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Forest Fire Hazard Mapping of a State Park in the Atlantic Forest, MG, Brazil

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ABSTRACT

Forest fire risk mapping is a basic method for planning and preventing forest fires. The objective of this work is to show the potential of using Geographic Information Systems for planning measures to prevent and fight forest fire fragments, by creating a fire risk map of Serra do Brigadeiro State Park, Minas Gerais (MG), Brazil. The methodology used for the development of maps for risk factors and the final fire risk map was based on several studies from various authors. The risk factors defined for the area were: vegetation, slope, relief orientation, distance from roads and trails, altitude, precipitation, drought, evapotranspiration and temperature. These classes were standardized according to the respective level of risk they offer to the propagation of fire - one (1) for low risk, two (2) to moderate risk, and three (3) for high-risk. After the overlap of nine factors, we obtained the map with the areas at risk of fire, where it was observed that 15.07% of the Serra do Brigadeiro State Park falls within Class 3 for susceptibility to fire, constituting a region high risk. About 76.74% of the area falls in class 2, medium risk, and 8.18% in the low risk, class 1. When the overlap between the fire risk map and the reports of occurrence in SBSP was performed, consistent results were obtained, that is, the areas classified with high risks are the same areas that have been through a fire in the past. Most of the SBSP is considered at moderate risk of fire, this indicates the necessity of planning activities to prevent and control the fire in these areas.

INTRODUCTION

The impacts of a forest fire go beyond the destruction of vegetation cover. Forest fires also affect ecological processes, soil characteristics, fauna, and the atmosphere, which in turn affect the availability of natural resources that are essential to people (Oliveira *et al*., 2004). This is especially true when it comes to a "Unity of Conservation" (UC) whose function is to preserve biodiversity, water resources, gene flow, and soil characteristics (Brasil, 2000).

Koproski *et al*. (2004) emphasize that every year, the fires destroy immense areas with natural forests. In Brazil, forest fires in natural ecosystems have brought serious concerns to many sectors that take care of the environment, and the lack of adequate prevention and firefighting policies have led to high environmental losses nationwide. Most of the causes of fires in natural environments are due to human actions. Hence, there is a necessity for plans of prevention, including fire control and fire suppression to ensure the conservation of natural resources (Santos *et al*., 2015). In this regard, forest fires have been one of the main causes for forest

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degradation, not only because of the direct destruction, but also because of small ignition points over the edge of the fragments, changing the local dynamics (Melo and Durigan, 2010).

Ribeiro *et al*. (2008) and Rodríguez *et al*. (2012), argue that the best way to mitigate losses caused by fire is by acquiring knowledge regarding the degree of risk and the development of specific methodologies for forecasting, prevention and control, in order to aid decision making when it comes to fire management. Thus, zoning risk of fires are key tools when planning the protection of forested areas, since these provide the spatial distribution of risk visualization throughout the protected area and enable adequacy of resources and equipment for prevention and combat in accordance with the hazard level in each region (Oliveira, 2002). Given that fighting forest fires is a costly process due to the difficulty in obtaining water near the fire outbreaks (Maraboti *et al*., 2016).

Thus, through the information obtained by the risk map, preventive measures can be taken to reduce the occurrence of fires, allowing the development of a careful analysis of each variable which would ensure the identification of degrees of risk according to their influence upon ignition and propagation of the fire (Batista, 2000).

In this scenario, the objective was to show the potential of using Geographic Information Systems for planning preventive measurements and fire fighting in forest fragments, by creating a fire risk map of Serra do Brigadeiro State Park, Minas Gerais (MG).

MATERIALS AND METHODS

Study area:

Serra do Brigadeiro State Park (SBSP) was created in 1996, and it is geographically located between the meridians 40° 20’ and 42° 40’ west, and in between the parallels 20° 33’ south (Rolim and Ribeiro, 2001; Bonfim *et al*., 2003; IEF, 2016).

The park includes an area approximately of 15 thousand hectares within the biome of the Atlantic Forest, where the predominant vegetation is known as Semideciduous Seasonal Forest and “Campos de Altitude”, which should be preserved due to the high risk of extinction (Bonfim *et al*., 2003).

