Forest Fire Fisk Analysis in China in the Context of Climate Change Based on Data Visualization

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Abstract. In recent years, due to the abundant forest resources in China, the frequency of forest fires has increased as a result of climatic influences. According to data from the "China Forestry Statistical Yearbook," from 2010 to 2019, the total area affected by forest fires in China reached 485,000 hectares, with the area of damaged forests amounting to approximately 190,000 hectares. A substantial amount of vegetation was destroyed, dealing a significant blow to the sustainable development of China's forestry. This paper employs visual statistical analysis methods to examine the characteristics of forest fire occurrence in China using data from 2005 to 2020, exploring the impact of climate change on forest fires in China, thereby providing a scientific basis for China's forest fire prevention efforts.

Keywords: Climate change; Forest fires; Statistical analysis methods

1 Introduction

In recent years, the magnitude of global climate change has been continuously increasing, with the frequency of compound extreme events rising, leading to natural and human perils in multiple regions. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[1-3], human activities are the primary cause of global warming. The global average surface temperature from 2011 to 2020 was 1.1°C higher than that from 1850 to 1900, while the temperature change influenced by natural factors did not exceed 0.1°C. The intensification of global warming will further lead to the occurrence of extreme weather such as high temperatures and heavy precipitation, and some areas will face severe drought problems, causing extensive adverse effects and damage to agriculture and ecology[4-10].

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Forests, known as the "lungs of the Earth," are fundamental conditions for the survival and development of humans and animals. They not only provide abundant raw materials for the development of forestry and a variety of foods for humans but also conserve water sources and maintain soil, prevent wind erosion, and mitigate the scouring of soil by water flow. Most importantly, they regulate the climate[11-18], purify the air, and are vast oxygen-producing factories, which can alleviate the "greenhouse effect." Moreover, soil drought increases the combustibility of forests, which can easily lead to forest fires. Forest fire prevention is an important task in the construction and development of forestry and is the premise and foundation for strengthening ecological construction. Fire is the greatest threat to forest land resources; once forest land is affected by fire, the forest's stock volume will decrease, and the growth cycle of the forest will be severely damaged, leading to extreme weather and natural disasters such as dust storms and droughts, increasing the risk of wildlife to endangered levels, and also threatening human life and property safety. Therefore, responding to climate change and accurately predicting forest fire risk is of great significance for the protection and planning of forest resources[19-25].

This paper will be based on forest fire data from 2005 to 2020, applying data visualization methods to more intuitively explore the spatiotemporal characteristics of forest fires in China and the extent of the impact of climate change on the occurrence of forest fires, in order to provide a scientific basis for the monitoring and management of forest fires.

2 Sources and Description of Data

The historical data of forest fires in China used in this paper is sourced from the ecological observation stations of the Chinese Academy of Forestry Sciences, and a total of 20,683 records of forest fire data from 2005 to 2020 were collected. The specific indicators include the time of forest fire discovery, the location of the fire, the type of forest fire, and the province and county where the fire occurred. The time of forest fire discovery refers to the time when the fire was detected by remote sensing satellites, which may differ from the actual time of the fire outbreak, but the discrepancy is not significant. Therefore, the time of forest fire discovery is considered as the time of the fire outbreak for statistical analysis in this paper.

Meteorological data also comes from the Chinese Academy of Forestry Sciences and the National Tibetan Plateau Data Center (http://data.tpdc.ac.cn/zh-hans/). A total of daily average data from 2007 to 2020 at 107 meteorological stations across the country has been organized, including the following:

(1)Daily average temperature: The average value of daily temperature observations, with the unit in degrees Celsius (°C).

(2)Daily average precipitation: The average value of precipitation from 8:00 am to 8:00 am the next day, with the unit in millimeters.

(3)Daily average wind speed: The average value of wind speed measurements at a fixed point each day, with the unit in meters per second (m/s).

(4)Daily average relative humidity: The average of four measurements of air relative humidity at 2 am, 8 am, 14 pm, and 20 pm each day, with values ranging from 0 to 100%.

