Revista GEOGRÁFICA VENEZOLANA
Volumen 61(2)2020 julio-diciembre
ISSNe 2244-8853 ISSNp 1012-1617
RECIBIDO: enero, 2019. **ACEPTADO**: julio, 2019
pp. 348-359

Uso de GIS para delimitar áreas

con clima homogéneo en estudios de incendios en plantaciones de eucaliptus

Using GIS for delimitation of areas with homogeneous climate for wildfire study in eucalyptus plantations

Fernando Coelho Eugenio[1]

Alexandre Rosa dos Santos[2]

Beatriz Duguy Pedra[3]

José Eduardo Macedo Pezzopane[2]

Lima Deleon Martins[4]

Cássio Carlette Thiengo[2]

1 Universidade Federal de Santa Maria (UFSM), Cachoeira do Sul (RS), Brasil
2 Universidade Federal de Espírito Santo (UFES), Programa de Postgrado en Ciências Florestais, Espírito Santo, Brasil
3 Universidad de Barcelona (UB), Departamento de Biologia Evolutiva, Ecología y Ciencias Ambientales, Barcelona, España
4 Universidade Federal de Espirito Santo (UFES), Programa de Postgrado en Producción Vegetal, Espírito Santo, Brasil
fernando.eugenio@ufsm.br; mundogeomatica@yahoo.com.br / pezzopane2007@yahoo.com.br; bduguy@ub.edu; deleon_lima@hotmail.com

Resumo

O objetivo deste trabalho foi realizar um estudo de caso sobre a metodologia de delimitação de áreas com clima homogêneo em plantações de eucalipto para investigação de incêndios florestais. Para melhor entendimento das metodologias utilizadas, a pesquisa foi dividida em seis etapas: 1) definição da área de estudo e preparação dos dados; 2) cálculo do balanço hídrico; 3) análise de agrupamento hierárquico; 4) validação do agrupamento hierárquico; 5) espacialização da classificação climática através da área de cobertura das estações agrupadas, e 6) análise do regime de incêndios florestais, regime temporal e regime espacial. A análise dos resultados permitiu verificar que existen três subzonas climáticas diferentes que geram três regimes distintos de incêndios florestais.
PALABRAS CHAVE: geotecnología; incêndio florestal; estatisticas; Brasil.

Abstract

This work aims at carrying out a case study about the methodology towards the delimitation of areas with a homogeneous climate in eucalyptus plantations for wildfire studies. For a better understanding of the methodologies used, the investigation was divided into six stages: 1) definition of the study area and data preparation; 2) calculation of the water balance; 3) hierarchical grouping analysis; 4) validation of the hierarchical grouping; 5) spatialization of the climatic classification through the area of coverage of the grouped stations and 6) analysis of the wildfire regime, time regime and space regime. The analysis of the results allowed to verify that there are three different climatic subzones, which generate three different wildfire regimes.
KEY WORDS: geotechnolgy; forest fire; statistics; Brazil.

1. Introduction

The analysis of a series of meteorological elements allows the identification of trends or changes in climate at local or regional scales. This analysis is a fundamental part for the planning of actions in various sectors of the economy, among them, the agricultural sector and especially the forestry sector stands out.

Within the forest sector, one of the major problems faced are theft and fires, which have always been recurring in eucalyptus plantations in the southeast coast of Brazil. Highlighting the economic part, the losses with wildfires in planted forests are high, so understanding the climate in order to understand the behavior and profile of wildfires that occur in the region is an integral part of the action plans traced by companies and researchers.

Among the types of climatic classification, the empirical analysis, according to Vianello & Alves (2012), focuses on the climatic configuration of the region based on a climatic element or on a combination of several of them. Specifically, in the cases of wildfires, it is necessary to have the combination of the more significant elements in the light of this purpose.

Aiming at the determining of areas with homogeneous climate, the following question emerges: how is it possible to group meteorological stations? There are several studies on grouping techniques. Hair *et al.* (2009) and Ferreira (2011) analyze such techniques as hierarchical and non-hierarchical. Fundamentally, the difference between them consists of the previous determination -or not- of the number (clusters), being the non-hierarchical the pre-determiner of the number of clusters.

