015 and 2020.

2 Material and Methods

2.1 Study Area

The study was carried out based on the boundaries of the municipality of Nova Timboteua (Figure 1), located in the Bragantina microregion in northeastern Pará, at latitude 02º 02' 47" S and longitude 47º 33' 02" W. According to an estimate by the IBGE (2022), the local population is 15506 people in a territorial area of 489853 km². The climate of the region defined according to Köppen and Geiger is classified as Am (humid tropical); therefore, it has a brief dry period and a rainy one, with an average temperature of 25 ºC and rainfall of 2250 mm year^{-1} (National Institute of Meteorology [INMET], 2021).

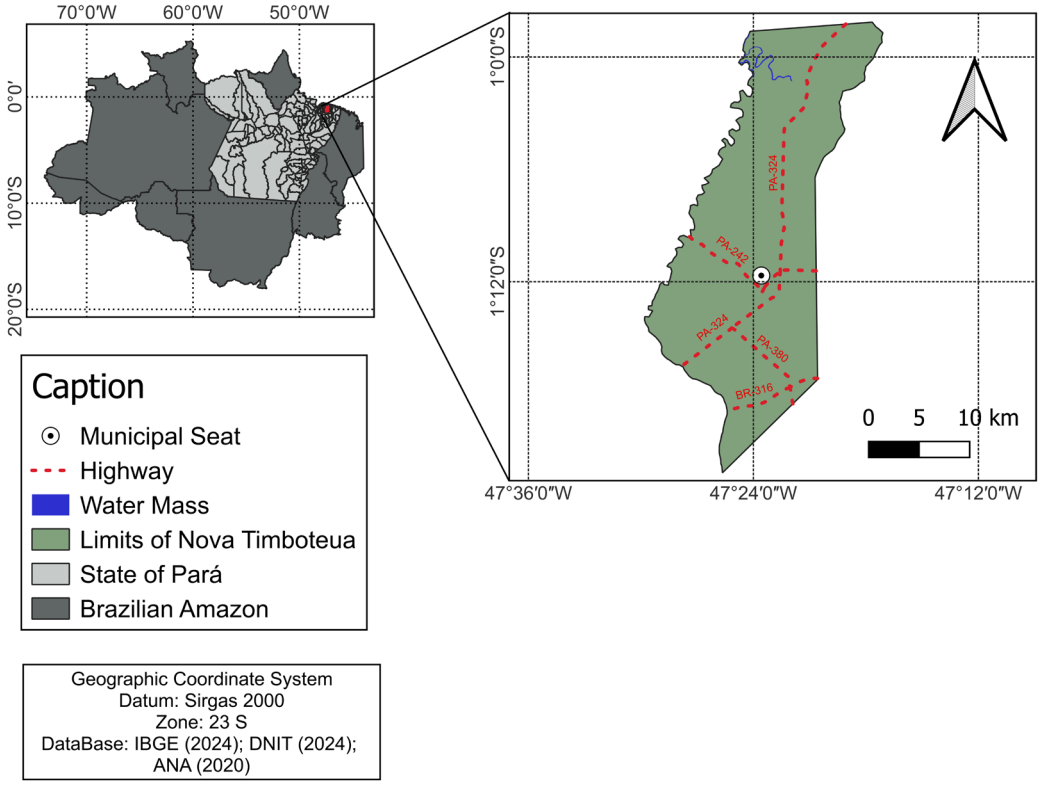

Figure 1 Location map of the Nova Timboteua municipality, PA.

2.2 Data

The data on the number of hot spots comes from the database of the National Institute for Space Research, made available by the Queimadas program, which detects fire fronts about 30 m long by 1 m wide with a pixel that varies from 1 km² to 4 km² (INPE 2022). The information was downloaded in shapefile format for the years 2015 to 2020. Daily precipitation was obtained from the conventional station (82145) on the website of the National Institute of Meteorology (INMET 2021).

2.3 Data Processing

In order to evaluate the occurrence of hot spots and rainfall over the years studied, the monthly values for each year were added up to obtain the accumulated value of the variables. Descriptive statistics were also carried out on the data on hot spots and rainfall to assess the monthly distribution, where the median, mean and standard error were calculated, considering the years as repetitions for the months. The degree of association between the variables was then assessed using Kendall's correlation. The above analyses were carried out using the R language (R Core Team, 2023).

