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Spatial analysis of heat sources in Pará state - Brazil

Análise espacial dos focos de calor no estado do Pará - Brasil

Análisis espacial de enfoques de calor en el estado de Pará - Brasil

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Abstract

The state of Pará has experienced a high occurrence of forest fires, which were strongly influenced by the El Niño phenomenon in 2015-2016. This study aims to analyze the conditions of heat sources in Pará, using the 2016 monthly bulletins provided by the Environment and Sustainability Secretariat. This data was analyzed through descriptive statistics. The IDW interpolation method was used to construct the density map, displaying the primary areas of concern. The results showed that the greatest detections were during the

Amazonian summer, occurring during the second half of the year. Specifically, the municipalities of the Southwestern and Southeastern Para meso-regions were mainly the ones affected. Fire is used as a primary economic tool. The Southwest was the one region that presented the highest densities of hotspots. Although the results do not indicate the actual configuration of the events, because of the technical limitations of remote sensing, the information obtained in this study communicates ideas concerning prevention and action in the most affected areas. *In loco* studies are needed to determine precisely the causes of these occurrences.

Keywords: Arc of deforestation; Monitoring of fire; Remote sensing.

Resumo

O Estado do Pará apresenta alta ocorrência de queimadas e incêndios e, em 2015 e 2016, sofreu forte influência do fenômeno El Niño. Assim, este estudo objetivou analisar as ocorrências de focos de calor no Pará, utilizando os boletins mensais de 2016 do monitoramento da Secretaria de Meio Ambiente e Sustentabilidade. Esses dados foram analisados por meio da estatística descritiva, além disso, utilizou-se o método de interpolação IDW para a construção do mapa de densidade de focos. Os resultados demonstraram que as maiores detecções foram durante o verão amazônico, segundo semestre do ano, principalmente entre os munícipios das mesorregiões paraenses sudoeste e sudeste, uma vez que o fogo é utilizado nas principais atividades econômicas. A sudoeste foi a que mais apresentou densidades alta e muito alta de focos. Necessita-se de estudos *in loco* para determinar precisamente as causas dessas ocorrências e, embora, os resultados não indiquem a real configuração dos eventos, por causa das limitações técnicas do sensoriamento remoto, as informações obtidas servem para concentrar as ações de fiscalização, prevenção e combate nas áreas mais afetadas.

Palavras-chave: Arco do desmatamento; Monitoramento de queimadas; Sensoriamento remoto.

Resumen

El estado de Pará tiene una alta incidencia de incendios e incendios y, en 2015 y 2016, fue fuertemente influenciado por el fenómeno de El Niño. Así, este estudio tuvo como objetivo analizar la ocurrencia de puntos calientes en Pará, utilizando los boletines mensuales de 2016 del seguimiento de la Secretaría de Medio Ambiente y Sustentabilidad. Estos datos se analizaron mediante estadística descriptiva, además, se utilizó el método de interpolación

IDW para construir el mapa de densidad de enfoque. Los resultados mostraron que las mayores detecciones se dieron durante el verano amazónico, la segunda mitad del año, principalmente entre los municipios de las regiones suroeste y sureste de Pará, ya que el fuego se utiliza en las principales actividades económicas. El suroeste fue el de mayor y muy alta densidad de focos. En los estudios *in loco* son necesarios para determinar con precisión las causas de estas ocurrencias y, si bien los resultados no indican la configuración real de los eventos, debido a las limitaciones técnicas de la teledetección, la información obtenida sirve para concentrar las acciones de inspección, prevención y combate en las zonas más afectadas.
Palabras clave: Arco de deforestación; Vigilancia de incêndios; Detección remota.

1. Introduction

Historically, the fire has been considered to be one of the constituent elements of matter responsible in part for the predominance of various terrestrial ecosystems. Although fire plays an important role in plant regeneration, its utilization on even the most legitimate terms can cause unfavorable outcomes, including those which cause environmental, economic, and social damage (Neves & Conceição, 2010; Sousa et al., 2015). Larger fires generally result from their usage as tools in managing livestock and agriculture, as they expand to adjacent forest areas (Cano-Crespo et al., 2015). This form of land use is a major cause of forest fires (White et al., 2016).

In the Amazon, agricultural techniques involving fire are widely used in the production process of crops and drive agricultural expansion (Martinez et al., 2007) as well as livestock. Doing so is valued as a simple, affordable method of conquering new areas of production by increasing soil fertility in the short term, as nutrients present in biomass are then allowed to be released. In Brazil, agriculture plays an important role in the production of food, employment, and income. In Pará, cattle are bred in extensive pastures, traditional agriculture (slash-and-burn), and the growing cultivation of soy.

It must be considered, however, that fires are not only caused for human actions but also natural, although with less frequency. In addition, according to Santos et al. (2006), climatic factors, such as drought and wind speed, or the relief of the place influence the spread of fire and determine its devastating effects. Root causes for these fires can be grouped into eight categories: lightning, arsonists, burning for cleaning, smokers, recreational fires, railways, and forestry and miscellaneous operations (Soares, 1988).

