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Artigos

Susceptibility to wildfire in a conservation unit located in the transition region of Cerrado and Atlantic Forest Biomes, Brazil

Suscetibilidade a incêndios florestais em unidade de conservação localizada na região de transição dos Biomas Cerrado e Mata Atlântica, Brasil

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ABSTRACT

Created in 2014, the Serra da Gandarela National Park (SGNP), is repeatedly affected by wildfires. This Conservation Unit is located in the Iron Quadrangle (MG), in a transition zone between the Cerrado and the Atlantic Forest biomes, and is characterized by a complex mosaic of phytophysiognomies. The aim of this investigation was to compare the performance of two risk mapping models for forest fire in the SGNP and its surroundings, based on two different approaches, being one by multicriteria analysis, AHP method and the other a simple probability method, called Hot Spot History, which provided information on the areas of highest and lowest risk and their environmental and human characteristics. Spatial data from remote sensing and GIS were used to simulate, in sequence, the fire ignition, the fire spread and, finally, the risk of wildfire. The validation of the risk models was performed by the Kappa coefficient (K). The results showed that the model based on the History of Hot Points obtained greater accuracy (0.61) than the model generated by the AHP method (0.54). The Brazilian Savanna, Rupestrian Fields and Field coverings were the most susceptible to wildfire, as they are formed by herbaceous vegetations and are located very close to urban agglomerations and roads. The slopes oriented to the North and West were important for the prediction of wildfires slope and, on the other hand, the slope of the terrain was not important to discretize the areas of greater and lesser fragility to the referred ecological disturbance.

Keywords: Rupestrian Fields; GIS; Multicriteria Analysis

RESUMO

O Parque Nacional da Serra da Gandarela (SGNP), criado em 2014, é repetidamente afetado por incêndios florestais. Essa Unidade de Conservação está localizada no quadrilátero ferrífero (MG), em uma área de transição entre os biomas Cerrado e Mata Atlântica, e é caracterizada por um complexo mosaico de fitofisionomias. O objetivo desta investigação foi comparar o desempenho de dois modelos de mapeamento de risco para incêndios florestais no SGNP e seu entorno, com base em duas abordagens distintas, uma por análise multicritério, método AHP e um método de probabilidade simples, denominado *Hot Spot History*, que forneceu informações sobre as áreas de maior e menor risco e suas características ambientais e humanas. Dados espaciais de sensoriamento remoto e SIG foram usados para simular, na sequência, a ignição do fogo, a propagação do fogo e, por fim, o risco de incêndio florestal. A validação dos modelos de risco foi realizada pelo coeficiente Kappa (K). Os resultados mostraram que o modelo baseado no Histórico de *Hot Points* obteve maior precisão (0,61) do que o modelo gerado pelo método AHP (0,54). As coberturas de Cerrado, Campos Rupestres e Campo foram as mais suscetíveis aos incêndios florestais, por serem vegetações herbáceas e localizadas muito próximas a aglomerações urbanas e rodovias. As inclinações orientadas a Norte e Oeste foram importantes para a previsão de incêndios florestais e, por outro lado, a inclinação do terreno não foi importante para discretizar as áreas de maior e menor fragilidade ao referido distúrbio ecológico.

Palavras-chave: Campos Rupestres; SIG; Análise multicritério

1 INTRODUCTION

The region of the iron quadrangle (IQ), in Minas Gerais, Brazil, is characterized by its complex vegetative composition, due to its location in the transition zone between the Cerrado (Brazilian Savanna) and Atlantic Forest biomes and because it contains a rocky substrate with a high concentration of iron (SILVA, 2016). The combination of these factors in the endemic vegetation, the Rupestrian Fields, which comprises sclerophyllous shrubs and sub-shrubs, presents itself in a rich mosaic of vegetative communities, controlled by the edaphic, topographic and microclimate environment, in addition to the great wealth of species and endemism (LE STRADIC *et al*., 2018). Despite its small extension in the Brazilian territory (less than 1%), the Rupestrian Fields harbour more than 5,000 species of vascular plants that, in their totality, represent 14% of the National Diversity (SILVEIRA *et al*., 2016).

The Conservation Units (UC) of Brazil suffer from the ecological disturbance of the fire, due to the anthropic factor, through the negligent use of fire for cleaning and renewing pastures in areas close to the UC (BONFIM; RIBEIRO; SILVA, 2003), demanding greater investment of resources to reduce the impacts of the forest fires. This scenario is no different at the SGNP where, only in the last 5 years, over 136 hot spots have been identified by the reference satellite of the National Institute for Space Research (INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS, 2020).

Investigations and monitoring of susceptibility to wildfire are important for better practices in the management and preservation of flora and fauna (GANTEAUME; JAPPIOT, 2013; SOARES NETO *et al*., 2016; LE STRADIC *et al*., 2018). Forest fire susceptibility maps provide users with spatial information relevant to landscape management, for example, the distribution and identification of forest fire area patterns (LE STRADIC *et al*., 2018). Susceptibility to wildfire has been carried out with geospatial data and Geographic Information Systems platforms, whose tools allow the interaction of environmental and man-made variables that simulate the ignition and propagation of wildfire through space-time models representing those natural and antrophic factors dynamics to enable the phenomena (GIGOVIĆ *et al*., 2018). The spatial models of wildfire have helped forest managers to improve the planning and management of the event, minimizing expenses that are already limited for the various actions that must be carried out in the UC, such as prevention actions, fuel management, pre-suppression measures and landscape restoration (MAVSAR; CABÁN; FARRERAS, 2010).

The spatial models are based on different approaches and probabilistic statistical algorithms, such as the most advanced ones, based on machine learning, whose use has been growing since 2000 and obtaining extremely high accuracy (SAYAD; MOUSANNIF; MOATASSIME, 2019), but also simpler and more easily reproducible models, such as by weighting fire occurrences (TORRES *et al*., 2017b) and multicriteria analyzes (POURGHASEMI; BEHESHTIRAD; PRADHAN, 2016; MOAYEDI *et al*., 2020).

