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MAPPING OF SUSCEPTIBILITY TO FOREST FIRES IN NIASSA PROVINCE, MOZAMBIQUE

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ABSTRACT
Forest fires are one of the agents that contribute to the reduction of forests. However, it is essential to know what conditions and favors its occurrence, to facilitate the mapping of susceptible areas and allow the development of specific programs for critical regions. The objective of this study was to prepare a forest fire susceptibility map for Niassa province, using the Geographic Information System (GIS). With the aid of the AcrGIS software version 10.8, fire susceptibility maps were produced referring to slope, slopes, altitude, road proximity, land use and occupation, population density and precipitation. These parameters were integrated by a summation, in which through a pairwise comparison hue using the Hierarchical Analysis Process (AHP) method, each variable was given a weight. The weights obtained were: Land Use and Occupation (0.22), Slope (0.15), Altitude (0.12), Slope Orientation (0.11), Demographic Density (0.17), Road Proximity (0.09) and Precipitation (0.14) with a consistency rate of 8%. The results reveal that low susceptibility represents an area of 2,297.2 km2 (2%), moderate susceptibility with 56,452.89 km2 (47%), high and very high susceptibility cover an area of 48,539.84 km2 (41%) and 8,415 km2 (10%) respectively. The most susceptible regions are: Lichinga City, Chimbonila district, Cuamba, Mandimba, Mecanhelas and Ngauma. In this way, it can be concluded by stating that the selected variables and the weights assigned, as well as the method applied, are efficient for the elaboration of the map of susceptibility to the occurrence of forest fires.

Keywords: Forest Fires. Susceptibility. Geographic Information System. Map and Hierarchical Analysis Process (AHP).

INTRODUCTION

Currently, tropical forests comprise a terrestrial ecosystem that is very threatened with extinction (Nanvonamuquitxo et al., 2019), with forest fires being one of the major sources of damage to these areas (GOFC-GOLD, 2014). To get an idea of the destructive power of forest fires, the report released by the Food and Agriculture Organization of the United Nations (FAO) states that in 2012 alone about 30 million hectares were affected by forest fires around the world (FAO, 2015).

Mozambique has a wide potential of natural resources and most of it is covered with vegetation, the most extensive being the miombo. These ecosystems are the source of many products, from timber to non-timber (Máquina et al., 2024). The miombo ecosystem is a type of vegetation from the African savannah that covers approximately 10% of the forest environments of the African continent, and constitutes the most important biome in the South and East African region in terms of biodiversity, as more than 150 million people depend on its goods and services in Africa (Dewees et al., 2010). In Mozambique it is no different, for example, about 76% of the country's energy needs are met by biomass energy from the Miombo (Ryan et al., 2016).

The pressure that forest ecosystems suffer due to the need for new areas for agricultural activities (Nhongo, 2018), hunting, honey gathering, charcoal manufacturing, scaring away wild animals, decreasing vegetation cover and the intensification of human activities result in an increase in the risk of forest fires (Mbanze et al., 2017; Máquina et al., 2023; Máquina et al., 2024). Most forest fires are also influenced by climatic factors (Sitoe et al., 2013). This has implications for biodiversity reduction, biomass change, and decline of important ecosystem services (Nanvonamuquitxo et al., 2019; Chidumayo, 2013; Maquia et al., 2013).

The Report released by the Ministry for the Coordination of Environmental Action – MICOA (2007) reveals that in 2006 alone, about 80,930 hot spots were observed in Mozambique, with the levels most comprising the Central and Northern regions, not only in terms of burned area, but also in distribution of the number of hot spots detected. According to Fernandes (2009), the province of Niassa is the one with the highest average values in terms of distribution of the number of fire outbreaks in the country. In a period of four (4) months (from June to September) of 2006 alone, 10,330 fire outbreaks were verified. In addition to this fact, the company Chikweti Forest of Niassa observed in three (3) years, (from 2010 to 2012) the occurrence of 196 fires and a burned area of 3468.35 ha in the districts of Lichinga, Lago and Sanga (Mbanze, 2013; Mbanze at al, 2013).