The data from hot spots in shapefile were processed in QGIS v. 3.16.6, where a vector file of points with the SIRGAS 2000/UTM zone 23S coordinate reference system was generated for each year. The point clouds served as the basis for generating Kernel density maps using the "Heat Map" tool and generating matrix files. From the function, other circular rasters of radius (h) were obtained from the result of the stacking sum of the total number of hot spots (n) for each entry point, according to Equation (1).

$$\hat{f}_h(x) = \frac{1}{nh}\sum_{i=y}^{n} \quad k\left(\frac{x-X_i}{h}\right) \qquad (1)$$

Where:
K = kernel estimation function;
h = search radius;
x = center position of each output raster cell;
Xi = position of point i from the centroid of each polygon;
n = total number of hot spots.

The estimation function (k) used in the production of the map was the Quartic, which assigns the greatest weight to the closest points and provides a gradual decrease.

The radius (h) was calculated according to that proposed by Rizzatti et al. (2020), that is, a distance matrix was generated in QGIS so that after performing the calculation with Equation (2), the radius used was the one originating from the subtraction, with a result of approximately 5974 m.

$$H = M \pm M_{\sigma} \quad (2)$$

Where:
M = average of the average distance;
M_{σ} = mean standard deviation.

3 Results and Discussion

Analysis of Inpe's spatial data indicated the incidence of 1026 hot spots in the studied period. The annual distribution of hot spots is shown in Figure 2. In the municipality of Nova Timboteua, hot spot events fluctuated during the studied period, peaking in 2015 and 2017, with 250 and 215 hot spots, respectively. In addition, in general, the highest number of hot spots occurred in years with less rainfall.

The behavior in the distribution of hot spots over the years, with an irregular pattern, was also observed by Jesus et al. (2020) and Lopes et al. (2017), who studied data from Brazilian biomes and from the municipality of Novo Progresso, in southwest Pará. The occurrence of climatic and/or meteorological events during the research period can affect the appearance of hot spots since they can occur in alternate years, leading to an irregular pattern in the distribution of hot spots. At the end of 2015 and the beginning of 2016, according to data from the National Oceanic and Atmospheric Administration (NOAA 2021), an El Niño weather event of high intensity occurred. The event reduced the rainfall in the Amazon region, which explains the lower rainfall. In periods with less rainfall, the vegetation becomes drier, which favors combustion (Nascimento & Senna 2020; Moreira et al. 2018). Alencar et al. (2015), when studying forest fires in the Amazon, found a relationship between periods of drought and an increase in the number of fires. In addition, the authors highlight deforestation, fragmentation, and forest degradation as factors that increase the risk of forest fires.

During the period studied, the highest number of hot spots occurred during the dry season. The months of November and December saw the highest number of hot spots, with respective median values of 66 and 58 records (Figure 3A). In these months, rainfall was low, with average values of 24.23 mm and 88.30 mm (Figure 3B). In April and May, months with high rainfall, no hot spots were recorded. It is worth noting that in the months of March, July, August and September there were outlines (Figure 3A), which were recorded in the years 2018 for the months of March and September and 2020 for July and August, these years being among the lowest rainfall for the respective months

