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Spatial Analysis and Temporal Variability of Biomass Burning Using Satellite Images in Gilé National Reserve from 2004 to 2014

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Abstract: The increasing pressure on the forests ecosystem, led by the need for new areas for agricultural activities in developing regions, is the main cause of the rising occurrence of wildfires that causes damage to these ecosystems. In Mozambique, uncontrolled wildfires are one of the environmental problems, and for its damage control, combat and mitigation are needed a greater efficiency in their detection and monitoring, as the lack of information on the location and extent of burnt area affect the estimation of its real impact on the ecosystem. This study was carried out as a result of increasing burnt areas in the Gilé Nacional Reserve (GNR) between 2001 and 2002. This study aimed to analyze spatial and temporal segregation of fires using satellite images, the results show that the maximum frequency of 15 times in 10 years, corresponding to a mean fire return interval of 3.9 years, with an average of 828 annual fires, registered greatly in August and September, resulting on 229.62 km^2 of burnt area, a feature average intensity of 25.09 Mega Watts, being justified in 99% by altitude, slope, and aspect of the plot. The equation developed for the intensity of fires in the GNR is *Y=52.504430, 0.061136*Forests - 0.002052* Appearance + 0.067099*Slope + ε*.

Keywords: Spatial Analysis, Temporal Variability of Fire, Land Cover Change

1. Introduction

Forest fires are the major damage sources of forest ecosystems in developing regions, and the pressure that these areas suffer due to the need for new areas for agricultural activities has increased significantly the fires and the extension of the burnt areas [7, 26].

The occurrence of fire in various ecosystems of the earth and its effects on the environment has been a subject of discussion in scientific circles because of the need to identify their environmental impact [16, 12, 19, 20].

The World checks the aggravation of burned, due to the growth of the world population, which leads to invasion of forest areas, triggering a greater human pressure on the environment and leading to the occurrence of fires [31, 38, 46]. In this case, it is estimated that approximately 85% of sub-Saharan Africa fires that occurred each year are related to anthropological causes [22].

In Mozambique, uncontrolled fires are one of the environmental problems that concern society. The North and Centre regions are the most affected, with 73.6% of extension burnt annually, and the intensity of fires-decrease as a result of agricultural area expansion [4, 56].

In the forests (open and dense) the burned area varies from 27 to 37.6% per year, and this is compounded by the difficulty of control that is mainly related to site conditions where it occurs, such as the wind speed, the topography, and content of moisture [19, 49].

To control, combat, and mitigate the damage of biomass burning, is necessary a greater efficiency in fire detection and monitoring [12, 55]. The inadequate knowledge of the location and extent of the burnt area affects the estimation of the real impact of this in the ecosystem [1, 34].

The Gilé National Reserve (GNR) in 2001 presented about 20 fireworks assets in 100 km^2, totaling 1881 burnt recorded, in 2002 the average occurrence of fires was 30 fireworks assets per 100 km^2 and a burnt area of 9526 km^2 [49].

The occurrence of the fire (intensity, frequency, return interval) in forest ecosystems causes major changes in vegetation structure and composition, facts that, lead to forest degradation. Forest degradation observed in Mozambique is due to a combination of many factors, in which we highlight burnt resulting from the opening of, cropland fields to chase away the animals and for hunting rats [49].

Taking into account the effects and consequences of the occurrence of fires, it is important the development of methodologies for assessing, monitoring and mitigating these events [45]. As well as understanding its influence on forest degradation, but for the development of these methods is important to have data and information about their current situation [1, 16]. And, for the Gilé National Reserve, existing data relating to the system of burnt, date back to the year 2003, produced by the Provincial Services of Forest and Wildlife (SPFB) of Zambezia, to every province, there is no such data on the current situation and location for the GNR, and so the need to analyze the spatial dynamics of burnt using satellite images in the Gilé National Reserve from 2004 to 2014.

2. The Study Area and Methodology

The National Reserve of the Gilé (GNR) is situated in the north-eastern part of Zambézia Province, in the Districts of Pebane and Gilé, occupying approximately 2,861 km^2 and a buffer of 1,671 km^2. Is Limited in the areas North, West, and East by rivers Nanhope, Naivocone [18]. The GNR is the only area of conservation in Mozambique that has no human population living within it, has rock precambric with intrusions of granite and dikes of stones, the soils are sandy-textured clear and red clay, with irregular distributions and prone to erosion of rainfall [18]. Is influenced by the tropical rainy climate of savanna where the average annual rainfall varies between 800mm to 1000mm, reaching most of the time the 1200mm or even 1400mm and, concentrating between November to March or April, temperatures range from 23°C in the dry period (minimum of June) and 35.7°C (maximum October) with an annual mean varying from 24 to 26°C [18, 36].

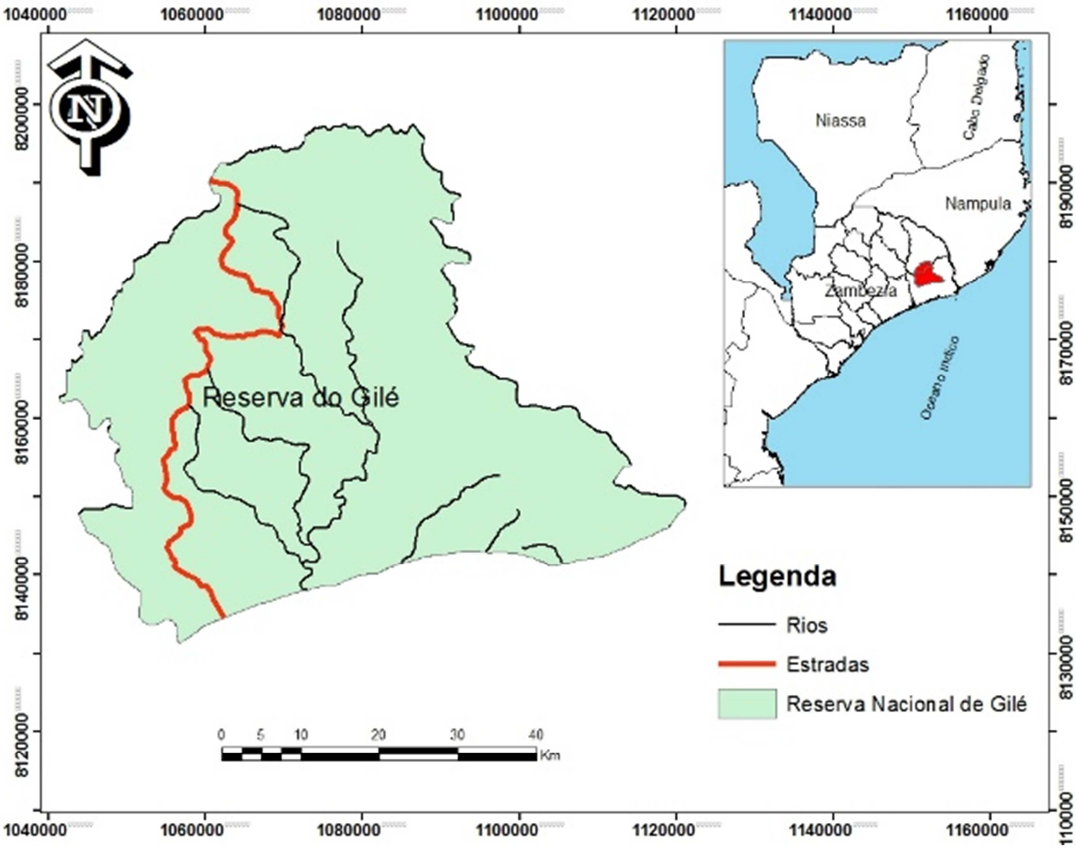

Figure 1. *Location of Study Area (National Reserve).*

2.1. Data Processing

2.1.1. MODIS Images (MCD14ML)

The determination of the intensity and density of fires in the study period (2004 to 2014) was made using the proceeds of the MODIS fireworks assets the MCD14ML correlate very well with the occurrence of fires, especially for large fires and, and the data corresponding to 10 years were downloaded free of charge at the NASA site: http://rapidfire.sci.gsfc.nasa.gov.