Within the universe of non-hierarchical techniques, the *k-means* method is the most common, being used as a criterion cluster, the centroid of each cluster. André *et al.* (2008), Dourado *et al.* (2013) and Uda *et al.* (2015) have made in their works a grouping analysis by means of the non-hierarchical *k-means* classification method.

Rao & Srinivas (2006), on the other hand, report that in the hierarchical technique there are several criteria of grouping, being the most common: the nearest neighbor, the most distant neighbor, and Ward method. According to Ferreira (2011), Ward method (1963), also known as 'method of increment of the sums of squares', is based on the analysis of variance. Therefore, the sums of squares between and within groups, relative to variables, are used as grouping criteria.

Rencher (2002), when analyzing several studies, affirms that the Ward's and the average link methods have the best performances. Some works that used the hierarchical technique for the grouping of stations and for the definition of homogeneous areas stand out, among them the work of Diniz (2002), Unal *et al.* (2003), Fechine & Galvincio (2008), Machado *et al.* (2010), Souza *et al.* (2012).

Unal *et al.* (2003) carried out a study towards the redefinition of the climate zones of Turkey and concluded that the Ward method obtained the best result. Fechine & Galvincio (2008), in their turn, determined the homogeneous regions for rainfall in the Brigida river basin, Pernambuco's semi-arid, in the years comprised between 1964 and 2006, using Ward's agglomerative hierarchical method. Souza *et al.* (2012) were also equipped with grouping analysis by this method, with the objective of investigating the climate of the State of Mato Grosso do Sul, based on the time series of air temperature and rainfall.

In view of what has been presented above, this work aims carrying out a case study about the methodology towards the delimitation of areas with a homogeneous climate in eucalyptus plantations for wildfires studies in southeast coast in Brazil.

2. Material and methods

The case study was carried out in a region with high number of eucalyptus plantation and, for a better understanding of the methodologies used, the investigation was divided into five stages: 1) definition of the study area and data preparation; 2) calculation of the water balance; 3) hierarchical grouping analysis; 4) validation of the hierarchical grouping; 5) spatialization of the climatic classification through the area of coverage of the grouped stations and 6) analysis of the wildfire regime, temporal regime and spacial regime.

2.1 Stage 1. Defining the area of the case study and data preparation

The study area corresponds southeast coast of Brazil, more specifically to the Central-North coast of the state of Espírito Santo and the south coast of Bahia, entering 70km to the mainland, between the coordinates located between the latitudes of 16° 26’ 57”S and 20° 49’ 27” S; and longitudes of 39° 07’ 13”W and 40° 55’ 09” W. The 70 km range was defined by the means of the analysis of the sites with the highest incidence of wildfires in the region.

The meteorological data were collected during the period comprised between January 1st 2010 and June 31st 2015 in the 26 meteorological stations. Although the data series is short, it is the only one with all the data for the study area and is believed to represent the climatic conditions, allowing a significant relationship between weather and fire, therefore, it is believed that enough to relate weather data to wildfire.

Due to the use of variables with different orders of magnitude, average monthly air temperature (°C), average monthly rainfall (mm), average monthly relative humidity (%) and average monthly water deficit (mm), there was a need for standardization of the data, which consisted in the subtraction of the data by the average and later division by the standard deviation. It should be noted that the choice of the four variables mentioned above is directly correlated with the different fire risk methodologies, since they are the variables most often used to calculate the fire risk.

2.2 Stage 2. Calculation of the water balance

These data were used in the elaboration of the climatological water balance, using the method of Thornthwaite and Mather (1955), through the program ‘BHnorm’ elaborated by Rolim *et al.* (1998). For the available water capacity (CAD), the value of 100mm was used and potential evapotranspiration (ETP) was estimated by the Thornthwaite method (1948).

The water balance provides estimates of real evapotranspiration (ETR), of the water deficit (DEF), of the water surplus (EXC) and of the soil water storage (MRA) for each month of the year.

2.3 Stage 3. Hierarchical grouping analysis

The grouping analysis was performed by means of the Ward method, which is based on group formation, minimizing the dissimilarity, or minimizing the total sums of squares within groups, also known as square sum of deviations (SQD). For the application of the method, the computational application IBM SPSS Statistics 22 was used, which produces as one of its results the dendrogram for the grouping.