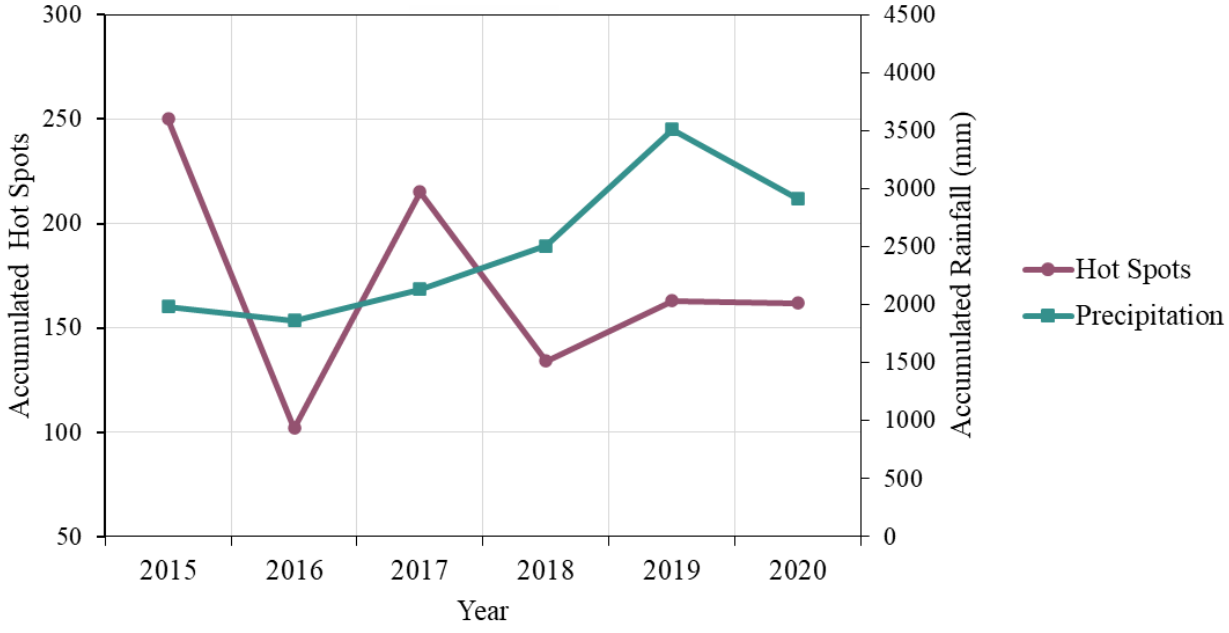

Figure 2 Annual distribution of hot spots and rainfall in the municipality of Nova Timboteua, PA.

in the period studied (Figure 3B). This trend is confirmed by the negative correlation (-0.52) between the factors heat spots and rainfall, which was significant (p-value < 0.01), so there is an association between the factors (Figure 3C).

The distribution pattern of hot spots throughout the year was similar to that of Lopes et al. (2017) and Silva & Furtado (2020), who studied the municipalities of Novo Progresso and São Félix do Xingu in the state of Pará, respectively, and attributed the pattern of records to the state's climatic and meteorological characteristics. Where rainfall is influenced by regional conventions and the intertropical convergence zone, the period from January to April is known regionally as the "Amazon winter", characterized by increased rainfall, and the others as the "Amazon summer", a period of drought (Alves et al. 2020). The lower humidity favors the spread of fire, which determines the number and degree of destruction caused by fires.

In 2019, the estimated kernel density showed that hot spots occurred in a larger area in the territory of the municipality, mainly in the low and medium classes. While the very high class occurred in the northern region of the municipality, close to the PA-324 and the Peixe-Boi River (Figure 4E). Unlike the years with the highest number of hot spots 2015 and 2017 were concentrated in the southwest and northeast regions, respectively, with very high densities (Figures 4A-C). In 2018, the hot spots were concentrated in the region close to the municipal seat and followed the PA-324 (Figure 4D). In 2020, the hot spots were concentrated in the southwest of the municipality, near the PA-242, PA-380, BR-316 roads, and south of the PA-324, with the occurrence of the middle, upper, and very upper classes (Figure 4F).

The spatial distribution of hot spots followed a pattern throughout the surveyed period, with higher focus densities observed in the southwest and northeast of the municipality. The hot spots are concentrated in the vicinity of state highways; this may be related to agricultural activity, which is historically carried out near roads in the state and is based on slash-and-burn agriculture for clearing swiddens (Da Silva & Rocha 2022; Da Silva et al. 2021; Rego & Kato 2018).