This product is daily on a global scale and with a spatial resolution of 1 km [24, 39].

To pre-processing the product, was based on the procedure described by, where, first was made the corrections in terms of projection, projecting them into a coordinate system UTM (*World Geodetic System*- WGS 1984, 36 S) using the geoprocessing tools of ArcGIS program for selection of study area [51, 44]. Then followed by operation *Query Builder*, have been selected the outbreaks that presented a level of confidence of detection equal or above 80%, because it avoids errors of commission related to burnt in Agricultural areas and high temperatures of soils [9, 10].

2.1.2. MODIS Images (MCD45A1)

The estimate of the burnt area, frequency, and range of mean fire return was based on product images from MODIS MCD45 on the burnt areas. The product is provided in a monthly grid of 500 meters per *pixel*. Were acquired 132 monthly images to cover the entire study period (1 January 2004 to 31 December 2014) and obtained free of charge in the format HDF-EOS at the NASA *site*: http://reverb.echo.nasa.gov [10].

Then the images MCD45A1 were transformed from HDF to Geotiff format, using the operation *date - Export Data*. Then the images followed the process of correction and projections to UTM Zone 36 S, datum WGS84 coordinates system. This process was followed by clipping of study area on the images, which was performed using tools of removing (*Spatial Analyst Tools - Extraction- Extract by Mask*). was considered burnt area only those *pixels* that were in the range of 1 to 366 Julian days, in terms of confidence of detection of burnt areas That were selected using *Spatial Analyst – Reclassify tool* [9, 10].

2.1.3. Landsat 5 and 8 Images (Sensor TM and OLI)

Satellite images used in this study were those of the Landsat series, specifically for the year 2004 and 2014 was the Landsat 5 TM (*Thematic Mapper)* and 8 OLI *(Operational Land Imager*) respectively. These were acquired free of charge on the platform that provides images of the USGS (*United States Geological Survey*), via the link http://glovis.usgs.gov/, both with a spatial resolution of 30 meters, with seven and eleven bands, respectively.

For its processing, first was made mosaic of images to cover the entire area of study, and then the delimitation of the area of interest in the two images using the ArcGIS v10.2.1, through the tool *"Extract by Mask",* and to facilitate the recognition of targets in the cropped image, were used a combination of color R4G3B2.

The next step consisted of supervised classification of the images, using the algorithm of maximum likelihood (MaxVer) in Erdas Imagine 2014. For the implementation of the classification first were collected samples of training of the classifier with the purpose to define the spectral characteristics and patterns that may allow to represent and distinguish properly the classes in the study area, having been harvested on average 70 per class of use and coverage.

This process was followed by the classification of images using the tool - *Raster Classification- Although, although the classification* in the Erdas Imagine 2014.

2.1.4. Data of Rainfall, Temperature, and Altitude

The data of temperature and precipitation were acquired for free at the WorldClim site http://www.worldclim.org/tiles.php?Zone=37, which were cropped to only represent the area of study, and in turn, were reclassified and extracted the temperature and precipitation monthly averages and yearly for a Microsoft Excel spreadsheet. It should be noted that the temperature data are available in the format t*10 (T=temperature), hence they were divided based on ten (10) to obtain the real values of temperature. The same was done for precipitation data, which are available in the form p/10 (P=precipitation), and thus, were multiplied by 10 (ten).

The data of altitude (ASTER DEM) were also acquired free of charge on the platform of NASA, http://lpdaac.usgs.gov/. These data were processed using the *Spatial Analyst Tools* extension, were generated the raster aspect of the terrain (aspect), slope.

2.2. Data Analysis

2.2.1. Frequency, Intensity, and Fire Return Interval

The characterization of fire intensity was made using the Fire Radiative Power (FRP) that represents the rate of release of radiant energy by a fire, expressed in *Mega Watts* (MW) or *KiloWatts*.

The frequency of fires is taken as the average of the number of fire events or occurrences at a given point or area during a period or period of registration, estimated using the MCD45A1, through the transformation into binary numbers (0, 1, 0=area not burnt, 1=burnt) and subsequent combination of all annual images to obtain the number of times that each pixel was affected by the outbreak, this was done in *raster calculator* in ArcGIS [39, 41, 43, 53].

The mean fire return interval is the time between two successive fires given in years [2, 52]. In which the determination of mean return interval was made using the expression:

$$IRMQ = {}^{Period\ (years)}\!/_{Frequency}$$

To understand the spatial patterns of distribution of outbreaks of fires, was made an analysis of spatial autocorrelation using Moran index, which ranges from -1 to 1, and to identify the factors that contribute in a significant way, as well as explain the intensity of fires to the study area (GNR), the Principal Component Analyse using the Regression Model with spatial effect site (when the process space is not stationary), the case of Geographical Weighted Regression (GWR), considered to be the best statistical method to analyze spatial data, assuming that the relationship between the parameters/variables measured at different locations is not constant over the whole space or ground [15]. The method of estimation of GWR is written as follows:

$$Y = \beta_0(m,n) + \beta_1(m,n)x_1 + \cdots + \beta_n(m,n)x_n + \varepsilon$$

Where Y is the dependent variable, $X1$ to Xn are independent variables, $\beta 0$ is the intercept, $\beta 1$ to βn are estimated coefficients and ε is the error random pattern, *m* and *n* are the coordinates of the data.

For the implementation of the GWR was considered as a dependent variable the intensity of fires (FRP-Fire Radiative Power) and independent the altitude, slope, and aspect (the direction of the slope).

The analysis of principal components using the Regression Model weighted Geographic in the GWR 3.2.2. First, was done a correlation analysis between the various independent variables in a study using the *Software R statistic*, not to allow the regression is carried out using independent variables. All variables with strong correlations were included in the analysis of principal components. Yet to see if there were significant differences between the years, as well as between the months in terms of intensity, burnt area, number of fire events, the Analysis of Variance (ANOVA) using 95% of confidence was made in the *R statistic* [15].