3 Climate Change and the Pattern of Forest Fire Occurrence in China

Climate change and human factors are the main causes of forest fires, and over a certain period, the impact of climate change on forest fires is more pronounced [26-31]. According to the "China Climate Change Blue Book," the global warming is still ongoing, and the average temperature in China in 2021 was 1.11°C higher than before the industrialization, with the warming rate in China higher than the global average. Global climate change can alter the amount of combustible material in forests, thereby affecting the frequency of forest fire occurrence. Therefore, statistical analysis of forest fire data and the study of the relationship between meteorological factors and forest fires can provide references for the formulation of forest fire prevention strategies, which is of great significance for reducing the occurrence of forest fires.

This study organizes the forest fire data from 2005 to 2020 in China, mainly for the statistical analysis of the number of forest fires, and analyzes the temporal distribution pattern of forest fires in China, including the analysis of the annual, seasonal, monthly, and hourly changes in the number of forest fires. Then, it statistically analyzes the number of forest fires by administrative region to study the spatial distribution pattern of forest fires in China.

3.1 The Temporal Distribution Pattern of National Forest Fires

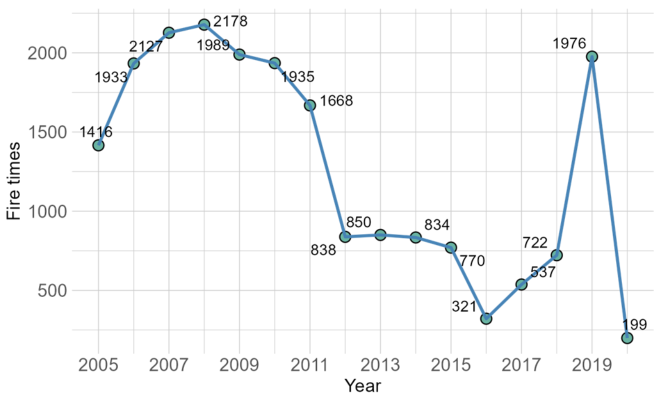

Fig. 1. Annual change in the number of forest fires in 2005-2020

Summarizing the number of national forest fire occurrences from 2005 to 2020 by year, Figure 1 shows the annual distribution of forest fires. Specifically, the number of forest fires was high from 2005 to 2011, with an average of 1893 occurrences per year, with the number of fires exceeding 2000 in both 2007 and 2008. Starting in 2012, the number of forest fires entered a low-incidence state, with relatively flat fluctuations. However, in 2019, the number of forest fires suddenly increased sharply to 1976 times, reaching a new peak, while in 2020, the number of forest fires plummeted to 199 times, a historical low. The analysis suggests that the reason may be the influence of the El Niño phenomenon in 2019, which led to extreme heat and drought in the northern regions of China, with a significant increase in extreme weather conditions such as high temperatures, strong winds, and dry thunderstorms, which are more likely to trigger forest fires than simple temperature changes.

(1)Trend analysis of the annual forest fire data was conducted using the non-parametric statistical method of the Mann-Kendall trend test. The test statistic z-value was -3.0165, which is less than 0, and the p-value of the test was 0.0026, which is less than 0.05, indicating a significant downward trend in the annual data of national forest fire occurrences. The main reason for this trend is that in the early period, the forest types in China were mainly natural forests with less rainfall, making the combustible materials dry and prone to burning. Coupled with strengthened fire prevention and management efforts, forest fires have been effectively prevented and controlled in recent years, hence the number of forest fire occurrences shows a downward trend.

(2)The seasonal variation pattern of forest fires in China

Based on the division of the four seasons in China: spring is from March to May, summer is from June to August, autumn is from September to November, and winter is from December to the following February. By categorizing the data by quarter, the statistics show that from 2005 to 2020, there were a total of 20,293 forest fires in China, with an average of 1,194 fires per quarter.

Table 1. Quarterly distribution of forest fires across the country.

Season	Spring	Summer	Autumn	Winter
Number of fires	11474	793	1608	6418
Proportion (%)	56.54	3.91	7.92	31.63