Given this scenario, the degradation of forests is the result of deforestation, burning and unsustainable management of areas, which includes the loss of biodiversity, reduced water cycling, nutrient recycling, reduced quality of life, among others (Araújo et al., 2011). Thus, fires, in particular, are also considered a threat and, for this reason, they have attracted the attention of the agencies linked to environmental wellbeing as well as the press, with constant information about new outbreaks and their damage to human and environmental health (Gerude, 2013).

In this sense, the continuous need to advance the control of fires in natural environments encourages the production of technologies capable of monitoring their occurrences, such as remote sensing, whose data from satellites allow a wide view on the temporal, spatial distribution and patterns of fires in different scales (Pereira et al., 2012; Gonçalves et al., 2016). Among these methods, satellite fire recording - heat focus - stands out for identifying the spatio-temporal dynamics of the affected areas, through information and estimates on the location, period, and frequency of events, contributing effectively to the ability to prevent, monitor, and combat potentially hazardous situations involving fire and its usage in the cultivation of agricultural goods. (Setzer & Morelli, 2011; Silva et al., 2013). It is important to note that this data does not indicate whether a given heat source is the result of controlled burns or fires. However, the number of occurrences and their spatial concentration are recorded (Piromal et al., 2008).

Since July 2015, the Secretariat of Environment and Sustainability (SEMAS), of the State of Pará, has been monitoring occurrences of hot spots in the territory through remote sensing within the region. The information is made available to the public electronically, in the form of weekly and monthly newsletters.

This monitoring was motivated by the strong influence of the *El Niño*[1] phenomenon 2015/2016, which contributed to the reduction of precipitation and increased temperatures in the Amazon region. Ultimately, factors such as these contributed to high cases of fire outbreaks. Therefore, this study aims to analyze the occurrences of hot spots in relation to the timing, municipalities and mesoregions of Pará, in the year 2016.

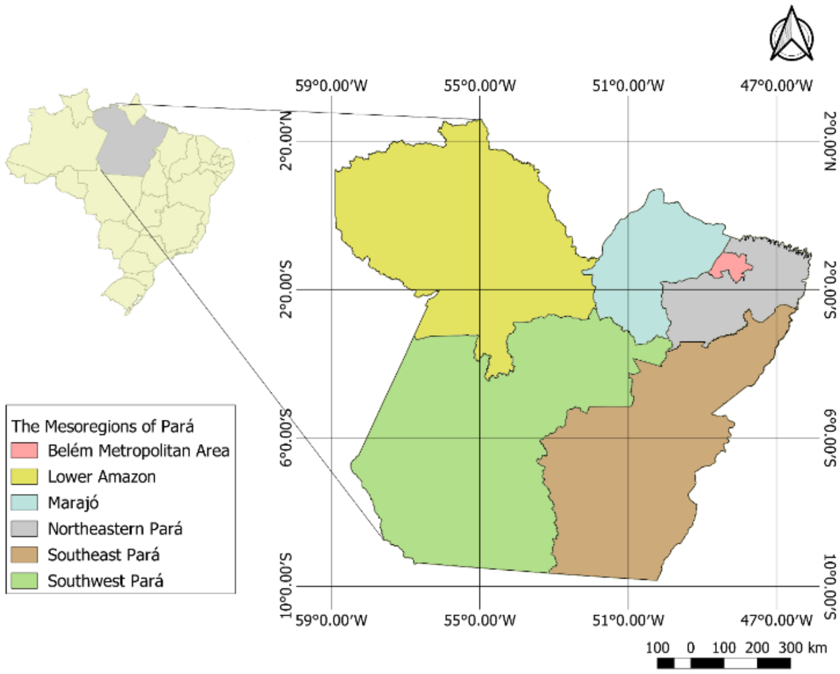
[1] Abnormal heating of the surface and sub-surface waters of the Equatorial Pacific Ocean. This phenomena alter the atmospheric circulation (from low to high levels), favoring changes in the moisture transport pattern and consequently contributes to a decrease in the amount of rainfall in tropical regions.

2. Material and Methods

Pará, located in the northern region of Brazil, has a territorial area of 1,247,955.381 km², making it the second largest state in the Federation, meaning it comprises 14.65% of the entire national territory. It is divided into 144 municipalities broken down into regional and political terms, into six mesoregions (Figure 1) and 22 microregions, with an estimated population of 7,581,051 inhabitants (IBGE, 2010), making it the most populous state in the Amazon.

According to Cohn et al. (2010), the State of Pará has heterogeneous and diversified vegetation and an equally rich fauna, countless rivers, boreholes, lakes, streams and water courses, in addition to a plain relief with various elevated regions.

Figure 1. Location of the Pará State with its respective mesoregions.



Source: Authors (2020).

Figure 1 illustrates the division of the State of Pará into six mesoregions - a configuration prepared by the Brazilian Institute of Geography and Statistics (IBGE), which were part of the object of analysis in this study to visualize the dynamics of hot spots in the state.

The climate of the state is well defined, between the months of January to April, a period regionally called "Amazonian Winter." It is characterized by large volumes of precipitation caused by local conventions and by the Intertropical Convergence Zone[2] (ZCIT), mainly in the northern portion. In the southern portion, rainfall is caused by the passage of frontal systems or by the South Atlantic Convergence Zone[3] (ZCAS). The rest of the year is referred to as the "Amazonian Summer." It is marked by the displacement of the ITCZ towards the Northern Hemisphere, which consequently favors the reduction of cloud cover and volume of rain over the northern strip of the State of Pará. In the southern portion of the state, it is common to establish a mass of dry air. This causes downward movement patterns in the airflow, which prevents the formation of convective clouds in the region, resulting in stark variations in temperature during the day and low levels of relative humidity.

