Floresta Ambient., Rio de Janeiro, 2023; 30(3): e20230010
https://doi.org/10.1590/2179-8087-FLORAM-2023-0010
ISSN 2179-8087 (online)

ORIGINAL ARTICLE - Conservation of Nature

Assessment of Land Use, Cover Changes, and Fire Hotspots in a Conservation Unit: A 20-Year Analysis

Edicleife Lino Santos[1]
Alan Cézar Bezerra[1]
Damião Alves Silva[2]
Anderson Santos Silva[2]
Cristina Rodrigues Nascimento[3]
Rodrigo Ferraz Jardim Marques[4]

[1]Universidade Federal Rural de Pernambuco (UFRPE), Unidade Acadêmica de Serra Talhada, Serra Talhada, Pernambuco, Brasil.
[2] Universidade Federal do Agreste Pernambucano (UFAPE), Garanhuns, Pernambuco, Brasil.
[3] Universidade Federal Rural de Pernambuco (UFRPE), Departamento de Agronomia, Recife, Pernambuco, Brasil.
[4]Agência Estadual de Meio Ambiente (CPRH), Serra Talhada, Pernambuco, Brasil.

Abstract

Conservation units are specially protected territorial spaces whose primary goals are to preserve biodiversity and natural resources. Thus, this paper aims to investigate the spatial-temporal dynamics of land-use and land-cover classes and hotspots in a conservation unit in the Caatinga region. We assessed land-use and land-cover classes based on Mapbiomas's data from 2002 to 2021. Then, we analyzed the hot spots made available by *Programa Queimadas* database, for the rainy and dry seasons, as well as data recorded on a yearly basis between 2002 and 2021. The class of agricultural activities in the buffer zone has increased; changes in the hotspots' distribution pattern were observed, such as displacement from the Park's central area towards the buffer zone's. Furthermore, 12 hotspots tended to increase in the dry season, over the 20-year assessment process. Insights into the growth of agriculture and changing hotspot patterns assist in creating more effective conservation strategies.

Keywords: Temporal analysis, Spatial distribution, MapBiomas, *Programa Queimadas,* Remote Sensing.

1. INTRODUCTION AND OBJECTIVES

Among the different biomes in Brazil, Caatinga has been significantly changed in recent years, and it has damaged local biodiversity, increased environmental degradation and worsened desertification processes, due to its biome's unique adaptation to climate conditions (BEZERRA et al., 2020; NASCIMENTO et al., 2020). Conservation units are delimited and protected spaces aimed at mitigating the deleterious effects of human actions and at preserving strategic natural resources. Thus, *Mata da Pimenteir*a State Park was launched in Pernambuco State, in 2012, as the first conservation unit in this biome (FONSECA; TAVARES JR.; CANDEIAS, 2020).

Conservation units suffer constant pressure from different agents, mainly anthropogenic pressure to establish agricultural and urban activities. Controlled burning is a resource often used in agricultural practices to clean a given area. This process enables vegetation to grow back within a short period-of-time - to be consumed as food by ruminants -, besides breaking seed dormancy, among others (TEIXEIRA et al., 2021). However, indiscriminate burning can lead to forest fires that, in their turn, lead to biodiversity loss, as well as to water availability and nutrient cycling decrease. Consequently, it affects individuals' quality of life (PAIVA et al., 2019).

Fire dynamics can influence ecological processes; therefore, understanding them enables developing environmental conservation strategies and reducing greenhouse gas emissions (JESUS et al., 2020; SOARES; RESENDE; PEREIRA, 2016). Thus, understanding hotspots' spatial distribution and temporal patterns helps avoiding uncontrolled fire – also known as wildfire - and makes land management processes more efficient (CHAVES et al., 2021). Accordingly, spatial Technologies (geotechnologies) provide tools for continuous, historical, and low-cost monitoring based on remote sensing principles.

Hotspots in remote sensing processes based on heat sensors can be understood as fire events. *Instituto Nacional de Pesquisas Espaciais* (INPE) has built a database based on information provided by different thermal infrared sensors used for heat spot monitoring purposes (RIBEIRO et al., 2021). INPE considers vector files representing geographic points captured on soil surface as hotspots when temperature higher than 47ºC is detected in a minimum area of 900 m² (DALL'IGNA & MANIESI, 2022). The aforementioned Institute provides data deriving from polar orbiting satellites, such as AQUA, TERRA, NOAA - 15, 16, 17, 18, and 19, as well as from geostationary satellites, such as METEOSAT-02 and GOES-12, on a daily basis, through the project known as *Base de Dados Queimadas* - BDQ (INPE, 2022). Each polar satellite produces two images, on a daily basis, whereas the geostationary ones generate a few images, on an hourly basis. INPE processes more than 200 images a day in order to identify vegetation-burning outbreaks.

Different studies have investigated hotspots based on using data made available by INPE, as well as applied spatial hotspots-distribution analysis, mainly through Kernel density. Among them, one finds a study conducted in municipalities with significant agrarian conflicts (BOTELHO et al., 2020; CRISTOVÃO and RAYOL; 2021; SALES et al., 2019; TEIXEIRA et al., 2021) in Western Amazonia (RIBEIRO et al., 2021) and in Paraíba State's mesoregions (Novais et al., 2019). Jesus et al. (2020) assessed different protected areas throughout Brazil, whereas some studies assessed protected areas in Minas Gerais State (SOARES; RESENDE; PEREIRA, 2016), as well as in *Parque Nacional da Chapada dos Guimarães* (PNCG) - Mato Grosso State (Neto et al., 2020).

Few studies available in the literature about this topic have focused on analyzing temporal trends. To the best of our knowledge, this analysis type was only conducted by Jesus et al. (2020). However, the aforementioned authors did not take into consideration the different rainfall seasons, namely: dry and rainy seasons. In addition, studies available in the literature did not confront this phenomenon with conflicts observed in conservation units located in the Caatinga biome; therefore, the current study seeks to fill this gap.

Our hypothesis is that Mata da Pimenteira State Park's launching helped reducing the number of hotspots in its coverage area. Thus, the aim of the current study was to investigate the spatial-temporal dynamics of land-use and land-cover classes, as well as of hotspots, in a conservation unit in the Caatinga biome.