According to what has been exposed, the question that arises is the following: which areas are most susceptible and prone to fire in Niassa province?

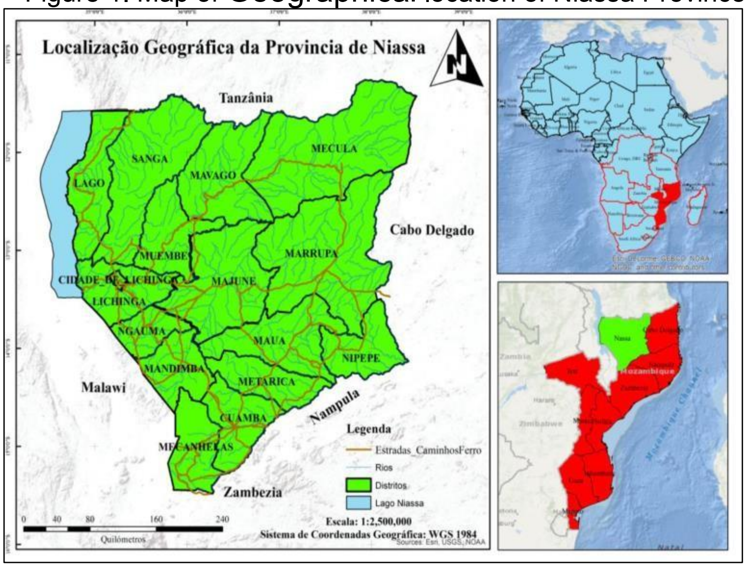
The scarcity of the study on spatial analysis of fires in Niassa means that information on the spatial variability of forest fires at the provincial level is limited, making it difficult to assess the spatial consequences after their manifestation and to know the distribution and extent of areas critical to the occurrence of forest fires. Studies related to fire analysis and susceptibility that adopt this methodology are of mere importance,

In this context, the management and assessment of fire risk and susceptibility is fundamental for fire prevention, as it allows the management of means and measures to be better organized For Soares and Batista (2007), within a prevention and combat plan, it is essential to know the danger and susceptibility indices for the occurrence of forest fires. Therefore, this study aims to prepare a forest fire susceptibility map for Niassa province, using the Geographic Information System (GIS).

MATERIAL AND METHODS

The study was carried out in Niassa province. According to the Ministry of Agriculture (MINAG, 2010), the province of Niassa, the largest in the country, with about 129 thousand km², is located in the Northwest region of Mozambique, between latitudes 11°25' North and 15°26' South and longitudes 35°58' East and 34°30' West. The province is bordered to the north by the United Republic of Tanzania, to the west by the Republic of Malawi, to the east by Cabo Delgado province, and to the south by the provinces of Nampula and Zambezia (Figure 1).

Figure 1. Map of Geographical location of Niassa Province.



Source: Authors (2024)

For the production of the fire susceptibility map, the methodology described by Julião et al. (2009) and employed by Máquina et al. (2023) was used. The variables used in the study were: climatic conditions (precipitation), topographic conditions (altitude, slope and orientation of slopes), demographic density, land use and cover, and proximity to roads.

Data on land use, precipitation and roads were obtained from the National Center for Cartography and Remote Sensing (CENACARTA) and the Provincial Geography and Cadastre Services of Niassa province. The generation of the population density map was based on data from the National Institute of Statistics (INE) referring to the 2017 population census. The topographic parameters (altitude, slope and slope orientation) were derived from the Digital Elevation Model (DEM), obtained through the modeling of data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

Thus, maps were created and reclassified according to susceptibility to fires using ArcGIS Software (ESRI) version 10.8, referring to land use and occupation, altitude, slope, slope orientation, population density (Classification adapted from Guillermo Júlio (1992), proximity to roads and precipitation. In this context, each preliminary map was obtained from the attribution of a susceptibility coefficient for each unit of susceptibility, according to a specific table for each variable.