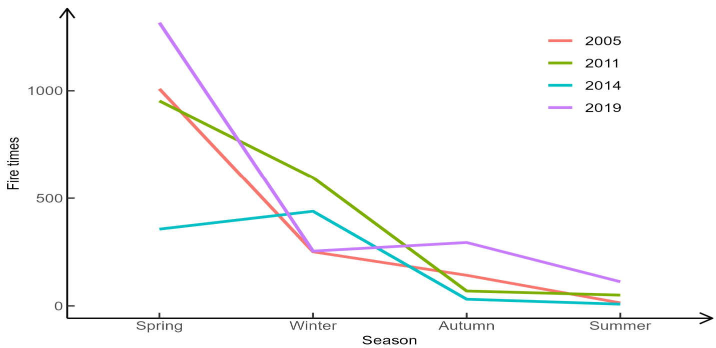

Fig. 2. Quarterly changes in the number of forest fires nationwide

Summarizing the number of national forest fire occurrences by season from 2005 to 2020, Tab.1 shows the quarterly distribution of forest fires. It can be observed that the highest number of forest fires occurs in spring, accounting for 56.54% of the total fire occurrences, followed by winter. The fewest forest fires occur in summer, representing only 3.91% of the total number of fires. To observe the quarterly variation of forest fire occurrences in each year, random samples of forest fire data from the years 2005, 2011, 2014, and 2019 were selected and analyzed by quarter, resulting in the line chart of Figure 2. It can be seen that in each year, the number of forest fires is the least in summer, and the occurrences are mainly concentrated in spring and winter. This suggests that there may be a seasonal cyclical pattern in the number of forest fire occurrences in China.

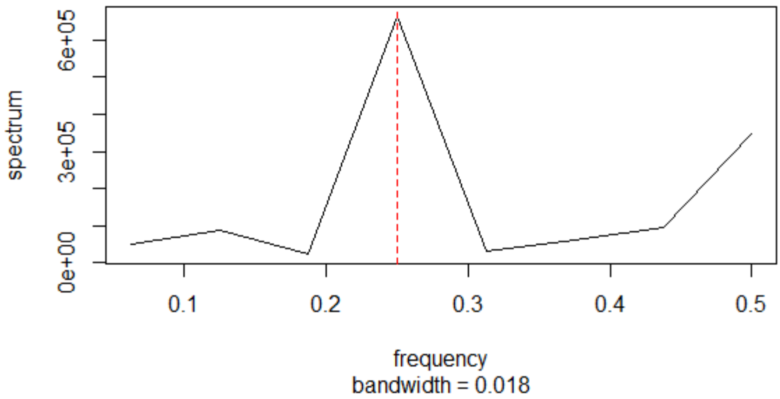

Fig. 3. Pedigree plot of the quarterly number of forest fires in 2005-2020

To verify the seasonal cyclical variation in the number of forest fire occurrences in China, this paper adopts spectral analysis methods to identify the periodic characteristics of the forest fire sequence. From the spectral density plot in Figure 3, the maximum spectral density is found at a frequency of 0.25, corresponding to a period of 4. A second peak appears at a frequency of 0.5, corresponding to a period of 2. This indicates that there is a significant seasonal pattern in the occurrence of forest fires in China, with the larger cycle being 4, meaning that the number of forest fire occurrences decreases in the order of spring—winter—autumn—summer. The smaller cycle is 2, indicating that spring and winter are periods of high forest fire occurrence, while summer and autumn are periods of low occurrence.

Summarizing the national forest fire data from 2005 to 2020 by month, as seen in Figure 4, it is evident from the inter-monthly variation chart of forest fire occurrences that forest fires mainly occur from January to May, accounting for 83.73% of the annual forest fire occurrences. March and April are the high-incidence periods for forest fires, with the main reason for the high incidence of forest fires in April being the human activities during the Qingming Festival, such as offering incense and burning paper. The months of July to September are the low-incidence periods for forest fires, with

August having the fewest occurrences, accounting for only 0.78% of the annual forest fires.

(3)The temporal variation pattern of forest fires in China

Summarizing the national forest fire data from 2005 to 2020 by the hour, as seen in Figure 5, it can be observed from the circular bar chart that the times when forest fires occur are concentrated between 13:00 and 17:00, accounting for 58.97% of the total number of forest fire occurrences, with the peak period for forest fires occurring between 14:00 and 15:00. The frequency of forest fires is the lowest between 23:00 and 7:00 the next day, with the 0:00 to 2:00 time slot having the fewest occurrences, accounting for only 0.18% of the total. The main reasons for this distribution are twofold: first, the climatic conditions at night are less conducive to ignition, and second, the human lifestyle and rest schedule result in fewer human-induced forest fires occurring in the early morning hours.