2. MATERIALS AND METHODS

2.1. Study site

Mata da Pimenteira State Park (PEMP) is located in Pernambuco State's central hinterland, in Pajeú river basin, rural area of Serra Talhada - PE (Figure 1): geographical coordinates 7°56'10" S and 38°17'55" W, mean altitude of 613 m. This environmental conservation unit covers 887.24 hectares (the red limit in Figure 1) and presents smooth and rounded terrain; hyper-xerophilic Caatinga is the typical vegetation growing on it. BSw'h climate type features this region as semi-arid, hot and dry, with annual rainfall of 657 mm year-1 and mean annual temperature of 25.8 ºC (ALVARES et al., 2013; BEZERRA et al., 2021; LINS et al., 2017). The park area (limited by the area in blue in Figure 1) corresponds to the buffer zone of the study area. Notably, buffer zones aim to limit these areas' use to more sustainable uses; moreover, they work as transition zones of areas subjected to different protection levels (SOUSA; SANTOS, 2020).

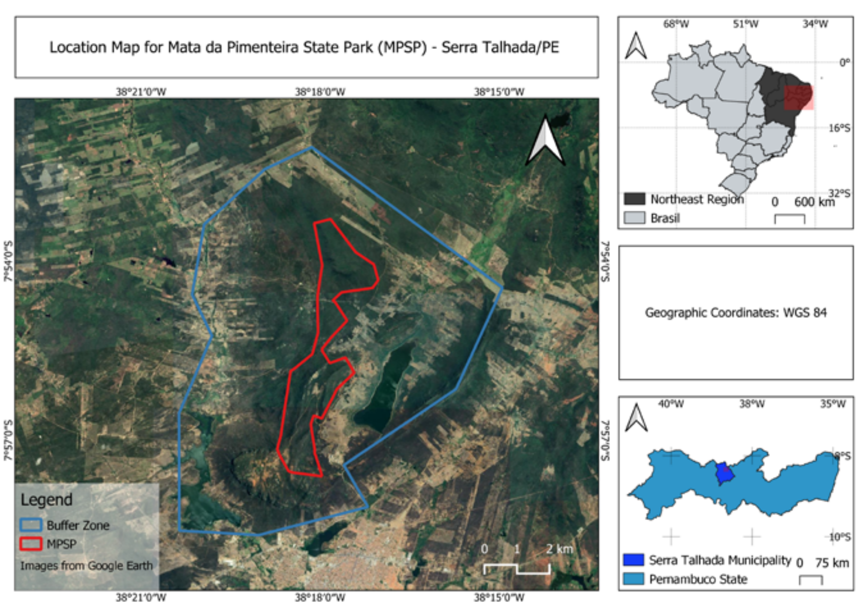

Figure 1. Map showing the location of Mata da Pimenteira State Park and the buffer zone, Serra Talhada, Pernambuco State, Brazil.

2.2. Database

We obtained land-use and land-cover data of Serra Talhada County corresponding to the time-period between 2002 and 2021. These data were available at the MapBiomas platform - collection 7 (Mapbiomas, 2023). We clipped the data of the study site and defined the classes found in it, as follows (Table 1).

Annual land-cover and land-use maps were generated by MapBiomas (2023) using Landsat satellite images with a pixel size of 30 x 30 meters. The classification process utilized machine learning algorithms on the Google Earth Engine (GEE) platform, which offers robust cloud processing capabilities. Thematic maps were prepared for the years 2002, 2006, 2007, 2011, 2012, 2016, 2017, and 2021. To determine the area of each class, we performed an analysis using the QGIS r.report tool, providing the results in hectares (ha)..

Hotspots' data, in their turn, comprised Park area and its buffer zone. Data were collected from shapefile format files comprising information about Serra Talhada municipality, which were recorded from 2002 to 2021 and stored at the database provided by *Programa Queimadas*, which is developed by *Instituto Nacional de Pesquisas Espaciais* (INPE, 2022). Jesus et al. (2020) pointed out that the remote sensing products identify hotspots, which can be either burning events or forest fires identified in the study site.

To assess whether there is a seasonal effect component on the dynamics of the hotspots, we aggregated the data in rainy months (Jan-Apr), driest months (Aug-Nov) and annual (Jan - Dec). *Programa Queimadas* uses different satellites as reference and described by INPE (2023). The definition of the rainy season, from January to April, and the dry season, from August to November, was based on the monthly averages of precipitation (Figure 2A) and air temperature and relative humidity (Figure 2B). Precipitation data were derived from the Serra Talhada pluviometric station database provided by the Pernambuco Agency of Water and Climate (Agência Pernambucana de Água e Clima - APAC), covering the historical period from 1990 to 2021. Meanwhile, temperature and relative humidity data were obtained from the Serra Talhada automatic station from National Institute of Meteorology (Instituto Nacional de Meteorologia - INMET) from 2010 to 2020.

We clipped each heat-focus layer of the area covered by PEMP's buffer zone after collecting the heat-focus files recorded for the Serra Talhada region. Subsequently, hotspots observed in each clipped layer were counted. These procedures were carried out in QGIS software, version 3.22.

After collecting the heat-focus data about the area of interest, we conducted kernel analysis to identify the areas showing higher incidence of fire events, based on the methodology presented by Cristovão and Rayol (2021), Jesus et al. (2020) and Teixeira et al. (2021).

In order to do so, we grouped the heat-focus layers into the following periods-of-time: 2002 to 2006, 2007 to 2011, 2012 to 2016, and 2017 to 2021. We performed this grouping by 5-year period in order to improve the visualization of the kernel density results. Since some years had few incidences of outbreaks, making it difficult to visualize the data. Therefore, we considered an aggregation in 5 years convenient for the representation of the thematic maps of kernel density.

Notably, this analysis aims at estimating hotspots' density per area, from an area weighted by the radius comprising the distance of each event from the reference point (BOTELHO et al., 2020). This analysis was carried out in QGIS software, based on using the "heat map" tool within a 1,500m radius. The methodology flowchart is presented in Figure 3.

Table 1. Land-use and land-cover classes, and their features.