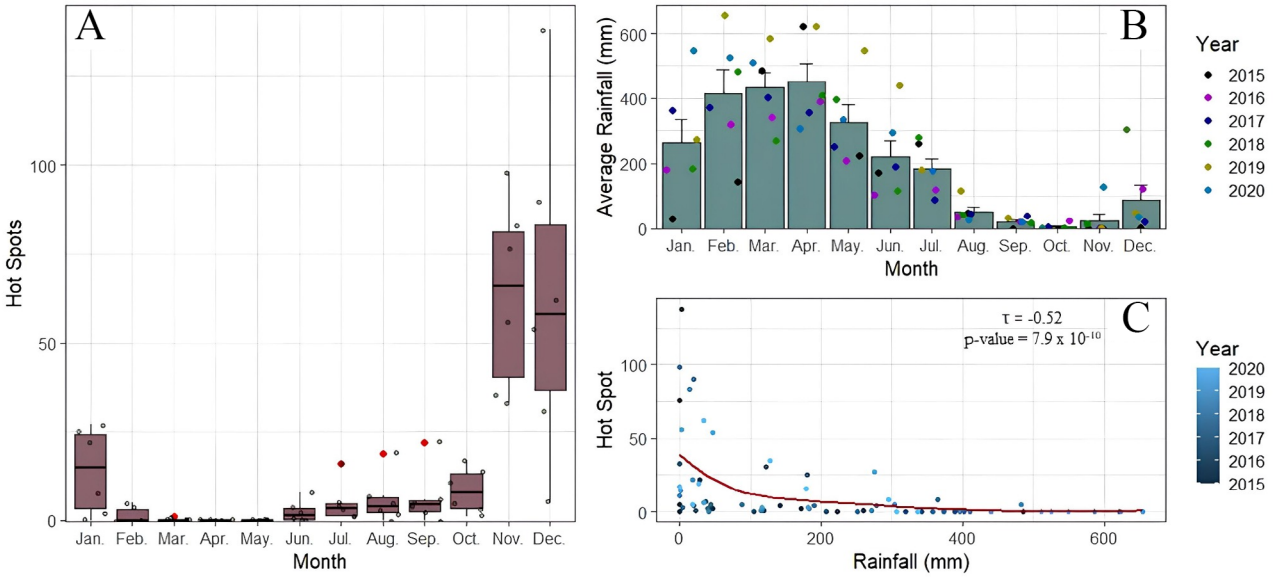

Figure 3 Monthly distribution of hotspots and rainfall between 2015 and 2020 in the municipality of Nova Timboteua, Para, Brazil: A. Box-plot of hotspots; B. Average rainfall (mm); C. Kendall's correlation. Red cycles are outlines. Bars are standard error (n = 6).

