Research Article

Fire Risk Assessment and Warning Based on Hierarchical Density-Based Spatial Clustering Algorithm and Grey Relational Analysis

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Understanding the spatial and temporal distribution patterns of fire is of ecological, social and economic importance. The purpose of this study is to examine the spatial distribution of high fire risk using machine learning algorithms and early warning weather in high-risk areas. Take the satellite monitored fire point data in Yunnan Province during 2015–2019 as an example. The spatial distribution law of high-density parts is found using hierarchical density-based spatial clustering of applications with noise (HDBSCAN) algorithm, and the correlation degree analysis of high-density fire areas based on clustering and annual mean meteorological factors is carried out using grey correlation analysis (GCA) method. Results illustrate that within five years, fires frequently occurred in the seven regions of Wenshan Zhuang and Miao Autonomous Prefecture, Honghe Hani and Yi Autonomous Prefecture, Lijiang City, Pu’er City, and Xishuangbanna Dai Autonomous Prefecture. Among them, the fire in Lijiang had the greatest relationship with precipitation, Pu’er and Xishuangbanna had the greatest correlation with temperature, and Honghe Hani and Wenshan Zhuang were most affected by wind speed. This article acclaims fire prevention in key periods, key areas, key weather and reinforces the protection of transmission lines in the risk area.

1. Introduction

With continuous expansion of the power grid, various natural disasters that affect its normal operation have attracted considerable attention. Among these disasters, fire has a wide range of impacts and easily causes short-circuit tripping of transmission lines; it may even cause the entire transmission line to paralyzed [1]; therefore, it has an important role in risk management of fires. With the development of remote sensing technology, the fire points monitored by satellites have the characteristics of rapid receiving information, wide monitoring range, and short data cycle. Thus, dynamic monitoring and real-time warning of fires can be implemented. The real-time transmission and early warning of satellite monitoring data alone cannot detect real-time fires accurately to prevent and control fire in time. Satellite monitoring records a large amount of fire point data, which implies the time distribution and spatial distribution of fire points. These data are important for the implementation of fire point prevention and control [2].

The use of remote sensing satellite monitoring data for fire risk zoning is a target for fire prevention measures recommendations and fire prevention management. Jaiswal et al. [3] used satellite data and GIS for fire risk zoning in Gorna Subwatershed area of Madhya Pradesh, India to improve local fire prevention. Zhang et al. [4] used convolutional neural network (CNN) combined with multiple influence factors for fire sensitivity modeling for fire risk prediction. Moayedi et al. [5] combined genetic algorithm (GA), particle swarm optimization algorithm (PSO) and
2. Method

To study the temporal and spatial distribution of fires in Yunnan Province from 2015 to 2019, hierarchical density-based spatial clustering of applications with noise (HDBSCAN) was used to find areas with high density of fire. Then, GCA ranks the correlation degree of meteorological factors in the high-density fire spots and finds the meteorological factors with the highest correlation degree in the high-risk fire areas. This research was completed in python3.6 environment.

2.1. HDBSCAN Algorithm. HDBSCAN algorithm is a clustering algorithm developed by Campello, Moulavi, and Sander [12, 13]. DBSCAN is extended by converting DBSCAN [14] into a hierarchical clustering algorithm. The striking difference from DBSCAN is that HDBSCAN can cluster dense data of any shape and can improve the clustering effect of DBSCAN due to inaccurate input parameters. Compared with DBSCAN, HDBSCAN’s clustering effect does not entirely depend on the input parameters, and the analysis efficiency is higher. The algorithm complexity can be referred to [15]. The algorithm realizes the selection of clusters from multiple levels to determine the final clustering results, and its robustness is stronger. The steps of the HDBSCAN algorithm are as follows:

1. Given a parameter $k$, the distance between all points in the data space and the $k$th nearest neighbor sample point, called the core distance, is calculated. The formula is as follows:

$$\text{core}_k(x) = d(x, N^k(x)).$$

2. Expressing the distance between two data points by mutual reaching distance does not affect the sample distance in the dense area, and the distance between the sample points in the coefficient area and other sample points is enlarged.

$$d_{\text{min}}(a, b) = \max\{\text{core}_k(a), \text{core}_k(b), d(a, b)\}.$$  

3. The data set is regarded as a distance weighted graph, and then the minimum spanning tree in the weighted graph through prim is calculated;

4. The minimum spanning tree is converted to a clustering hierarchy tree containing connected branches, and the clustering tree is compressed to obtain stable clustering hierarchical structure. The same label is assigned to all objects. All edges are iteratively deleted from the hierarchy in descending order of weight. After each deletion, the label is assigned to the cluster containing the end vertices of the deleted edge, and the final cluster label is obtained. If the amount of data in the group is less, then the group is marked as an outlier.