The simplest approaches to modeling susceptibility to wildfire, such as weighting the occurrence of fire based on the occurrence probability of the event by explanatory variables based on the history of occurrences, and the multicriteria analysis, based on the knowledge of the analyst / researcher on the fire ecology fire for the calibration of explanatory variables, are widely disseminated and have a greater reach for managers of protected areas, however there are still few works that validate the cartographic products created.

In the IQ region, there are studies with different approaches on the relationship between fire and vegetation, such as in the Serra do Cipó National Park (RIBEIRO; FIGUEIRA, 2011) and in the Serra do Espinhaço Biosphere Reserve (MENEZES *et al*., 2019), for example. However, studies on susceptibility to wildfire have not been identified for the SGNP, knowledge that can assist in understanding the dynamics of wildfire in that area.

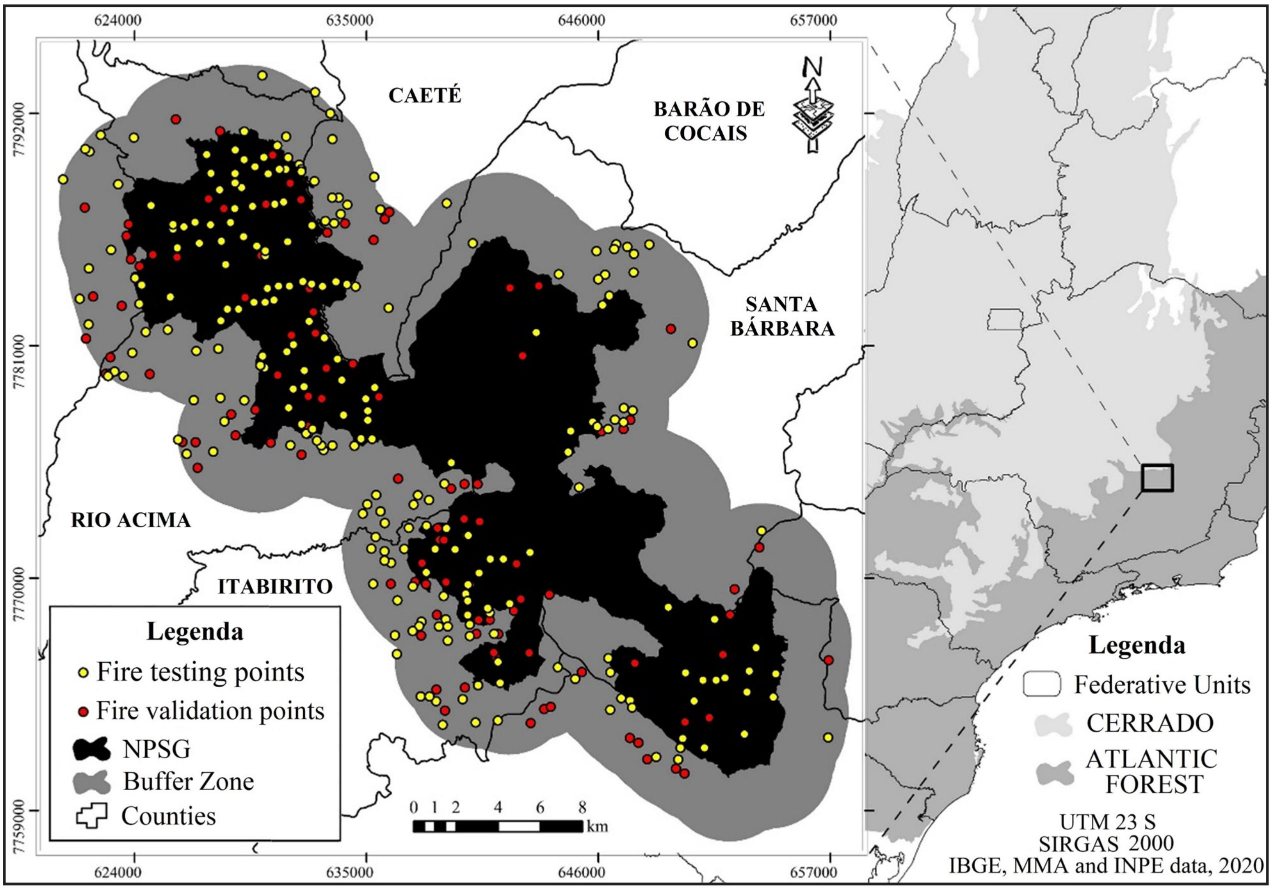
In this perspective, the objective of the research was to compare the models of susceptibility to wildfire based on the approach of fire occurrence probability by the historical and the multicriteria analysis, pointing out the environmental and anthropic characteristics most susceptible to the event, in order to provide the best cartographic product to predict the event in a transition area between the Brazilian Savanna and the Atlantic Forest biomes, with complex phytophysiognomic mosaic. It is expected that the predictive model based on the occurrences history will perform better due to the training with the historical events of forest fire and because it is a field of study that is still little explored on this topic, which may limit the effectiveness of the multicriteria analysis. Furthermore, it is expected for the herbaceous vegetation, the sloping topography and the proximity to roads and urban agglomerations to be characteristics that better predict the referred ecological disturbance.