According to Research Agencies, such as INPE (National Institute for Space Research), Pará is among the first in the ranking of states with the highest incidence of burns/fires, making the Amazon Biome one of the most critically affected. Justino and Andrade (2000) suggest certain Amazonian municipalities are particularly prone to be high-risk areas because of their historical roots as colonization centers with the intense activity of wood extraction, livestock, and subsistence agriculture. It is noteworthy that this activity is still ongoing, as they contribute to the local, regional, and national economy.

This is a documentary research, with data from fire reports to analyze the scenario of hot spots in the state of Pará (Pereira et al., 2018). Methods of data collection consisted of the compilation and analysis of secondary information from the 2016 Monthly Bulletins for Monitoring Heat Sources and Forest Fires in the State of Pará, prepared by the Monitoring Team of the Directorate of Meteorology and Hydrology, of SEMAS, which used information from the MODIS sensor, present in the AQUA reference satellite. The 2015 bulletins were not used in this study, as monitoring was carried out in non-continuous periods throughout the year, making it impossible to carry out a more concrete and standardized analysis, as was done in 2016.

Subsequently, this data was transcribed and prepared in an Excel 2010 spreadsheet for further analysis by means of descriptive statistics for the determination of absolute and relative frequencies, as well as supporting the preparation of graphs and tables. In a GIS environment, the centroids of each municipality were extracted to establish the relationship of the outbreaks of fire to these points. The interpolation method IDW (inverse of the weighted

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[2] Band of highly convective cloudiness that surrounds the terrestrial globe close to the equator that accompanies the apparent movement of the Sun causing a great amount of rain.

[3] Meteorological system formed by a band of convective cloudiness of Northwest/Southeast orientation, extending from the south of the Amazon region to the central region of the South Atlantic.

distance) was used to build the focus density map. This interpolator is commonly used to generate a continuous surface using sample data, usually points. Five density classes were defined: 1) very low, 2) low, 3) medium, 4) high and 5) very high. For this, the software used in this processing was QGIS 2.8.1 Wien.

Pearson's correlation test was used between the number of hotspots and the number of municipalities. Also, the data of heat sources were separated by seasonality and Student's test was applied to the variables. Both tests were compiled in software R 3.4.3.

3. Results

In 2016, the most frequent occurrence patterns of fires generally and fires in the State of Pará was in November, with 7,908 detections; October, with 5,281 and August, with 4,863, while March and April had the lowest records (78 and 61, respectively) (Figure 2).

In the three months mentioned above, 136 municipalities participated in November; 123 in October, and 119 in August, which can be directly proportional; as the number of municipalities increased, so did the number of hotspots.

Statistically, there is a strong correlation between the variables: the month of the year and the number of hotspots are connected. Having established the criteria for normality of data, the Pearson correlation test was applied and presented a result $\rho = 0.87$ and p-value = 0.0002314, therefore, it presents a directly proportional relationship. The greater the number of fire outbreaks, the greater the number of municipalities affected.

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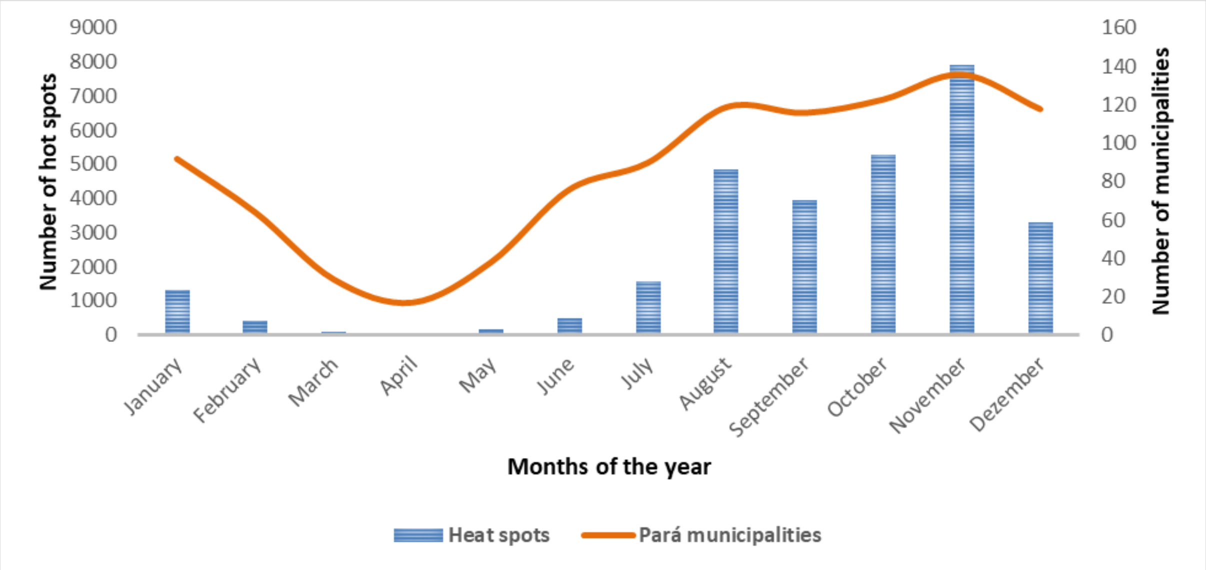
Figure 2. Relationship between the number of hot spots and the number of municipalities per month, in 2016.



