Advances in Forestry Science
Original Article

Forest Fire susceptibility index for assessing the history of fire occurrences in the indigenous land of Kraholândia, Brazil

Lawrence Oliveira de Nóbrega[1] Gustavo Maximiano Junqueira Lazzarini[2] Marcelo Ribeiro Viola[3] Antônio Carlos Batista[4] Edmar Vinícius de Carvalho[1]* Marcos Giongo[1]

[1] Universidade Federal do Tocantins, Centro de Monitoramento Ambiental e do Fogo, Rua Badejós, Chácaras 69 e 72, Lt. 07, Gurupi - TO, 77402-970
[2] Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, St. A Sul - Ed. Sede, Brasília - DF, 70818-900
[3] Universidade Federal de Lavras, Aquenta Sol, Lavras - MG, 37200-000
[4] Universidade Federal do Paraná, Rodovia Régis Bittencourt, 9082-9174 - Jardim Botânico, Curitiba - PR, CEP: 80050-540

*Author for correspondence: carvalho.ev@uft.edu.br
Received: 08 November 2017 / Accepted: 16 April 2018 / Published: 30 June 2018

Abstract
The aim of this study was to examine the major factors influencing the occurrence of fires by analyzing the frequency ratio (FR) of areas with the greatest occurrence of prescribed burning and wildfire and to generate the susceptibility map of these occurrences for the Indigenous Territory of Kraholândia (Tocantins state), Brazil. A supervised classification method was apply using the Mahalanobis algorithm, and the fire scars were delimited from 2003 to 2014 based on images obtained from the Landsat-5, CBERS-2, ResourceSat-1, and Landsat-8 satellites. The higher recurrence fire class was using as a reference to assess the following variables: topography; type of land use; soil classification; and distances from human settlement, roads, and waterways. The FR of prescribed burning or wildfire occurrences was determined for each variable and a subsequent map for all the variables was create wiht the FR value of the sum of each pixel was denoted as the fire susceptibility index (FSI). The factors showing the greatest correlation with the highest frequencies of prescribed burning and wildfire occurrences were vegetation types of farmland and rock field, areas used for agriculture, areas with slopes higher than 30%, altitudes above 350 m, areas in ridgelines, and proximity to roads. The FSI map can be an effective tool in planning and controlling forest fires.
Keywords: Cerrado. Frequency ratio. Recurrence. Remote sensing.

Introduction

In Brazil, the practice of the biomass burning occurs in different cultures for varied purposes, as maintaining pasture for livestock or expanding agricultural frontiers (Piromal et al. 2008). This fact is justified because the controlled burning is an inexpensive method for preparing land for crop cultivation, renew pastures and remove unwanted vegetation and fallen trees. Moreover, the resulting ashes can be enriched the soil with nutrients that enhance soil fertility and increase crop productivity (Lara et al. 2007).

However, the last four decades have witnessed an increase in the incidences of forest fires or wildfires around the world that has attracted the attention of the scientific community with respect to the correlations of human activities and the effects in the ecosystem (Kehrwald et al. 2013). The vulnerability of the forest area to a fire is dependent on diverse features such as vegetation, topography, and distance from roads, rivers, and human settlements (Jaiswal et al. 2002), beyond the weather.

With the ever-increasing human occupancy and conversion of the Cerrado into agriculture, the frequent wildfires have consistently affected the protected areas in this biome (Medeiros and Fiedler 2004). However, Mistry et al. (2005) studied the indigenous population of Krahô in Tocantins state and they were finding that the use of fires in certain periods protects and maintains the Cerrado.

The state of Tocantins includes the largest remnants of the Brazilian Cerrado (Sano and Almeida 1998) and it is among the Brazilian states most affected by forest fires (Pivello 2011). In this context, Lazzarini et al. (2012) emphasize the importance of the researches about the wildfires in susceptible areas using the knowledge of the influence factors (Hong et al. 2017). Thus, their results can be used for the prevention and suppression of wildfires (Wang and Niu 2016) and to prevent the degradation of biodiversity.

In addition, many studies have shown a good probabilistic model for the fire occurrence (as the frequency ratio) by using topographical and social data (e.g. Pradhan et al. 2007; Daldegan et al. 2014; Pereira Júnior et al. 2014). However, the studies about fire susceptibility indexes are scarce in Tocantins state (cerrado). Thus, the aim of this study was to examine the major factors influencing the occurrence of fires by analyzing the frequency ratio (FR) of areas with the greatest occurrence of prescribed burning and wildfire and to generate a susceptibility map of these occurrences for the indigenous territory of Kraholândia (Tocantins state), Brazil.

Material and methods

The study area, the indigenous territory of Krahôlandia, is located on the northeastern portion of the state of Tocantins. This area lies approximately 100 km from the capital city (Palmas) between longitudes 47°05′W and 47°50′W and latitudes 07°50′S and 08°50′S. A portion of this area is included in the municipality of Goiatins and the remainder in the municipality of Itacajá.

The indigenous territory Krahôlandia was approved in 1990 and it occupies approximately 3,608 km2. This area is located on the Tocantins River basin, and much of its perimeter has border by the Red and Manuel Alves rivers. The population is approximately 2,000 and it is clustered in 26 villages of varying sizes and at the time of this study the Krahô people practicing agriculture by cutting and burning the forest and planting crops on the ashes (Mistry et al. 2005).