2 MATERIALS AND METHOD

2.1 Area of study

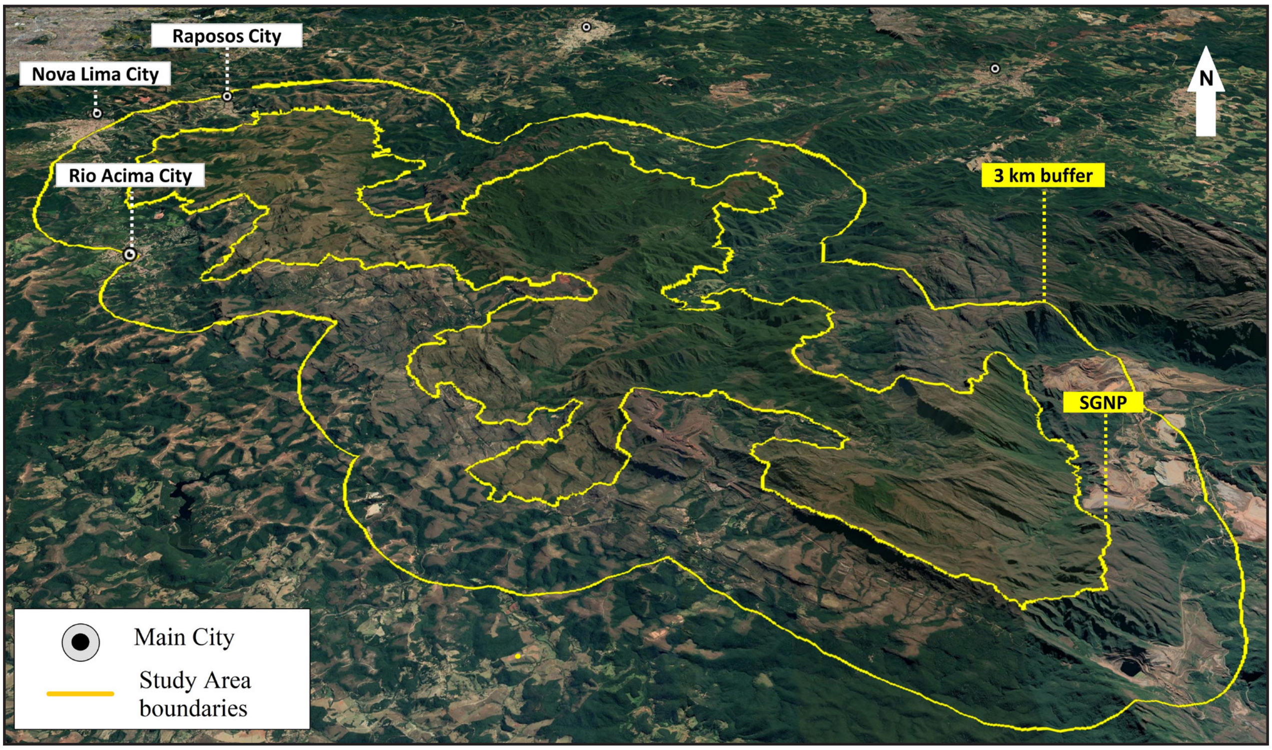
The Serra of Gandarela National Park (SGNP) was created recently (Decree nº 13 of October 2014), being considered a priority landscape for conservation due to the diversity of the landscape, potential for water recharge and rich diversity of flora and fauna, in addition to pressure from the mining sector in the region (LAMOUNIER; CARVALHO; SALGADO, 2011). The SGNP is located in the mesoregion of Belo Horizonte (MG), approximately 40 km from the state capital and covers an area of 31,270 ha. The Conservation Unit is located in one of the most important mineral provinces in the country (Iron Quadrangle in Minas Gerais) and is bordered by 8 municipalities (Figure 1 e 2).

Figure 1 – Location of the Serra of Gandarela National Park and hot spots that were used as training samples and validation of the elaborated spatial models



Source: Authors (2021)

Figure 2 – Serra of Gandarela National Park panoramic image taken from *Google Earth Pro*



Source: Authors (2021)

The SGNP has a Cwa (Koppen climate classification), mesothermal climate, with humid summers and an average annual rainfall of 1,300 mm to 1,400 mm (MARTINS *et al*., 2018). Less developed tree vegetation, such as the formation of ferruginous rupestrian fields, in addition to savannas and fields, are generally associated with higher and sloping sites, which present shallow soils with rocky outcrops. On the other hand, larger vegetation, such as forests, are common to areas of deeper soils and with a greater presence of moisture, associated with both drainage areas and flat areas where lower flow energies favor the processes of pedogenesis (MESSIAS *et al*., 2012).

The geological context of Serra da Gandarela is complex (LAMOUNIER; CARVALHO; SALGADO, 2011), composed of rocks of different types of formation, mainly by metamorphic substrate with iron content, such as itabirite. Together with the itabirite, the quartzite rock also makes up the upper altitude range of the study area, giving a dissected and rugged feature of the relief. In the intermediate levels, there is a predominance of metamorphic rocks, such as schist-phyllites and granite-gneiss, which are moderately resistant and imprint stronger wavy slopes on the relief. Equally important, continental sedimentary rocks are found on the edges of this mountain range, such as marbles and dolomites, which are characterized by being less resistant to the regional humid climate and provide 74 catalogued caves and 44 others under investigation by their physicochemical nature (LAMOUNIER; CARVALHO; SALGADO, 2011).

2.2 Database and elaboration of Environmental and Anthropic Variables

A vector file was used referring to the limit of the Serra da Gandarela National Park (SGNP), with a 3 km buffer, acquired on the website of the *Chico Mendes Institute for Biodiversity Conservation* (ICMBIO), which served as a limiting mask for the analysis of the variables. On the site for fire monitoring at the National Institute for Space Research (INPE), hot spots were acquired between the years 2000 and 2020 for the study area, adding up to 349 spots captured from the reference satellite – AQUA, by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor. From this total, 70% of the spots were separated for training the model that was based on the occurrences history (dated between 2003/05/13 to 2014/10/11) and the other 30% (dated between 2014/01/12 to 2019/11/05) for validation of the risk models.