Source: Monthly Bulletins for Monitoring Heat Sources and Forest Fires in the State of Pará (2016).

Figure 2 shows a time scale of months in the year 2016 and the dynamics of the number of hot spots concerning the number of municipalities in Pará that contributed to the phenomenon studied. In the first six months of the year, we observed a smaller number of affected hot spots and municipalities, and in the last six months, a considerable increase number of hit heat sources and municipalities.

In detail, Table 1 shows 32 municipalities in Pará that had the highest records of hotspots in January, a total of 1,018 fires/burns (77.0% of the amount monitored in the month), the main contributors being: Santarém, with 135; Monte Alegre, 109; Porto de Moz, 103 and Alenquer, 93. As for February and March, there were 28 municipalities in each, totaling 340 and 78 fires / fires (79.0% and 96.2% of the general amount), respectively. The following stood out in February: Paragominas, with 28 hot spots; Monte Alegre, 25; Santarém, 23 and Uruará, 20; and in March: Santa Maria das Barreiras, with 11; São Felix do Xingu, 10 and Santana do Araguaia, 8 (Table 1).

Table 1. Detail of records of heat focus in Pará municipalities in 2016.

Citys	Months												Total/ Year
	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dez	
Abaetetuba	-	-	-	-	2	11	-	29	-	-	30	37	109
Acará	-	-	-	-	-	17	36	59	52	150	291	79	684
Água Azul do Norte	-	-	-	-	-	-	16	73	62	-	-	-	151
Alenquer	-	-	-	-	3	4	12	-	38	-	102	68	227
Almeirim	51	-	1	-	-	-	-	-	-	-	202	152	406
Altamira	19	12	2	4	6	17	241	913	413	138	83	29	1877
Anapu	-	-	-	-	-	-	-	15	48	84	200	30	377
Aurora do Pará	-	-	-	-	-	-	-	-	-	-	33	37	70
Aveiro	16	-	1	-	-	-	16	28	37	68	85	-	251
Baião	12	-	-	-	-	2	-	-	-	-	94	-	108
Belterra	16	-	-	-	-	-	-	-	-	-	37	-	53
Bragança	-	-	-	-	-	-	-	-	26	-	-	26	52
Brasil Novo	22	-	-	-	-	-	-	-	-	-	50	29	101
Breu Branco	-	10	1	-	-	-	-	-	-	-	32	-	43
Breves	-	-	1	-	-	9	19	39	31	65	43	-	207
Bujaru	-	-	-	-	-	3	13	15	-	-	63	-	94
Cachoeira do Arari	-	-	-	-	-	3	-	-	-	-	32	-	35
Cachoeira do Piriá	10	-	-	-	-	2	-	-	-	-	31	79	122
Cametá	-	-	-	-	-	12	10	-	-	125	211	-	358
Canaã dos Carajás	-	-	-	1	-	7	29	77	-	-	-	-	114
Capitão Poço	18	-	-	-	-	2	-	-	-	-	-	75	95
Chaves	12	-	-	-	-	-	-	-	28	74	48	81	243
Conceição do Araguaia	-	-	3		6	15	37	27	99	58	-	-	245
Concórdia do Pará	-	-	-	-	-	-	-	-	-	-	40	34	74
Cumaru do Norte	-	-	1	2	2	5	57	114	97	65	-	-	343
Curralinho	-	-	-	-	-	2	11	23	36	61	-	-	133

Dom Eliseu	-	8	-	-	1	14	21	32	-	-	39	-	115
Floresta do Araguaia	-	-	-	2	-	-	12	19	-	54	-	-	87
Goianésia do Pará	-	8	1	-	-	3	-	-	-	45	38	31	126
Gurupá	14	-	-	-	-	-	-	-	-	-	74	52	140
Igarapé-Miri	-	-	1	-	-	8	15	-	-	-	31	25	80
Ipixuna do Pará	13	-	-	-	4	6	-	-	-	-	141	40	204
Itaituba	19	-	-	3	3	9	96	297	116	147	48	33	771
Itupiranga	-	9	-	-	-	2	9	31	69	104	90	-	314
Jacareacanga	-	6	-	1	6	7	127	426	104	-	-	-	677
Juruti	50	-	-	-	-	5	-	18	-	-	116	26	215
Marabá	-	5	2	-	3	16	43	49	118	120	72	-	428
Medicilândia	34	13	-	-	-	-	-	-	-	51	89	40	227
Mocajuba	-	-	-	-	-	9	-	-	-	-	65	-	74
Moju	19	18	4	-	-	14	47	65	42	124	405	100	838
Monte Alegre	109	25	-	-	3	3	-	-	-	68	205	159	572
N. Esperança do Piriá	-	-	-	-	-	5	-	-	-	-	55	60	120
Novo Progresso	-	12	1	-	3	6	157	725	300	57	-	-	1261
Novo Repartimento	-	10	-	-	-	2	18	34	101	232	298	26	721
Óbidos	43	-	1	1	4	8	43	40	35	100	203	133	611
Oeiras do Pará	-	-	-	-	-	-	-	-	-	54	182	44	280
Oriximiná	29	7	1	-	-	3	10	21	32	97	166	75	441
Ourilândia do Norte	-	-	2	-	2	2	-	44	33	-	-	-	83
Pacajá	26	9	-	-	-	-	-	32	126	264	419	64	940
Paragominas	44	28	4	4	9	61	26	80	32	63	94	52	497
Parauapebas	-	-	3	9	19	18	24	47	32	-	-	-	152
Placas	27	-	-	-	-	-	-	18	-	245	197	-	487
Portel	11	-	7	1	-	6	18	63	106	205	601	164	1182
Porto de Moz	103	5	2	-	-	2	-	-	-	54	247	183	596
Prainha	45	19	1	-	-	-	-	-	-	-	220	86	371