2.4 Stage 4. Group Validation

The grouping validation was performed using the Coefficient of Cophenetic Correlation (CCC) proposed by Sokal & Rohlf (1962). The CCC measures the degree of preservation of the distances paired by the dendrogram resulting from the grouping in relation to the original distances (Sneath & Sokal, 1973, apud, Ferreira, 2011). The CCC has a variation between 0 and 1, and the upper end of the scale represents the maximum similarity, that is, lower distortion caused by the grouping.

2.5 Stage 5. Spatialisation of the climatic classification through the area of coverage of the grouped stations

The area of coverage of each station was defined by means of the polygon techniques of Thiessen, which assigns a proportional weighting value to the area of influence (Bertoni & Tucci, 2001). The ArcGIS 10.2 software was used to spatialize the coverage areas of each station present in the study area. Finally, the grouping of the stations was carried out through the union of the areas of coverage of the stations that presented the same weather in Stage 03.

2.6 Stage 6. Analysis of the wildfire regime, temporal regime and spacial regime

2.6.1 Analysis of the wildfire regime

The analysis of the wildfire regime in the study area was divided into three important aspects: temporal, spatial and causal.

The statistical analysis of the return period was performed using the IBM SPSS Statistics 22 computational application. The bivariate analysis was performed by Pearson's coefficient and its interpretation based on Cohen (1988), which considers as low correlation the values comprised between 0.1 and 0.29; average correlation, the results between 0.3 and 0.49; and high correlation, the occurrences between 0.5 and 1.0. The analysis of the cross-correlation between wildfires (monthly burned area and monthly number of fires) was related to the climatic conditions of the year using regional climatic data (average data for the study area), being defined as the return period 6 months, since the database is only 5 years old.

2.6.2 Temporal regime

The data on the occurrences of wildfires and burned areas within each of the three subzones delimited by Eugenio (2017) were added according to the month of occurrence in order to identify the time of occurrence. After the sum, the average and the deviations were calculated since the months of July and August had not completed 5 full years.

In order to verify whether or not there is grouping of occurrences by the months, the hierarchical cluster algorithm (with predefinition of two clusters) was used in order to indicate if the month is present or not at the time of occurrence of wildfires. This part of the study was performed with the help of the IBM SPSS Statistics 22 computational application.

It was also sought to understand the behavior of wildfires within the daily perspective, in order to verify the day that presents a higher incidence; for that purpose, the grouping of the occurrences was done by the days of the week. In order to obtain a better understanding of the time of greatest incidence of occurrence of wildfires, the occurrence grouping was done through its hourly distribution.

2.6.3 Spacial regime

The data for burned areas were grouped according to what is proposed by Ramsey & Higgins (1981), in five size classes, being: I) up to 0.1 ha; II) from 0.1 to 4.0 ha; III) from 4.1 to 40.0 ha; IV) from 40.1 to 200.0 ha; and V) more than 200.0 ha.

3. Results and discussion

The dendrogram have three groups of meteorological stations in the study area, with 9, 6 and 11 stations in each subzone. This arrangement is validated by means of the value obtained from the cophenetic correlation coefficient, CCC = 0.832, so it is possible to say that there are 3 climatic subzones in the study area.

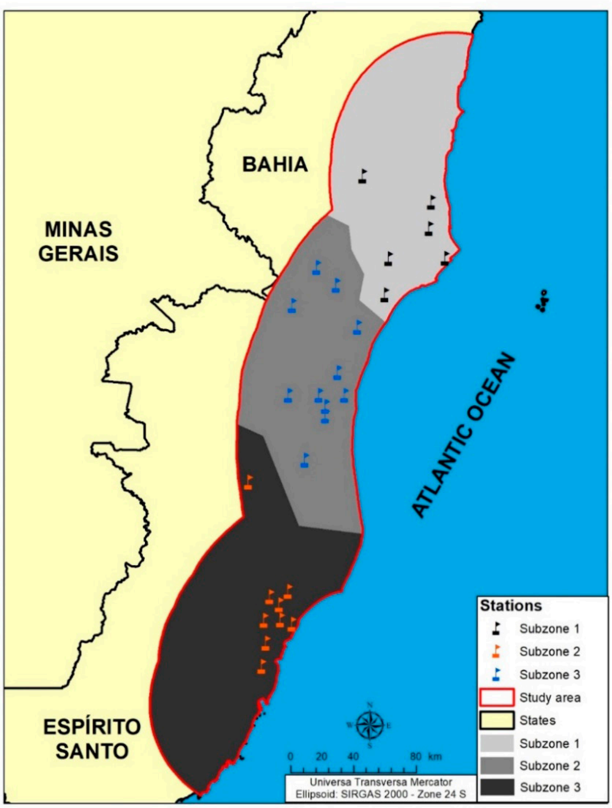
Many authors use the Thiessen polygons to represent the area covered by each meteorological station, among which stand out the works of Singla *et al.* (2014) and Chang *et al.* (2014). After analyzing the area covered by each station and for better visualization of the spatial arrangement of the three subzones, the study area was mapped with the stations and their areas of coverage - that were already groupe (FIGURE 1).