Table 1. Criteria used to classify the variables regarding susceptibility to Forest Fires.

Land use and occupation	Orientation of Slopes	Altitude (m)	Precipitation	Population inhabitants/km2	System Road	Slope (%)	Weight	Susceptibility
Lakes and ponds; Semi-urban housing areas; Non-urbanized housing areas; Uncovered areas; Areas Industrialized	135° to 225°	1017.1 to 1996	1303,1 à 1671	< 40	3000.1 to 4000	0 – 15	1	Low
Riverine forest; Plantations; Bushes; Area Grassy Escassa	45° to 135°	742.1 to 1017	1175,1 à 1303	40 to 80	2000.1 to 3000	15 to 30	2	Moderate
Dense forest; Crops shrubs; Thicket; Pasture.	225° to 315°	512.1 to 742	1025.1 à 1175	80 to 120	1000.1 to 2000	30 to 45	3	High
Open forest; Wooded pasture; Grass area; Rainfed cultivation.	315° to 45°	33 to 512	0 to 1025	Ahh	0 – 1000	Over 45	4	Very High

Source: Authors (2024)

To this end, the Hierarchical Analysis Process Method (AHP), proposed by Saaty (2008), was selected, which consists of the creation of a pair-by-pair comparison matrix of the variables, allowing each of them to have its corresponding weight. Pairwise comparison matrices of the variables selected for the study were generated, along with the analysis of the weights assigned to these variables and the degree of consistency, as illustrated in the table below (Table 1).

Table 2. Pairwise comparison and weights assigned to each variable

Variables	Roads	Hillside	Altitude	Precipitate.	Decline	D. Dem.	UOS	Weight
Roads	0,09	0,11	0,13	0,07	0,08	0,08	0,06	9%
Hillside	0,09	0,11	0,13	0,13	0,15	0,08	0,09	11%
Altitude	0,09	0,11	0,13	0,13	0,15	0,17	0,09	12%
Precipitate.	0,09	0,11	0,13	0,13	0,15	0,17	0,19	14%
Decline	0,18	0,11	0,13	0,13	0,15	0,17	0,19	15%
D. Dem.	0,18	0,22	0,13	0,13	0,15	0,17	0,19	17%
UOS	0,27	0,22	0,25	0,25	0,15	0,17	0,19	22%
Total	1	1	1.00	1.00	1.00	1.00	1.00	1.00

Legend: Precipita. = Precipitation; D. Dem. = Demographic Density; UOS = Land Use and Occupation.
Source: The Authors (2024).

The Fire Susceptibility map was generated by combining the reclassified maps of the variables: slope, slope exposure, land use and occupation, population density, roads, altitude, and precipitation by ArcGIS through the Wighted Sum extension (ArcToolbox → Spatial Analyst Tools → Overlay). The formula used for the weighting of the variables is presented below (formula 1):

SOIF = (0,15*Dec) + (0,11*EE) + (0,12*Alt) + (0,14 *Prec) + (0,17*D. Dem) + (0.9*Est) + (0,22*UOS)

Where:

SIF: Forest Fire Susceptibility; Dec: Coefficient of susceptibility according to Slope; OE: Coefficient of susceptibility according to Slope Orientation; Alt: Coefficient of susceptibility according to altitude; Prec: Coefficient of susceptibility according to Precipitation; D. Dem: Susceptibility coefficient according to Demographic Density; Est: Coefficient of susceptibility according to Estradas; UOS: Coefficient of susceptibility according to Land Use and Occupation.