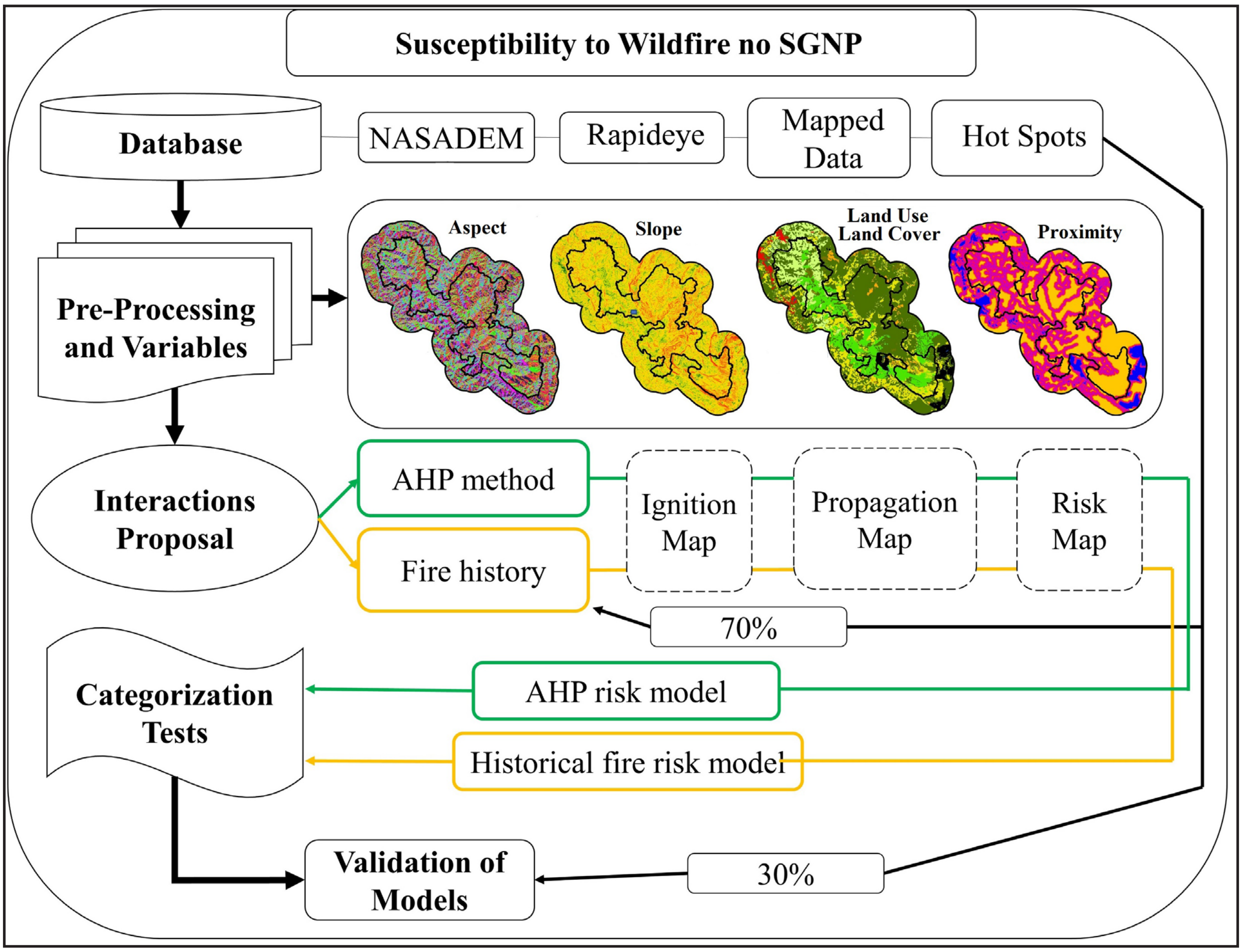
The NASADEM images (UNITED STATES, 2020), whose product is a reprocessing of the Shuttle Radar Topography Mission (SRTM) for quality improvement, with a 30-meter spatial resolution, were downloaded for the elaboration of the secondary variables - Slope and Aspect, in the ArcGis 10.5 software. Rapideye images, with spatial resolution of 5 m and five bands (B, G, R, Red-edge and Near-infrared), dated between September and October of 2015, were acquired for the elaboration of the Land Use and Coverage map. The first step was radiometric calibration and atmospheric correction by the Fast line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) algorithm of the images, using the ENVI 5.3 software. The second was the semiautomatic classification of the images, at first with training and classification being supervised by the Random Forest method available in QGis 3.12.1, in the *Dzetsaka* plugin, and next, there was a manual adjustment of the classes to improve the classification accuracy. Nine classes were established: Rupestrian Fields; Thick; Field; Capoeira; Forest; Planted Forest; Urban area; Mining; and water bodies. After manual adjustments, using the Google Earth Pro software, 154 samples of class validation were collected to evaluate efficiency through the confusion matrix, using the Kappa coefficient. Google Earth Pro was used to map the "neighborhood" variable, which refers to the distances of the trails, roads and urban and rural infrastructure of the park and its surroundings.

2.3 Interaction and Grades Proposal

The method of interaction between environmental and anthropic variables for the preparation of maps of ignition, propagation and fire risk was based on the work of Torres *et al*. (2014). The referred methodology proposes to interact the variables from the weighted arithmetic mean, being the first interaction between Use and Land Cover (weight 0.5) and Aspect (weight 0.5), which generates the Fire Ignition model (Figure 3). Then, the Fire Ignition (0.66) model interacts with the slope (0.34), resulting in the fire propagation model. Finally, the fire propagation model (0.75) is crossed with the proximity map (0.25), generating the risk model (Figure 3).

The method used to assign grades to the classes of environmental and anthropogenic variables was based on the Analytic Hierarchy Process (AHP) methods and the history of hot spots. The AHP method developed by Saaty (1987) is widely adopted in multicriteria studies and in several areas of knowledge, including the mapping wildfire risk, to which researchers report moderate accuracy (ABBA *et al*., 2013; POURGHASEMI; BEHESHTIRAD; PRADHAN, 2016).

Figure 3 – Methodological flowchart of the present research



Source: Authors (2021)

The AHP method is based on a hierarchical and comparative analysis in order to pair the importance between the attributes (Table 1) for the solution of a given problem, being operationalized in a matrix. The steps can be summarized by (SAATY, 1987): 1) Setting up a structured hierarchical model; 2) Assembling attribute matrices for comparison; 3) Estimating the weight of the vectors and make sure that the analysis has consistency; 4) Measuring the weight of the combined vectors and checking the consistency of the combined hierarchical arrangement.

The importance attributed to the components for comparison is based on the authors' experience on the topic and on the review of fire-related characteristics in other studies.

Table 1 – The comparison scale of pairwise Saaty

Numerical values	Verbal scale	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favor one element over another
5	Strong importance of one element over another	An element is very strongly dominant
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favored by at least an order of magnitude
2, 4, 5, 6 and 8	Intermediate values	Used to compromise between two judgments

Source: Saaty (1987)

The Consistency Rate is the most important parameter to indicate whether the comparison was made consistently, with a value under 0.10 being the recommended for consistency. The calculations of the importance of environmental and anthropogenic variables by the AHP method were performed on the website https://bpmsg.com/ahp/ahp-calc.php, which has an online platform for this type of calculation, which generates the weights for each attribute and the consistency rate.