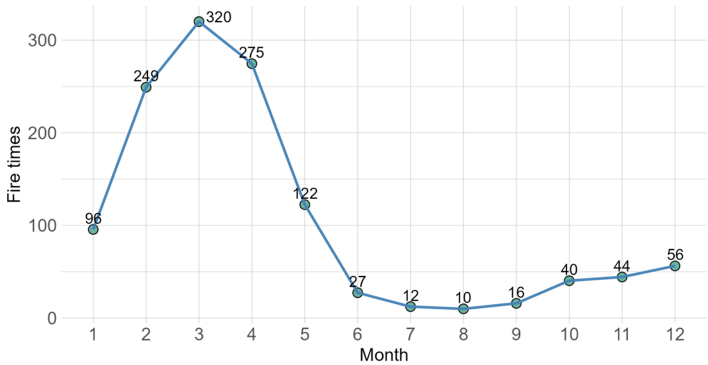

Fig. 4. Inter-monthly changes in the number of forest fires in 2005-2020

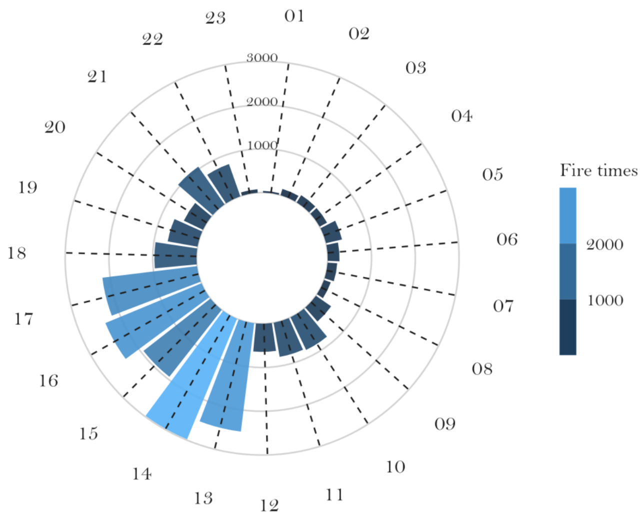

Fig. 5. Intertemporal changes in the number of forest fires in 2005-2020

3.2 The Spatial Distribution Pattern of National Forest Fires

Forest fire occurrences are influenced by a variety of factors, with climate, topography, and population distribution being significant factors affecting forest fires. Due to regional differences in the geographical environment, the impact of various geographical elements on the occurrence of forest fires will also differ, which constitutes the spatial pattern of forest fires. This section explores the spatial pattern of forest fires by looking at the distribution area and vegetation type of forest fires.

(1)The provincial-level administrative regional distribution of forest fire occurrences.

Summarizing the national forest fire occurrences from 2005 to 2020 by province, the heatmap in Figure 6 shows that the distribution of forest fires is uneven across different regions, with a higher frequency of fires in areas south of the Yangtze River and in the northeastern regions, while the frequency of forest fires in the northwest regions such as Xinjiang and Tibet is relatively low. The three provinces with the highest number of forest fires are Yunnan, Hunan, and Sichuan, accounting for 14.41%, 13.63%, and 10.32% respectively, and the distribution of fire occurrences within these provinces is also uneven, concentrated in more than 50 key counties and districts. The main reasons for the uneven spatial distribution of forest fires in China are that forests are primarily distributed in the eastern regions, while the western regions are mostly deserts, grasslands, and mountains, resulting in fewer combustible materials and less likelihood of fires; on the other hand, the southern regions have a denser population than the north, leading to more human-induced forest fires.

