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Analysis of Spatiotemporal Patterns and Driving Factors of Forest Fires in Liangshan Prefecture

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Abstract

This study analyzes the spatiotemporal patterns and driving factors of forest fires in Liangshan Prefecture based on fire data from 2016 to 2024 using statistical methods. The results indicate: 1) From 2016 to 2024, forest fires in Liangshan Prefecture occurred predominantly between January and May (140 incidents), accounting for 97.90% of the total. March recorded the highest number of fires (48 incidents), representing 33.57%. Within a 24-hour period, 113 fires occurred between 12:00 PM and 9:00 PM, constituting 79.02% of all incidents. 2) Spatially, Mianning County recorded the highest number of forest fires (28 incidents, 19.58%), followed by Xichang, Muli, and Yanyuan with 22, 23, and 20 incidents, respectively. Human activities, particularly agricultural burning, outdoor smoking, and other causes, were the dominant factors, collectively accounting for 41% of incidents. 3) Forest fires predominantly occurred at elevations between 1500 and 3000 meters (132 fires, 92.31%), on slopes with gradients of 5 - 25 degrees (81 fires, 56.65%), on west-facing aspects (northwest, west, southwest) (72 fires, 53.14%), in areas with NDVI values between 0.51 and 0.8 (79 incidents, 55.24%), within 500 - 2000 m residential buffer zones (151 incidents, 98.60%), and within 500 m road buffer zones (103 incidents, 72.03%). 4) Among meteorological factors, the 20-day average temperature (0.3041), 80-day maximum temperature (0.3487), 20-day minimum temperature (0.2594), 20-day minimum relative humidity (−0.3132), 70-day maximum wind speed (0.1885), and 70-day peak wind speed (0.1965) showed the strongest correlations with forest fire burned area. Burned area also exhibited a positive correlation with the Meteorological Drought Index (MCI) on the day of the fire (0.1990). This study confirms the lagged and persistent effects of meteorological factors on forest fire occurrence, providing key scientific evidence for constructing regional fire prediction models that integrate multi-scale meteorological indicators.

Keywords

Liangshan Prefecture, Forest Fires, Spatiotemporal Patterns, Driving Factors

1. Introduction

Forest resources are among the most vital resources on Earth, playing crucial roles in climate regulation, soil and water conservation, and the prevention or mitigation of natural disasters such as droughts, floods, and sandstorms (Li & Sun, 2007). Forest fires are natural disasters characterized by sudden onset, extensive destruction, and significant challenges in response and rescue efforts, exerting profound impacts on the development of forest ecosystems (Chu et al., 2015). In recent years, global warming and the increasing frequency of extreme weather events have contributed to a continuous rise in the global occurrence rate of forest fires, making them one of the most destructive natural disasters. Studying the spatiotemporal patterns of forest fires and their driving factors is essential for effective fire prevention and the formulation of mitigation measures, which holds great significance for the protection and management of forest resources, as well as for disaster prevention and mitigation (Shen, 2025).

Previous studies indicate that forest fire drivers are typically categorized into four types: meteorological conditions, vegetation, topography, and human activities (including infrastructure and socioeconomic factors) (Schulte & Mladenoff, 2005). Meteorological conditions are considered a primary factor influencing forest fires (Ma et al., 2020). The maximum daily wind speed has been identified as the primary factor affecting the duration of large fires in the western United States (Wang, Leung, & Qian, 2025). In Serbia, rising temperatures and reduced precipitation were found to significantly influence the probability of forest fire occurrence (Zivanovic et al., 2020). For the Belgrade region from 1986 to 2017, reliable forest fire occurrence prediction models could be constructed using only relative humidity or precipitation as predictors, based on analyses of various combinations of meteorological factors and fire danger indices (Tosic et al., 2019). China's forest fire data from 1998 to 2017 revealed that the overall forest fire situation in southern regions is more severe than in the north, with a recent rebound in fire occurrences (Huang et al., 2021). The spatial distribution of forest fires in China from 2010 to 2022 generally exhibited a clustered pattern, with most provinces and municipalities showing "high-high and low-low clustering" (Huang & Wang, 2025). In Henan Province, forest fire occurrence exhibits a significant negative correlation with relative humidity and precipitation, and a positive correlation with average temperature, with high-temperature and dry conditions significantly increasing fire risk (Zhang, 2025). Significant correlations ($P < 0.05$) were identified between forest fire frequency in Hunan Province and monthly average temperature, monthly average daily maximum temperature, and monthly average daily minimum temperature, with fire frequency exhibiting an increasing-decreasing-increasing trend with rising temperatures, while no clear association was found with monthly total precipitation or monthly average wind speed (Xiao, Long, & Wu, 2024). In Zhejiang Province, forest fire occurrence was found to be inversely correlated with daily precipitation and relative humidity, and positively correlated with daily maximum temperature, wind speed, and consecutive days without precipitation under mild or no drought conditions (Zhang et al., 2024b). Relative humidity was found to have the strongest influence on forest fire occurrence in the Yichun region, followed by surface temperature, while distance from residential areas had the weakest impact (Liang et al., 2015). This indicates that the spatiotemporal distribution of forest fires and their coupling mechanisms with meteorological factors are significantly influenced by regional differences.