Classes	Features
1. Forest	Natural forest, forest formation, savanna formation, and planted forest.
2. Natural non-forest formation	Flooded fields, swamp areas, grassland formations, apicum, rocky outcrops, and other non-forest formations.
3. Farming	Pasture, agriculture, temporary crops, perennial crops, and agriculture-pasture mosaic.
4. Non-vegetated areas	Urban infrastructure, mining, and other non-vegetated areas.
5. Water	Rivers, lakes, dams, reservoirs, and other water bodies.
6. Not Observed	Not Observed

Source: Mapbiomas, 2021

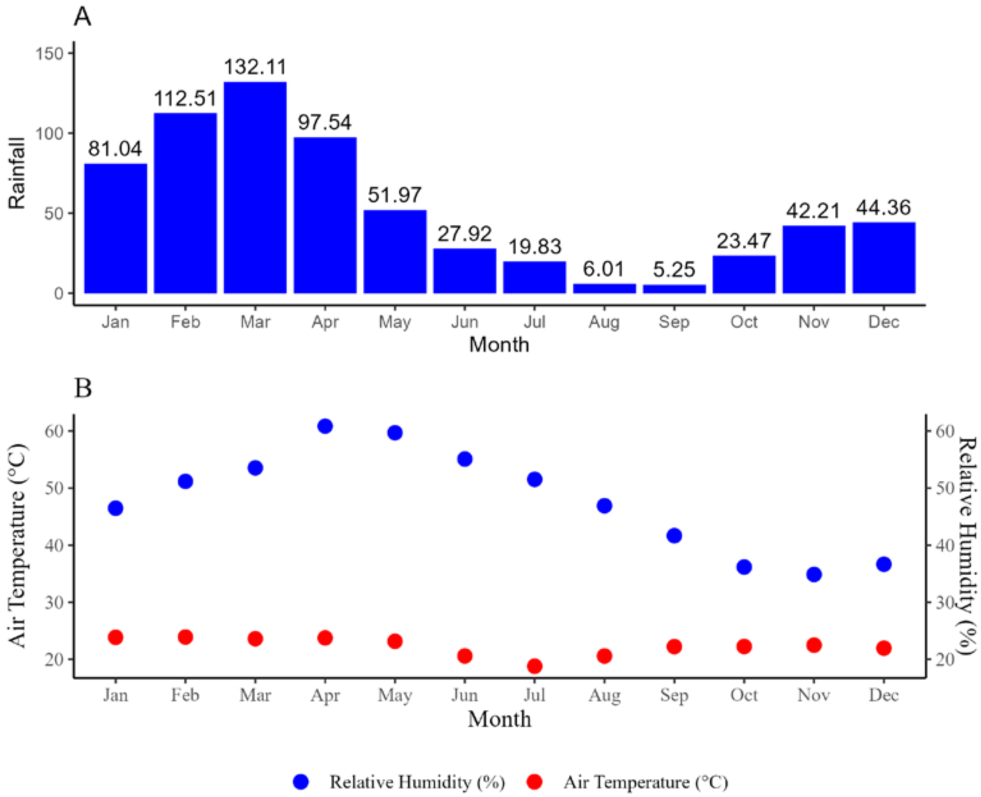

Figure 2. *Meteorological variables:* (A) Monthly average rainfall in Serra Talhada, Pernambuco State, Brazil - Source: APAC; (B) Air temperature (°C) and Relative humidity (%) - *Source*: INMET.

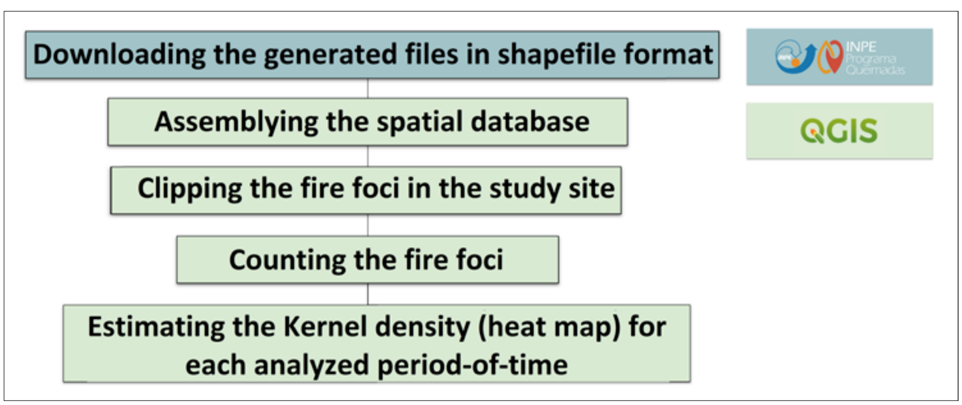

Figure 3. Flowchart of the methodology adopted to collect and process heat focus data.

2.3. Temporal trend analysis of vegetation cover and hot spots in Mata da Pimenteira State Park (PEMP)

Mann-Kendall non-parametric test for temporal trends (KENDALL M. G., 1975; MANN, 1945) was used to analyze hotspots' trends over the aggregated study periods. In order to do so, the sum of hotspots observed in each aggregated study periods – i.e., dry, rainy and annual - was taken into consideration in each assessment year, which required data to be independent and homogeneous (JESUS et al., 2020; OLIVEIRA et al., 2018; SALVIANO; GROPPO; PELLEGRINO, 2016).

The independence of time series' variables was determined through autocorrelation function test. Then, Mann-Kendall test was applied to variables that did not show autocorrelation (SNEYERS, 1975), whereas the modified Mann-Kendall test, proposed by Hamed and Rao (1998), was applied to variables showing autocorrelation. The null hypothesis (H0) considers no trend in the data series; on the other hand, the alternative hypothesis considers the incidence of temporal trend, at α% significance level – the current study adopted at 5% significance level.

In addition, Kendall's τ coefficient, which indicates whether the trend is growing (greater than 0) or dropping (less than 0), was herein analyzed. Theil-Sen slope β, determined by non-parametric Theil-Sen test (SEN, 1968; THEIL, 1950), was used to measure the magnitude of the trend (CAMPOS; MARINHO; CHAVES, 2020).