RESULTS AND DISCUSSION

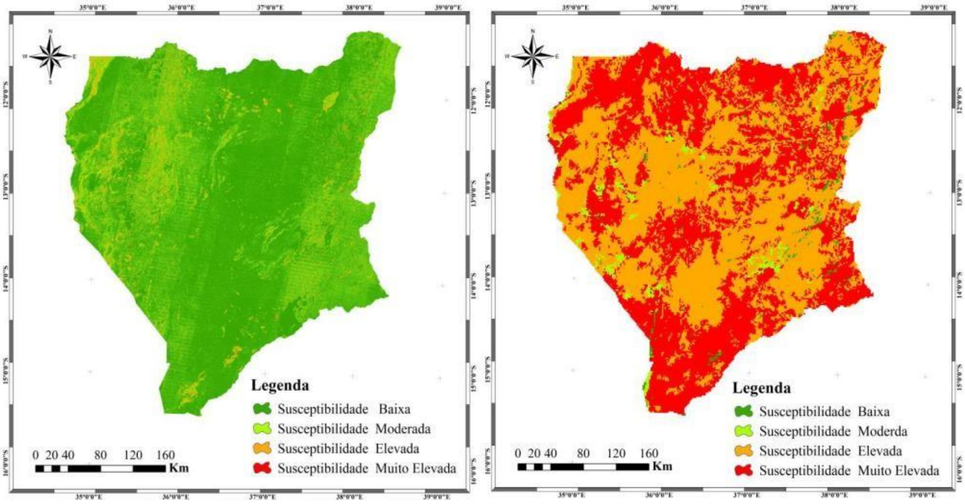
The results indicated that the factors studied, such as slope exposure, slope and land use, can significantly influence the access, propagation and extent of burning, as well as the behavior of fire.

FOREST FIRE SUSCEPTIBILITY COEFFICIENTS OF THE SELECTED WETLANDS

With regard to the slope, most of the study area has slopes between 0 to 10° and 10.1 to 20°, totaling 118,954 km² (96.9%), which implies the predominance of areas with low and moderate susceptibility to fires. Fernandes (2009), in his study, mentions that the northern region of the country concentrates smaller slopes (99.65%), corresponding to 281,376 km² of its total area, which indicates a low and moderate level of susceptibility to fires. The areas of high and very high susceptibility totaled 3,823 km² (3.1%), as shown in the figure below (Figure 2A) A steep slope tends to favor the spread of fire due to the proximity of fuel to the flames and creates situations that can facilitate or hinder the combat work of the firefighters (Correia, 2014; Nunes et al., 2015).

As for land use and occupation, areas of low susceptibility were recorded in 1,040 km² (0.8%). On the other hand, the areas with very high, high and moderate susceptibility presented the following proportions: 56,074 km² (45.7%), 63,045 km² (51.4%) and 2,487 km² (2.0%), respectively. The areas with the greatest susceptibilities are due to the high accumulation of combustible material (such as areas with grasses and forests) and to the intense anthropogenic activity (rainfed cultivation), as can be seen in the figure below (Figure 2B).

Figure 2. (A) SOIF map referring to Slope; (B) SOIF Map referring to Land Use and Occupation.



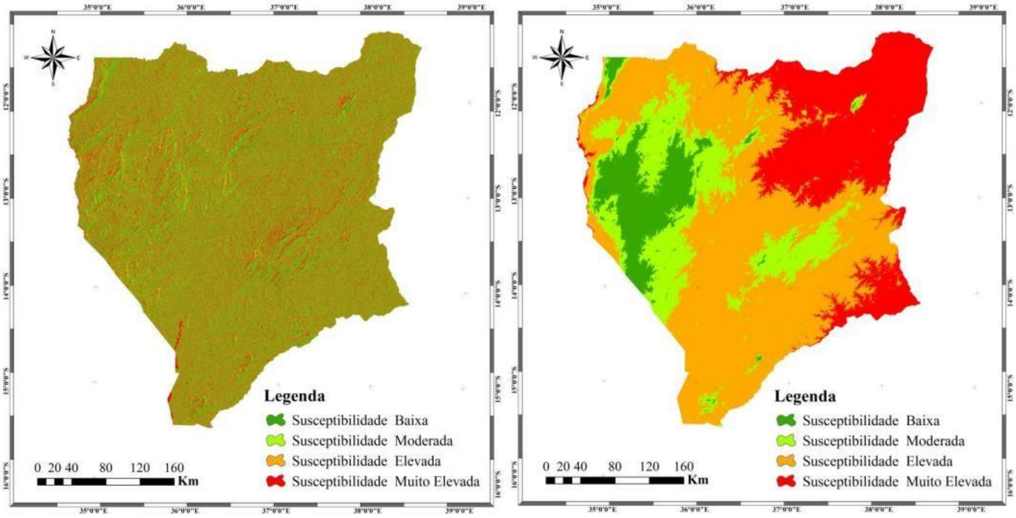
A B

Source: Authors (2024).