Rio Maria	-	5	1	-	-	3	-	16	-	-	-	-	25
Rondon do Pará	11	18	1	-	6	7	10	-	-	102	78	-	233
Rurópolis	22	14	-	-	3	-	10	23	-	130	64	-	266
Santa Maria das Barreiras	-	14	11	7	18	46	63	90	264	107	-	-	620
Santana do Araguaia	-	12	8	23	21	27	21	67	109	85	-	-	373
Santarém	135	23	5	-	5	10	-	21	25	130	413	135	902
S. Domingos do Capim	-	-	-	-	2	11	16	30	-	-	56	72	187
São Félix do Xingu	-	8	10	3	2	8	63	589	465	176	61	-	1385
Senador José Porfírio	-	-	-	-	-	5	-	-	-	76	110	-	191
Tailândia	-	5	-	-	-	3	-	-	-	-	54	31	93
Tomé-Açu	11	-	-	-	-	12	9	19	-	65	102	-	218
Trairão	11	-	-	-	-	-	12	72	-	142	-	-	237
Tucumã	-	-	-	-	-	-	-	16	52	-	-	-	68
Tucuruí	-	-	-	-	-	-	-	17	-	-	32	-	49
Ulianópolis	-	17	-	-	4	15	9	-	-	-	-	-	45
Uruará	42	20	2	-	-	3	-	-	31	119	188	37	442
Viseu	24	-	-	-	-	-	-	-	-	-	37	65	126
Total/month	1018	340	78	61	137	470	1376	4413	3159	4104	6997	2489	**24642**

Source: Monthly Bulletin of Monitoring of Forest Fires and Heat Foci in the Pará State (2016).

Table 1 shows the 72 municipalities in the State of Pará that had records of hot spots - detected by satellite - during the months of 2016, allowing to obtain the total number of occurrences in each month of the year and also by municipality.

In April, 14 municipalities corresponded to 61 hot spots (92.4% of the total), whose main contributors were: Santana do Araguaia, with 23; Parauapebas, 9 and Santa Maria das Barreiras, 7 (Table 1). In May, there were 25 municipalities, totaling 132 fires / fires, equivalent to 85.7% of the detections, being the main representatives: Santana do Araguaia, with 21 outbreaks; Parauapebas, 19 and Santa Maria das Barreiras, 18 (Table 1). In June, Pará had a higher concentration of fires/burns, 438 outbreaks, distributed in 50 municipalities (87.2% of the total), the main ones being: Paragominas, with 61; Santa Maria das Barreiras, 46 and Santana do Araguaia, 27 (Table 1).

As for the month of July, 37 municipalities were responsible for 1,312 outbreaks (41.1% of the detected amount), with emphasis on Altamira, with 241; Novo Progresso, 157 and Jacareacanga, 127 (Table 1). In August, 42 municipalities had the highest number of outbreaks of fires/fires, 4,252 (35.2% of the total), the main contributors being: Altamira, with 913; Novo Progresso, 725 and São Felix do Xingu, 589. In September, 33 municipalities accounted for 3,007 areas (28.4% of the overall monitored), notably: São Félix do Xingu, with 465; Altamira, 413 and Novo Progresso, 300 (Table 1).

In the month of October, there were 39 municipalities with the highest number of fires/fires, 3,954 (31.7% of the total registered), with the largest contributions being: Pacajá, with 264; Plates, 245 and Novo Repartimento, 232 (Table 1). In November, there were 55 municipalities, totaling 6,574 hot spots (46.4% of the general), with highlights: Portel, with 601; Pacajá, 419, and Santarém, 413 (Table 1). In December, 38 municipalities contributed predominantly to 2,305 foci (32.2% of the month's records), being the main contributors: Porto de Moz, with 183; Portel, 164 and Monte Alegre, 159 (Table 1).

As for Pará's mesoregions, they stood out mainly in the Southwest, with 7,618 hot spot detections in 13 municipalities, and in the Southeast, with 6,217 records in 22 communes (Table 2). In 2016, this first mesoregion presented the places with the highest frequency of fires / fires, such as Altamira, Pacajá and Itaituba, since the number of municipalities in the southwest was smaller than in the southeast, but more significant in number of outbreaks (Table 2). It was found that the Metropolitan Region of Belém, during the year studied, presented only one municipality with 94 occurrences: Bujaru, which is a traditional agricultural producer and also has charcoal producers active in the region (Table 2).