Liangshan Prefecture, located in southwestern Sichuan Province, spans 100˚03'E to 103˚52'E and 26˚03'N to 29˚18'N. With a total area of approximately 60,400 km^2, it possesses a forest area of about 3.17 million hectares, and a forest coverage rate of 51.9%. The widespread distribution and diverse types of forests make the forest fire prevention situation in Liangshan Prefecture relatively complex (Zhang, 2020). Wildfire drivers were analyzed using a random forest model based on Liangshan Prefecture's MCD14DL fire dataset from 2001 to 2015, revealing meteorological factors as the most significant drivers of wildfires in the region, with annual mean temperature contributing the most (Zhang et al., 2024a). Using MODIS data from 2005 to 2020, annual sunshine duration, annual average relative humidity, annual average wind speed, annual precipitation, and annual average temperature were found to exert the greatest influence on the occurrence of forest fire hotspots in Liangshan Prefecture (Zhu, 2023). Using MOD14A1 data from 2005 to 2015, annual average relative humidity, annual average temperature, and annual precipitation were identified as the most influential factors affecting forest fires in Liangshan Prefecture (Zhang, 2020).

In summary, studies on the meteorological drivers of forest fires have been conducted in provinces and cities including Hunan, Henan, Zhejiang, Sichuan, and Yichun. Forest fire data were obtained from local forestry bureaus, fire prevention offices, and satellite remote sensing, combined with meteorological data from municipal and county meteorological bureaus. Methods such as geographic detectors, fire risk prediction models, correlation analysis, and variance analysis were employed to investigate the impact of meteorological factors. However, the application of data exhibits the following shortcomings: 1) Meteorological observations were typically selected from conventional local ground-based stations, which are often geographically distant from forest fire sites, resulting in insufficient precision of the matched meteorological data; 2) The temporal scales of meteorological factors influencing forest fires primarily relied on annual averages, monthly averages, and daily values, neglecting the effects of factor persistence and lag on fire occurrence. Building upon prior research, this study utilizes data from 143 forest fires in Liangshan Prefecture between 2016 and 2024. It employs regional station meteorological data with higher spatial matching accuracy to the fire locations and extends the temporal scale to three months prior to each fire occurrence to investigate the effects of meteorological factor persistence and lag. It analyzes the spatiotemporal patterns of forest fires in Liangshan Prefecture and their driving factors, aiming to improve the accuracy and timeliness of forest fire risk forecasts and provide scientific references for forest fire prevention and management in the region.

2. Materials and Methods

2.1. Study Area

The elevation and distribution of meteorological stations in Liangshan Prefecture are shown in **Figure 1**. Liangshan Yi Autonomous Prefecture has consistently ranked among the top regions in Sichuan Province for forest coverage and land greening. With 4.12 million hectares of forest land, the terrain is complex, characterized by high mountains, steep slopes, and deeply incised river valleys. Strong convective winds prevail in the valleys, while persistent droughts occur during winter and spring. Extreme weather events such as high temperatures and strong winds are frequent, creating highly susceptible natural ignition sources. This makes the region a typical high-risk area for forest fires, presenting a severe fire prevention challenge.