2.2. GCA. GCA is a multifactor statistical analysis method to judge the degree of correlation between factors. First, the analysis sequence is determined. The sequence is divided into two types, namely, reference sequence and comparison sequence. Among them, the reference sequence is the feature, and the comparison sequence is the influencing factor. Second, the dimensionless data are processed, that is, the data are preprocessed, generally indicating the mean or maximum and minimum value normalization. Finally, the correlation coefficients are calculated and sorted.

3. Study Area and Data

3.1. Study Area. Yunnan is located in the southwestern border of China, between 97°31' to 106°11' east longitude and 21°8' to 29°15' north latitude. The Tropic of Cancer traverses the southern part of the province and is a low-latitude inland area. The climate belongs to the subtropical plateau monsoon type, the 3D climate features are remarkable, with many types, small annual temperature
difference, large daily temperature difference, distinct dry and wet seasons, and unusual vertical changes in temperature with the terrain. It is a mountainous plateau. From the perspective of landform types, the areas of plains, terraces, hills, and mountains account for 4.85%, 1.55%, 4.96%, and 88.64% of the country’s land area, respectively.

3.2. Data Source. The firm website (https://firms.modaps.eosdis.nasa.gov/map/) is used to download the fire point data monitored by MODIS satellites. The attributes include fire point confidence, latitude and longitude, and time; a total of 21615 data are obtained. Fire spots with a confidence of more than 75% are selected as the research data. The correlation analysis of the annual number of fires and meteorological data in the risk area is conducted. The four types of meteorological data, including annual average temperature, annual average relative humidity, precipitation, and wind speed in Yunnan from 2015 to 2019 are obtained from the China Meteorological website (http://data.cma.cn/site/index.html).

4. Results and Analysis

4.1. Time Distribution. Figure 1 shows the statistical results of the quantity distribution in different time scales in Yunnan Province from 2015 to 2019.

According to the statistical results in Figure 1, the number of fire points in Yunnan Province from 2015 to 2019 has a visible peak at different time scales.

4.1.1. Annual Distribution. Figure 1 shows that fires in Yunnan Province frequently occur in December of each year and January, February, March, April, and May of the following year. This finding is analyzed from two aspects, namely as natural factors and human factors.

Natural factors: although all seasons are similar to spring in Yunnan Province, the temperature difference throughout the year is insignificant. The province mainly experiences dry season and rainy season. The rainy season is from the end of May to the end of November each year. The dry season is from the beginning of December to the beginning of May of the following year. Yunnan Province has a large forest area with many litters, weeds, and bushes. In the dry season, the air is dry, ultraviolet rays are strong, and vegetation water content is low; thus, wildfires are common. After the 1990s, Yunnan Province has experienced a significant increase in temperature and a decrease in annual average relative humidity [16]. This climate change increases the probability of fires, indicating a serious detriment to fire prevention.

Human factors: Yunnan Province has the largest number of ethnic minorities in China. In the past few months, several important traditional festivals, such as New Year’s Day, Spring Festival, and Qingming Festival, are celebrated. Sacrificial activities have increased significantly compared with other months. The frequent existence of fires is also a significant cause of normal fires. However, people are busy ploughing in spring, and some fields are close to the forest, thereby effortlessly causing human-made fire in the forest.

4.1.2. Weekly Distribution. Fires are generally higher from Monday to Friday than Saturday and Sunday. Many people go out on weekends, and the awareness of fire prevention is high. Fire prevention is more important. On the contrary, vigilance is relaxed during workdays. A large number of people still play outside. At this time, the relaxation of fire protection awareness has caused more frequent fires on weekdays than on weekends. At the same time, the finding shows that the educational work on fire prevention propaganda is effective, and the people’s awareness of fire prevention needs to be strengthened.

4.1.3. Daily Distribution. This article calculates the ratio of the number of fire points during the day and the night given the data source. The number of fires during the day is much higher than that at night. On the one hand, people perform outdoor work and activities during the day, and their behavior brings fire sources. On the other hand, the temperature during the day is higher than that at night, and the ultraviolet rays in Yunnan Province are extremely strong. Fires are far more likely to break out at night.