Regarding the orientation of the slopes, it is verified that most of the susceptibility to fires is in the low class (38.5%) occupying an area of 47,137 km2 and very high (25.9%) with an area of 31,742 km2. The moderate and high susceptibilities obtained the following results: 30,167 km2 (24.6%) and 13,478 km2 (11.0%), respectively (Figure 3A). Fernandes (2009) found that 99,652 km2 (34.8%) of the slopes in the northern regions of the country have a low risk of fire, 73,172 km2 (25.6%) are facing the northwest and west directions, which correspond to a high risk.

As for altitude, in the study area it has mostly very high susceptibility with 30,067 km2 (24.7%) and high 59,700 km2 (49.0%) followed by moderate susceptibility 20,782 km2 (17.0%) and low susceptibility 11,346 km2 (9.3%) (Figure 3B). Altitude represents a variable that influences the risk of fire due to its relationship with the relative humidity of the air (Ribeiro et al., 2008).

Figure 3. (A) SOIF map referring to Slope Orientation; (B) SOIF map referring to Altitude.



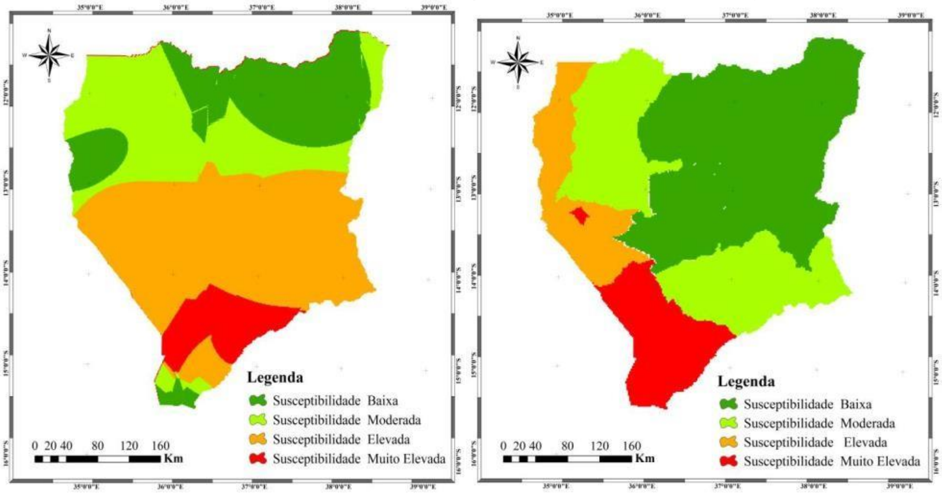
A B

Source: Authors (2024).

Regarding precipitation, the studied area has about 27,407 km2 (22%) with low susceptibility, 31,557 km2 (25.7%) moderate, 9,918 km2 (8.1%) very high and 53,858 km2 (43.9%) high (Figure 4A). According to Torres (2006) that the months with the highest rainfall are the ones that concentrate the least amount of fires, on the other hand the months with the greatest water deficit have a greater number of cases, this is due to the greater amount of water in the system, which makes the formation of dry combustible material unfeasible.

With regard to population density, it is known that the population is the main cause of forest fires due to frequent use that sometimes becomes uncontrolled. Thus, about 56,040 km2 (53.7%) correspond to low susceptibility, 17,981 km2 (17.2%) moderate. Very high susceptibility was 15,341 km2 (14.7%) and 14,900 km2 (14.3%) for high (Figure 4B). About 90% of fire occurrences are the result of human activities, related to anthropogenic causes, with arsonists and burning for land clearance for agriculture being the main causes (MICOA, 2007; Mbanze, 2013; Mbanze et al, 2013; Máquina et al., 2023; Máquina et al., 2024).