2.2.2. Changes of Use and Coverage

Made the classifications of images in land use and cover, then it was the assessment of the accuracy of the classification of the same images through the construction of an array of confusion by comparing information of reference sites (truth found in the field) with map information for a specific number of sample areas, it was later determined the Kappa index (K) as described by [13, 35], having been ranked the Kappa index according to Table 1.

Table 1. *Example of a matrix of error (matrix confusion).*

	1	2	K	Total line (ski+)
1	N11	N12	N1k	N2+
2	N21	N22	N2k	N2+
K	Ng1	Ng2	Nkk	Ng+
Total in column (n+j)	N+1	N+2	N+k	N

$$n_{i+} = \sum_{j=1}^{k} n_{ij}$$

is the number of samples classified in the category "*I*" in the classification and digital number:

$$n_{+j} = \sum_{i=1}^{k} n_{ij}$$

is the number of samples classified in category "*j*" in the set of reference data. The accuracy/Precision between the reference data and the classification digital is written using the following expressions:

$$Global\ Accuracy = \frac{\sum_{i=1}^{k} n_{ii}}{n}$$

$$Producer\ Accuracy\ j = \frac{n_{jj}}{n_{+j}}$$

$$User\ Accuracy\ i = \frac{n_{ii}}{n_{i+}}$$

$$K = \frac{n\sum_{i=1}^{k} n_{ii} - \sum_{i=1}^{k} n_{i+} n_{+i}}{n^2 - \sum_{i=1}^{k} n_{i+} n_{+i}}$$

Table 2. *Classification of the Kappa index (K).*

Kappa index	Quality of Classification
[0.00-0.20]	Poor
[0.20-0.40]	Reasonable time
[0.40-0.60]	Good
[0.60-0.80]	Very Good
[0.80-1.00]	Excellent

Assessed classification, was followed by the analysis phase of changes on use and soil cover for the period 2004 to 2014, which was made using the "*Software Idrisi taiga*" through the tool "*CROSSTAB*".

In this study, the areas that went from dense forest to open during the study period were considered as forest degradation and the passage of dense and open forest to other classes was considered deforestation.

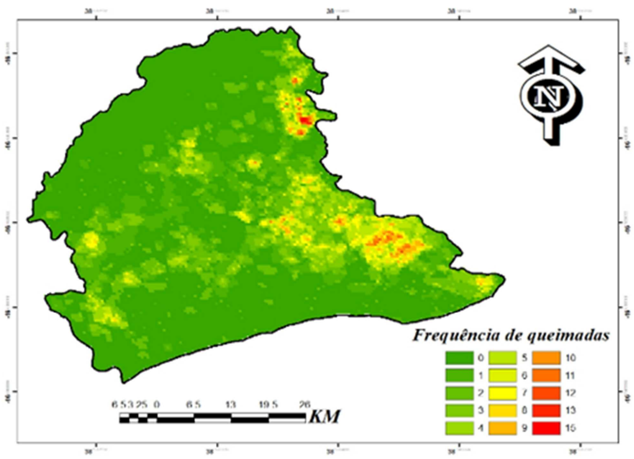

Figure 2. *Distribution of the frequency of fires in the Gilé National Reserve period (2004 to 2014).*

3. Results and Discussion

3.1. Frequency Range, Return and Intensity of Fires in the Gilé National Reserve

It should be noted that in terms of frequency of fires in the Gilé National Reserve for this period (10 years) ranged from 1 to 15 times, related to the incidence of scars throughout the period analyzed, but there were also areas in which there was no record of any burnt in the period under study as shown in Figure 2, on the spatial distribution of the frequency of fires for the period under study.

For this study, the value zero (0) presented as frequency value, represents the areas that were not burnt in 10 years of analysis, yet, within the reserve some areas have suffered burnt more than once a year, thus justifying the frequency value greater than the period under study in certain areas (the case of regions with a frequency between 11 to 15 times). And the areas occupied by each class of frequency are shown in Table 3.

Making a relationship between the distribution of the frequency of fires (Figure 2) and the distribution of average precipitation for the same period can establish the existence of an inverse relationship, being that the areas of less precipitation are the most frequently noted and vice-versa. Results of this study differ from those found in studies in the savannahs of Australia, which found a direct relationship between the frequency of fires and the precipitation, explaining that this is favoring the growth of grasses, sufficient to perform burned every year in the areas of higher rainfall and once every year in areas with lower rainfall [48].

The biggest bands in regions of lower precipitation found in this study may be related to the combined effect of the precipitation and the condition of the fuel, in which lower rainfall and higher temperatures propitiate greater availability of fuel able to burn, by reducing the moisture content of the same, since the humidity is one of the factors that may reduce the availability of material to burn (accessibility of the material) due to the "effect drowning".[1]

Table 3. *The area occupied by frequency of fires in km^2.*

Frequency	Area (m^2)	%
0 Area (not burned)	1658.35	40
1	371.22	13.4
2	307.44	10.75
3	181	6.33
4	108.32	3.79
5	84.32	2.95
6	63.42	2.22
7	33.8	1.18
8	21.859	0.77
9	14.45	0.51
10	7.12	0.25
11	4.96	0.17
12	0.86	0.03
13	1.08	0.04
15	0.65	0.02
Sum	2858.9	100.00

Analyzing the area occupied by each frequency, we can see that frequency 1 presents a greater area and the lower area is verified at a frequency 15, showing a tendency of decrease of the burnt area with the increase of the frequency. The same trend here observed was also found in a study of the savannah fires of West Africa [42].

In the period 2004 to 2014, between July to October, there were approximately 9109 active fires across GNR (Figure 3), which corresponds on average to 828 fires per year. In general, during this period there were no significant differences (P <0,768) to the number of fires between years, there was not a clear trend in terms of increase or reduction in the number of burnt, having been only fluctuations between the years.

When these fires occur with greater frequency can be a danger to the ecosystems, there may be greater mortality of trees and that can lead to a change in the composition of species, as is the case of the forests of miombo woodlands which can be converted into grassland or shrubland [32].

The spatial distribution of biomass burning in the GNR is best shown by the density of burnt per km^2, which was made for any period. The central region showed the highest concentration of burnt, around 3 to 5.6 burnt per km^2 (Figure 4). The Northern region, Southeast, and Southwest had the lowest densities/concentrations of burnt. These values differ from those found by [11] where were 20 to 30 dwellings per km^2, this difference can be explained by the density of elephants in the NNR which somehow influenced the occurrence of fires on the GNR.

1 Effect of drowning is the process of expulsion of oxygen that, to occur makes the occurrence of fire since oxygen is one of the components of the fire triangle.