This region is characterized as C2wA'a' (humid/sub-humid with moderate water stress in winter), by Thornthwaite climate classification (Tocantins 2012). The rainy season is well-defined (from October to April) with 75% of the rainfall occurs during these period that is followed by a dry season, when the occurrence of wildfires is high. The mean annual rainfall ranges from 1,600 to 1,800 mm and the mean annual temperature ranges from 26 to 27 ºC.

The scarring caused by prescribed burning and wildfire occurred in this region from 2003 to 2014 were delimited using images of four different satellites to ensure complete temporal and spatial coverage of the study area (Table 1). These images were initially concentrated from the months of

June to September, however, due to visualization difficulties caused by intense cloud cover, the collection of images expanded to October–December, and thus they were used 51 different images, as shown in Table 1, for the representation of the period with the highest occurrence of wildfires.

Table 1. Description of the images used for delimitation of fire scarring / wildfires in Indigenous Territory Krahôlandia, from 2003 to 2014, which each date represents an image.

Year	Satellite	Path/Row	Dates			
			I	II	III	IV
2003	Landsat 5	222/65	jul/09	ago/10	-	-
		222/66	jul/09	ago/10	set/11	
2004	Landsat 5	222/65	out/15	-	-	-
		222/66	jun/25	ago/12	set/29	out/15
2005	Landsat 5	222/65	jul/14	set/16	-	-
		222/66	jul/14	ago/15	set/16	-
2006	Landsat 5	222/65	ago/02	set/03	-	-
		222/66	jul/17	ago/18	nov/06	-
	CBERS 2	158/109	set/03			
2007	Landsat 5	222/65	jun/18	ago/05	set/06	-
		222/66	jul/20	set/06	-	-
2008	Landsat 5	222/65	jul/22	set/08	-	-
		222/66	jul/22	set/08	-	-
	CBERS 2	159/109	set/19	-	-	-
2009	Landsat 5	222/65	jul/09	-	-	-
		222/66	jul/09	set/11	-	-
2010	Landsat 5	222/65	set/14	out/16	-	-
		222/66	jul/28	set/14	out/16	-
2011	Landsat 5	222/65	set/17	-	-	-
		222/66	ago/16	set/01	set/17	-
2012	Resourcesat-1	327/82	ago/17	set/10	out/28	-
2013	Landsat 8	222/66	jul/20	set/22	nov/25	-
2014	Landsat 8	222/66	jul/23	set/09	-	-

The scarred landscape was detected by Daldegan et al. (2014) methodology with the Mahalanobis algorithm applied to perform the supervised classification (steps for this procedure depict in Figure 1). After this process, the indigenous territory was subdivided in four distinct categories based on the frequency of fire occurrences: NQ, areas with no incidences of fire; REC1, areas burned for 1–4 times; REC2, areas burned 5–8 times and; REC3, areas burned 9–12 times (Table 2).

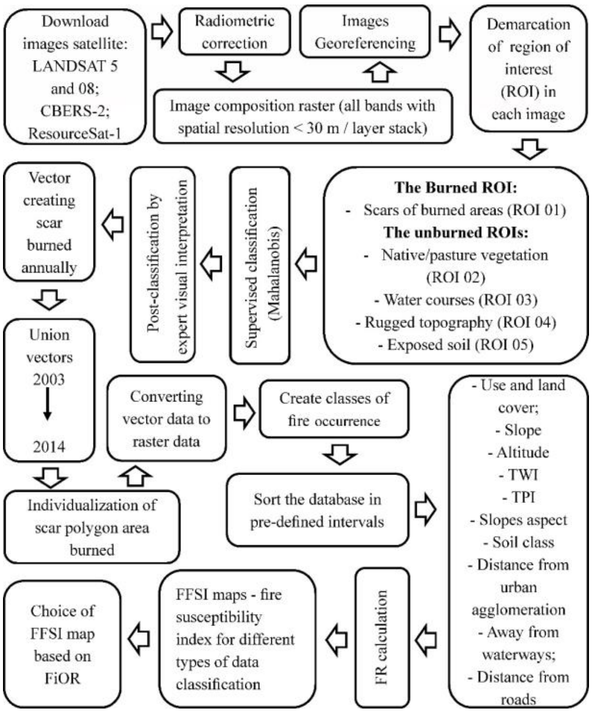


Figure 1. The sequence methodology used in this study.

Table 2. Fire occurrence number for each class

Class	Number of times burned	Burned area in the year of occurrence (ha)
NQ	0	29,764.47
REC1	1	19,102.10
	2	21,284.93
	3	29,320.25
	4	35,988.06
REC2	5	37,528.04
	6	35,223.33
	7	33,036.45
	8	26,872.64
REC3	9	18,641.16
	10	12,597.85
	11	5,818.84
	12	1,692.92

NQ =areas with no incidences of fire. REC1 = areas burned for 1–4 times. REC2 = areas burned 5–8 times. REC3 = areas burned 9–12 times.

The next calculations were basis on the data obtained from the map shown in Figure 2 that was produced after the supervised classification and with it use of the four distinct categories of the frequency of fire occurrences, which displays the regions with the most forest fires occurring during the study period in the REC3 class areas. The GIS databases used to generate the results are described in Table 3 and all raster images generated in this work were standardized in a pixel size of 30 × 30 m using the Nearest

Neighbor method (Richards 1999).