The (SBSP) has an irregular relief, with some elevated areas (IEF, 2016; Campos, 2008). The high altitude and the relief alleviate the local temperature, hence, the predominant climate is the mesothermal of Koppen (Cwb) with an average temperature of 18 °C and lowest below 0 °C around the elevated areas. Average precipitation is 1,500 mm/year, and the dry period of the year is from June to August (Campos, 2008). In addition, the state park encompasses several waterways that belong to the formation of important watersheds in the state of Minas Gerais (MG) (IEF, 2016).

Variables used:

The occurrence and spread of fire depend on factors associated with the combustion phenomenon. The available amount of combustible material in a forest, the characteristics of this material, the terrain slope, rainfall and ambient temperature are factors that affect the fire behavior in different ways. The action of these factors varies depending on the time of year and the region of occurrence, which explains the variety of different behaviors of forest fires (Motta, 2008).

The methodology used for the preparation of maps of risk factors as well as the final fire risk map was based on several studies from many authors, including Chuvieco and Congalton (1989), Salas and Chuvieco (1994), Ribeiro *et al*. (2008), Prudente (2010); Eugenio (2014), Eugenio *et al*. (2016).

The risk factors defined for the area were: vegetation, slope, relief orientation, distance from roads and trails, altitude, precipitation, drought, evapotranspiration and temperature. These classes were standardized according to their respective level of risk they offer to the propagation of fire - one (1) for low risk, two (2) to moderate risk, and three (3) for high-risk, as proposed by Prudente (2010).

The interpretation, processing and generation of maps of fire risk factors were carried out with the aid of ArcGIS® software 10.3.1 (ESRI, 2015).

Vegetation and Land Use:

The main factor affecting the spread of a forest fire is the type and characteristics of vegetation and land uses (Salas and Chuvieco, 1994). Additionally, fire may act as an important environmental filtering, selecting species that are more likely to occur within a given community, based on their abiotic tolerances (Verdú and Pausas, 2007). In this sense, the frequency that fire occurs might determine the ecological similarity and the degree of relatedness of plant species occurring in the same area (Webb *et al*., 2002; Slingsby and Verboom, 2006).

Distance from Roads and Trails:

Both roads and trails are elements that allow the exploration of a region, hence, they shall also be considered as a triggering factor of prominent risk of forest fires, therefore they should be included when performing a zoning analysis of fire risks (Ribeiro *et al*., 2008). Moreover, the fact that trails and roads ease the access of people affects the likelihood of a criminal fire setting (Ferraz and Vettorazzi, 1998; Santos *et al*., 2006).

The defined area of influence, was 50 meters from the existing roads located within the study area. This specific value was chosen due to the low traffic flow, since the roads and trails are within the unit of conservation. If there were highways involved, the average risk radius would be 100 meters, according to Chou *et al*. (1990). The land use data, as well as roads and trails information were obtained from the Forestry Development Center (CEDEF - IEF).

Altitude:

The altitude affects the risk of fire because of its relationship with humidity. An increasing altitude will lower the air temperature, and consequently raise the relative humidity (Salas and Chuvieco, 1994; Ribeiro *et al*, 2008; Prudente, 2010). Moreover, with high altitudes come also lower concentrations of oxygen.

Slope:

Speed and direction of fire propagation are directly related to slope. The slope of a terrain might contribute to spread the fire by pre-heating the combustible material. Subsequently, the radiation process allows for a faster transfer of heat, resulting in the combustion of the combustible material (Ribeiro *et al*., 2012). This explains the rapid spread of fire in steep areas. Thus, the higher the degree of slope, the greater the speed of propagation and intensity of the fire (Oliveira, 2002; Sant'anna *et al*., 2007). Therefore, slope analysis is essential for predicting the direction, speed and intensity of the fire in different directions of propagation (Martins, 2010).

Aspect:

The relief features influence the wind, relative humidity, type of combustible and temperature, creating its own microclimate (Motta, 2008). The north face, located at the south of the equator, receives more radiation and therefore transmits more heat due to the larger aspect (Soares and Batista 2007). Hence, the north face will receive more energy, generating higher temperatures and lower relative humidity, causing the combustible material to dry more quickly and the environment to be more susceptible to fires (Nicolete and Zimback, 2013).

The data used for the variables altitude, slope and aspect were obtained from the Digital Elevation Model (DEM), and originated from the mission of mapping the relief of the Earth Shuttle Radar Topography Mission (SRTM), with spatial resolution of 30 m, obtained from the website Geological Survey of the United States (USGS).