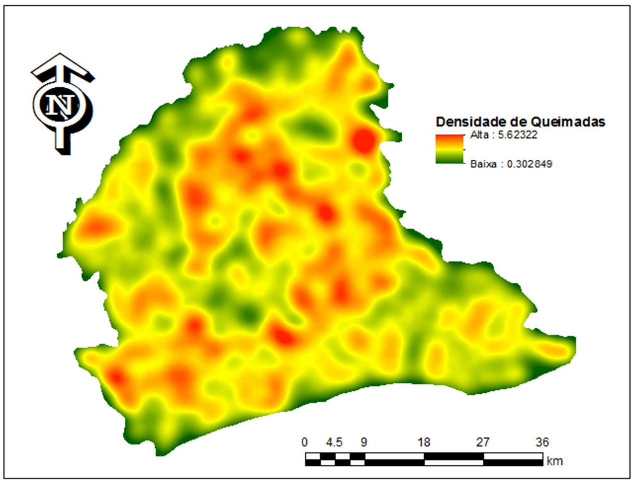

Figure 4. *The density of burnt per km^2 in the GNR.*

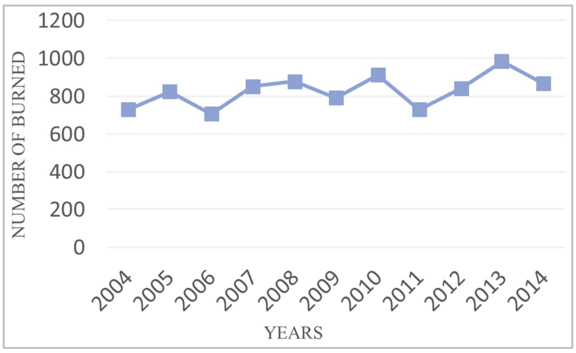

Figure 3. *The number of fires per year.*

An inverse relationship between the density of fires and the population density was found, having been increased density of fires in areas with lower population densities [33, 40]. Comparing the results of this study with other done in NNR, there is a big difference, in which for the NNR hoped that had a lower density of burnt on the GNR, once the NNR has the highest population density about GNR that presents no population to dwell therein [11, 33, 40]. The concentration of fire in the central region of the GNR can be related to the fact that the fire does not occur completely dispersed, but generally tend to be grouped, that the number of factors such as the prevention practices, characteristics of the region (the case of the distribution of vegetation) [45].

Also depending on the availability of water (through the rain), there may be the stimulation of primary production and as a result, there is an increase in the availability of fuel which is an important factor for the activity of fire [3].

In terms of the medium return interval calculated, shows that for the Gilé National Reserve, the burning return affects the same place every 3.9 years (Figure 5). These values of the mean return interval are following the intervals determined in four locations with the ecosystem of Miombo woodlands in Zambia, finding 1.6 years and 3 years for a broader region [23]. Then other studies, mapping the burnt at the Niassa National Reserve dominated by Miombo woodlands found a mean interval of 3.29 and the shortest interval of lower return was 1 year 1 [11].

The smallest interval values of return can be justified by burning from the opening of cropland because the GNR although it has the population to dwell therein, the people who live around and nearby exerts pressure on it [18].

The consequences of lower values of mean return interval were discussed by many studies, the case of studies conducted in the savannahs of Zimbabwe, which found that in areas that burnt once or twice every two years, there have been changes in vegetation structure, density, and its composition. Over 50 years with a return interval of burnt one (1) year resulted in the eradication of woody biomass at the expense of the area [37]. These events are expected to occur in the GNR in areas where they have burnt 10 times in 10 years (mean return interval-IMRQ=1) in a study if these levels of burnt still, but for the conversion of forests into grassland the period is not known.

Payback periods of less than two years (IMRQ < 2) can promote the invasion by species that are more tolerant to frequent fires about dominant species of the miombo woodlands [37]. 1-3 smaller returns even retard the development of the species of dominant trees and consequently expose the tops to the flames, thus increasing the susceptibility to fires.

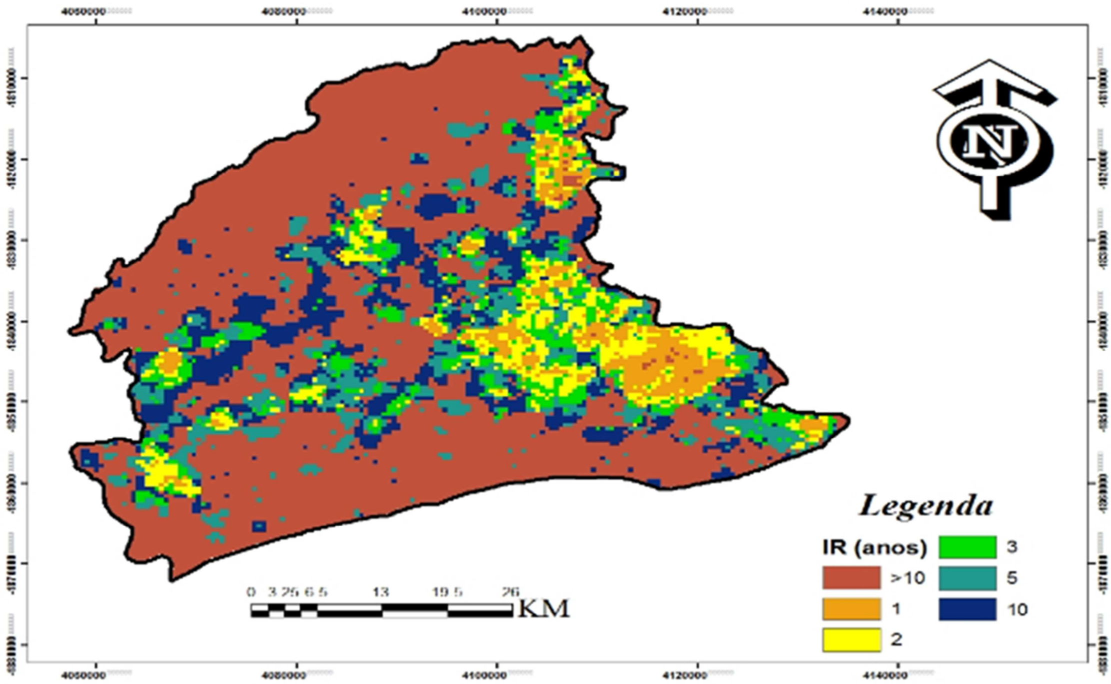

Figure 5. *Range of mean return interval in the national reserve of the Gilé.*

3.2. Seating and Seasonality of Fires in the GNR

During the period, approximately 41.99% of the Reserve has been affected by fires and 58.1% did not record any burned out. On average, 8.03 burning annually about 229.67 km^2, as illustrated in Table 4. In the NNR founded values differentiated with values with the results in this study, having observed that NNR in 12 years has burned 91% of its total area and about 14% burn annually [11]. This difference may be linked to factors such as population density, being one of the factors that influence the occurrence of fires, since the NNR has the population to dwell within it, while for the GNR their population to dwell therein.

Table 4. *Burned area per year in m2 and percentage (%).*

Year	Burned area (km^2)	%
2004	99.52	3.48
2005	518.12	18.12
2006	224.5	7.85
2007	135.49	4.74
2008	51.59	1.8
2009	353.8	12.38
2010	369.6	12.93
2011	272.23	9.52
2012	196.22	6.86
2013	239.83	8.39
2014	65.67	2.29
Average	229.67	8.03

The years 2005, 2006, 2009, 2010, and 2013 were those who had a peak area affected by fire, highlighting the year 2005, in which there was 518, 12 km^2 of burned area, which corresponds to 18.12% of the total area of GNR and, there were no significant differences (P<0,631) in the area burnt annually. But, at the same time, there were two moments in terms of burnt area, in which the first 5 (five) years the peak of the burned area was found in 2005 and then had a decreasing trend until the year 2008 (approximately 51.59 km^2). This trend came to change early in the second period in the years 2009 and 2010, which has been the peak of this period in 2010 (about 369.60 km^2).