Therefore, from January to May and December of each year, the monitoring of wildfires should be strengthened, especially on normal working days, to strengthen the prevention of fires and focus on the situation around important power grid lines at key times. The statistical information of each period in Figure 1 shows that the fire prevention education for the masses is relatively useful. Further strengthening the awareness of fire prevention and transmission line protection awareness reduces the occurrence of fire.

4.2. Spatial Distribution. Yunnan province has a high incidence of fires. From the perspective of the density of fires, areas with higher fire risk are determined. Transmission line corridors in fire risk areas are prone to damage caused by fire disasters. Thus, the monitoring and prevention efforts should be strengthened in the risk area. Simple statistics cannot accurately divide the area of frequent fires. The density-based HDBSCAN clustering algorithm can provide a more objective and scientific approach of division. The HDBSCAN clustering algorithm was used to divide the area in accordance with the fire density. The parameters of the smallest cluster should be set. The fire distribution changes every year, and the parameter settings are also different.

The HDBSCAN algorithm is used for the fire detection data of Yunnan Province from 2015 to 2019 year by year to obtain high-density clusters of fire center points, and the fire center points are displayed as hot spots [10], which can more intuitively view the annual high fire risk area. As shown in Figure 2, the risk area is displayed with a highly concentrated fire center point.

Figures 2(a)–2(e), generally in Yunnan province, fires mostly occurred in the southeast, southwest and northwest
of Yunnan province and appeared steadily throughout the year, mainly in Wenshan Zhuang and Miao Autonomous Prefecture, Honghe Hani Ethnic Yi Autonomous Prefecture, Xishuangbanna Dai Autonomous Prefecture, Pu’er City and Chuxiong Yi Autonomous Prefecture. A large number of ethnic minorities live in these areas. They have a large number of religious sacrificial activities, production activity festivals, commemorative celebration festivals, and social entertainment festivals. These large-scale activities have brought great hidden dangers of human-made fire sources. The topography and landforms of the province are intricate, with various forest climates, tropical rain forests, tropical monsoon rain forests, southern subtropical evergreen broad-leaved forests, southern subtropical coniferous and broad-leaved mixed forests, bamboo and wood mixed forests, shrubs, grasses, and many other types. It has a dry climate during the dry season, with large areas of combustible materials, and extremely high fire risks. Although the cluster center is in Lijiang City, the fire spots are also all over DAli and northern Chuxiong all year around, the classification results indicate that the density of fire is lower than that of Honghe Hani and Yi Autonomous Prefecture and Wenshan Zhuang and Miao Autonomous Region. Lijiang is also famous for its ancient cities and has many natural attractions. Human activities are an important reason for the frequent occurrence of fires. However, the Nujiang Lisu Autonomous Prefecture showed signs in 2015 and 2017, the risk is low in these areas.

The annual fire hot spots can provide several key areas with frequent fires in Yunnan Province. These key areas can guide the development of differentiated fire management. The HDBSCAN algorithm is an improved hierarchical clustering that integrates five-year fire points. The fire-prone areas are divided into three levels, as shown in Figure 3. The first-level risk areas are Wenshan Zhuang and Miao Autonomous Region and Honghe Hani and Yi Autonomous Prefecture; the second-level risk area is Lijiang City, D. Ali Bai Autonomous Prefecture and Chuxiong Yi Autonomous Prefecture; the third-level risk areas are DAli and northern Chuxiong all year around, the classification results indicate that the density of fire is lower than that of Honghe Hani and Yi Autonomous Prefecture and Wenshan Zhuang and Miao Autonomous Region. Lijiang is also famous for its ancient cities and has many natural attractions. Human activities are an important reason for the frequent occurrence of fires. However, the Nujiang Lisu Autonomous Prefecture showed signs in 2015 and 2017, the risk is low in these areas.

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Fire point distribution map of Yunnan Province in 2015

(a)

Fire point distribution map of Yunnan Province in 2016

(b)

Figure 2: Continued.
Figure 2: Risk areas from 2015 to 2019. (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019.

Figure 3: Risk region grade chart of Yunnan Province.
areas are Xishuangbanna Dai Autonomous Prefecture and Pu’er City. The emergency prevention of fires provides regional suggestions and increased monitoring of transmission lines within the scope of the region.

4.3. Meteorological Factors. GCA method was used to calculate the correlation coefficient and correlation between the number of fire points and the seven meteorological factors in the three risk areas (Table 1). The number of fire points each year was set as the reference series, and the seven meteorological factors, including temperature ($X_1$), average relative humidity ($X_2$), average minimum temperature ($X_3$), average maximum temperature ($X_4$), annual precipitation ($X_5$), annual average wind speed ($X_6$), and maximum daily precipitation ($X_7$), are set as comparison series. The correlation degree and correlation sequence between each meteorological factor and the number of fire points are calculated.