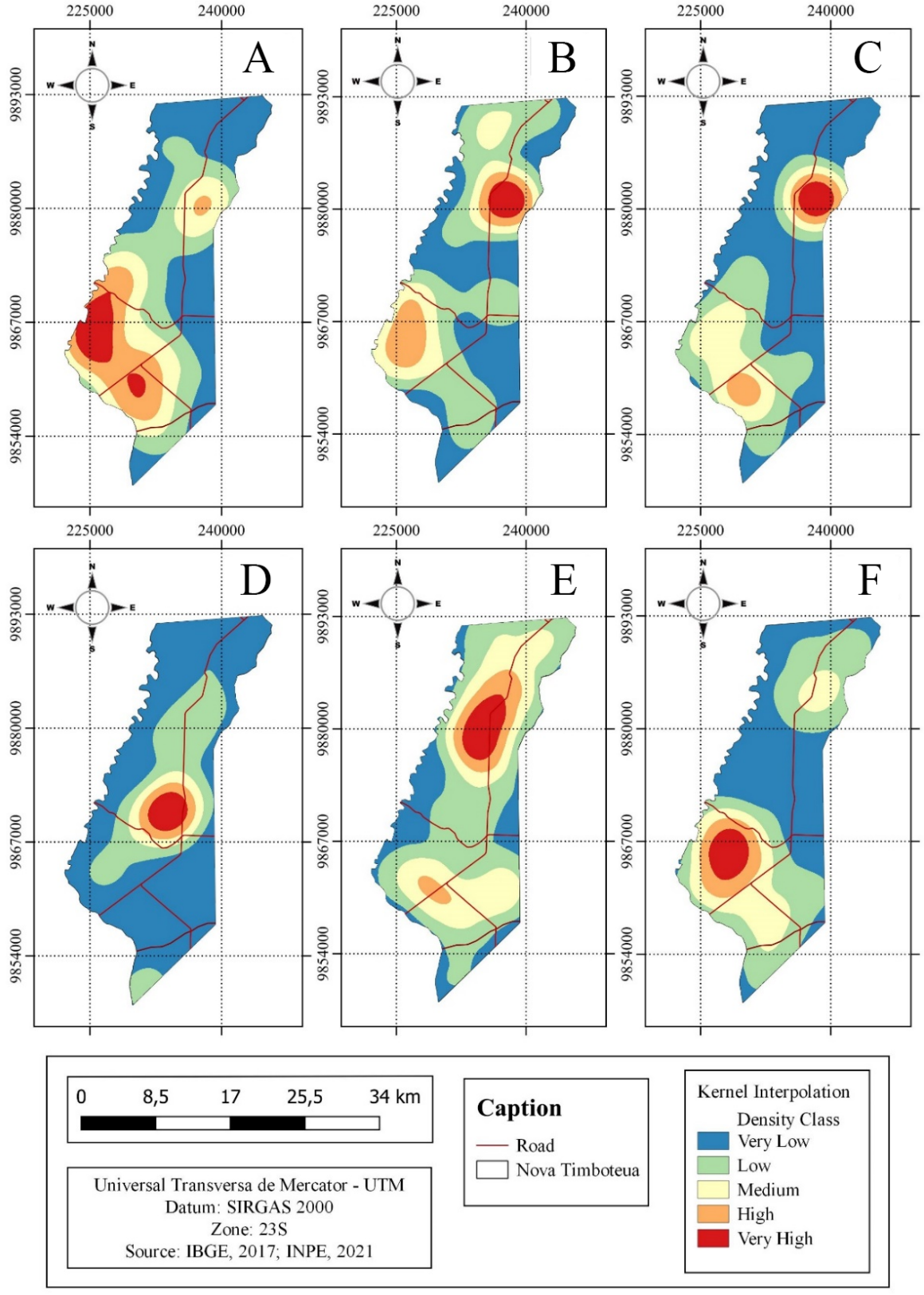

Figure 4 Spatial distribution for different years of study of hot spots in Nova Timboteua, PA: A. 2015; B. 2016; C. 2017; D. 2018; E. 2019; F. 2020.

4 Conclusion

The results show that hot spots fluctuate between years, with peaks in years with lower rainfall. In addition, the occurrence of hot spots was higher in the dry months, so there is a negative correlation between hot spots and rainfall, where the months with the highest rainfall have a low number of hot spots. The spatial analysis of hot spots revealed that, during the period in question, the southwest and northeast regions of the municipality were more vulnerable to the occurrence of hot spots. The road network surrounding these regions may have an impact on the spatial variation of hot spots within the municipality.

The results can be used to allocate fire prevention and firefighting brigades to the most vulnerable times and places. In addition, information and training actions with producers on fire control practices, firefighting techniques and agricultural practices that do not use fire can reduce the use of slash and burn practices in rural areas. As well as environmental education in schools and for society in general, with the aim of raising awareness about the damage caused by the use of fire, the risk of fires, and the relationship between fire and drought and deforestation. Since fire can reduce soil and air quality and cause forest fires.

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Author contributions
Victor Henrique Rodrigues Dias: conceptualization; formal analysis; methodology; validation; visualization; writing-original draft; data curation; visualization; writing – review and editing. **Breno Pinto Rayol**: conceptualization; methodology; supervision; writing – review & editing.

Conflict of interest
The authors declare no conflict of interest.

Data availability statement
Reference datasets can be downloaded from: https://terrabrasilis.dpi.inpe.br/queimadas/bdqueimadas/; https://portal.inmet.gov.br/
Scripts and code are available on request

Funding information
Not applicable.

Editor-in-chief
Dr. Claudine Dereczynski

Associate Editor
Dr. Luís Augusto Koenig Veiga

How to cite:
Dias, V.H.R. & Rayol, B.P. 2025, 'Spatial-Temporal Distribution of Hot Spots in the Municipality of Nova Timboteua, Pará, Brazil', *Anuário do Instituto de Geociências,* 48:e59361. https://doi.org/10.11137/1982-3908_2025_48_59361