Table 2. Number of heat focus and municipalities involved per meso-region of Pará in 2016.

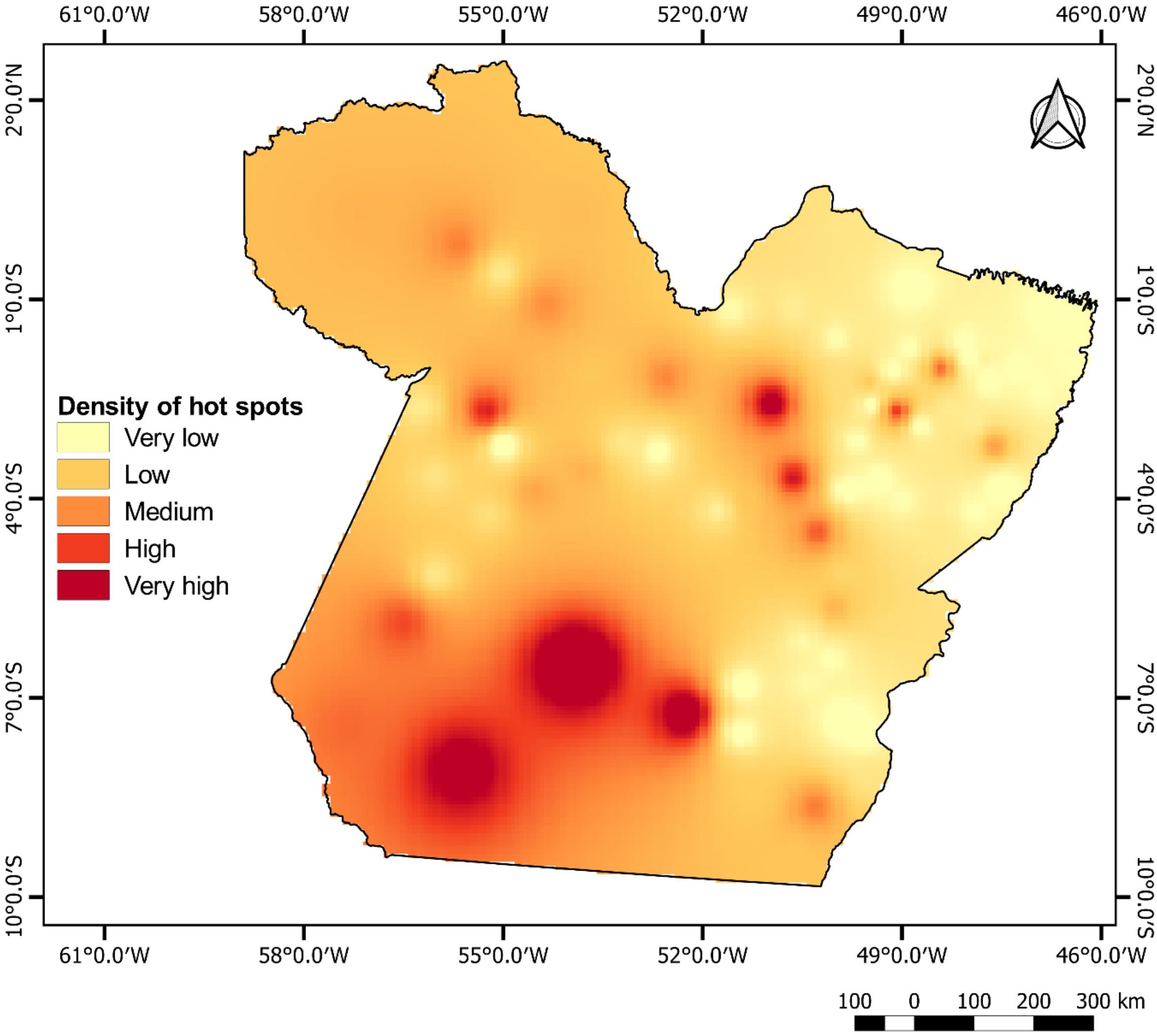
Mesoregion	Number of hot spots	Number of municipalities involved	Municipalities Names
Lower Amazonas	4.881	11	Alenquer, Almeirim, Belterra, Juruti, Monte Alegre, Óbidos, Oriximiná, Placas, Porto de Moz, Prainha, Santarém.
Marajó	1.940	6	Breves, Cachoeira do Arari, Chaves, Curralinho, Gurupá, Portel.
Northeastern Pará	3.892	19	Abaetetuba, Acará, Aurora do Pará, Baião, Bragança, Cachoeira do Piriá, Cametá, Capitão Poço, Concórdia do Pará, Igarapé-Miri, Ipixuna do Pará, Mocajuba, Moju, Nova Esperança do Piriá, Oeiras do Pará, São Domingos do Capim, Tailândia, Tomé-Açu, Viseu.
Metropolitan Region of Belém	94	1	Bujaru
Southeast Pará	6.217	22	Água Azul do Norte, Breu Branco, Canaã dos Carajás, Conceição do Araguaia, Cumaru do Norte, Dom Eliseu, Floresta do Araguaia, Goianésia do Pará, Itupiranga, Marabá, Novo Repartimento, Ourilândia do Norte, Paragominas, Parauapebas, Rio Maria, Rondon do Pará, Santa Maria das Barreiras, Santana do Araguaia, São Félix do Xingu, Tucumã, Tucuruí, Ulianopólis.
Southwest Pará	7.618	13	Altamira, Anapu, Aveiro, Brasil Novo, Itaituba, Jacareacanga, Medicilândia, Novo Progresso, Pacajá, Rurópolis, Senador José Porfírio, Trairão, Uruará.