This trend of decrease in terms of burnt area after the years of peak of burnt area is related on the one hand by the reduction on availability of material fuel to burn, which after some period, it is again available and, it is in these periods that there are peaks of burnt area.

In monthly terms, the burnt area showed a non-uniform distribution between July to October, with significant differences (P>0.0465) between them, where the minimum areas burned in July and the months of September and October were the peaks of burned areas in all years. The trend of registering peaks of the burned area during September and October was also accompanied by the registration of a greater number of fires in the same months (Figure 6). These data corroborate with the trend found in which a greater concentration of unburnt fuel in the period from July to September, with a peak in September [48].

The difference between burnt area for several months can be combined with the fact that the temperatures of winter, which runs between June and July does not favor the spread of fire, while temperatures of September and October (relatively high) have favored this spread, hence larger areas burnt during these months [3].

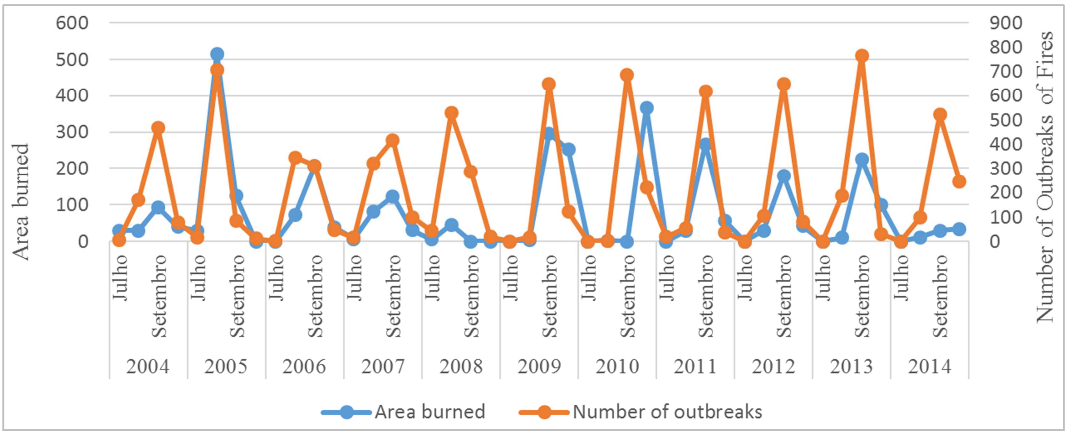

Figure 6. *Relation between the variation of annual burnt area in km^2 and the variation of annual outbreaks of fires.*

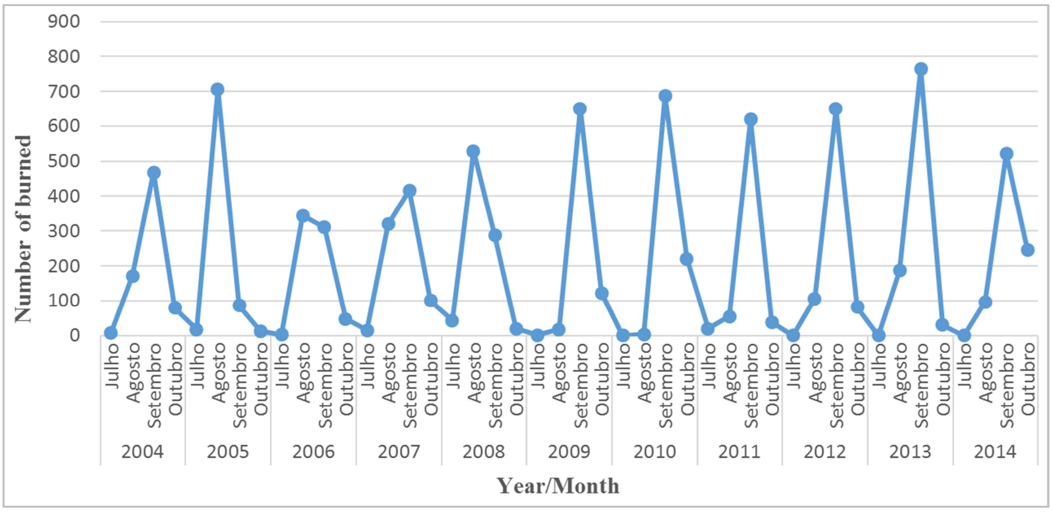

Figure 7. *Seasonality of fires in the GNR.*

In terms of the seasonality of fires within the reserve, during the period under study, there was variability in terms of months of peaks of fire occurrence but was no significant differences (P<0,768) between years. The years 2005, 2006, and 2008 had 707, 345, 529 as values of the peak number of burnt, respectively. In monthly terms, there were no significant differences (P> 3.88e-08), the case of August showed a higher number of burnt to the case of the years 2005, 2006, and 2008, while in other years the peaks were recorded in September. In general, the burning in the reserve during this period occurred between July to October (dry season).

This is similar to those found by SPFFB in the years 2001 and 2002 although, for this study, the period of fires has started earlier (July) about that found by the author cited above (August) [49]. The same was found in the Niassa National Reserve (NNR) during the period 2000 to 2012, were found a tendency of concentration of unburnt fuel from August to November [11]. A study on a global scale found the months of July, August, and September as the highest peak of occurrence of fires [25].

For the whole period, from November to June, corresponding wet and dry seasons, respectively, are the least burnt there, coinciding with the facts reported with Cangela and SPFFB [11, 49].

The high records of fires in August and September may be the result of the combined effect of the high maximum temperatures and low precipitation (sometimes without precipitation) in recent months, as well as strong winds [3].

3.2.1. Intensity of Burned

The average intensity for the study period of 10 years was 25.09 Megawatts, the peak was 477,287 megawatts registered in August 2006 and the minimum was 12.1 megawatts (Figure 8), in which there were no significant differences between the months and years (P<0,378, P<0,332, respectively). The behavior of fires tended to have homogeneous, although, there has been registration of intensities outside the normal for the year 2006, particularly in July (Figure 9).