3. RESULTS

3.1. Land use and cover in the buffer zone

Among the findings, notable differences in land use and land cover were observed, with the forest class being maintained within the park area and an increase in farming class in the buffer zone. Regarding the analysis of hotspot occurrences, a concentration of hotspots was identified during the dry season, accompanied by a shift in their spatial pattern towards peripheral regions. Furthermore, a considerable increase in hotspots was observed between the years 2018 and 2021.

Figure 4 presents the space-time variability of land-use and land-cover classes identified in the Buffer Zone of Mata da Pimenteira State Park. It is possible seeing changes in these classes around the Park over the study period - 2002 to 2021. The Eastern, Northern and Northwestern sectors of the study area stood out for presenting the majority of changes, such as increased farming activities and reduced water surface in reservoirs, mainly in the one located to the East.

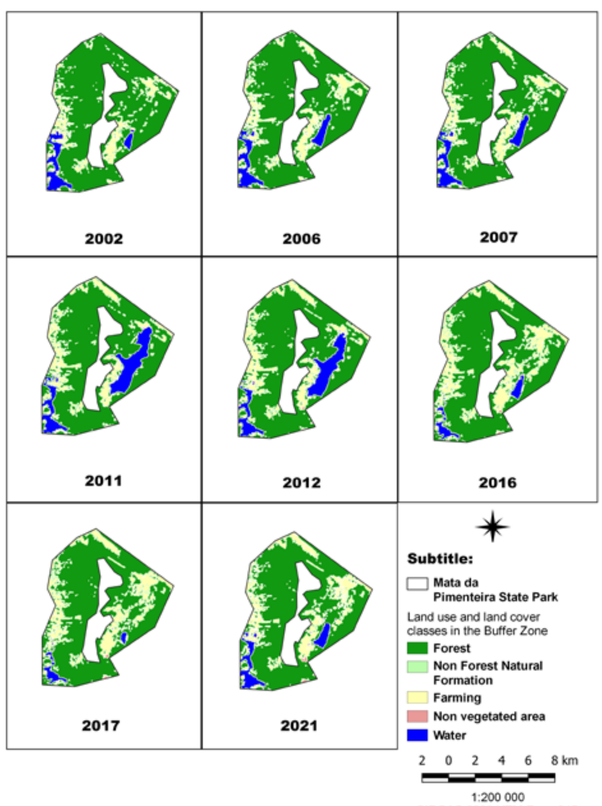

Figure 4. Land-use and land-cover maps of *Mata da Pimenteira* State Park buffer Zone (PEMP). Source: MapBiomas (2023).

3.2. Land use and cover in Mata da Pimenteira State Park (Preservation area)

The forest class areas showed an average of 4665 ha and a reduction of 10.69%, while the farming areas presented an average of 877 ha and an increase of 54.03% in the buffer zone (Table 2). The other classes also underwent changes during this period, with an increase in areas from 30.58 to 77.34 for the Non-Forest Natural Formation and Non Vegetated Area classes, respectively, while the water class decreased by 4%.

Figure 5 depicts land-use and land-cover classification in Mata da Pimenteira State Park, from 2002 to 2021, at 5-year observation intervals. These maps highlight the preservation of the Park's typical vegetation and, consequently, the biological conservation of its fauna and flora.

The results of the area count indicate the stability of the region, with the forest class averaging 805 ha and representing 97.68% of the entire conservation unit (Table 3). The other classes also underwent changes, with an increase of 0.44 ha and 0.62 ha for the Non-Forest Natural Formation and Non-Vegetated Area, respectively, while no water class was recorded within the park area.

Tabela 2. Temporal variability of land use and land cover classes within the buffer zone of the Mata da Pimenteira State Park.

Classes	Observed Years and their Areas in Hectares							
	2002	2006	2007	2011	2012	2016	2017	2021
Forest	5082.79	4811.06	4759.87	4467.41	4489.29	4546.05	4623.19	4539.50
Non-Forest Natural Formation	276.59	274.29	300.24	414.05	412.63	511.03	509.88	361.17
Farming	651.40	820.57	845.19	764.95	832.89	1064.22	1036.42	1003.38
Non Vegetated Area	24.62	24.97	24.18	35.51	42.16	28.16	26.92	43.66
Water	322.62	372.84	372.22	726.93	626.94	167.11	117.78	308.81

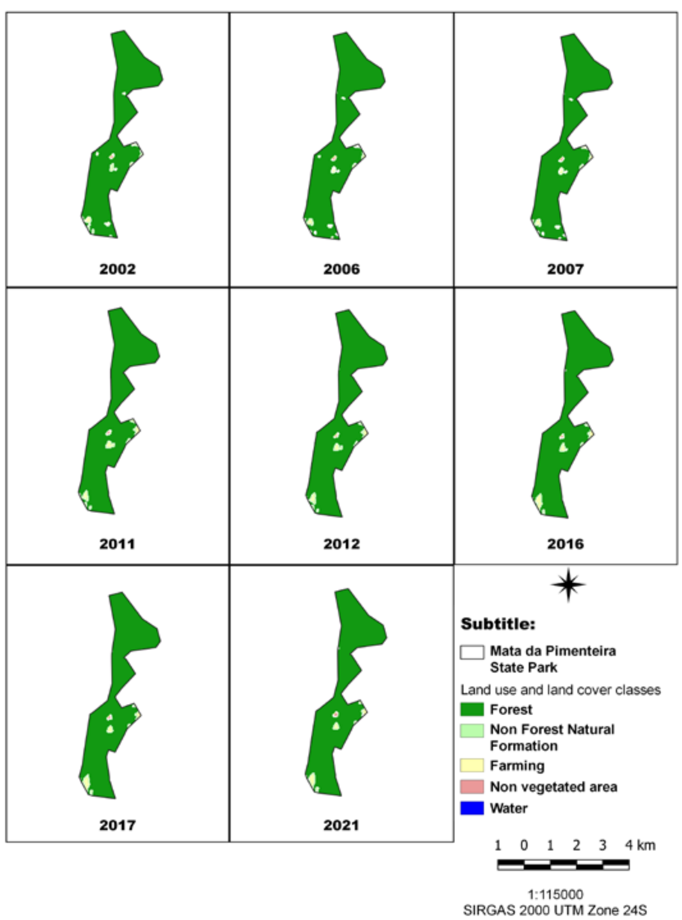

Figure 5. Land-use and land-cover maps of *Mata da Pimenteira* State Park (PEMP). Source: MapBiomas (2023).