Source: Monthly Bulletin of Monitoring of Forest Fires and Heat Foci in the Pará State (2016).

Table 2 provides an overview of the number of hot spots by Pará mesoregion and the number of municipalities responsible for this problem. In this way, we can observe the distribution of the heat sources concerning the state mesoregions.

The result of the interpolation is shown in the Kernel map, through the point intensities of the hot spots, thus estimating its density. The areas with the highest density of hot spots, indicated by red-brown spots, went to the Southwest, Southeast, and Northeast meso-regions that integrate the southern and eastern regions of Pará, whose territories, in part, constitute the arc of deforestation (Figure 3).

Figure 3. Map of the average density of hot spots in the State of Pará in 2016.



Source: Authors (2020).

Figure 3 shows the configuration of hot spots during 2016 throughout the State of Pará, allowing to infer the mesoregions of the territory that least and most contributed to the incidence of heat sources, considering a five-point scale (from very low to very high).

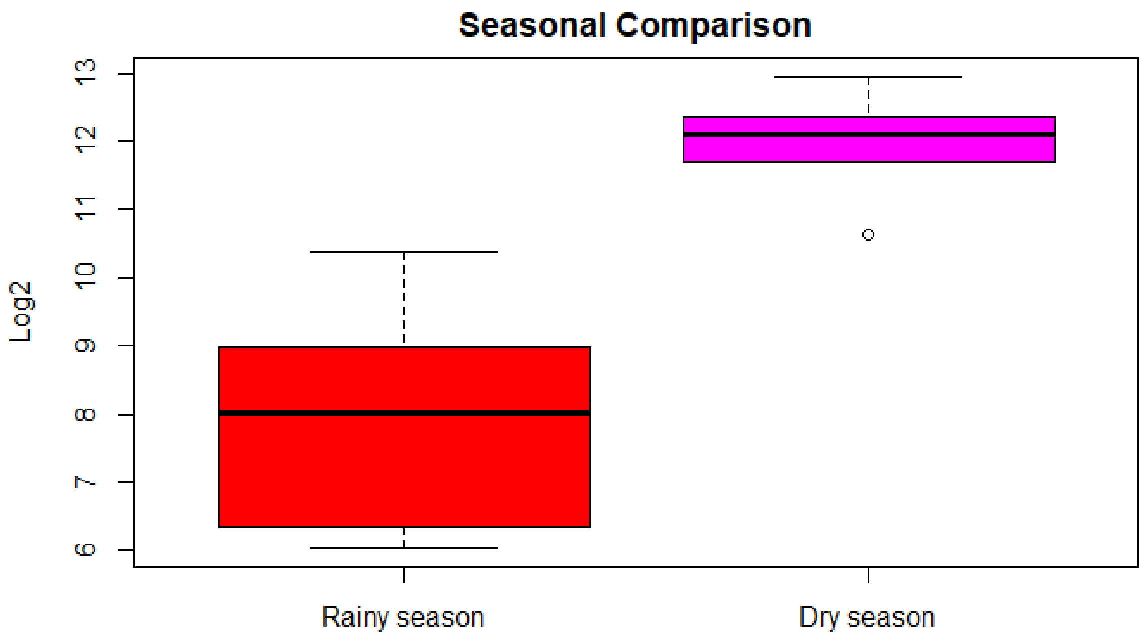
In this way, these areas form the highest density of hot spots, mainly in the southwest, with high and very high classification. Patches of dark orange and light orange color, of medium and low density, respectively, are distributed throughout the State, as well as those of shades close to white, indicating very low focus density, but with greater concentration in the Marajó mesoregion. and the Metropolitan Region of Belém.

4. Discussion

In the scenario under study, it was found that the highest incidence of hot spots occurred in the second half of the year, which comprised the “Amazonian summer”, a low rainy season.

The data of heat sources, separated by seasonality, were submitted to Student's t test, with the result of *p-value* = 0.001104. Therefore, the number of fires is significantly higher in the dry season. The variables presented normal distribution and statistically equal variances, criteria that allow the analysis and the aforementioned test.

Figure 4. Boxplot of the difference between the dry and rainy periods related to the number of hotspots. The number of hot spots was normalized by Log2.



Source: Authors (2020).

Figure 4 shows the significant difference between the number of fires and seasonality. We can observe a strong correlation between the dry period and a high number of heat sources. Its percept a marked decrease in the number of heat sources in the rainy season.