The second method of attributing grades was based on the focus history of the study area and, therefore, 70% of this information was separated for the training of classes of variables (Figure 3). Thus, the number of fires per unit area of the classes for each variable was weighted in an electronic spreadsheet, resulting in grades depending on the probability of the event to occur. The classes of variables that did not present any occurrence of fire outbreaks had a value of 0, whereas classes of variables that presented events obtained a higher value the greater the density of fire outbreaks per area.

The grades were inserted into the variables by reclassifying the values in the ArcGis 10.5 software. The integration of the variables with the grades was also carried out in the aforementioned Geographic Information Systems software through map algebra. The method of categorization of risk models, which seeks grouping values based on different logics, has a notorious influence on the size and distribution of risk classes, since, in the models, this information is continuous. Therefore, it was decided to test three different methods, such as the Geometric Interval, Equal Range and Quantile, with five risk classes, called “Very Low”, “Low”, “Medium”, “High” and “Very High”.

2.4 Validation of Risk Models

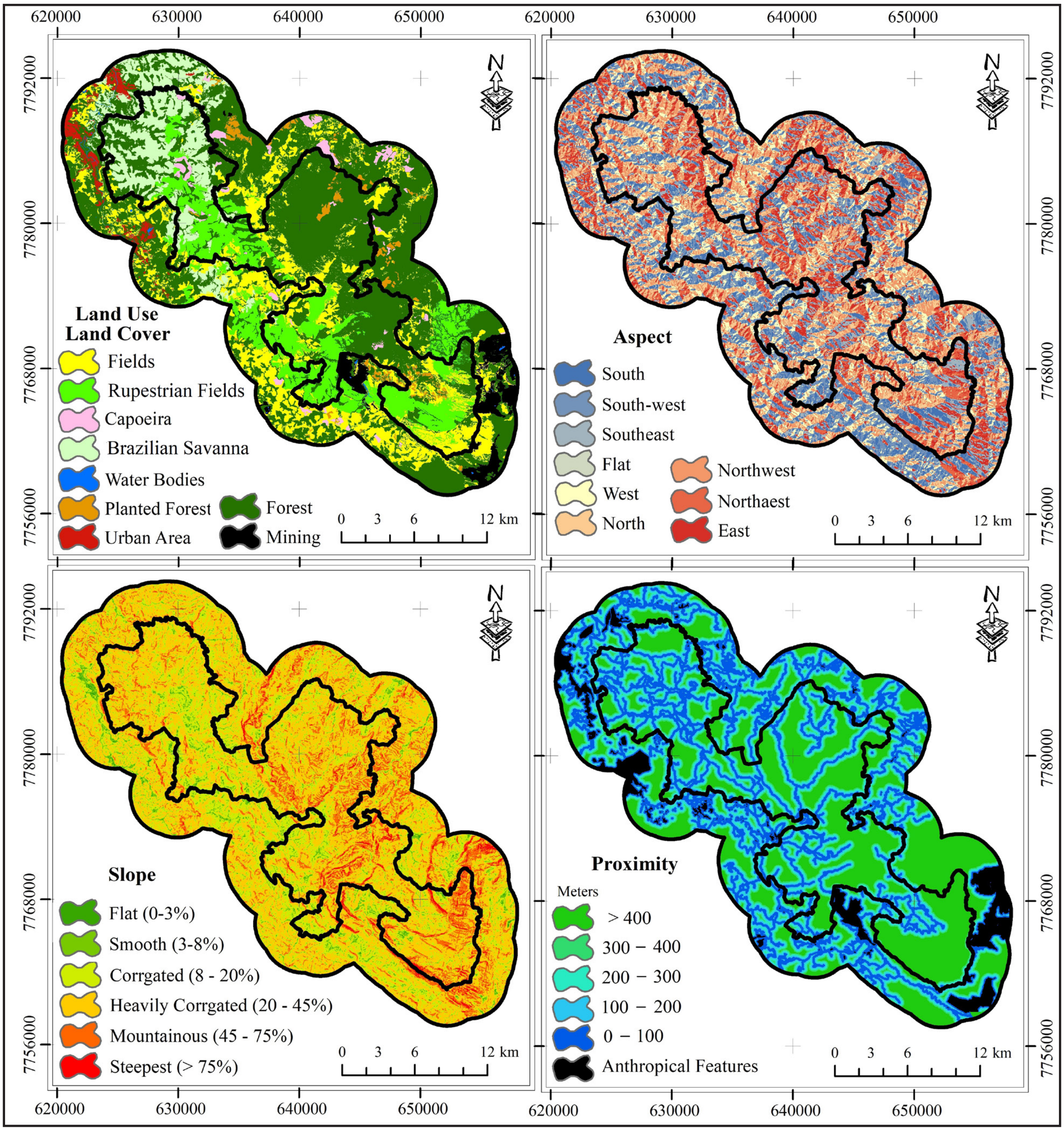
The risk map, by itself, is not sufficient for forecasting purposes, since it is necessary to evaluate the reliability of the results of the predictive model. Validation is an attempt to increase the degree of reliability of events inferred by a model under the assumed conditions (PAZ *et al*., 2011). Thus, 30% of the most recent hot spots in the study area (105 spots) were separated and another 105 random points, where no fire outbreaks were found in the investigated period, were created for validation by the Kappa coefficient. It was assumed that the “Very Low”, “Low” and “Medium” risk classes would not contain points with fire outbreaks, but would contain points without occurrences, while the “High” and “Very High” risk classes would be the reverse.

3 RESULTS

3.1 Environmental and Anthropogenic Variables concerning Forest Fire in the SGNP

The Consistency Rate (TC) of the AHP method for the environmental and anthropic variables used was satisfactory, since the values were below 0.10, such as 0.098 for Land Use and Land Cover (LULC); 0.07 for Proximity (P); 0.072 for Slope Orientations (A); and 0.017 for Slope (S). The grades of the classes for these variables can be seen in Figure 3, as well as the grades of the heat history. It should be noted that the grades of the two criteria should not be compared (Figure 3), since they do not start from the same principle and were not normalized in this step (only the final models were normalized).