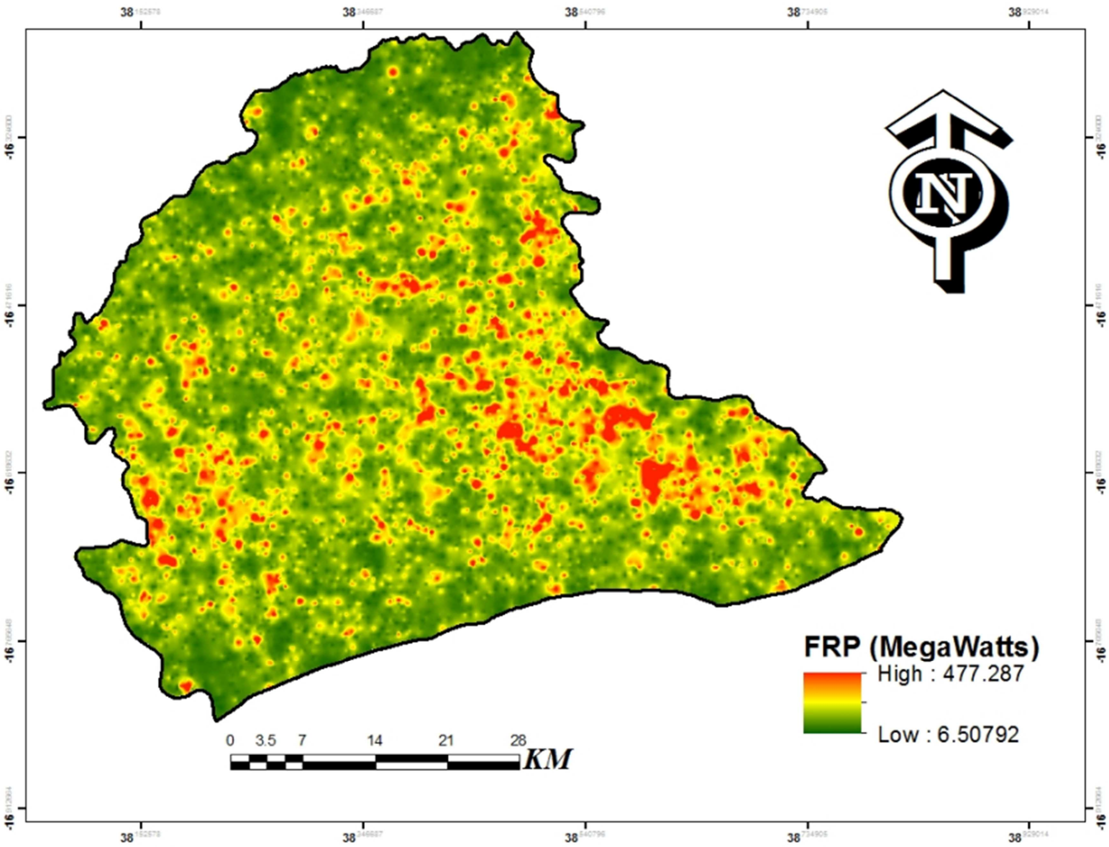

Figure 8. *The intensity of burnt (FRP) in the national reserve of the Gilé from 2004 to 2014.*

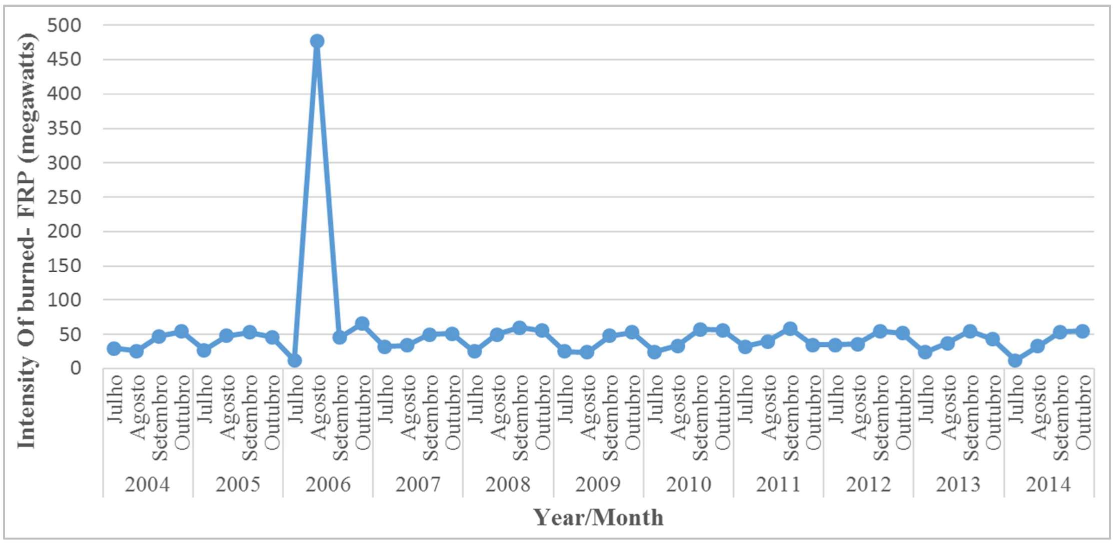

Figure 9. *Distribution within the intensity of burnt (FRP) in the national reserve of the Gilé from 2004 to 2014.*

The high intensities were checked in the central and east region which also showed a higher density of burnt and increased frequency of fires. In the case of a forest reserve, and that the vegetation is one of the main factors if not the most important for the maintenance of wildlife and, if these facts remain in the same magnitude, we will be able to see committed the objectives for which the GNR was established, since, in tropical forests, a single fire can reduce the richness of species of woody plants in one third to two thirds and, depending on the severity of the fire can be negative impacts on a wide range of components of the fauna [8].

A study in NNR found an inverse relationship between the density of burning with the intensity, finding the greater intensity of fires in regions with lower density and, justifying this as a result of increased biomass accumulation due to infrequent burned, hence during the passage of the fire occur larger emission rate of heat [11].

But, for this study, the peak intensity occurred in August 2006 may be coupled with the availability of fuel material to burn at the beginning of the rainy season, coupled with the considerable low humidity of vegetation in this period, which resulted in a greater intensity to these burnt [28]. The intensity and the destructive capacity of burnt tend to increase at the end of the dry season and the beginning of the rainy season (from August to November) [54]. When the Miombo woodlands are exposed to these fires, the species composition may change, and exposure to repetitive intense burning at the end of the dry season possibly can be fully converted into pasture, with few trees tolerant to fire [5, 7, 17].

The savannahs of South Africa has found an intensity above 3000 kW/m, and found also significant differences in intensity between the burning of winter and summer, explaining the difference in humidity between the two seasons and found an average of 2314 kW/m and 1225 kW/m in the winter and summer, respectively, and for this study, the intensities for the GNR were on average 25.09 Mega Watts (Medium to High Strength), that indicates the occurrence of fires of medium intensity, although, some months there is registration of high intensities (above 40 Mega Watts), according to the classification of intensities [25, 28, 29].

Usually, the low intensities (15 MegaWatts) of burnt (FRP) are associated with areas with forest cover dense, while the larger (40 MegaWatts) tend to occur in areas of pasture. The low levels in tropical forests are due to high levels of moisture content of fuels, not allowing the occurrence of fires [25].

3.2.2. Factors Affecting the Intensity of Fires in the Gilé National Reserve (GNR)

As a way to understand the factors that influence the intensity of fires, the regression analysis using the logistic regression weighted geographically was performed, in which was considered as independent variables of the model the altitude, slope, and aspect. The type of Geographically Weighted Regression (GWR) Performed was kernel adaptive biquadrate, applying the model the dependent variable the FRP, and three independent variables the altitude, slope, and aspect.