Average air temperature:

The temperature of the air acts in the combustion of fuel material and spread of fire (Torres *et al*, 2011.). The higher the air temperature, the higher the temperature of the combustible material. With the high temperature of the combustible material, the moisture content will consequently lower causing it to decrease the amount of heat required to reach ignition temperature (Sant'anna *et al*., 2007).

Annual precipitation:

According to Soares (1985), Prudente (2010) and Eugenio (2014), the distribution of rainfall is a key factor for determining the risk of fire. When rain occurs, it causes the combustible material to keep the moisture, hindering or making it impossible to start and spread the fire.

Annual water defict: According to Soares (1985) and Eugenio (2014), prolonged periods of drought are highly correlated with fire, specially because in certain times of the year, the material loses moisture to the environment, inducing favorable conditions for fire. Thus, the higher the water stress, the greater the chance of occurrence of fire. In order to calculate water deficit, the methodology proposed by Thornthwaite and Mather (1955) was used.

Variables of temperature and precipitation were obtained from the website Global Climate Data (Worldclim) with a spatial resolution of approximately 1 km^2.

Annual potential of evapotranspiration:

According to Prudente (2010), this variable is considered the maximum value of water loss in the atmosphere, with no water restriction on the ground. Therefore, this variable is correlated with the risk of fire as followed: the higher the value, the lower the humidity of the combustible material, increasing the likelihood of fire.

Australian Journal of Basic and Applied Sciences, 10(15) October 2016, Pages: 223-230

The annual data of actual and potential evapotranspiration was acquired through images from the sensor Moderate Resolution Imaging Spectroradiometer (MODIS), with spatial resolution of approximately 1 km^2, and the meteorological data were obtained from the Global Modeling and Assimilation Office (GMAO).

For visualization purposes and to ensure the same spatial resolution for all data in raster format, the data for temperature, precipitation, and actual and potential evapotranspiration was interpolated by using the Kriging Ordinary. Finally, we reclassified all grids according to the weight of each risk class.

Table 1: Classes, risk levels and coeficiente. Source: Prudente, 2010

Original classes	Risk	Coefficient
Vegetation and land use		
Antrhopic areas	Medium	2
Campos de altitude	High	3
Semideciduous Seasonal Forest	Medium	2
Administrative center	Low	1
Distance from roads and trails (m)		
< 50	High	3
> 50	Low	1
Elevation (m)		
< 1,200	High	3
1,200 – 1,500	Medium	2
> 1,500	Low	1
Slope (%)		
0 - 12	Low	1
12 – 40	Medium	2
> 40	High	3
Aspect		
Flat/ Southeast/ South/ South-west	Low	1
East/ West	Medium	2
Northwest/ North/ Northeast	High	3
Temperature (°C)		
< 16.6	Low	1
16.6 – 19.3	Medium	2
> 19.3	High	3
Precipitation (mm)		
< 1,250	High	3
1,250- 1,350	Medium	2
> 1,350	Low	1
Water deficit (mm)		
< 600	Low	1
600 - 800	Medium	2
> 800	High	3
Potential evapotranspiration (mm)		
< 1,477	Low	1
1,477 – 1,577	Medium	2
> 1,577	High	3

Fire Risk Map:

The data integration model was previously analyzed and proposed by Chuvieco and Congalton (1989) and adapted by Prudente (2010). The model is expressed by the equation below:

$$FR = 30\ VEG + 15\ WDEF + 10\ SLP + 10\ DRT + 10\ P + 10\ T + 5\ EVAP + 5\ ALT + 5\ ASP$$

Where:
FR= Fire Risk;
VEG= Vegetation and Land Use;
SLP= Slope (%);
DRT= Distance from Roadsand Trails (m);
DEF= Annual Water Deficit (mm);
P= Precipitation (mm);
EVAP= Potential Evapotranspiration (mm);
T= Average air Temperature (ºC);
ALT= Altitude (m);
ASP= Aspect.

The risk map generated by this equation has been validated through the overlapping of the polygons of fire occurrence in SBSP. This occurrence data was made available by the Forestry Development Centre (CEDEF - IEF).

RESULTS AND DISCUSSION

Figure 1 shows the fire risk map that was generated and reclassified to meet the SBSP standards according to three defined classes: low (1), medium (2), high (3).