Figura 4 – Representations of Environmental and Anthropic Variables



Source: Authors (2021)

The supervised classification of the Rapideye image, used for the preparation of the Land Use Land Cover (LULC) map, obtained 0.91 in the Kappa index, a value considered excellent (LANDIS; KOCH, 1977). The LULC presented approximately 50% of the total Forest area, significantly present in the center-north of the park and in the buffer zone (Figure 4), followed by 17.64% of the Field, 14.30% of the Rupestrian Fields and 8% do Brazilian Savana, representing 91.15% of the total area (Figure 5) and located largely within the SGNP. Regarding the weight of the areas of the LULC classes with the number of outbreaks, it is noted that the Brazilian Savanna, the Rupestrian Fields and the Capoeira coverings are the vegetations most susceptible to fire. The Forest, despite containing 32% of these hotspots, was not as relevant as others vegetations due to its wide spatial coverage. In the AHP method, weight patterns were similar to the historical hotspots, high for herbaceous vegetation and low for forest (Figure 5).

The spatial distribution between the Aspects (A) was similar (Figure 4), except for the flat relief (0.5% of the total area). Despite that, the flat relief concentrates a greater number of hotspots when considering its area in relation to the other classes (Figure 5). It should be noted that the West, followed by the North, presented more hot spots than the other classes (Figure 4), therefore, the greatest weight for the hot spot history method. The AHP method presented greater weight for the North than for the other terrain orientations, unlike the first method, in which the weight of this class was considerably greater than the other features in general.

The slope (S) of the SGNP is predominantly strong wavy (52.27%) and wavy (28.22%), in comparison, the flat area is very small (0.90%). Flatter lands are associated with urban areas, while the steeper areas are found in inner of the SGNP and close to the limit of the conservation unit (Figure 5). It is noteworthy that the flat relief concentrated more hotspots per area, as seen in Aspect, while the mountainous and steep reliefs were the ones least concentrated (Figure 4). In this perspective, for the method of history of hot spots, the highest scores were for flat areas, Smooth, Corrugated, Heavily Corrugated, on the other hand, for the AHP method, the lowest grades were attributed from the less accentuated reliefs to the steeper reliefs, with higher grades (Figure 5).

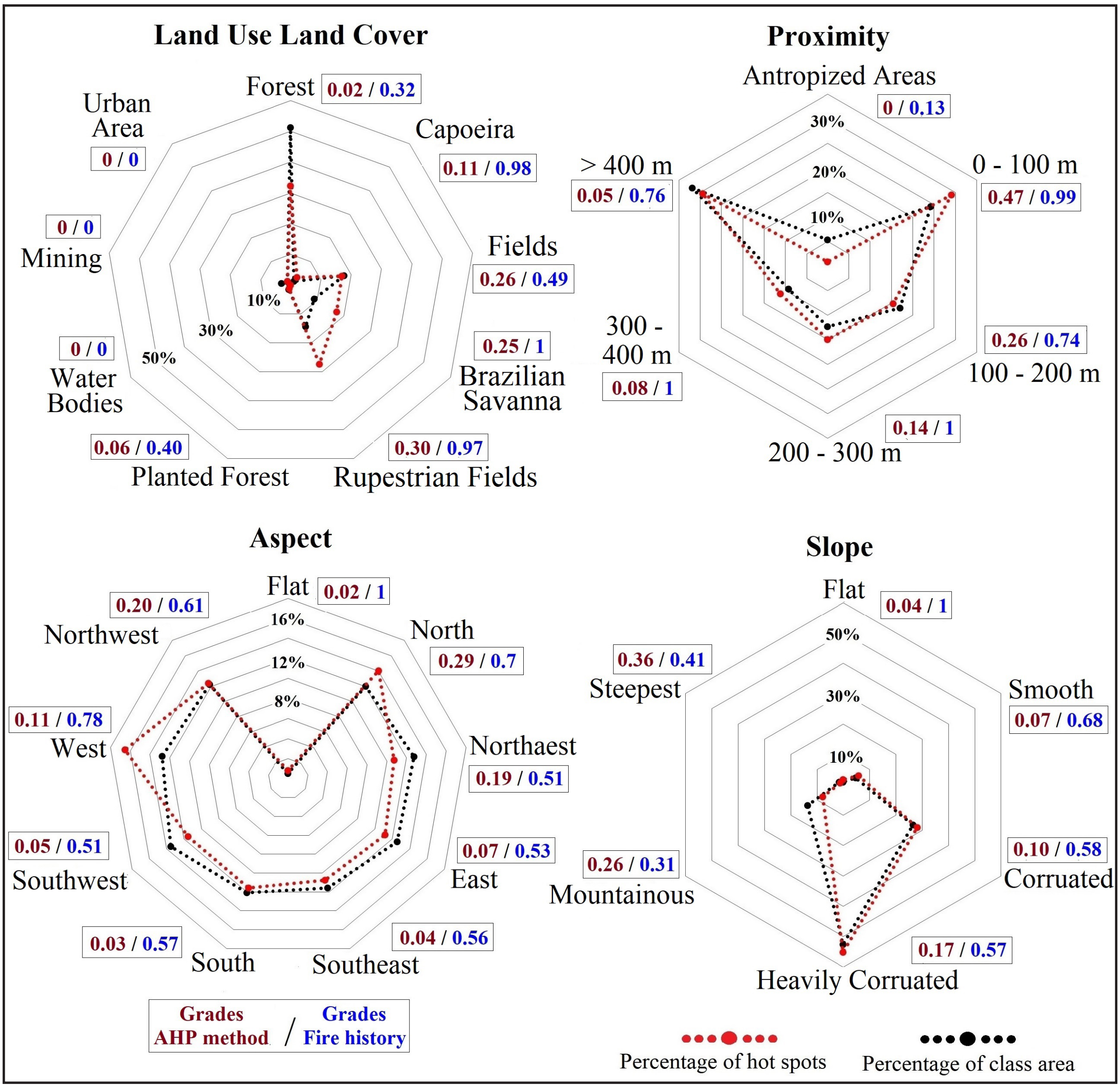
The proximity (P) of the trails, rural roads, urban perimeters and mining areas showed the largest area in the classes of 0 - 100 meters in distance and above 400 meters, with a high density of trails being observed inside the SGNP (in Brazilian Savanna Coverage, countryside and Rupestrian Fields) and high density of roads in the buffer area close to urban areas (Figure 4). Little occurrence of fires in anthropic areas was observed, while the distance between 0 to 100 meters and greater than 400 meters predominated in the occurrence of hot spots (Figure 5). However, the hot spot history method showed a low amplitude of the grades from the shortest to longest distances, distributing close weights between such zones. On the other hand, the AHP method grades are higher the closer to urban areas (Figure 5).