Table 5. *Results of the GWR Regression (Geographically weighted) for intensity (FRP).*

Variable	Average	STD
Intercept	52.504430	0.005708
Altitude	-0.061136	0.000007
Aspect	-0.002052	0.000000
Slope	-0.067099	0.000007
R2	0.999998	
Adjusted R2	0.999997	

The R^2 and R^2 adjusted obtained using the model GWR was 0.999998 and 0.999997, respectively, showing a good adjustment of the model, these results may be hostages of the behavior more efficiently the model GWR since it considers all spatial variations of the relations between the variables thus getting local parameters that reflect the closest to the influence of independent variables of the model in the dependent variable [30]. Similar results were found in a study on the spatial and temporal dynamics of burnt, which noticed a strong relationship between the intensity of fires (FRP) with the appearance of the terrain, slope, and values of forests [27].

With an adjusted R^2 of 0.99, these results show that about 99% of the variation in the intensity of fires in the Gilé National Reserve (GNR) is because of variations in altitude, slope, and aspect, and 0.01% are due to other factors which were not possible to evaluate in this study.

According to Table 5, the intercept (βo), has an average of 52.50, which means that when we consider at all independent variables (altitude, slope, and aspect) are equal to zero (zero), the value of intensity remains positive. The GWR model estimated for the intensity of fires (FRP) in the national reserve of the Gilé is:

$$Y = 52{,}504430 - 0{,}061136 * Altitude - 0{,}002052 * Aspecto + 0{,}067099 * Declive + \varepsilon$$

Table 6. *Analysis of variance (ANOVA) of the GWR Regression (Geographically weighted).*

Source	SS	DF	MS	F
OLS Residuals (Global)	21050963.513	9195.000		
Improved GWR	21050924.703	3047.331	6907.988	
Residuals of GWR	38.810	6147.669	0.006	1094254.74326

The F-test value shown in Table 6, indicates a relationship non-stationary between the dependent variable and the independent variables that are to say that relations between these variables are not constant in space, showing that this made the best adjustment to the GWR method (local and non-stationary) when compared to the OLS method (global and stationary). Similar results were found by other studies, which have also found high values of the *Fisher test (F),* proving the relationship non-stationary between the variables and showing a better adjustment of GWR than OLS [29].

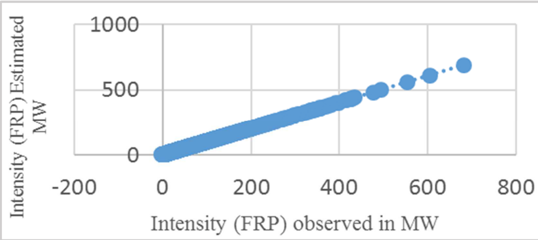

Figure 10. *Data dispersion of intensity as estimated by GWR model and observed (MODIS PRODUCT MCD14).*

Figure 10 shows the dispersion of data of intensity observed and estimated by the GWR method, showing a good relationship with the data MODIS MCD14, specifically the data intensity (FRP) and the estimated using the model GWR, with the coefficient of determination set in a suit of 0.99 (99%).

3.3. Land Use and Land Cover Changes in the GNR

The estimate of changes of use and soil cover in the Gilé National Reserve was performed using images from the Landsat series, namely the sensor TM and OLI (Landsat 5 and Landsat 8, respectively). Were found five (5) classes of coverage, being the dense forest, open forest, Rocky expanses, exposed soil, and water bodies. These classes of coverage were found for the two years (2004 and 2014) as shown in figures 11 and 12.

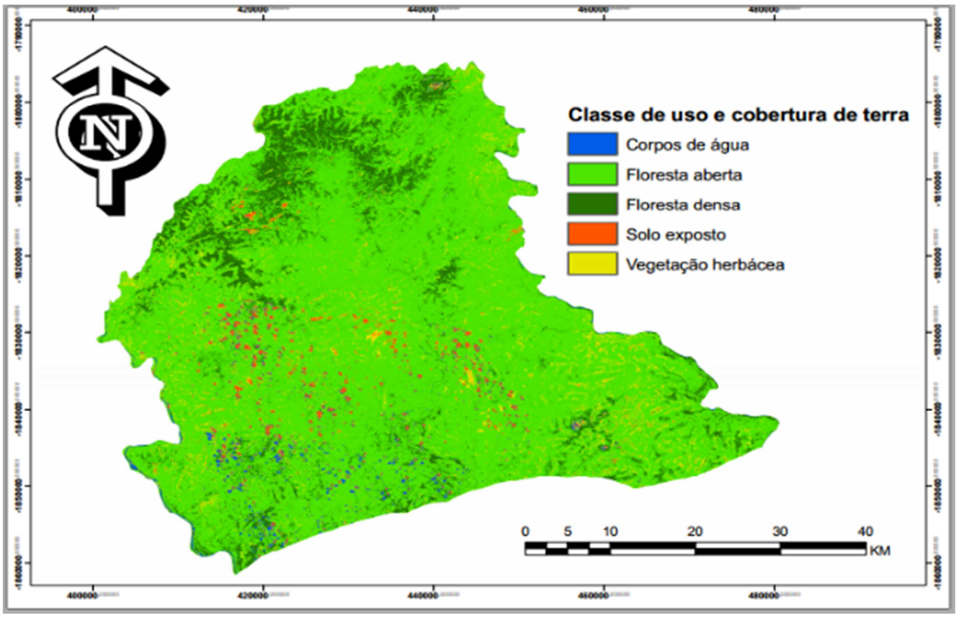

Figure 11. *Types of soil cover in the Gilé National Reserve for the year 2004.*

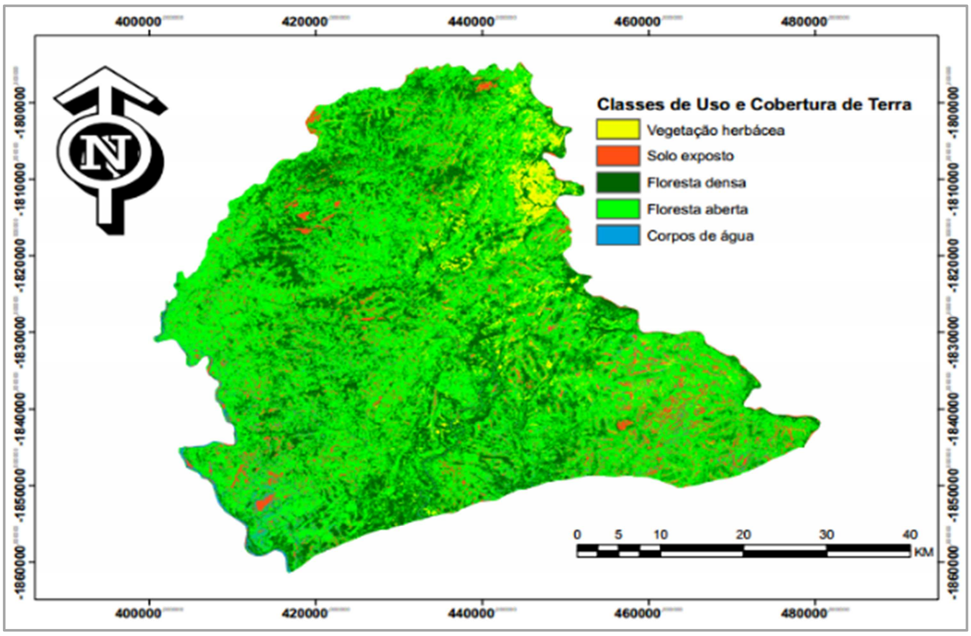

Figure 12. *Types of soil cover in the Gilé National Reserve for the year 2014.*

Table 7. *Areas occupied by each class of land usage of the GNR for the year 2004.*