It's observed that the grouping made by the *Ward* method originated clusters of neighboring stations, with the stations present in the North portion of the study area, in the border region of the states of Bahia and Espírito Santo and in the South portion of the study area.

The results corroborate those presented by Dourado *et al.* (2013) that analyzed the homogeneous zones in rainfall time series between 1981 and 2010 on the state of Bahia and reported that the stations located in the southern region of Bahia belong to the same cluster, characterized by drier subzones.

Another study that meets the data that is hereby demonstrated is the work of Alvares *et al.* (2013), which produced in their study the climatic classification of Köppen for the whole of Brazil, with resolution of 1 hectare. This study was carried out with data from climatic seasons comprised between the years of 1950 and 1990. The analysis of the work of these authors shows three types of

FIGURE 1 Spatial distribution of meteorological stations and climatic subzones after clustering
SOURCE: THE AUTHORS



climate in the region studied: a) on the North Coast of the study area there is a predominance of climate Af (Tropical Humid Climate); b) the climate Am (Monsoon Climate) appears more inwards in the continent, in the northern portion of the study area and to the south it inverts, covering all the Coast; and c) the climate Aw (Tropical Climate with dry season of summer) dominates the Continental region in the southern region of the study area.

It is important to note that the study by Alvares *et al.* (2013) corroborates the present work, thus supporting that the use of 5 years of meteorological data was sufficient for the analysis since 3 climatic subzones were found with the data.

It is noteworthy mentioning that there is a very dry subzone in the south of Bahia and northwest of Espírito Santo (within subzone 1), as indicated by the National Action Program for the Combat of Desertification (PAN-BR), which classifies the region of southern Bahia and surrounding areas as areas susceptible to desertification (MMA, 2005). Therefore, the formation of a grouping in this area meets what was expected.

This fact is also observed by Eugenio *et al.* (2016), whose work in mapping the risk of wildfires on the state of Espírito Santo pointed to the northwest region of this state as a region susceptible to wildfires due to low rainfall and high evapotranspiration in the region, when compared to the average climate of the state of Espírito Santo.

The analysis of air temperature averages (FIGURE 2) allows a visual perception of the differentiation of the data obtained by the stations belonging to different groups. There is no expressive visual differentiation in relation to the average monthly temperature between the three subzones present in the study area - the annual averages for subzones 1, 2 and 3, respectively, were 23.9°C; 23.3°C; and 23.5°C. This fact corroborates the need for using the Ward method in order to be establishing a definition of climatic zones in the study area.

In relation to total rainfall, there were visual differences between the total annual precipitation average for the subzones analyzed, with subzone 1 having the highest annual precipitation average of 1,175.7 mm; followed by subzone 2 with 1,115.1 mm; and, lastly, subzone 3 with 914.1 mm. On FIGURE 3 it is possible to visualize the average monthlies of precipitation among the subzones studied.

Lower precipitation was expected in subzone 2 - center of the study area - since it is an area prone to desertification. However, what happened can be

FIGURE 2 Graph of the distribution of average temperature (Temp) and the average number of occurrences of wildfires in the months of the year (Occ.), for each subzone in the study area
SOURCE: THE AUTHORS