Tabela 3. Temporal variability of land use and land cover classes within the Mata da Pimenteira State Park.

Classes	Observed Years and their Areas in Hectares							
	2002	2006	2007	2011	2012	2016	2017	2021
Forest	803.65	804.63	805.25	805.78	806.13	804.01	806.40	806.84
Non-Forest Natural Formation	7.97	5.76	6.47	10.36	10.27	10.72	9.65	8.41
Agricultural	8.32	8.77	8.06	9.30	9.56	10.98	10.36	10.36
Non-Vegetated Area	0.89	0.97	0.97	0.80	0.35	0.80	1.15	1.51
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.3. Temporal dynamics of hotspots

The total evaluated area, encompassing the park and its buffer zone, averages ten (10) critical hotspots per year, with variations over the years (Figure 6). As anticipated, the dry season predominates in terms of fire hotspots compared to the rainy season. Nonetheless, the findings reveal an escalation in hotspot numbers subsequent to the park's establishment in 2012, particularly from 2018 onwards, encompassing both the annual and dry season.

Hotspots' temporal trend statistics results have indicated stability, i.e., non-significant values, for both the annual and rainy season(Table 4).On the other hand, the dry period recorded significant trend to increase by 0.62 in the number of *foci* per year, which represented total increase by 12 in the number of hotspots from 2002 to 2021.

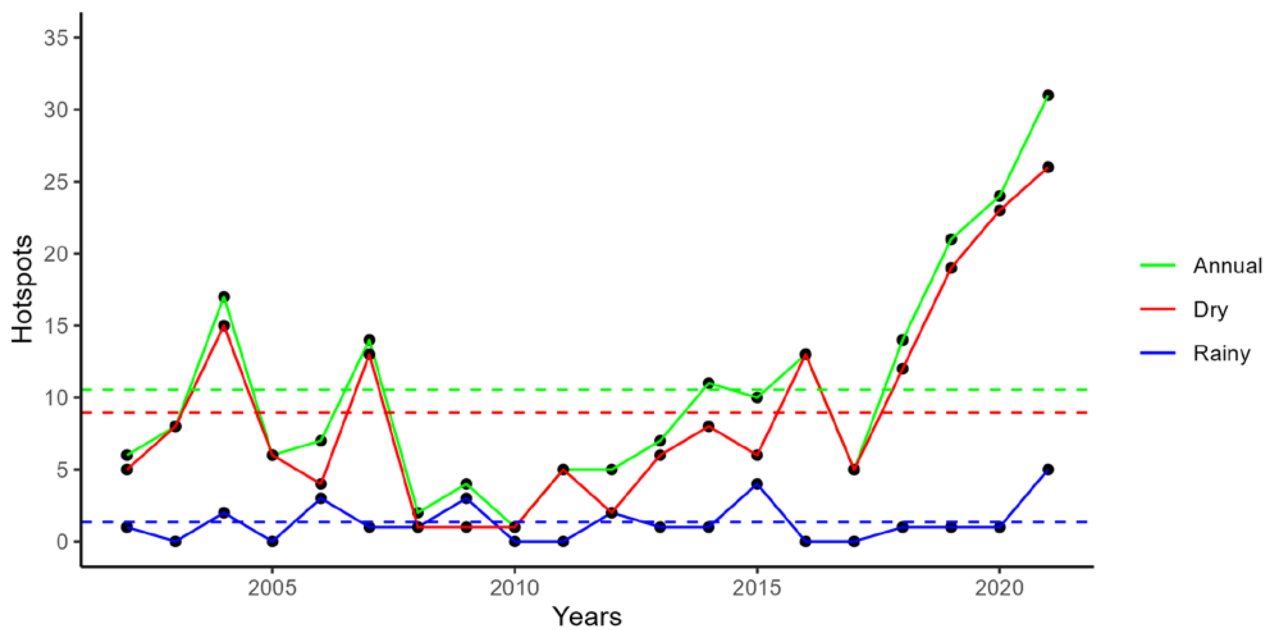

Figure 6. Hotspots in the Buffer Zone / PEMP combined area between 2002 and 2021.

Table 4. Parameters of Mann-Kendall temporal statistics applied to hotspots in PEMP's Buffer Zone, during the study period.

Temporal Statistics Parameters		
Period	Sen's Slope	Tau
Annual	0.76^{ns}	0.36
Rainy	0^{ns}	0.09
Dry	0.62*	0.34

Significance Code: ^{ns} Not Significant; * 5%; **1%

3.4. Spatial variability of hotspots

The representation of hotspots identified within the Park and its Buffer Zone during the study period is depicted in Figure 7.

The hotspots were grouped into four clusters spanning five-year intervals. Critical points were identified within the area highlighted by the most intense yellow color, highlighting the distinction between the dry and rainy seasons. Additionally, a concentration of fire hotspots is observed within the park's conservation area (red polygon) during the initial analysis period (2002-2006), prior to its establishment.Fi

During the years 2007-2011 and 2012-2016, a decrease in fire hotspots is observed, along with a shift in their distribution pattern towards the peripheral areas and boundaries of the Buffer Zone. However, the period 2017-2021 exhibited a notable increase in occurrences within the Buffer Zone, particularly in the eastern, northwestern, and southeastern regions, approaching the core conservation area of the park (red polygon).