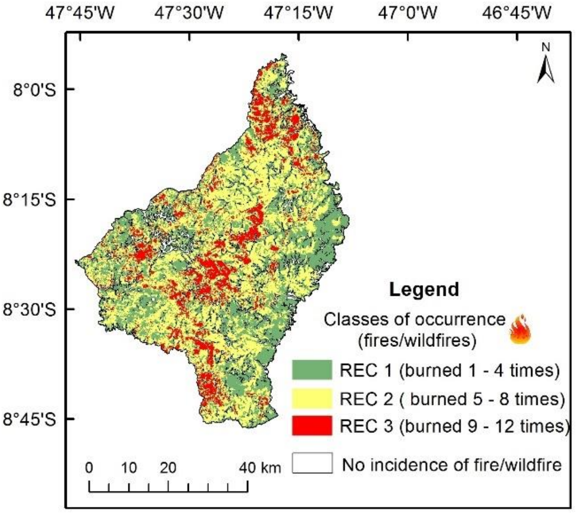


Figure 2. Classes of occurrence (fires / wildfires)

Table 3. Database feature used

Layer data	Data format	Source of data	Scale
Type of land use	polygon	SEPLAN	1:100,000
Roads	raster	Landsat 8	30 m x 30 m
Waterways	line	SEPLAN	1:100,000
Soil classification	polygon	SEPLAN	1:1,000,000
City	point	SEPLAN	1:100,000
Human settlement	raster	RapidEye	5 m x 5 m
Topography	raster	NASA/SRTM	30 m x 30m

SEPLAN = Department of Planning and Modernization of Public Management of the State of Tocantins.

The activities performed by the indigenous brigades were registered in the fire occurrence reports (FiOR). These documents included a pair of location coordinates where managed fires occurred and this information were systematized and spatialize and then included in the geographic database.

The topographic factor considered in the analysis include topographic wetness index (TWI) and the topographic position index (TPI). The TWI refers to the tendency of water to accumulate in the basin due to gravitational force moving water downstream (Pourtaghi et al. 2015). Thus, higher values indicate greater TWI formation of water flow at the surface and, consequently, higher saturation in these environments. The TWI was calculated by using the Moore et al. (1991) formula.

The topographic position index (TPI) is characterized by the difference in the elevation between a pixel and the average of its neighbors. A positive value indicates that a pixel has a higher altitude than its neighbors do, and a negative value indicates the converse. The TPI was classified according Dickson et al. (2005): canyons: TPI ≤ −8; gentle slope: −8 <TPI ≤ 8, with slope < 6º; steep slope: −8 <TPI ≤ 8, with slope ≥ 6º and; ridges: TPI ≥ 8. The data on the slope maps, TWI, TPI, and the orientation of the slopes were derived from the SRTM data (Farr et al. 2007).

The Department of Planning and Modernization of Public Management of the State of Tocantins (SEPLAN) conducted a study of land use and occupation for the 2007 year. The remaining area consisted of native Cerrado vegetation in the following proportions (Figure 3): cerrado restricted sense (50.0%); piparian forest or gallery forest (21.0%); grassland (20.6%); stone grassland (1.6%); cerradão (1.5%); semi-deciduous alluvial forest (1.8%), and veredas (1.1%). Beaches, dunes, and inland water bodies comprised an area lower than 0.05% (Tocantins 2012).

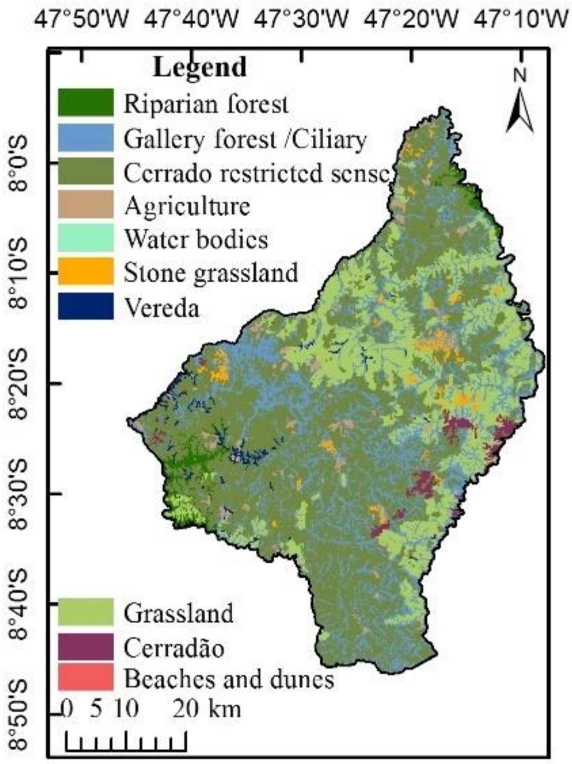


Figure 3. Land use and occupation.

Additional factors were evaluated in terms of any relationship to fire occurrence, including soil class, human agglomeration distance (m), distance from watercourses (m), road distance (m), slope (%), and altitude (m). The maps in Figure 4 show the distribution class for each of the nine evaluated factors.