Figure 4. (A) SOIF Map for Precipitation; (B) SOIF map referring to Population Density.

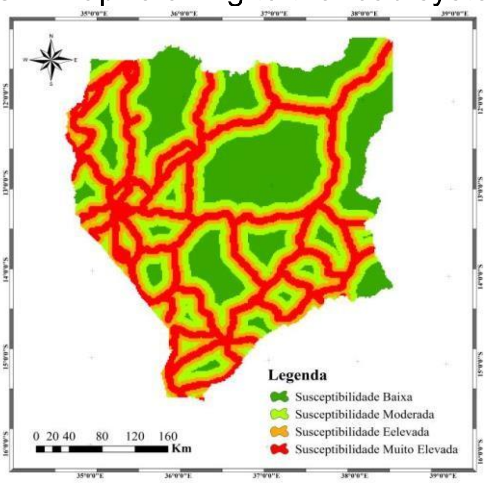


A B

Source: Authors (2024).

In the study area it has mostly unpaved roads and having vegetation in its limits, connecting the urban core and the rural area, however, the roads occupy a smaller extension of the province. Thus, low and moderate susceptibility correspond to 55,514.89 km2 (45.57%) and 37,470.55 km2 (30.76%), respectively. The high susceptibility with 19,828.37 km2 (16.28%) and, finally, the very high susceptibility with a lower value of 9,012 km2 (7.4%), as can be seen in the following figure (Figure 5).

Figure 5. SOIF map referring to the road system (Roads).



Source: The Authors (2024).

ANALYSIS OF THE VARIABLES SELECTED IN THE AHP METHOD

The highest weights were observed for land use and occupation (22%), Demographic Density (17%) and Demographic Density (15%). Ferreira et al. (2011) observed high values (higher weight) for land use and occupation, as it is the variable that most influences the degree of risk because it represents the fuel to be consumed and without fuel, there is no fire. In turn, Juvanhol et al. (2015) obtained high values in the variable demographic density, a fact observed in the present study. Studies carried out by De Oliveira et al. (2004); Ribeiro et al. (2008); Aguiar et al. (2015); Tetto et al. (2012); De Assis et al. (2014); De Assis et al. (2013); Andrade et al. (2011); Ferreira et al. (2011); Torres et al. (2014) found that the main variables that interfere in forest fires are land use and occupation, population density and slope. These findings were observed in the present study.

Table 2. Consistency Rate Calculation Results.

Matrix Valuation Indicators	Results
λmax: Vector Own	7,62
CI: Consistency Index	0,10
CR: Consistency Rate	0.08
RI: Random Consistency Indexes (tabulated)	1.32

The consistency rate was 0.08 (8%), which was lower than 0.1 (10%) according to the determination established by Saaty (2008), which was successful for the attribution of weights to the variables. Juvanhol et al. (2015) state that the consistency relationship is calculated to determine whether the evaluation was successful or not, and when less than 0.1 (10%) indicates good consistency. If it indicates inconsistency (greater than 0.1) in the comparison of pairs, it should be reassessed.

AREAS SUSCEPTIBLE TO FIRE

Applying the AHP methodology to the variables Land Use and Occupation, Slope, Altitude, Slope Orientation, Demographic Density, Proximity to Roads and Precipitation, it was possible to obtain the map of susceptibility to the occurrence of fires, whose values vary from 1 to 3.9.

Low susceptibility corresponds to an area of 2,297.2 km² (2%), while moderate susceptibility covers 56,452.89 km² (47%). The areas of high and very high susceptibility cover, respectively, 48,539.84 km² (41%) and 8,415 km² (10%).

According to the results obtained in the forest fire susceptibility map of Niassa province, it can be highlighted that the South and Northwest regions of the province have greater susceptibility to the occurrence of fires. This fact may be related to the existence of different types of land use and cover, greater population density and proximity to roads, factors that directly influence susceptibility to fires.