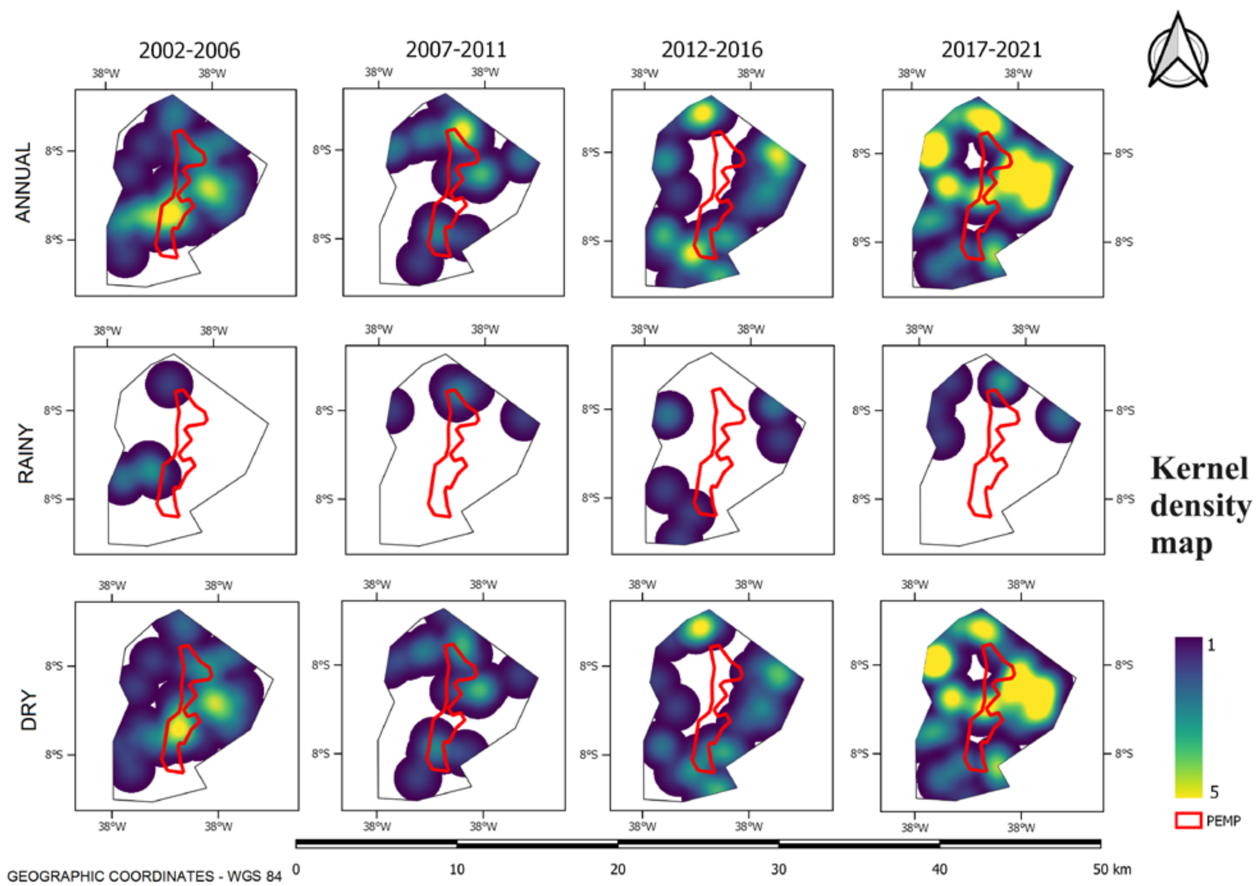

Figure 7. Kernel density map of hotspots in the buffer zone and in the PEMP during the annual, rainy and dry season, from 2002 to 2021.

4. DISCUSSION

As stated by Silva et al. (2020), the utilization of satellite imagery for land use and land cover classification enables the assessment of regional and temporal conditions in specific locations, as demonstrated in Figures 4 and 5. Bezerra et al. (2019) have emphasized the importance of using geotechnologies to monitor the native vegetation, as well as the macro and micro fauna, to avoid the unwanted effects of unplanned or illegal anthropogenic interventions, which can compromise the function and the ecosystems services provided by PEMP.

Silva et al. (2018) applied remote sensing in an EPA located in São Francisco River basin, on the banks of Sobradinho lake in neighboring Bahia State. These authors observed environmental degradation due to unlicensed occupation, which harmed the local fauna and flora, as well as made it susceptible to erosion and water quality issues. Another study conducted by Rodrigues et al. (2019) used the Google Earth Engine platform for land-use and occupation classification purposes. It detected significant changes in natural vegetation cover and illegal deforestation areas in the Cerrado Biome.

Figure 6 highlights the seasonality of hotspots throughout the assessment years; this is a standard behavior in different regions, as observed by Jesus et al. (2020), who assessed hotspots in all Brazilian biomes and conservation units from 2003 to 2017. According to Novais et al. (2019), hotspots are not a regular phenomenon, since they presented different behaviors in mesoregions and municipalities of Paraíba State, during the analyzed years. These authors have emphasized the concentration of hotspots during the dry season in their study site, from September to December.

Meteorological conditions, mainly rainfall volume, affect the number and distribution of hotspots, as highlighted by Araújo and Ferreira (2015), Moreira de Araújo, Ferreira and Arantes (2012), and Ribeiro et al. (2021). According to Alves et al. (2021), fire events and weather conditions are closely related to each other, since weather conditions can influence the likelihood of wildfire incidence, maintenance and propagation. Therefore, the concentration of hotspots in this time of the year is an expected behavior; however, it leads to concerns about the significant trend of increased number of hotspots in the study site in the dry season (Table 4).

The condition of the last evaluation period (2017 to 2021), which presented steep increase in the number of hotspots, may have interfered with the result of the temporal trend statistics. This interval recorded 19 hotspots per year, on average, the peak in the number of hotspots was recorded in 2021 (n = 31). The five previous years (2012 to 2016) recorded 9.2 hotspots per year, on average; however, if one takes into consideration the entire evaluation period (2002-2021), this number increases to ten (10) hotspots per year, on average. Thus, the number of hotspots has increased by approximately 100%, if one compares the period from 2017 to 2021 to the one from 2012 to 2016.

As the rainy season from 2018 to 2020 recorded rainfall rates above the historical average for the study region, according to the study by Rocha et al. (2022), the hope for a good rainy season may have increased the number of hotspots during this last five-year period. As suggested by Alves et al. (2021), there is increase in the number of hotspots due to farmers' expectation of good rainfall rates, given the tradition of burning dry and worn vegetation for rainy season cultivation in the Caatinga biome.