The model frequency ratio (FR) establishes the relationship between the distributions of areas vulnerable to fire incidents and analyzes each factor, as well as the correlation between these factors and the study area (Pradhan et al. 2007). Thus, this model was considered simple (Pourtaghi et al. 2015) and it was used with successful as probabilistic model among the variables in the multiple maps (Oh et al. 2011). Finally, the FR values were calculated based on Pourtaghi et al. (2015) with the following adaptations:

$$FR=(A/B) / (H/L)$$

where A = the number of pixels affected by fire in the class factor or the number of fire occurrence reports (FiOR) in the class factor; B = the total number of pixels in the class factor or the total number of fire occurrence reports (FiOR) in the indigenous territory; H = the total number of pixels in the class factor; and L = the cumulative number of pixels in the entire study area (3,409,679 pixels).

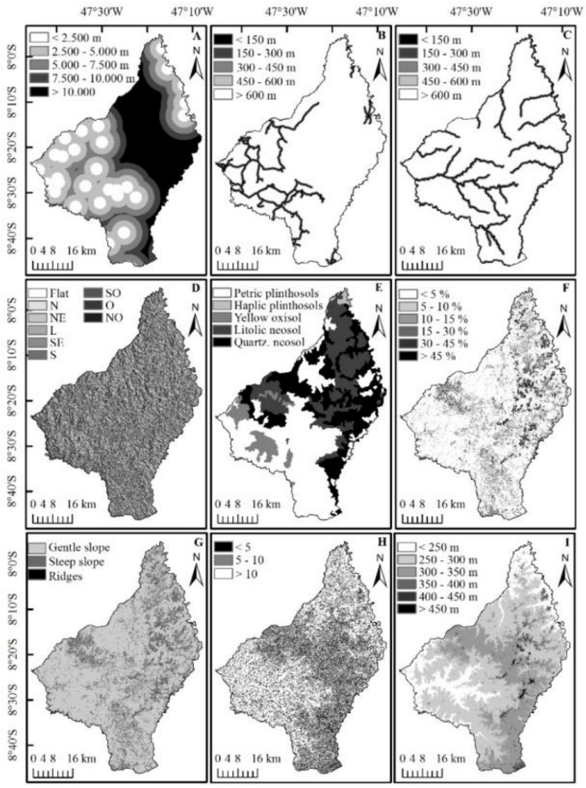


Figure 4. Distance of the study area from human settlements (A), roads (B), waterways (C), slope aspect (D), soil class (E), declivity (F), TPI (G), TWI (H) and altitude (I).

The FR represents the likelihood of the occurrence of the variable under study (Sujatha et al. 2013) and the values higher than one indicate a high correlation and values lower than one indicate a low correlation (Lee and Pradhan 2007). These values were calculated only for the REC3 category for each of the nine evaluated factors, because these areas represented the locals with the greatest occurrence of prescribed burning and wildfire.

Mohan and Jeyaseelan (2010) generated a map of susceptibility to landslides using FRs that were correlated with each pixel. The FR in this study can be similarly use to generate maps of fire susceptibility indexes (FSIs). To calculate the index, the sum value of each pixel of the raster images was overlaid according to the following formula by Pradhan et al. (2007):

$$FSI = FR_1 + FR_2 + \cdots + FR_n$$

The resulting map of calculated FSI was group into five distinct classes of fire risk: low, moderate, high, very high, and extreme. The five different maps were generated based on five frequency distribution models: equal intervals, geometrical intervals, natural breaks, standard deviation, and quantiles. To assess the most suitable fire susceptibility map for the study region, each map was cross-reference with the geographic coordinates of the FiOR generated by the indigenous combat brigade formed by the National Prevention and Combating Forest Fire Center (PrevFogo), which is link to the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). The data refer to all incidents recorded from 2013 to 2014 (86 total cases of fighting forest fires). The most appropriate risk map for the indigenous territory Krahôlandia was select based on the highest value between the sums of FR values for the high-risk, very high-risk, and extreme risk classes according to:

$$FSI_{ind} = FR_{high} + FR_{very-high} + FR_{extrema}$$

where $FFSI_{ind}$ = the map susceptibility index; FR_{high} = the FR value in the high susceptibility class; $FR_{very\text{-}high}$ = the FR value in the very-high susceptibility class; and $FR_{extreme}$ = the FR value in the extreme susceptibility class.

Results

The frequency ratio (FR) values were calculated as the number of pixels and are represented in Table 4, where each class is associated with a specific FR value that expresses a high or low correlation with fire occurrence. In the FR data in Table 4, the environment for agriculture and occupancy of vegetation of vereda or stone grassland have been emphasized. For the slope, it was observed that areas above 30% slope were most affect by the occurrences of managed fires and forest fires, it is including areas at altitudes higher than 350 m, with an emphasis on the areas at higher than 450 m of altitude, with an FR value of 37.51.