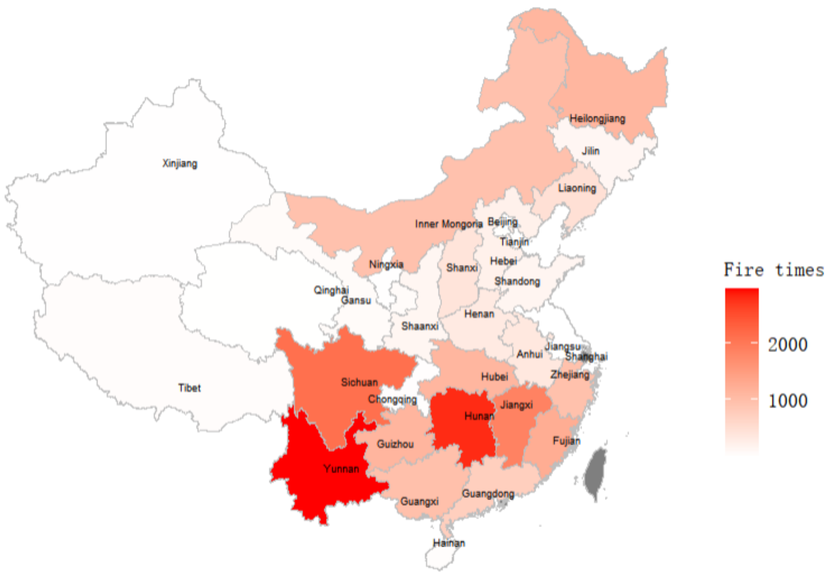

Fig. 6. Spatial distribution of frequent forest fires in different provinces

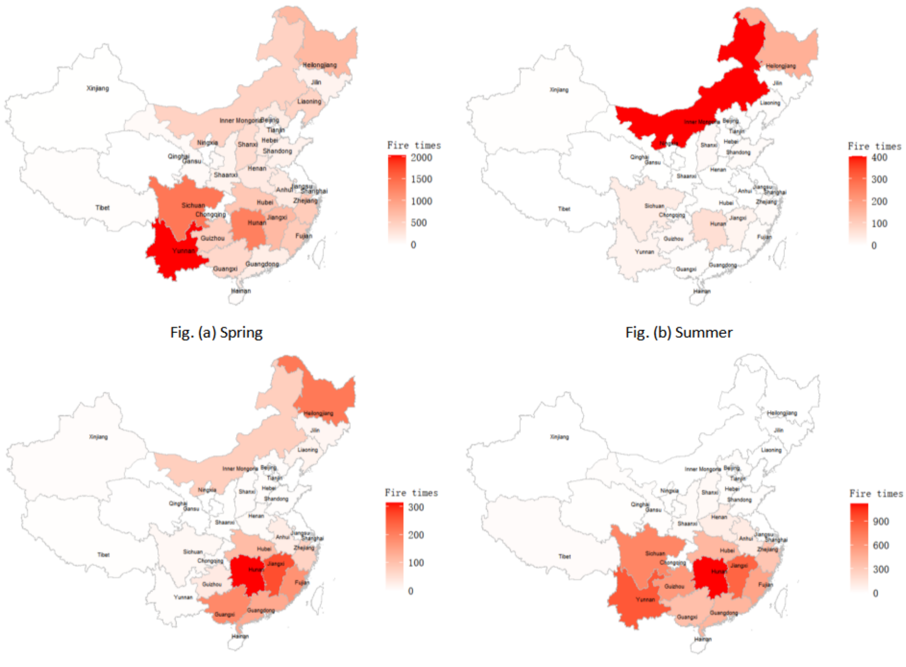

Fig. (c) Autumn Fig. (d) Winter

Fig. 7. Spatial distribution of the number of forest fires in different seasons

The distribution of forest fire occurrences is uneven across different regions and times, as shown in Figure 7. With the change of seasons, the spatial distribution of high-incidence areas for forest fires also shifts. During spring and autumn (Figures a and c), the high-incidence areas for forest fires are both concentrated in the regions south of the Yangtze River and in the northeast. The difference is that during spring, the provinces with the highest number of forest fires are Yunnan, Sichuan, and Hunan, with the rest of the eastern regions showing a more balanced distribution of fire occurrences. In autumn, Hunan Province has the highest frequency of forest fires, mainly concentrated in the southeast region and in Heilongjiang and Inner Mongolia, with the central and western regions experiencing very low frequencies of fire occurrences.

During the summer season (Figure b), forest fires are concentrated in the northwest regions, with Inner Mongolia and Heilongjiang having the highest frequency of forest fires. The rest of the regions have a relatively low frequency of fire occurrences, mainly because the southern regions receive more rainfall than the north in summer, and with tender leaves, the combustible materials have a high water content, making ignition difficult.

In the winter season (Figure d), forest fires mainly occur in the regions south of the Yangtze River, with Hunan Province having the highest frequency of forest fires. Except for the southern regions, the rest of the regions have very low frequencies of fire occurrences, mainly because the ground in the northern regions is covered with ice and snow in winter, making ignition difficult.