3.2 Risk Models

From the validation by the Kappa coefficient (K), the model based on the historical fire spot criterion obtained a better performance than the model based on the AHP method, which obtained 0.61 and 0.54 in the Geometric Interval classification, respectively (Figure 6). The other classifications used, Equal Intervals and Quintile obtained lower results, so they were not presented.

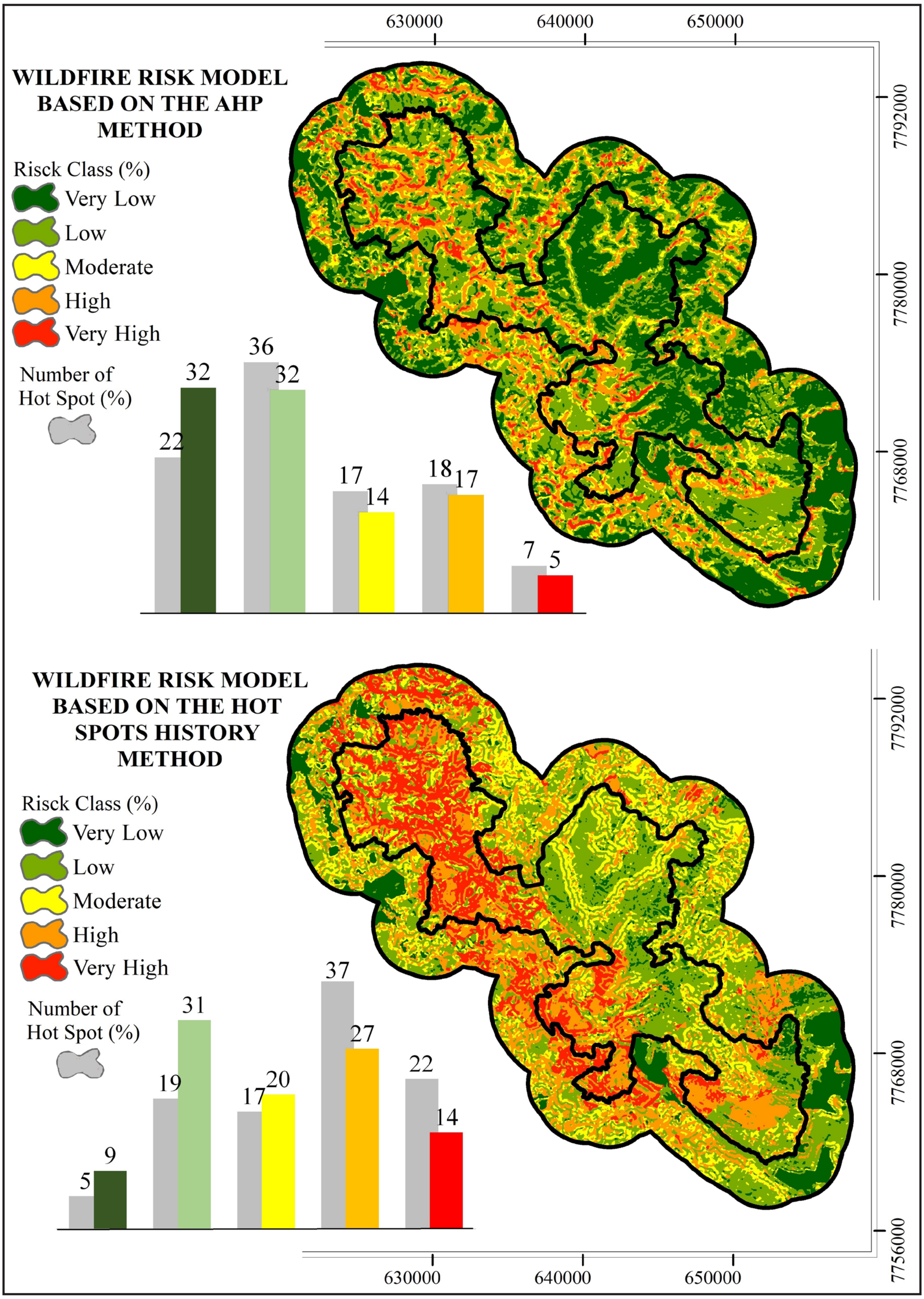
The risk models showed some similarities in susceptibility to wildfire, such as the extremely low risk for the urban agglomerations and mining areas. Differences can be seen in the establishment of the AHP model, which classified 84% of the study area from very low to moderate in areas with forest coverage, urban agglomerations and mining, including areas with herbaceous vegetation, while the areas with highest risk being restricted to the proximity of trails and roads with herbaceous vegetation. The model based on the history of hotspots, on the other hand, classified 60% of the SGNP as very low to moderate, but different from the compared model, Forest areas had low and moderate risk, while in the first model it was predominantly very low. Regarding the higher risk classes, which comprised 40% of the study area, it is noted that herbaceous vegetation was widely covered.