Table 4. The FR values for the variables of distance of the study area from human settlement, waterways, and roads and declivity, altitude, TWI, TPI, slope orientation, soil class, and land use and occupation

Class	A	B	A/B	A_{class} (%)	FR
Type of land use					
Riparian forest	658	61,143	0.01	0.02	0.60
Stone grassland	5,537	53,421	0.10	0.02	6.62
Cerradão	200	52,656	0.00	0.02	0.25
Grassland	74,521	700,639	0.11	0.21	0.52
Agriculture	24,423	66,649	0.37	0.02	18.75
Vereda	4,698	36,350	0.13	0.01	12.12
Cerrado restricted sense	303,697	1,718,248	0.18	0.50	0.35
Gallery forest	16,239	717,581	0.02	0.21	0.11

Slope (%)					
0 |-- 5	204,245	1,401,198	0.15	0.41	0.35
5 |-- 10	148,811	1,132,418	0.13	0.33	0.40
10 |-- 15	45,268	410,245	0.11	0.12	0.92
15 |-- 30	28,684	355,104	0.08	0.10	0.78
30 |-- 45	3,017	73,601	0.04	0.02	1.90

> 45	698	37,210	0.02	0.01	1.72
Altitude (m)					
< 250	87,598	641,276	0.14	0.19	0.73
250 |-- 300	231,661	1,672,979	0.14	0.49	0.28
300 |-- 350	105,319	996,249	0.11	0.29	0.36
350 |-- 400	4,873	74,670	0.07	0.02	2.98
400 |-- 450	610	16,845	0.04	0.00	7.33
> 450	662	7,757	0.09	0.00	37.51
TWI					
< 5	79,719	650,928	0.12	0.19	0.64
5 |-- 10	105,779	945,350	0.11	0.28	0.40
> 10	245,225	1,813,498	0.14	0.53	0.25
TPI					
Canyons	-	11	0.00	0.00	0.00
Gentle slope	360,490	2,595,284	0.14	0.76	0.18
Steep slope	69,635	806,663	0.09	0.24	0.36
Ridges	598	7,818	0.08	0.00	33.36
Slope aspect					
Flat	1,662	11,403	0.15	0.00	43.58
North	56,041	421,060	0.13	0.12	1.08
Northeast	50,016	415,194	0.12	0.12	0.99
East	47,871	437,598	0.11	0.13	0.85
Southeast	45,584	422,361	0.11	0.12	0.87
South	46,479	402,492	0.12	0.12	0.98
South-west	54,533	408,331	0.13	0.12	1.12
West	65,025	448,416	0.15	0.13	1.10
Northwest	63,512	442,921	0.14	0.13	1.10
Soil classification					
Petric Plinthosols	227,304	1,440,233	0.16	0.42	0.37
Haplic Plinthosols	2,066	23,996	0.09	0.01	12.23
Yellow Oxisol	14,341	215,317	0.07	0.06	1.05
Litolic Neosol	98,131	736,527	0.13	0.22	0.62
Quartzarenic Neosol	88,891	993,606	0.09	0.29	0.31
Distances from human settlement (m)					
0 |-- 2,500	53,563	515,572	0.10	0.15	0.69
2,500 |-- 5,000	137,076	939,098	0.15	0.28	0.53
5,000 |-- 7,500	90,619	604,563	0.15	0.18	0.85
7,500 |-- 10,000	68,014	405,988	0.17	0.12	1.41
> 10,000	81,461	944,458	0.09	0.28	0.31
Distances from waterways (m)					
0 |-- 150	8,553	199,067	0.04	0.06	0.74
150 |-- 300	16,096	165,662	0.10	0.05	2.00
300 |-- 450	18,981	158,524	0.12	0.05	2.58
450 |-- 600	20,081	153,239	0.13	0.04	2.92
> 600	367,022	2,733,187	0.13	0.80	0.17

Distances from roads (m)					
0 |-- 150	25,791	132,302	0.19	0.04	5.02
150 |-- 300	19,395	116,130	0.17	0.03	4.90
300 |-- 450	17,581	117,407	0.15	0.03	4.35
450 |-- 600	16,334	116,898	0.14	0.03	4.08
> 600	351,632	2,926,942	0.12	0.86	0.14

A: the number of pixels in the factor affected by the fire class; B: the number of pixels occupied by the factor of class.

The TWI index was highest in areas with the lowest accumulation of water; however, the FR value was lower than one and this is not representing a correlation with fire occurrence. The TPI had a significant amount of FR on the ridgeline, with an FR value of 33.36.

Except for the flat areas (FR = 43.58), the slopes aspects had low discrepancies between classes. The areas in the north, southwest, west, and northwest directions demonstrated a mild correlation with the burned areas, with FR values of 1.08, 1.12, 1.10, and 1.10, respectively.

In the soil class factor, the Plinthosol Haplic had shown the highest FR value (12.23). The Yellow Oxisol had shown a mild correlation with the incidence of fire (FR = 1.05). As for overcrowding distances, the only class to be highlight was place in the 7.5–10.0 km area, with an FR of 1.41. All other values were lower than 0.85, including areas below 2.5 km with an FR of 0.69. Longer distances from roads significantly influenced fire activity in the region, as separation from roads gradually narrowed the factor from 5.02 (0–150 m away) to 4.08 (450–600 m away), with distances higher than 600 m did not show any association with fire (FR = 0.14).