According to Sá et al. (2007), during this period, particularly from August to November, the so-called Burning Station in the Amazon occurs annually, releasing dense smoke that leads to the closure of airports and difficulty on visibility on the roads, generating economic losses and risk of accidents. In addition, it must be considered that this occurrence causes high rates of respiratory diseases to local populations, death of biodiversity, and flight of wild animals to urban areas.

Forest fires are closely related to rainfall and other meteorological variables, which determine the number and degree of fire destruction over the years (Santos et al., 2006). Among these weather conditions, drought, low air humidity, and high temperatures stand out, as in studies carried out in the States of Paraná, from 1991 to 2001 (Vosgerau et al., 2006); Sergipe, 1999 and 2015 (White & White, 2017), in addition to the presence of combustible material. Likewise, such fires can occur via manmade causes, such as through arson, and burning to clear the area for agricultural and/or real estate purposes, Firework displays, accidents in means of transport and buildings, mainly regarding the electrical part; or by lightning, seasonal climatological variables, among others.

From 2008 to 2013, the main occurrences of fires in Pará were accidental, followed by criminal acts and, finally, naturally, although the unidentified causes were higher, which masked the real result (Sousa et al., 2015). However, it was found, at national level, from 1994 to 1997, that arsonists - those who premeditated for revenge, mental imbalance, among other reasons, set fire to vegetation - are the main causes of fires (Soares & Santos, 2002), the same occurred, from 1998 to 2002, in protected areas of the Brazilian territory (Santos et al., 2006). In both studies, burning to clear the land was the secondary cause, especially when dealing with agricultural activities.

In relation to the present study, the main municipalities that contributed to the hot spots in the State of Pará in 2016 are: Altamira, São Félix do Xingu, Novo Progresso, Portel, and Pacajá. A large part of these municipalities in Pará is part of the so-called Arc of deforestation in the Amazon, as agricultural activities are carried out in them, mainly under the use of fire, in addition to the illegal exploitation of hardwood, real estate expansion, and road construction. According to Justino et al. (2002), the Arc of deforestation comprises the states of Acre, Rondônia, southern Amazonas, central and northern Mato Grosso, southern and eastern Pará, central and northern Tocantins and western Maranhão, in which the majority of the municipalities uses fire for new areas of deforestation, logging, livestock, and agriculture.

In the regions mentioned previously, the expansion of soy cultivation is increasing, particularly in Pará, which may occur under the use of fire for opening borders and initial soil preparation. According to Domingues and Bermann (2012), the soybean culture has expanded, especially in the north direction from the central Brazilian region, generating socioenvironmental impacts through burning to expand the planted area, clearing the forest, implanting livestock, and transforming areas of mechanized agriculture.

In the Southwest and Southeast mesoregions are the ten most prominent municipalities in livestock (São Félix do Xingu, Novo Repartimento, Cumaru do Norte, Altamira, Marabá, Santana do Araguaia, Novo Progresso, Água Azul do Norte, Santa Maria das Barreiras and Pacajá, respectively), which together correspond to 81.0% of the total production of the State of Pará (FAPESPA, 2015) and most of them are located in the southeastern portion of Pará. Also, according to the Agricultural Bulletin, cassava - the state is the largest national producer -, sugar cane, corn, and soybeans are, respectively, the most produced temporary crops in the territory of Pará.

In 2016, in the State of Pará, despite the end of the El Niño phenomenon in July 2016, the Walker circulation pattern showed a delay of almost four months to return to normal. In addition to the presence of a dry air mass over the central region of Brazil, the subsidiary movements coming from the Walker cell accentuated the reduction of rain and relative humidity, in addition to favoring an increase in air temperature over much of the State of Pará during the “Amazonian summer” period. The meteorological conditions present in the second half of the year showed favorable conditions for the occurrence of outbreaks of burns/fires in large numbers. Vasconcelos et al. (2013), drought episodes from the El Niño phenomenon, provide a higher rate of fires when compared to normal years (without the existence of El Niño).

5. Conclusion

The occurrence of hot spots was greater mainly from the second semester of 2016 in relation to the number of records and participation of municipalities, which is related to the period of lower rainfall (Amazonian summer), a favorable time for expansion and production agriculture - common in the region of Pará, especially in the southwest and southeast of Pará. It is common among municipalities furthest from the capital of the State of Pará to have minimal action by competent public bodies, which can contribute to the greatest occurrences of burnes/fires in the region, in addition to the lack of technical and financial support for sustainable production, without the use of fire, since agricultural activities are fundamental for the economic flow of the municipalities.

It cannot be concluded that the fires and fires are mainly due to agriculture and livestock, as studies in locus are needed to determine their causes. It is believed that the records obtained and analyzed do not indicate the real configuration of these events due to technical limitations, such as: presence of clouds, small size of the phenomenon, period between the passage of satellites. However, through remote sensing it is possible to measure the time and place where the events take place, in order to concentrate resources and efforts in the most affected areas through inspection, prevention, and combat actions, especially in the period of greatest occurrences of fires.

Additional research should be carried out for a clearer understanding of the dynamics and causes of heat sources in the state of Pará. Thus, for further studies, we intend to prepare a temporal analysis to investigate the evolution of hot spots, observing trends and predicting the behavior through robust statistical methods, contributing to the monitoring and mitigation of burnes/fires in the region.

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