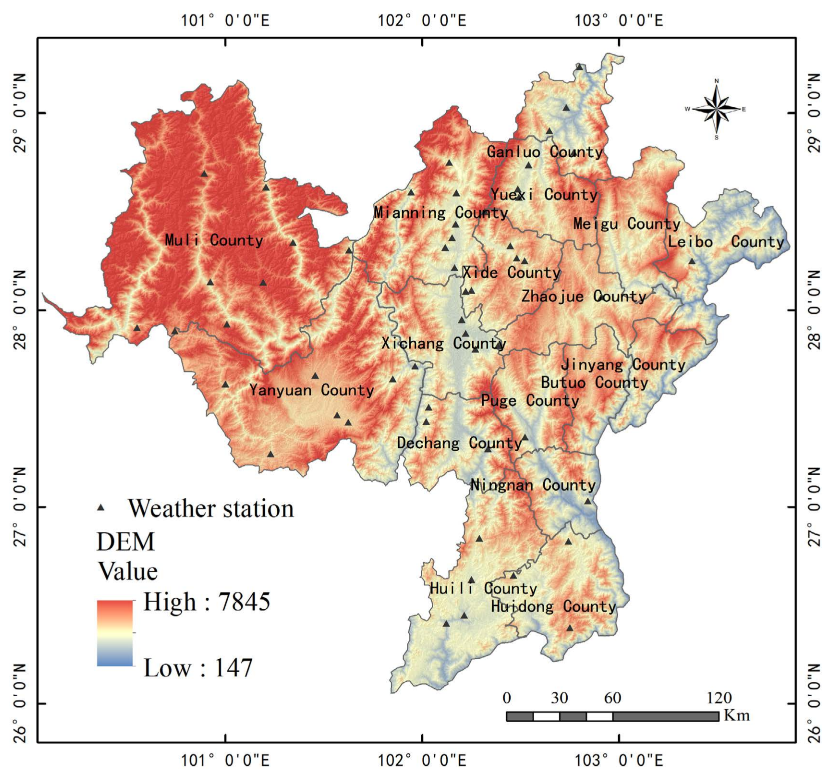


Figure 1. Elevation and meteorological station distribution in Liangshan prefecture.

2.2. Data Sources

All meteorological data in this study were obtained from the Liangshan Prefecture Meteorological Bureau. This primarily includes daily sunshine duration records from 17 national conventional ground meteorological observation stations in Liangshan Prefecture for the period 2016-2024, as well as daily data on average temperature, maximum temperature, minimum temperature, average relative humidity, minimum relative humidity, precipitation, average 2-minute wind speed, maximum wind speed, and peak wind speed from 775 regional automatic stations. Forest fire data were obtained from the Liangshan Prefecture Forestry Bureau, primarily including fire occurrence dates, locations, causes, and burned areas (hectares) from 2016 to 2024. Elevation data were sourced from the Geospatial Data Cloud website with a spatial resolution of 30 m. Vegetation data were obtained from the National Geographic Information Resource Directory Service System with a spatial resolution of 30 m; NDVI data were sourced from the Resource and Environmental Science Data Platform with a spatial resolution of 30 m; Social infrastructure data (settlements, highways, etc.) were provided by the National Center for Basic Geographic Information.

2.3. Research Methods

1) Haversine Formula

The Haversine formula calculates the great-circle distance between two points on a sphere given their longitudes and latitudes. The formula is as follows:

$$d = 2R \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\phi_2 - \phi_1}{2}\right) + \cos(\phi_1)\cdot\cos(\phi_2)\cdot\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right) \tag{1}$$

Where: R is the Earth's radius (typically taken as 6,371 km); the latitude and longitude coordinates of points A and B are (ϕ_1, λ_1) and (ϕ_2, λ_2), respectively.

2) Meteorological Drought Index (MCI)

The MCI comprehensively evaluates the severity of meteorological drought in a region over a specific period, calculated as follows:

$$\text{MCI} = Ka \times \left(a \times \text{SPIW}_{60} + b \times \text{MI}_{30} + c \times \text{SPI}_{90} + d \times \text{SPI}_{150}\right) \tag{2}$$

Where: MI_{30} denotes the 30-day relative moisture index, SPI_{90} represents the 90-day standardized precipitation index, SPI_{150} indicates the 150-day standardized precipitation index, SPIW_{60} denotes the standardized weighted precipitation index over the past 60 days, a, b, c, d are weighting coefficients, and Ka is the seasonal adjustment coefficient.

3) Spearman's Rank Correlation Analysis

The "occurrence rate" and "severity" of fires are described in forest fire research by fire frequency and burned area, respectively. This study uses burned area as the primary response variable in order to explicitly show how meteorological factors influence fire scale and ecological impact severity, rather than just how often they are to occur. Spearman's correlation analysis is used to examine the link between forest fire burned area and meteorological parameters since fire and meteorological data frequently have non-normal distributions and contain outliers. The following is the calculating formula:

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n\left(n^2 - 1\right)} \tag{3}$$

Where: n is the number of paired observations; d_i is the rank difference between variable X and variable Y for the i-th pair of observations; S^2 is the sum of the squares of all rank differences.