According to Table 1, in the risk zone, the seven impact factors have different Grey correlations with the number of fire points in different risk zones. Higher ranking indicates closer relationship between the corresponding meteorological factors and the number of fire spots, as well as greater impact on fire spots.

4.3.1. Analysis of the First-Level Risk Area and Meteorological Factors. The table shows that the first-level risk areas are Wenshan Zhuang and Miao Autonomous Region and Honghe Hani and Yi Autonomous Prefecture. According to the GCA, the first degree of correlation is the annual average wind speed ($X_6$), which is one of the direct factors affecting fires. It has a certain impact on the development and spread of fire. Wind can accelerate the evaporation of vegetation water content, resulting in dry ground. No severe cold in winter and no scorching heat in summer are experienced, and the temperature difference is relatively small because Wenshan Zhuang and Miao Autonomous Prefecture have a subtropical climate. Therefore, the annual average relative humidity ($X_2$) has the second-highest impact on the risk area. Honghe Hani and Yi Autonomous Prefecture has the second and third relevance for average maximum temperature ($X_4$) and average temperature ($X_1$), respectively. Wet and dry in winter and summer exhibit slight difference because the climatic feature is a low-latitude subtropical humid monsoon climate. However, a large difference is observed in extreme temperature. Wind speed affects moisture volatilization and high temperature affects moisture. Evaporation causes the vegetation to reach the conditions for fire.

4.3.2. Analysis of Secondary Risk Areas and Meteorological Factors. Lijiang City, DAli Bai Autonomous Prefecture, and Chuxiong Yi Autonomous Prefecture are divided into second-level risk areas. The most closely related to this risk
area is the maximum daily precipitation ($X_7$), of which less precipitation in the dry season is the most important for fires in this risk area. The factor. Secondly, the second degree of correlation and the third degree of correlation between Lijiang City and D. Ali Bai Autonomous Prefecture are wind speed ($X_6$) and average temperature ($X_1$). Because of its low rainfall, wind speed accelerates the evaporation of vegetation moisture, reduces water content, and extremely strong ultraviolet rays. The second degree of correlation in Chuxiong Yi Autonomous Prefecture is the average temperature ($X_1$), and the third degree of correlation is the lowest temperature ($X_4$). It shows that the conditions for the occurrence of fire in Chuxiong Yi Autonomous Prefecture are compared with the previous two cities. The temperature is more relevant. In this risk zone, rainfall is the most important meteorological factor, followed by temperature and wind speed.

4.3.3. **Analysis of the Third-Level Risk Area and Meteorological Factors.** The Xishuangbanna Dai Autonomous Prefecture and Pu’er City are classified as third-level risk areas, which border each other. The top two risk areas of this level are the highest temperature ($X_4$) and average temperature ($X_1$). The occurrence of fires has a close relationship with temperature. Temperature is also a significant factor affecting fire. Pu’er City’s third degree of correlation is the annual average wind speed ($X_6$). Wind speed and temperature greatly impact Pu’er fires. The third degree of correlation in Xishuangbanna Dai Autonomous Prefecture is the average minimum temperature ($X_4$), indicating that the fire in Xishuangbanna Dai Autonomous Region is the most important. The meteorological factor is temperature.

According to the analysis of the correlation degree of meteorological factors, the meteorological factors that satisfy the fire conditions in each risk area are different. For key areas, focusing on the composition of their meteorological factors can obtain a more effective fire protection and reduce the occurrence of transmission line fires.

5. **Conclusion**

In this paper, we examined the spatial and temporal patterns of satellite monitoring data in Yunnan Province at different time scales with HDBSCAN density clustering algorithm and GCA algorithm, originate the spatial and temporal distribution characteristics of fire occurrence in Yunnan power grid, mapped the high-risk areas of fire hotspots based on facts, and conducted GCA of meteorological factors based on high-risk areas, and found that the correlation degree of meteorological factors in different areas. The meteorological data with high correlations in different risk areas are counted distinctly to achieve more precise hill fire warning effect. It provides decision support for fire prevention and control at key times, key areas and key meteorological conditions, and for fire work on transmission lines in risk areas.

**Data Availability**

All data, models, and code generated or used during the study appear in the submitted article.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

**References**