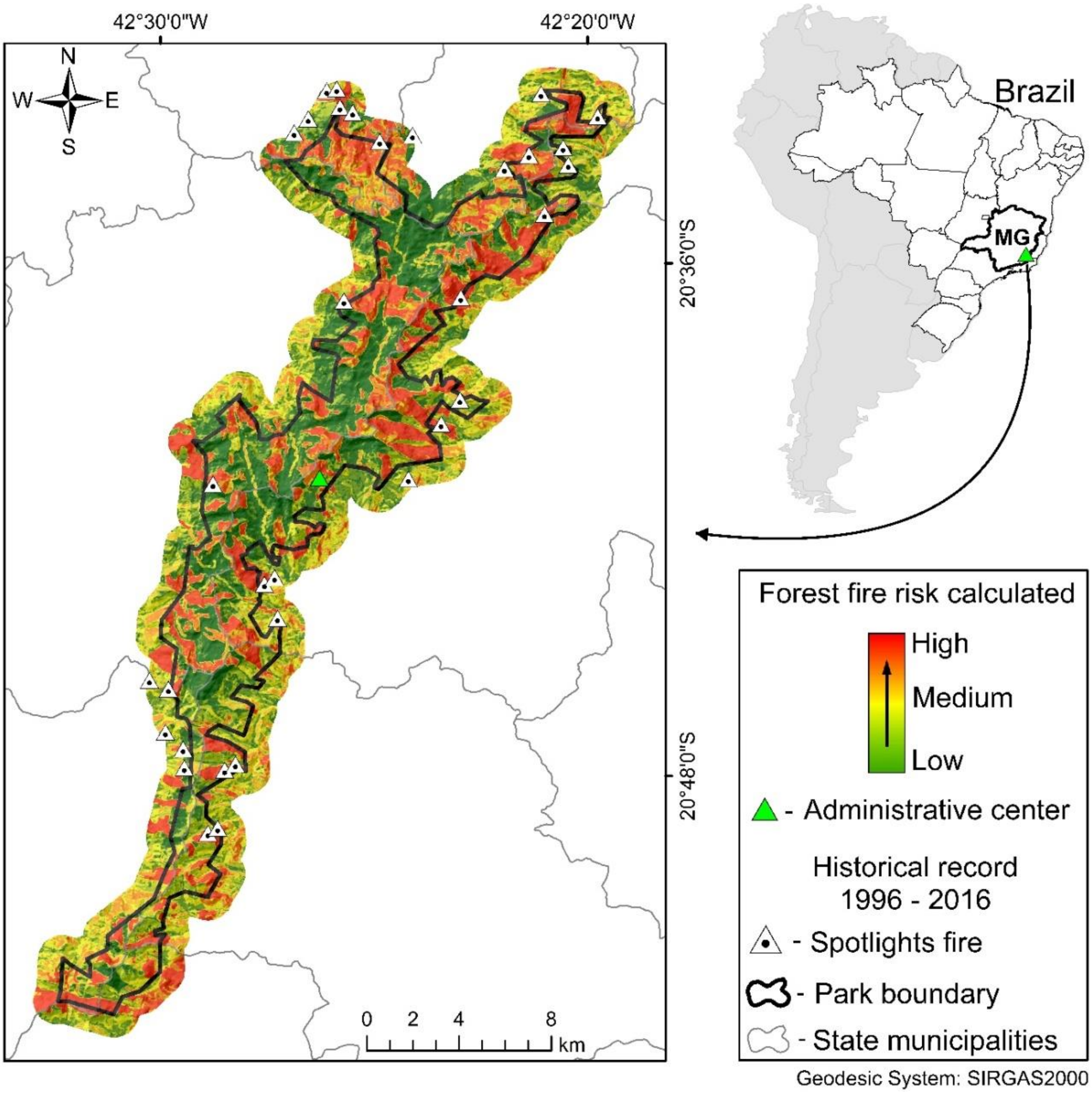

Fig. 1: Forest fire hazard map of a state park in the atlantic forest, MG, Brazil and fire history log.

It was noticed from Figure 1 that the areas with greater risks of forest fires are distributed in the vicinity of the SBSP. These areas are characterized with high levels of water stress, lowest elevations of the study area, and a strong anthropic influence due to the existence of nearby private lands. However, the areas of low fire risk are concentrated at the central regions, where there is a greater occurrence of higher altitudes and low water stress.