(2)The distribution of forest fire occurrences by land type

After excluding the fire spot data with unknown land types, the forest fire occurrences were counted according to the land types, as shown in Table 2. From 2005 to 2020, a total of 20,675 forest fires occurred, among which forest land accounted for 16,910 forest fires, with a proportion of 81.79%, ranking first. Grassland came in second with a proportion of 9.09%, and other land types had very few fire occurrences. Analyzing the forest fire data by the vegetation type of the forest land, Figure 8 shows that evergreen coniferous forests are the most prone to fires, accounting for 41.9% of the forest land fire occurrences, followed by mixed forests, with broad-leaved forests being the least susceptible to forest fires.

Table 2. Category distribution of forest fires from 2005 to 2020.

Land Type	Forest Fire Occurrence Times	Proportion
Forest land	16910	81.79
Meadow	1880	9.09
Plowland	94	0.45
Wet land	12	0.06
Other	1779	8.60

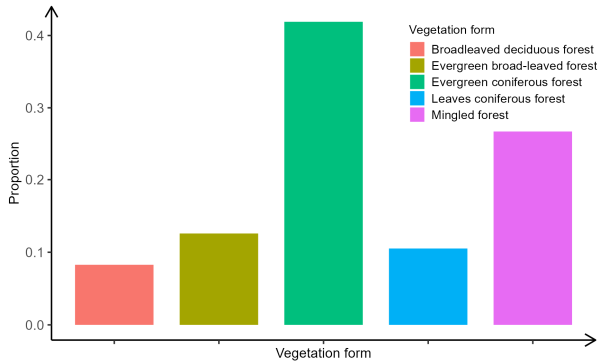

Fig. 8. The vegetation distribution of forest land fire occurrences

3.3 Chapter Summary

Analysis of the temporal characteristics of national forest fires reveals an overall downward trend in annual occurrences, with a seasonal pattern of high incidence in spring and winter and low incidence in summer and autumn, peaking in March and April. The spatial distribution shows that forest fires are concentrated in the southern and northeastern regions, with minimal occurrences in the northwest regions like Xinjiang and Tibet. The main reasons for this distribution are the concentration of forests in the eastern parts of China and the prevalence of deserts, grasslands, and mountains in the west, which have fewer combustible materials and thus fewer fires, while the south's denser population leads to more human-induced fires.

4 Conclusions

4.1 Conclusions

In the context of national climate change, this paper uses the activity data of the crested ibis, national forest fire data, and meteorological data as research objects. By employing statistical analysis methods, the paper analyzes the impact of four meteorological factors—rainfall, temperature, wind speed, and relative humidity—on the occurrence of forest fires, drawing conclusions about their correlation.

The study of the temporal and spatial distribution patterns of national forest fire occurrences from 2005 to 2020 reveals the following:

(1)The number of forest fire occurrences shows an uneven distribution over time and space.

(2)Inter-annual variations are significant, but there is an overall downward trend.

(3)There is a pronounced seasonal pattern, with high incidence in spring and winter and low incidence in summer and autumn. Authorities should enhance fire prevention and management, particularly in March and April, to prevent major forest fires.

(4)The peak times for forest fire occurrences are from 13:00 to 17:00, with the highest frequency between 14:00 and 15:00.

(5)Spatial analysis indicates that forest fires are more frequent in the eastern and southern regions compared to the western and northern regions.

(6)Combining temporal and spatial analyses, it is observed that summer forest fires are concentrated in the northern regions, while in winter, they are concentrated in the southern regions.

4.2 Discussion

For Case Study II, this paper explores the main meteorological factors affecting forest fire occurrences in Yunnan Province using Pearson correlation analysis and regression analysis. It constructs daily forest fire risk prediction models based on logistic regression and the XGBoost algorithm, providing guiding suggestions for forest fire prevention departments to mitigate fire risks. However, the study only selected the four most common meteorological factors: rainfall, temperature, wind speed, and relative humidity, without considering the impact of other meteorological factors such as atmospheric pressure and sunshine duration. Literature indicates that sunshine duration has a significant effect on forest fires in Panzhihua City. Additionally, numerous factors influence forest fires, including human behavior, fuel moisture content, and topography, which are also important factors. Therefore, the models constructed in this paper have certain limitations. If topographical factors and other meteorological factors were included in the construction of forest fire risk prediction models, the prediction accuracy might be higher.

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