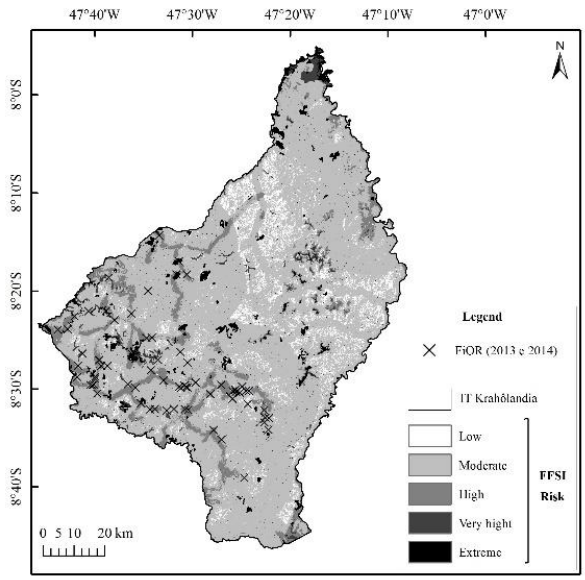
Distances to watercourses showed a significant correlation with the results of the burned areas, but only from 150 to 600 m, with FR values of 2.00–2.92. At distances, less than 150 m and higher than 600 m away from watercourses, the FR values were lower than one.

The calculation of the FSI resulted in an image with a value distribution among 2.95-90.93, but several of these values were accumulated in the first class. The frequency of FSI values were analyzed by five different distribution models (Table 5).

Table 5. Values for the FR based on different types of distribution values of FFSI.

Distribution of the map data	Class of FSI				
	Low	Moderate	High	Very high	Extreme
Equal intervals	0.95	3.29	0.00	0.00	0.00
Geometric distribution	0.40	2.04	2.15	0.25	1.66
Natural breaks	0.32	3.05	1.82	2.33	0.00
Standard deviation	0.29	0.66	4.10	0.00	2.43
Quantile	0.26	0.44	0.22	0.55	3.86

According to the methodology used, an appropriate study area was prepared using the standard deviation of intervals (Figure 5), with FR values of 4.10 and 2.43 per the susceptibility classes of high and extreme risk types. As for this data distribution model, 8.00% of the indigenous territory area resides in the low, 77.71% in the moderate, 9.36% in the high, 1.58% in the very high, and 3.35% in the extreme susceptibility regions.



Discussion

The vegetation of the vereda has high FR values probability because the environment of the region is associated with hydromorphic soils. Fire incidents in this region occurs during extreme drought periods, when the dry organic material in the environment can be promove fires to last for weeks with flame heights reaching 20 m (Maillard et al. 2009).

It is a common practice to use fire in areas bordered by grasses for regenerating pastures, for example, Mistry et al. (2005), in study of the use of fire by the natives in indigenous territory Kraholândia, had concluded that the fire can be stimulated the regrowth of grasses. Nevertheless, research on traditional fire rescues in indigenous communities in Mato Grosso State revealed that the native population are totally opposed to burning in these areas. These perceptions are based on the effect in devastation on the farm land, that resulting in higher mortality of important trees to indigenous subsistence as sources of food, fiber, or wood, or damage to wildlife, as these environments serve as shelter to macaws, parrots, and several other animals (Falleiro 2011).

The greatest FR value was find in agricultural areas, which confirms that the indigenous community applies fire to agro-pastoral activities and that this can trigger similar behavior in the forested areas. Furthermore, it is common to use fire stump farms; these are usually low-lying regions in topographical locations with higher soil moisture content and close to forest areas. The stone grassland areas are prominent in this environment, as this vegetation type typically occurs in mosaics in shallow soils, with individual trees developing between cracks highlighted in the rocky outcrops (Sano and Almeida 1998).

The high FR value along the stone grassland class is strongly relate to the high fire frequency values in the areas with slopes higher than 30%. In this sense, the spatial analysis of the fire risk indicate that the slope factor was prominent compared to the other factors analyzed (Lopes et al. 2009). In the uphill area, the fire tended to propagate faster and resembled a fire in the flat area under the influence of strong to medium winds (Ribeiro et al. 2008) and these characteristics influenced the frequency of fire occurrences in areas with higher than 30% slope.

The hilliest regions are typically at higher altitudes such as indigenous territory Kraholândia (higher than 350 m altitude); they had shown strongly influences the FR value. The winds are stronger at higher altitudes; this favors the drying of fuel loads and contributes to more intense fire propagation, as documented by Fule and Laughlin (2007) for temperate forests. Thus, in addition to the high frequency of fire occurrences in these environments, the contributions of other factors negatively influence the development of plants.

In indigenous territory Kraholândia, the TWI was not associated with fire occurrence. However, the TPI presented values that reinforce the influence of altitude and steep areas, with reported FR values of 33.36 in the ridgeline areas. Surveys in Australia have indicated that topographical location, elevation, and slope orientation are important factors in the explanation of fire occurrences and that the probability of crown fire ridgelines in higher regions is greater than in ravines or valleys, which explains the high dispersion of fires in these environments (Wood et al. 2011).

The slope aspect in the north, southwest, west, and northwest direction showed a mild correlation compared with fires in the study region, but the flat surfaces showed a greater correlation to the FR. The fire behavior associated with flat regions is related to the influence of solar energy on these areas throughout a typical day.

The soil type indirectly influences the risk of fire because the soil characteristics define the type of human use and the associated vegetation. Plinthosols are form under restriction conditions for the water percolation, and it occupies areas of relief mostly flat or gently undulating and rarely wavy (Embrapa 2013). These characteristics are related to the presence of farmland in an area, corroborating the association of this type with the FR of fire occurrences.