Above 1,500 m altitude there are hardly any large trees, this happens because when droughts start to occur, humidity decreases in the higher parts first, and then progressively to the valleys (Troppmair, 2004). In these regions, it is possible to find the characteristic vegetation of "campos de altitude", where plant species have physical characteristics that enable them to retain a certain amount of water needed to survive. The predominant species are herbaceous and small shrubs, in which the amount of water content is smaller when compared to hardwood species, thus causing them to be more combustible, especially in critical seasons (Torres *et al*., 2011).

When the overlap between the fire risk map and the reports of occurrence in SBSP was performed (Figure 1), consistent results were obtained, that is, the areas classified with high risks are the same areas that have been through a fire in the past, therefore obtaining a high potential for combustion.

It can be noticed from Figure 2 that 15.07% of the Serra do Brigadeiro State Park falls within "class 3" of susceptibility to fire, representing a high-risk area. 76.74% falls "in class 2" or medium risk, and 8.18% in the low risk "class 1". Thus, most of the SBSP can be considered at moderate risk of fire.

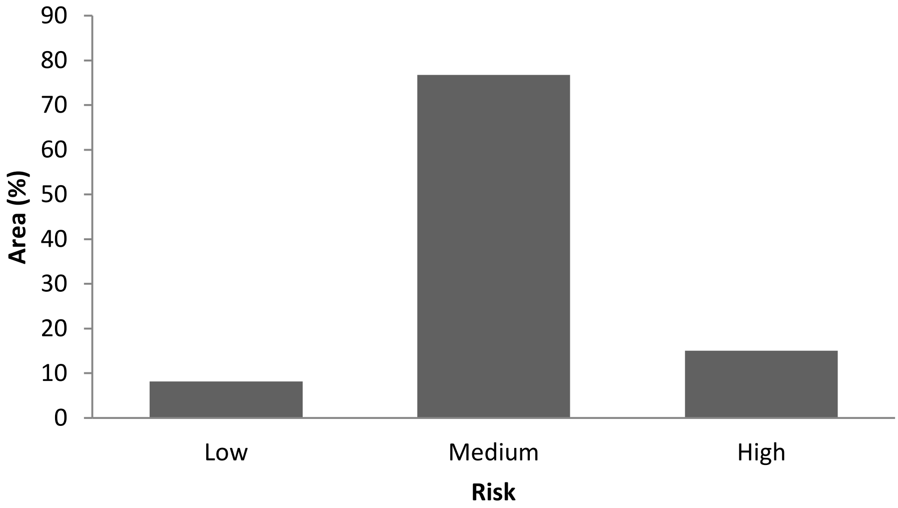

Fig. 2: Graphic representation of each class of fire risk, in percentage.

The areas classified as high risk should have better planning for the implementation of preventive and logistical practices for the access and combat of fire when necessary (Nicolete and Zimback, 2013). Thus some preventive measures for rapid fire detection and outbreaks of fighting in SBSP are recommended, for instance, measures such as optimal fire detection towers, the creation of SBSP partnerships with official entities and non-governmental agencies, the creation of an environmental and educational plan for community awareness and intensified surveillance around and within the park, and the placement of signposts warning fire risks according to the map generated in this study.

Some actions have been implemented by the SBSP team in order to prevent and combat forest fires. These actions include cleaning and maintenance of trails and roads, orientation to individuals with burning licenses, training volunteer brigades, daily monitoring of satellite hot spots, aircraft monitoring support, adaptation and maintenance of firefighting tools, educational activities in schools, distribution of leaflets and booklets to the people from the local communities with guidelines addressing environmental issues, and the danger of fire during dry seasons of the year, through the Plan of Prevention and Fighting Forest Fires (IEF, 2007).

Conclusions:

The majority of the SBSP area falls into moderate risk (76.74%) of occurrence of forest fires, but also with a significant area of high risk (15.07%).

The map of risk areas for forest fires generated for the SBSP is an important material for the planning of preventive measures and for fighting forest fires inside the park.

The methodology proposed in this study was proved to be efficient, producing information about the spatial distribution of forest fire risk in the study area, especially after observing that the fires that have already occurred in the past took place in areas that were considered of high risk by the fire risk map developed in this study.

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Australian Journal of Basic and Applied Sciences, 10(15) October 2016, Pages: 223-230

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