3. Temporal Characteristics of Forest Fires

3.1. Annual Variation

The annual variation characteristics of forest fires in Liangshan Prefecture from 2016 to 2024 are shown in Figure 2. From 2016 to 2024, Liangshan Prefecture experienced 143 forest fires, with a cumulative burned area exceeding 8,242.81 km^2. The number of fires peaked in 2019 (38 incidents, 26.57%). The lowest occurrence was in 2023 (3 fires, 2.10%). From 2016 to 2019, annual fire counts were relatively high (≥22 incidents), while 2020 saw a reduction to 14 fires. From 2021 to 2024, fire numbers continued to decrease (3 - 7 incidents annually). The burned area peaked in 2020 (3956.06 km^2, 48% of the total) and was lowest in 2024 (106.45 km^2, 1.29%). From 2019 to 2021, burned areas remained substantial (>1200 km^2 annually). Both fire frequency and burned area exhibited an initial increase followed by a decline, with peaks in 2019 and 2020, respectively.

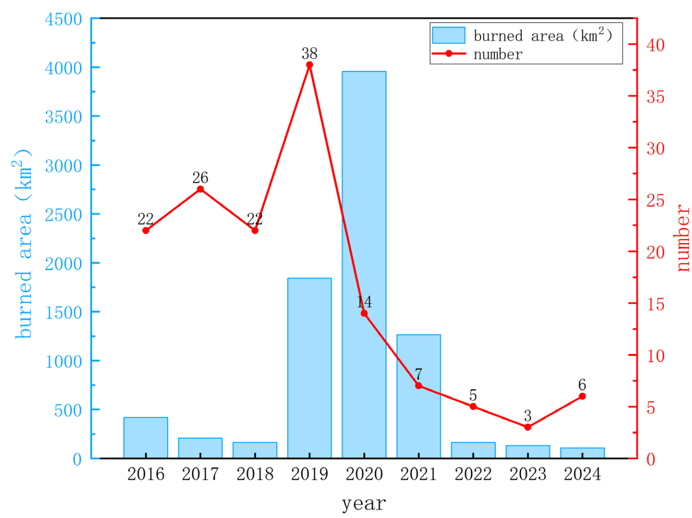


Figure 2. Annual variation characteristics of forest fires in Liangshan prefecture, 2016-2024.

3.2. Seasonal Patterns

The seasonal variation characteristics of forest fires in Liangshan Prefecture from 2016 to 2024 are shown in Figure 3. Forest fires predominantly occurred during spring (March-May, 91 incidents, 63.64%) and winter (December-February, 49 incidents, 34.27%), together comprising 98% of all occurrences. Summer and autumn saw only 2 and 1 fire(s), respectively. Spring recorded the largest cumulative burned area (7703.42 km^2, 93.46%), far exceeding other seasons. Winter had the second-largest cumulative burned area (470.39 km^2, 5.70%).

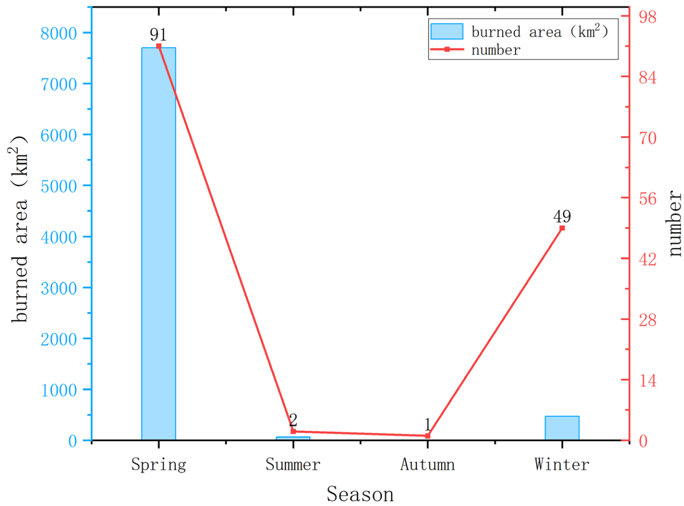


Figure 3. Seasonal variation characteristics of forest fires in Liangshan prefecture, 2016-2024.

3.3. Monthly Variation

The monthly variation characteristics of forest fires in Liangshan Prefecture from 2016 to 2024 are shown in **Figure 4**. Forest fires were primarily concentrated between January and May (140 incidents, 97.90%). March recorded the highest number (48 fires, 33.57%). Only 2 and 1 fires occurred in June and October, respectively; no fires were recorded in July, August, September, November, or December. March also recorded the largest cumulative burned area (4510.38 km^2, 54.72%). Months with significant burned areas were concentrated from February to May (cumulative >8084.43 km^2, 98.08%).