Results in the current study, in their turn, have indicated that preservation has been influential to the Park area, since its hotspot distribution pattern has changed over the years and started concentrating in the most limiting areas of the buffer zone (Figures 5 and 7). Still, there was record of hotspots in the Park's preservation area in the last five-year period; most likely due to fuel material accumulation, since the region went through a long period without hotspots (2007-2016). Soares, Resende and Pereira (2016) have stated that a given region is more susceptible to wildfire when it goes through long unburned periods.

Thus, likely conflicts in and anthropogenic pressures on the Park stand out since areas with increased agricultural class (Figure 5) are the ones presenting the highest hotspot concentrations (Figure 7) during the evaluation period. Sousa and Santos (2020) have pointed out that the increased population in the vicinity of the Park tends to cause conflicts due to pressure put on resource using to meet communities' needs. Therefore, it is essential adjusting policies focused on managing hotspots and wildfire events, as well as on promoting awareness campaigns in the region surrounding the Park, to avoid likely wildfire and damage to local biodiversity.

5. CONCLUSIONS

Results in the current study have shown changes in hotspot distribution pattern, such as higher hotspot concentrations in the buffer zone's Eastern, Northwestern and Southeastern regions, which were in line with changes in land-use and land-cover classes. The last five-year period (2017-2021) recorded increase by 100%, on average, in the number of hotspots, in comparison to the previous five-year period (2012-2016). The study area tended to show increased number of hotspots during the dry season, since it recorded approximately 12 *foci* over the 20-year assessment (2002-2021). It is recommended to have these areas monitored and well-managed by responsible institutions to prevent hotspots from posing greater danger to local biodiversity.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the State Environmental Agency (*Agência Estadual de Meio Ambiente* - CPRH) for providing the vector data of the conservation unit. We also thank the Federal Rural University of Pernambuco (*Universidade Federal Rural de Pernambuco* - UFRPE) for providing the necessary infrastructure and logistical support. Special thanks go to the University's Scientific Initiation Program (PIC/UFRPE) for selecting our project, and we are also grateful to the anonymous reviewers for their valuable comments and suggestions.

SUBMISSION STATUS

Received: 16 Apr. 2023
Accepted: 19 Sep. 2023
Associate editor: Bárbara Bomfim Fernandes

CORRESPONDENCE TO

Edicleife Lino Santos
Av. Gregório Ferraz Nogueira, s/n, 56909-535, Serra Talhada, PE, Brasil
e-mail: linoedicleife@gmail.com

AUTHORS' CONTRIBUTIONS

Edicleife Lino Santos: Conceptualization (Lead), Investigation (Equal), Methodology (Equal), Visualization (Equal), Writing – original draft (Equal), Writing – review & editing (Equal).
Alan Cézar Bezerra: Conceptualization (Equal), Funding acquisition (Equal), Methodology (Equal), Project administration (Equal), Validation (Equal), Writing – original draft (Equal), Writing – review & editing (Equal).
Damião Alves Silva: Methodology (Equal), Validation (Equal), Visualization (Equal), Writing – original draft (Equal).
Anderson Santos Silva: Methodology (Equal), Validation (Equal), Visualization (Equal), Writing – original draft (Equal).
Cristina Rodrigues Nascimento: Methodology (Equal), Validation (Equal), Visualization (Equal), Writing – original draft (Equal).
Rodrigo Ferraz Jardim Marques: Methodology (Equal), Validation (Equal), Visualization (Equal), Writing – original draft (Equal).

REFERENCES

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 2013; 22(6): 711-728.

Alves JMB, Silva EM, Araújo FC, Silva LL. Um Estudo de Focos de Calor no Bioma Caatinga e suas Relações com Variáveis Meteorológicas. Revista Brasileira De Meteorologia 2021; 36(3): 513-527.

Araújo FM, Ferreira LG. Satellite-based automated burned area detection: A performance assessment of the MODIS MCD45A1 in the Brazilian savanna. International Journal of Applied Earth Observation and Geoinformation 2015; 36: 94–102.

Bezerra AC, Silva JLB, Silva DAO, Batista PHD, Pinheiro LC, Lopes PMO, et al. Monitoramento Espaço-Temporal da Detecção de Mudanças em Vegetação de Caatinga por Sensoriamento Remoto no Semiárido Brasileiro. Revista Brasileira de Geografia Física 2020; 13(1): 286.

Bezerra AC, Costa SAT, Silva JLB, Araújo AMQ, Moura GBA, Lopes PMO et al. Annual Rainfall in Pernambuco, Brazil: Regionalities, Regimes, and Time Trends. Revista Brasileira de Meteorologia 2021; 36: 403-414.

Bezerra JVA, Andrade JS, Melo FP, Vigoderis RB, Galvíncio JD, Souza WM. Degradation of the Vila Maria Spring in Garanhuns-PE. Journal of Hyperspectral Remote Sensing 2019; 9(6): 320-329.

Botelho MGL, Furtado LG, Lima DA, Pimentel BS, Machado ASO, Júnior JPA et al. Temporal and spatial evaluation of hot spots in Paragominas, PA, Brazil. Research, Society and Development 2020; 9(7): e589974501–e589974501.

Campos JDO, Marinho H, Chaves L. Tendências e Variabilidades nas Séries Históricas de Precipitação Mensal e Anual no Bioma Cerrado no Período 1977-2010. Revista Brasileira de Meteorologia 2020; 35(1): 157-169.

Chaves M, Martins F, Mataveli G, Conceição K, Barros K, Guerrero J. Focos de calor no Cerrado e na Caatinga de Minas Gerais identificados por sensor orbital. Revista Brasileira de Sensoriamento Remoto 2021; 2(1): 42-54.

Costa SAT, Bezerra AC, Araújo AMQ, Silva MF, Alves RM, Souza LSB. Dinâmica espaço-temporal das anomalias de precipitação em uma região semiárida, Nordeste do Brasil. Revista de Gestão de Água da América Latina 2021; 14(18).

Cristovão EEM, Rayol BP. ANÁLISE ESPAÇO-TEMPORAL DE FOCOS DE CALOR NO MUNICÍPIO DE SÃO FRANCISCO DO PARÁ, NORDESTE PARAENSE. Acta Tecnológica 2021; 15(2): 69-79.