Figure 5 – Radar graphs illustrate the percentage of fire outbreaks, percentage of class areas and beside the classes the respective grades assigned under the AHP method and history of hotspots



Source: Authors (2021)

Figura 6 – Forest Fire Susceptibility Models elaborated from the AHP method and history of hot spots



Source: Authors (2021)

4 DISCUSSION

In the Serra of Gandarela National Park (SGNP) the vegetation of the Brazilian Savanna and the Rupestrian Fields are the most affected by wildfire, and has being associated to environmental conditions with periods of fires, which led to the evolution of this vegetation and high resilience to adversities (SARTORELLI; CAMPOS FILHO, 2017). This herbaceous vegetation is more susceptible to wildfire than other phytophysiognomies due to low moisture storage capacity and, therefore, are even more susceptible in drought, when the climate is drier (GANTEAUME; JAPPIOT, 2013; TORRES *et al*., 2017a). Both vegetations are associated with the border area between the buffer zone of the SGNP and its interior, and the urban areas of the municipalities of Rio Acima, Nova Lima, and Raposos are a few kilometers from the park. The Capoeira, formed by secondary vegetation, has another risk class in the SGNP and it is noted that the fragments of this vegetation are close to others of high risk (B. Savanna, Fields, Rupestrian Fields) and planted forests. Secondary vegetations are areas of forest regeneration and can suffer considerably with forest fire events, since it does not yet have a formation of more resistant species, with more humid microclimatic environments (SARTORELLI; CAMPOS FILHO, 2017).

The pattern of fires found in the SGNP is similar to other conservation units, which were also identified with herbaceous formations, such as pastures, altitude fields, dirty fields, and closed fields (SOARES NETO *et al*., 2016). This patternoccurs due to the drought season, which leaves this type of vegetation cover dry, promotes combustion and the anthropogenic activities of cleaning the land with fire, close to the limits of protected areas.

The Aspect (OV) is related to the climate control of the surface, which differs depending on the latitude and influence on the greater or lesser exposure to solar radiation. In the northern hemisphere, the warmest and driest slopes are those facing south, while in the southern hemisphere, the slopes with these conditions are the

North ones, favoring forest fire events (GANTEAUME; JAPPIOT, 2013; TORRES *et al*., 2014). The SGNP is located approximately at Latitude 46º South, which means that the northern slopes receive a higher rate of solar radiation than the other orientations. The favorability of a higher rate of occurrence of forest fires on the North-facing side was identified in the study area, followed by the Westside, a trend that occurs in other territories in the same hemisphere (TORRES *et al*., 2014; SOARES NETO *et al*., 2016).

The steeper slopes favor the spread of fire and make it difficult to control the event (GANTEAUME; JAPPIOT, 2013). Considering the profile of wildfire in protected areas in Brazil, between 2008 and 2012 (TORRES *et al*., 2016), regarding the slope, its importance in the occurrence of fires was identified, analyzing it together with the other variables. However, the more inclined areas of the SGNP terrain did not show considerable preference for wildfire and, therefore, it can be said that considering only this variable, it is not possible to predict wildfire in the study area. Although the flatter region has more fire spots per area, it is noteworthy that this type of relief has a small extension in the study area and is located close to urban agglomerations and where there was a greater density of fire spots.

The anthropogenic factor is pointed out as the main cause of wildfire around the world, in Switzerland, Brazil, and Chile it was observed that the highest occurrence of wildfire is positively correlated with the density of roads and inhabitants (DÍAZ HORMAZÁBAL; GONZÁLEZ, 2016). It is noteworthy that the areas closest to the anthropized areas in the SGNP are correlated to hot spots in the following characteristics: proximity between 0 to 100 meters and 200 to 400 meters; with the northwest region of the park, which borders the municipalities of Rio Acima and Raposos, where there is a high density of trails and which is close to roads and urban areas; added to this information, the accounting of 45 independent entries inside the park from its surroundings, which points to a high anthropic influence on the dynamics of the SGNP buffer zones.

In conservation units in the Brazilian territory (AGUIAR *et al*., 2015; SOARES NETO *et al*., 2016; TORRES *et al*., 2016; 2017b) the anthropic presence decisively influences the occurrence of wildfire. Despite this, the high density of roads and trails in and near the parks, as it is the case of the SGNP, can facilitate the suppression of fires by brigade members, as well as serve as curbs to prevent the spread of fire on the surface.

Similar to this research, with the same method and variables for preparing the ignition, propagation and fire risk maps, TORRES *et al*. (2017a; 2017b) compared the methods based on multicriteria analysis and the history of burned areas (polygonal area) in the Serra of Brigadeiro State Park (SBSP) and in the municipality of Viçosa, in Minas Gerais state, and noted that the occurrence history had better efficiency in the Conservation Unit and multicriteria analysis in the municipality. In the Himalayan region of Bhutan (TSHERING *et al*., 2020), the prediction by models based on the AHP method and frequency rate was compared and, the second method, respectively, obtained greater efficiency. The fact that the risk models based on the history of burned areas is the most efficient in regions little altered by anthropic actions may be associated to the particular configuration of the regional landscape, which still does not have many studies, where the knowledge of the preferential arrangement for forest fires in other areas of study is not yet fully reproducible, requiring calibration of variables according to local, environmental and human factors, as occurred in the present research and in the investigations at SBSP and in the Himalayan region, in Bhutan.

The different categorizations used had the expected effect, since they influenced the efficiency of the models, due to the spatial and quantitative distribution of the risk classes according to the logic of the categorization. The *Geometric Interval* method, which provided better classification, is indicated for continuous data that are not normally distributed, with the occurrence of duplicate values, a situation observed in SIG risk models.

5 CONCLUSION

The model based on the history of fire outbreaks was the most efficient, not only by the validation result, but also by the consistency in representing the areas with vegetation cover of Fields, Brazilian Savanna, Rupestrian Fields, and aspect the West and North slopes as the most susceptible to fires, the proximity of anthropized areas with medium to high and very high risk, and urban and mining areas with little, very low risk. The slope of the terrain was not an efficient variable for the prediction of forest fire in the SGNP.

Although the history of the hot spots model has higher efficiency for the AHP method, it is suggested that for the next studies in the topic for the area under investigation, other multicriteria methods should be used for comparison, since it is believed that the efficiency of the risk model may increase. Similarly, for better understanding the environmental system in force in the SGNP, regarding the favorability to wildfire, it is suggested to couple other environmental and anthropic variables in the methodology, such as kernel density of the variable proximity, the proximity of rivers/roads/urban areas/productive activities, wind dynamics, accumulated solar radiation, vegetative indices, distance from nearest neighbors, etc.

The importance of testing categorization methods for risk models was identified, since it changed the efficiency of forest fire prediction when compared and, it is highlighted, that the *Geometric Interval* method was the most recommended for risk models developed under the systematized conditions in this research.

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