C. of Coverage	Area (m^2)	%
Bodies of water (CA)	41.698	1.47
Herbaceous vegetation (VH)	184.90	6.52
Dense Forest (FD)	44.09	1.55
Open Forest (FA)	2253.22	79.39
Exposed soil (IF)	314.07	11.07

Table 8. *Areas occupied by each class of land usage of the GNR for the year 2014.*

Class of Coverage	Area (m^2)	%
Bodies of water (CA)	47	0.91
Herbaceous vegetation (VH)	133.56	4.77
Dense Forest (FD)	729.37	26.05
Open Forest (FA)	1713.18	0
Exposed soil (IF)	198.70	7.01

Tables 7 and 8 show the areas occupied by each use in percentage and m^2.

In the year 2004, the largest area of the GNR was occupied by open forest, followed by dense forest, herbaceous vegetation, and exposed soil occupying approximately 2215.27, 314.07, 181, 90, and 44.09 m^2, respectively. And the class of use and coverage with the smaller area where the water bodies occupy 41.81 m^2. For the year 2014, the uses that appeared with greater emphasis were the open forest, dense forest, exposed soil, herbaceous vegetation, and the lesser highlights were the bodies of water, corresponding to 1713.56, 729.37, 106.9, 133.56, 25.35%, respectively.

The changes on use and soil cover were estimated using the "*Software Idrisi taiga*" was used the tool "*CROSSTAB*" and, to improve the perception of the spatial dynamics of changes on use and coverage in the Gilé National Reserve, generated matrix of changes for each class of coverage (Figure 9).

Table 2. *The array of changes of Land Use and Land Cover Changes for the Gilé National Reserve in the period 2004 to 2014.*

		Coverage of the reference year					
		CA	VH	If	FA	FD	Total (m^2)
Current Cover	CA	3.88	16	1.18	2.33	2.23	47
	VH	0.93	19.29	1.32	120	1.40	133.56
	If	9.32	74.30	12.89	99.32	2.87	106.9
	FA	7	63.81	19.64	1474.76	136.65	1713.18
	FD	9.96	12.42	10.32	528.24	170.92	729.37
	Sum (m^2)	41.81	184.9	44,087	2253.22	314.07	2800.16

By analyzing the changes of use and coverage for the GNR in the period 2004 to 2014 it is possible to notice that in terms of maintenance, the CA, VH, IF, FA, and FD showed 3.88, 19.29, 12.89, 1474.76, 170.92 km^2, respectively. The use that has a greater reduction was the open forest (FA) which initially (the year 2004) occupied an area of 2253.22 m^2, but in 2014 it was 1713.18 m^2, which corresponds to a reduction of 502.09 km^2.

In terms of gain, the highlight goes to the dense forest, which became 314.07 km^2 in 2004 for the approximately 729.37 km^2 in 2014, representing an increase in 415.30 km^2. The largest contribution to this increase in the dense forest is coming from open forest, with a passage from open to dense about 528.24 km^2.

In this period, the GNR was about 218.77 km^2 deforested and 136.617 km^2 that have suffered degradation, and the continuation of these events can lead to irreversible loss of vegetation and the fauna.

Making the relationship between the changes of use and coverage in the GNR with the frequency and range of mean return interval of fire, it can be noted that areas with less frequency and range of higher return, had gained more dense forest at the expense of loss of open forest, and to the regions of higher frequency and shorter interval of the mean return of burned, having been small passages from dense to open forest, but there was a significant increase in the areas covered by herbaceous vegetation and exposed soil.

The increase in areas of dense forest was due to the non-existence or low frequency of disorders (burnt), which has favored the development of the forest, leading to the closure of the canopy. While the replacement of open forest, as well as the dense herbaceous vegetation, was the result of the biggest disturbances by frequent and intense burning, which led to the elimination of areas with forest cover (dense and open forest), thus giving space to this vegetation (regeneration).

Thus, it is possible to observe that these fires have a significant contribution to the changes of use and soil cover in the Gilé National Reserve (GNR).

To assess the accuracy of the classification of Land Use and Land Cover (LULC) for the years 2004 and 2014, regarding the Gilé National Reserve, was used the Kappa index (K), which considering the classification presented in Table 6, is excellent [13]. The accuracy was approximately 89.11% probability that the classes of LULC shown in Figure 12 (of the image Landsat 8) corresponds to the truth of the Gilé National Reserve.

The Kappa index that expresses the quality or perfection of classification was 81.23%. These values of the indices are in the same magnitude as the values found with other studies, were found 71, 82.26 to 94.08, 80.17 to 87.77 and 87%, respectively, which considered these values of statistical indices for the validation of the classification as satisfactory/good [6, 14, 47, 50].

Table 10. Confusion matrix for validation of the classification.

Current	References					
	CA	VH	If	FA	FD	Total
CA	0	0	0	0	0	0
VH	2	10	1	0	0	13
If	0	0	2	0	0	2
FA	0	0	0	24	3	27
FD	0	0	0	5	54	59
Total	2	10	3	29	57	101
				Kappa index (K) 0.8123		

4. Conclusions

With this work aimed to analyze spatial and temporal segregation of fire using images satellites in the Gilé National Reserve in the period between 2004 and 2014, the conclusion is the following:

The fire of GNR is characterized by a high frequency of fires, presented an average frequency of 4 times a year, a range of mean return of 3.9 years. In every period the GNR was affected by fires in about 41.99% of its total length.

The GNR is on average 828 fires per year, burning on average each year 8.03%, approximately 229.67 square kilometers (km^2). As for the years included in the study period, there were no significant differences in terms of area burnt.

The largest registration of fire was verified in August and September and the biggest areas during September and October; the largest areas are the result of the combined effect of the high maximum temperatures and low precipitation (sometimes without precipitation) in recent months, as well as strong winds.

The Burnings that are recorded in the GNR are of medium intensity, with variations for high intensity (from 40 Megawatts), recording an average of 25.09 megawatts, with no significant differences between the months, as well as between the years. This intensity of fires is justified in approximately 99% by altitude, slope, and aspect of the plot.

The GNR presents five types of coverage, with a focus on the dense forest, open forest, herbaceous formation, exposed soil, and water bodies. The GNR has the highest loss of open forest, but also an increase in dense forest, where deforestation is 218.77 km^2 and degradation is 136.65 km^2.

The frequency of fires influences changes in use and soil cover in the GNR.

5. Recommendations

For the academic community, it is recommended to carry out other complementary studies to assess the effect of these fires on forest degradation, as well as a thorough investigation of the factors that contribute to the occurrence, density, as well as seasonality of fires in GNR.

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