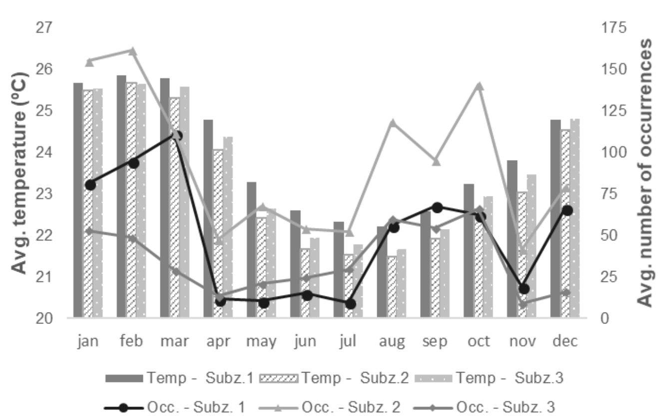
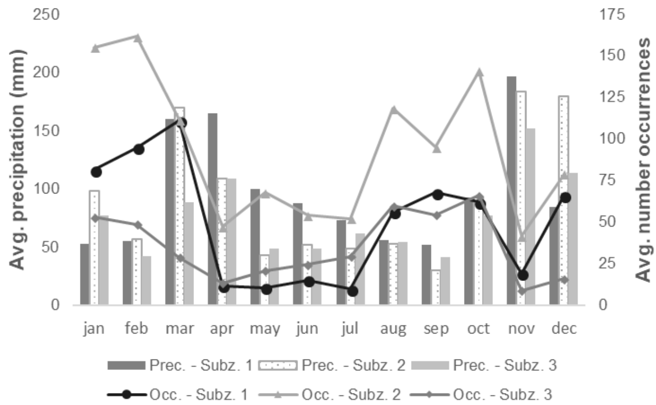


FIGURE 3 Graphic for the average precipitation distribution (Prec.) and average number of occurrences of wildfires for the months of the year (Occ.), for each subzone in the study area
SOURCE: THE AUTHORS



explained by the fact that the analysis involves only 5.5 years, that is, a small sample when compared to the recommended by the World Meteorological Organization, which is 30 years to characterize the climate of a region. The distribution of the average monthly relative humidity among the subzones studied can be visualized on FIGURE 4. There is a dissiparity present between the study subzones in relation to the months with the lowest relative humidity, the month of September being for subzones 1 and 2 and the month of February for subzone 3.

The average relative humidity is 80.24%, 79.85% and 81.00% for subzones 1, 2 and 3, respectively, with the lowest values found in the months of September for subzones 1 and 2, and February for the subzone 3.

FIGURE 5 shows the distribution of the average monthly water deficit in the climatic subzones present in the study area; it is possible to note that subzone 3 presents the highest values and this is the one with the highest accumulated water deficit for the study area with 292.0 mm; followed by subzone 1, with 157.5 mm; and, finally, subzone 2, with 143.6 mm.

All in all, the analyzes of the climatic variables of air temperature, rainfall, relative humidity and water deficit are in agreement with what was verified by the correlation coefficient calculated for cluster analysis by the Ward method.

In TABLE 1, we find the result of the clustering performed through the hierarchical cluster for the time of occurrence of wildfires for the study subzones and the average number of occurrences. This analysis allowed to verify whether or not there are different behaviors in the period of occurrence of fires in the three subareas studied, therefore, it can also be used as validation of the areas with homogeneous climates of the present study.

It is possible to verify the existence of two periods of occurrence of wildfires for both subzones, and the second season of fires for all subzones is identical, from August to October. It is also noted that the second season of occurrence is of lower intensity for subzones 1 and 2, and higher of intensity for subzone 3.

The first time of occurrence varies between subzones; for subzone 1, it is from December to March; for subzone 2, it is from January to March; and for subzone 3, it is in the months of

January and February. Being of greater intensity for subzones 1 and 2.

The second season of wildfires for the three subzones of the study area is similar to that described by Soares & Santos (2002), who state that the months between July and October characterize the period of forest occurrence in Brazil.

It is also worth noting that the months between mid-June and October cover the periods of fire occurrence also in the state of Minas Gerais, as can be observed in the works of Lima (2000), Torres & Ribeiro (2008), Aximoff & Rodrigues (2011) and Magalhães *et al.* (2011). For the state of Paraná, this fact is also observed, as can be seen in Soares and Cordeiro (1974), Soares (1989), Soares and Santos (2002), Koproski *et al.* (2004), Rodríguez & Soares (2004), Rodríguez (1998) and Tetto *et al.* (2010).