Dall'igna F, Maniesi V. Spatial and temporary dynamics of hotspots in the amazon ecological corridor conservation unit: the case of intense anthropic pressure in the National Forest of Jamari/RO. Research, Society and Development 2022; 11(6): e42011629271.

Fonseca RC, Júnior JRT , Candeias ALB. Programação Python e índices físicos na detecção de bordas na Unidade de Conservação Parque Estadual Mata Da Pimenteira (Pernambuco). Revista Brasileira de Sensoriamento Remoto 2020; 1(2): 42-57.

Hamed KH, RAO AR. A modified Mann-Kendall trend test for autocorrelated data. Journal of Hydrology 1998; 204(1-4): 182-196.

Inpe. Instituto Nacional de Pesquisas Espaciais. Programa Queimadas. Accessed on 14 ago 2018 through the link: https://queimadas.dgi.inpe.br/queimadas/portal.

Jesus JB, Rosa CN, Barreto IDC, Fernandes MM. Análise da incidência temporal, espacial e de tendência de fogo nos biomas e unidades de conservação do Brasil. Ciência Florestal 2020; 30(1): 176.

Kendall MG. Rank Correlation Methods. London: Charles Griffin, 1975.

Lins FAC, Silva JLB, Moura GBA, Ortiz PFS, Oliveira JDA, Alves MVC. Quantile technique to precipitation, rainfall anomaly index and biophysical parameters by remote sensing in Serra Talhada, Pernambuco. Journal of Hyperspectral Remote Sensing 2017; 7(6): 334-344.

MapBiomas Project- Collection 7 of the Annual Series of Land Use and Land Cover Maps of Brazil, accessed on 24 mar 2023 through the link: https://mapbiomas.org/en

Mann HB. Non-parametric test against trend. Econometrica1945; 13: 245-259.

Araújo FM, Ferreira LG, Arantes AE. Remote Sensing Distribution Patterns of Burned Areas in the Brazilian Biomes: An Analysis Based on Satellite Data for the 2002-2010 Period 2012; 4: 1929-1946.

Nascimento KRP, Alves ER, Alves MVS, Galvíncio JD. Impacto da precipitação e do uso e ocupação do solo na cobertura vegetal na Caatinga. Journal of Environmental Analysis and Progress 2020; 5(2): 221-231.

Neto APM, Batista AC, Soares RV, Biondi D, Batista APB, Oliveira ATM. Evaluation and quantification of heat hotspots in the Chapada dos Guimarães-MT National Park. Floresta 2020; 50(2): 1151-1160.

Novais DB, Souto PC, Souto JS, Santana JAS. Temporary series of heat sources in mesoregions of Paraíba, Brazil. Floresta 2019; 49(2): 181-188.

Oliveira AS, Pereira GA, Rodrigues AF, Neto JOM. Tendências em índices extremos de precipitação e temperatura do ar na cidade de Uberaba, MG. Sustentare 2018; 2(1): 118-134.

Menezes ES, Mucida DP, França LCJ, Aguilar MVM, Pereiral IM. Análise multitemporal dos focos de calor na Reserva Biológica do Gurupi-MA. AGROPECUÁRIA CIENTÍFICA NO SEMIÁRIDO 2019; 15(4): 307.

Ribeiro TM, Mendonça BAF, Júnior JFO, Filho EIF. Fire foci assessment in the Western Amazon (2000–2015). Environment, Development and Sustainability 2021; 23(2): 1485-1498.

Rocha AHG, Cruz JCG, Silva BAC, Silva JLB, Alba E, Marques RFJ, et al. Environmental diagnosis by vegetation indices in the Mata da Pimenteira State Park during the rainy and dry seasons. Journal of Hyperspectral Remote Sensing v 2022; 12(2): 36-44.

Rodrigues T, Sano EE, Almeida T, Chaves JM, Doblas J. Detecção de mudanças da cobertura vegetal natural do Cerrado por meio de dados de radar (Sentinel-1A). Revista Sociedade e Natureza 2019; 31: 1-22.

Sales LLN, Silva DDS, Lima EV, Fonseca GTC, Almeida GS, Rodrigues JB. 10 MUNICÍPIOS MARANHENSES MAIS ATINGIDOS POR FOCOS DE QUEIMADAS NOAS ANODES DE 2014 E 2015. Revista de Geografia 2019; 36(1): 59-74.

Salviano MF, Groppo JD, Pellegrino GQ. Análise de tendências em dados de precipitação e temperatura no Brasil. Revista Brasileira de Meteorologia 2016; 31(1): 64-73.

Sen PK.. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 1968; 63: 1379-1389.

Silva WB, Bezerra JM, Feitosa AP, Silva PCM & Rêgo ATA. Uso e Ocupação do Solo na Bacia Hidrográfica do Açude Santa Cruz do Apodi – RN. Anuário do Instituto de Geociências – UFRJ 2020; 43(1): 397-407.

Silva RM, Santos SM, Lopes I, Junior ECA. Identification of conflicts of use and land cover in the environmental protection area of Sobradinho Lagoon, Bahia. Journal of Hyperspectral Remote Sensing 2018; 8(2): 67-77.

Sneyers R. On the statistical analysis of series of observations. Organisation Meteorologique Mondial - Note Technique 1975; 143: 192.

Soares TBO, Resende FC, Pereira G. Distribuição espacial dos focos de calor em Unidades de Conservação de Minas Gerais no período de 2007 a 2012. Revista Ud Y la Geomática 2016; 11: 39-45.

Sousa JS, Santos EM. Dinâmica da mudança do uso e cobertura da terra em uma paisagem da Caatinga protegida e sua zona de amortecimento. Revista Ibero-Americana de Ciências Ambientais 2020; 11(7): 219-234.

Teixeira NC, Danelichen VHM, Pereira OA, Seixas GB. Dinâmica de Queimadas no Município de Cuiabá-MT por Sensoriamento Remoto. Revista Brasileira de Geografia Física 2021; 14(2): 607-618.

Theil HA. A rank-invariant method of linear and polynomial analysis, Part 3. Proceedings of Koninalijke Nederlandse Akademie van Weinenschatpen A 1950; 53: 1397-1412.