Yellow Oxisol consists of well drain soils and thick (Embrapa 2013) and this soil is commonly used for agricultural purposes because of the ease of machining and the advantage of a flat topography. Therefore, when these results are associated with the abovementioned conditions on the formation of strong relationships with the use of fire and agriculture, an interaction between these two factors is observed.

Distances related to human settlement, hydrography, and roads are influential factors in the occurrence of managed fires and forest fires. The distances for roads and road density are important parameters for promoting public access to pastures and forests (Adab et al. 2013). Thus, our results showed that the distance to roads is a prominent variable for fire risk on indigenous land. The distance to watercourses also showed high favorability at 150–600 m and this may be related to the proximity of the veredas.

With respect to the proximity of human settlements, only one class showed FR values higher than one, which indicates that the influence of other factors occasionally occurring in that zone (7,500–10,000 m), thus representing a relation with the factor of overcrowding.

The FSI presented as standard deviations of variations established a scroll list of data across the middle, providing five different levels of susceptibility to wildfires. The high, moderate, and extreme susceptibility rates were observed for areas located to the north and southwest of the study area, despite being in small patches throughout the territory. The areas of low risk to susceptibility were accumulated in the central portion of indigenous territory Krahôlandia, which were the most distant and isolated human agglomerates. The areas with moderate content were distributed uniformly throughout indigenous territory Krahôlandia.

Conclusions

It was possible to identify the class factors most correlated with the occurrence of burning: stone grassland; other grasslands; areas with slopes higher than 30%; and areas at altitudes higher than 400 m (particularly when positioned on the ridgelines with slope orientations to the north, southwest, west, and northwest and in flat areas).

In relation to the others factors, the most affected soil classes were Haplic Plinthosols and Yellow Oxisol, which are 7.5–10.0 km away from overcrowded areas and therefore highly susceptible to fire, and regions at 150–600 m distance away from watercourses. The proximity to a road from a vulnerable area was directly proportional to fire occurrences and this correlation was confirmed in regions 600 m from a road.

Finally, the form of distribution of the FSI data was as important as the values used in generating fire susceptibility maps because the standard deviation for the distribution values presented the highest correlation with firefighting events of the local brigade.

Acknowledgements

This study was carried out with support of the Master's Degree in Forestry and Environmental Sciences from Federal University of Tocantins.

References

Adab H, Kanniah K, Solaimani K (2013) Modeling forest fire risk in the northeast of Iran using remote sensing and GIS techniques. *Natural Hazards*, 65(3): 1723-1743. doi: 10.1007/s11069-012-0450-8

Daldegan G, Carvalho O, Guimarães R, Gomes R, Ribeiro F, Mcmanus, C (2014) Spatial patterns of fire recurrence using remote sensing and gis in the brazilian savanna: Serra do Tombador nature reserve, Brazil. *Remote Sensing*, 6(10): 9873-9894. doi: 10.3390/rs6109873

Dickson B, Jenness JS, Beier P (2005) Influence of vegetation topography, and roads on cougar movement in southern California. *Journal of Wildfire Management*, 69(1): 246-276. doi: 10.2193/0022-541X(2005)069<0264:IOVTAR>2.0.CO;2

Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA (2013) *Sistema brasileiro de classificação de solos*. 3ª Edição. Brasília: EMBRAPA-CPAC

Falleiro RM (2011) Resgate do manejo tradicional do cerrado com fogo para proteção das Terras Indígenas do oeste do Mato Grosso: um estudo de caso. *Biodiversidade Brasileira*, (2): 86-96.

Farr TG, Rosen PA, Caro E, Crippen R, Duren R, Hensley S, Kobrick M, Paller M, Rodriguez E, Roth L, Seal D, Shaffer S, Shimada J, Umland J, Werner M, Oskin M, Burbang D, Alsdorf D (2007) The shuttle radar topography mission. *Reviews of Geophysics*, 45(2): 1-33. doi: 10.1029/2005RG000183

Fule PZ, Laughlin DC (2007) Wildland fire effects on forest structure over an altitudinal gradient, Grand Canyon National Park. *Journal of Applied Ecology*, 44(1): 136-146. doi: 10.1111/j.1365-2664.2006.01254.x

Hong H, Naghibi SA, Dashtpagerdi MM, Pourghasemi HR, Chen W (2017) A comparative assessment between linear and quadratic discriminant analyses (LDA-QDA) with frequency ratio and weights-of-evidence models for forest fire susceptibility mapping in China. *Arabian Journal of Geosci*ence, 10: 167-180. doi: 10.1007/s12517-017-2905-4

Jaiswal RK, Mukherjee S, Raju KD, Saxena R (2002) Forest fire risk zone mapping from satellite imagery and GIS. *International Journal Applied Earth Observation and Geinformation*, 4(1): 1-10. doi: 10.1016/S0303-2434(02)00006-5

Kehrwald NM, Whitlock C, Barbante C, Brovkin V, Daniau AL, Kaplan JO, Van Der Werf GR (2013) Fire Research: Linking Past, Present, and Future Data. *Earth & Space Science News*, 94(46): 421-422. doi: 10.1002/2013EO460001

Lara DX, Fiedler NC, Medeiros MB (2007) Uso do fogo em propriedades rurais do cerrado em Cavalcante, GO. *Ciência Florestal*, 17(1): 9-15. doi: 10.5902/198050981930

Lazzarini GMJ, Ferreira LCC, Felicíssimo MFG, Lira RG, Justino, AG, Gomes CS, Ribeiro JCN, Magalhães GRD (2012) Análise da distribuição de focos de calor no Tocantins entre 2002 e 2011. *Interface,* 5:24-35.