FIGURE 4 Graph of the distribution of the average relative humidity (RH) and the average number of occurrences of wildfires for the months of the year (Occ.), for each subzone in the study area
SOURCE: THE AUTHORS

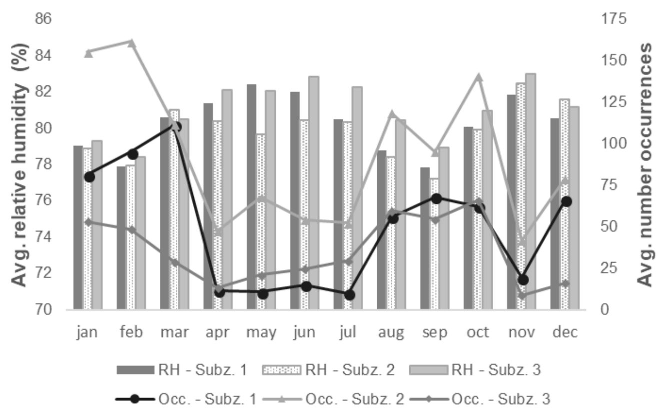


FIGURE 5 Graph of the distribution of the mean water deficit (WD) and the average number of occurrences of wildfires in the months of the year (Occ.), for each subzone in the study area
SOURCE: THE AUTHORS

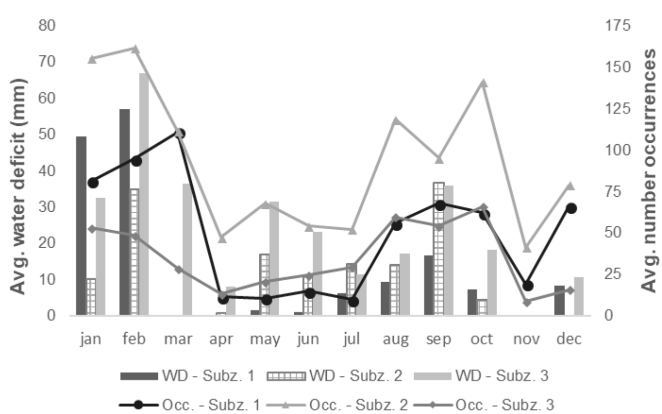


TABLE 1 Average number of occurrence and definition of the time (months of the year) of occurrence of wildfires for the study subareas

SOURCE: THE AUTHORS

Month	Average number of occurrence			Is the month at the time of occurrence?		
	Subzone 1	Subzone 2	Subzone 3	Subzone 1	Subzone 2	Subzone 3
January	81.4^{a}	155.2^{a}	53.0^{a}	YES	YES	YES
February	94.8^{a}	161.6^{a}	48.6^{a}	YES	YES	YES
March	111.0^{a}	111.6^{a}	28.8^{b}	YES	YES	NO
April	11.6^{b}	47.4^{b}	13.4^{b}	NO	NO	NO
May	10.6^{b}	67.8^{b}	20.8^{b}	NO	NO	NO
June	15.0^{b}	54.2^{b}	24.6^{b}	NO	NO	NO
July	9.75^{b}	52.3^{b}	29.5^{b}	NO	NO	NO
August	56.0^{a}	118.5^{a}	59.8^{a}	YES	YES	YES
September	67.8^{a}	101.2^{a}	54.4^{a}	YES	YES	YES
October	62.2^{a}	141.0^{a}	66.0^{a}	YES	YES	YES
November	19.2^{b}	41.6^{b}	8.8^{b}	NO	NO	NO
December	66.2^{a}	79.0^{b}	16.0^{b}	YES	NO	NO

* MEANS FOLLOWED BY THE SAME LOWER-CASE LETTERS IN A COLUMN DO NOT DIFFER SIGNIFICANTLY TO THE LEVEL OF 5% PROBABILITY

4. Conclusions

- The methodology adopted proved to be efficient for the grouping of meteorological stations in three climatic subzones homogeneous and distinct from each other for the study area.
- The cophenetic correlation coefficient proved to be efficient when validating the cluster obtained by the Ward method.
- The analyses of climatic variables, air temperature, rainfall, relative humidity and water deficiency are useful for the consolidation of the study, however, the visual analysis alone is impractical to perform the climatic classification.
- The analysis of the results allowed to verify that there are 3 different climatic subzones which generates 3 different wildfire regimes.

5. Acknowledgements

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Local e data de finalização do artigo:
Cachoeira do Sul (RS), Brasil; agosto, 2019