On the other hand, the Northeast region has low susceptibility to fires, which can be explained by the presence of watercourses, low population density, low slope and the absence of roads. Nhongo (2015) relates the existence of different types of land use and land cover to the occurrence of fires.

It is observed that the areas of very high susceptibility to fires are concentrated in the region between the City of Lichinga, districts of Chimbonila, Cuamba, Mandimba, Mechanhelas, Metarica and Ngauma. On the other hand, the districts of Majune, Marrupa, Maua, Mavago, Mecula, Muembe, Nipepe and Sanga have a high susceptibility. Arone (2002) identified the districts of Mandimba, Marrupa and Mecula as areas most affected by fires in Niassa province.

According to Batista (2000), topography modifies local climatic conditions and directly influences the type of fuel present in a region. Considering that fire behavior is largely determined by climate and available fuel, it can be inferred that topography also plays a decisive role in this behavior. In addition, the topography exerts a physical influence on the inclination of the flames, which intensifies the preheating phase of combustion. This fact is corroborated by Ribeiro et al. (2008), who state that the spread of fire in uphill areas is more intense due to the overheating of the combustible material above the fire line, caused by the greater proximity of the flames compared to flat terrain. Thus, when there is a minimum of slope, the rate of fire propagation tends to increase, and this intensification is directly proportional to the microclimatic transformations in the combustion zone.

Surfaces with different orientations and inclinations receive unequal amounts of global solar radiation compared to horizontal surfaces, even considering the same locality and time of year (Torres & Machado, 2011). This directly influences the drying of the various types of combustible material, varying according to the slope and/or inclination. However, it is not sufficient that the factors directly associated with the occurrence of forest fires are favourable to the initial ignition and spread of fire. Vulnerability can last for long periods, because for the fire to occur, the presence of an initial flame is necessary to trigger the combustion reaction.

Several authors, such as Soares and Cordeiro (1974), Soares and Santos (2002), Bonfim et al. (2003), Santos et al. (2006) and Torres et al. (2010), point out that the main cause of forest fires is anthropic activity in rural areas, manifested by different behaviors that range from simple carelessness in the use of fire to its intentional use. Máquina et al. (2024), and a study on local community participation in the management of uncontrolled fires in Mozambique, found that most respondents do not follow any procedures for burning the combustible material in their agricultural fields. Based on this, areas close to public roads and urban agglomerations tend to be more susceptible to the start of fires.

Corroborating the aforementioned authors, it was observed in this study that the areas with the highest number of fire occurrences are concentrated near urban areas. In research carried out by Torres et al. (2010), it was identified that, despite the conditions imposed by the physical environment such as slope, exposure of slopes and land use and occupation, without the presence of a causative agent (mostly of anthropic origin), there is no occurrence of fires. Thus, in any area, regardless of whether it is classified as very high or very low risk, the event will only occur in the face of a cause or an initial source of heat. Therefore, any forest fire prevention strategy must focus on eliminating their causes (Nogueira et al., 2002).

FINAL CONSIDERATIONS

The study developed on the Susceptibility to the Occurrence of Forest Fires (SOIF) in the province of Niassa allowed us to reach the following conclusions: the factors described in this study were sufficient to identify the areas susceptible to the occurrence of fires. Among these factors, the ones that most influenced were the proximity of roads, demographic density and land use and occupation. It was possible to develop a susceptibility map from the selected variables. It is important to highlight that the weights assigned to the classes within the variables, the weights attributed to the variables themselves and the method applied were crucial for the elaboration of the susceptibility map.

Regions identified as susceptible to fires include the City of Lichinga and the districts of Chimbonila, Cuamba, Mandimba, Mechanhelas, Metarica, Ngauma, Majune, Marrupa, Maua, Mavago, Mecula, Muembe, Nipepe and Sanga.

That said, it is submitted to the idea that proposed measures for the mitigation of forest fires are necessary, which should include investment in fire information policies, environmental education and awareness, and elimination or reduction of sources of spread.

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