Lee S, Pradhan B (2007) Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. *Landslides.* 4(1): 33-41. doi: 10.1007/s10346-006-0047-y

Lopes SF, Vale VS, Schiavini I (2009) Efeito de queimadas sobre a estrutura e composição da comunidade vegetal lenhosa do cerrado sentido restrito em Caldas Novas, GO. *Revista Árvore*, 33(4): 693-704. doi: 10.1590/S0100-67622009000400012.

Maillard P, Pereira DB, Souza, CG (2009) Incêndios florestais em veredas: coneitos e estudo de caso no Peruaçu. *Revista Brasileira de Cartografia*, 61(4): 321-330.

Medeiros MB, Fiedler NC (2004) Incêndios florestais no Parque Nacional da Serra da Canastra: desafios para a conservação da biodiversidade. *Ciência Florestal*, 14(2): 157-168. doi: 10.5902/198050981815

Mistry J, Berardi A, Andrade V, Krahô T, Krahô P, Leonardos O (2005) Indigenous fire management in the Cerrado of Brazil: the case of the Krahô of Tocantins. *Human Ecology*, 33(3): 365-386. doi: 10.1007/s10745-005-4143-8

Mohan VR, Jeyaseelan A (2010) Landslide susceptibility mapping using frequency ratio method and GIS in South Eastern part of Nilgiri District, Tamilnadu, India. *International Journal of Geomatins and Geosciences,* 1(4): 951-961.

Moore ID, Grayson RB, Ladson A (1991) Digital terrain modeling: a review of hydrological, geomorphological, and biological applications. *Hydrological Process*es, 5(1): 3-30. doi: 10.1002/hyp.3360050103

Oh HJ, Kim YS, Choi JK, Lee S (2011) GIS mapping of regional probabilistic groundwater potential in the area of Pohang City, Korea. *Journal of Hydrology,* 399(3-4):158–172. doi: 10.1016/j.jhydrol.2010.12.027

Pereira Júnior AC, Oliveira SLJ, Pereira JMC, Turkman MAA (2014) Modelling fire frequency in a Cerrado Savanna protected area. *PLoS one*, 9(7): 1-11. doi: 10.1371/journal.pone.0102380

Piromal RAS, Rivera-Lombardi RJ, Shimabukuro YE, Formaggio AR, Krug T (2008) Utilização de dados MODIS para a detecção de queimadas na Amazônia. *Acta Amazonica,* 38(1): 77-84. doi: 10.1590/S0044-59672008000100009

Pivello VR (2011) The use of fire in the Cerrado and Amazonian rainforests of Brazil: past and present. *Fire Ecology,* 7(1): 24-39. doi: 10.4996/fireecology.0701024

Pourtaghi Z, Pourghasemi H, Rossi M (2015) Forest fire susceptibility mapping in the Minudasht forests, Golestan province, Iran. *Environmental Earth Sci*ences, 73(4): 1515-1533. doi: 10.1007/s12665-014-3502-4

Pradhan B, Dini Hairi Bin Suliman M, Arshad Bin Awang M (2007) Forest fire susceptibility and risk mapping using remote sensing and geographical information systems (GIS). *Disaster Prevention and Management,* 16(3): 344-352. doi: 10.1108/09653560710758297

Ribeiro L, Koproski LP, Stolle L, Lingnau C, Soares RV, Batista AC (2008) Zoneamento de riscos de incêndios florestais para a fazenda experimental do Canguiri, Pinhais (PR). *Floresta*. 38(3): 561-572. doi: 10.5380/rf.v38i3.12430

Richards JA (1999) *Remote Sensing Digital Image Analysis*. Berlin: Springer-Verlag. 240p.

Sano SM, Almeida SP (1998) *Cerrado: ambiente e flora.* Planaltina: EMBRAPA-CPAC. 556p.

Silvani X, Morandini F, Dupuy JL (2012) Effects of slope on fire spread observed through video images and multiple-point thermal measurements. *Experimental Thermal and Fluid Science*, 41: 99-111. doi: 10.1016/j.expthermflusci.2012.03.021

Sujatha ER, Rajamanickam V, Kumaravel P, Saranathan E (2013) Landslide susceptibility analysis using probabilistic likelihood ratio model a geospatial based study. *Arabian Journal of Geosciences*, 6(2): 429-440. doi: 10.1007/s12517-011-0356-x

Tocantins (2012) *Atlas do Tocantins: Subsídios ao planejamento da gestão territorial*. Palmas: SEPLAN. 80 p.

Wang S, Niu S (2016) Fuel Classes in Conifer Forests of Southwest Sichuan, China, and Their Implications for Fire Susceptibility. *Forests*, 7(3): 52-75. doi: 10.3390/f7030052

Wood SW, Murphy BP, Bowman DMJS (2011) Firescape ecology: how topography determines the contrasting distribution of fire and rain forest in the south-west of the Tasmanian Wilderness World Heritage Area. *Journal of Biogeography,* 38(9): 1807-1820. doi: 10.1111/j.1365-2699.2011.02524.x