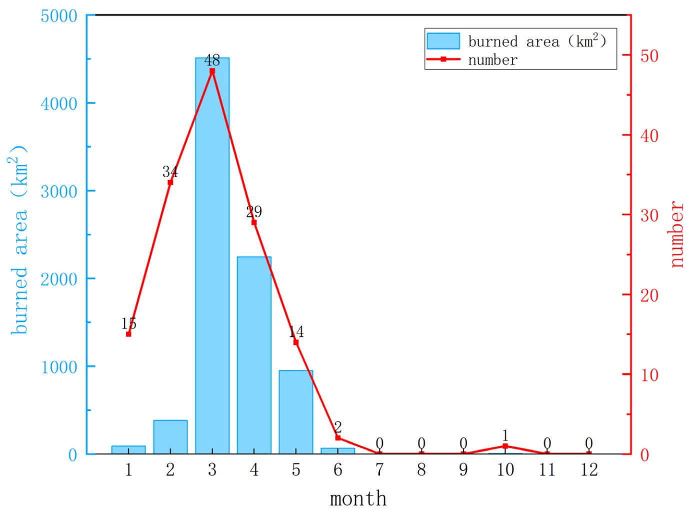


Figure 4. Monthly variation characteristics of forest fires in Liangshan prefecture, 2016-2024.

3.4. Diurnal Patterns

The daily variation characteristics of forest fires in Liangshan Prefecture from 2016 to 2024 are shown in Figure 5. The daily distribution of forest fire occurrences exhibited two high-frequency periods: from 00:00 to 02:00 and from 12:00 to 21:00. The peak occurred at 16:00 (23 fires, 16.1%). The lowest occurrences were between 03:00 - 09:00 and at 24:00 (one fire each). The cumulative burned area peaked at 16:00 (3611.27 km^2, 43.81%), followed by 17:00 (1691.36 km^2, 20.52%). Together, 16:00 and 17:00 accounted for 64.33% of the total daily cumulative burned area over the nine-year period.

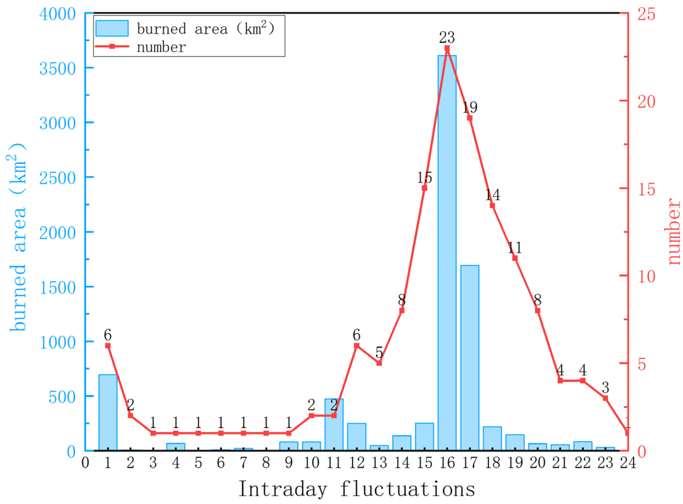


Figure 5. Diurnal variation characteristics of forest fires in Liangshan prefecture, 2016-2024.

4. Spatial Distribution Patterns

The spatial distribution of forest fires in Liangshan Prefecture from 2016 to 2024 is shown in Figure 6. Forest fires in Liangshan Prefecture exhibited an uneven spatial distribution. Mianning County had the highest number (28 incidents, 19.58%). Xichang, Muli, and Yanyuan recorded relatively high and similar numbers (22, 23, and 20 incidents, accounting for 15.38%, 16.08%, and 13.99%, respectively). Puge experienced only one fire, while Meigu and Butuo recorded none.

5. Analysis of Forest Fire Causes

Figure 7 illustrates the causes of forest fires in Liangshan Prefecture from 2016 to 2024, with human activities identified as the leading factor. Among these, agricultural fire use (15%) occurs at elevations between 1543 and 2066 meters, on slopes ranging from 1˚ to 37˚. Outdoor smoking (14%) is predominantly observed in relatively gentle terrain at elevations of 1647 - 2669 meters and slopes of 0˚ - 22˚. Other human activities (12%) are also concentrated in moderately flat areas with elevations of 1519 - 2184 meters and slopes of 4˚ - 25˚. Collectively, these

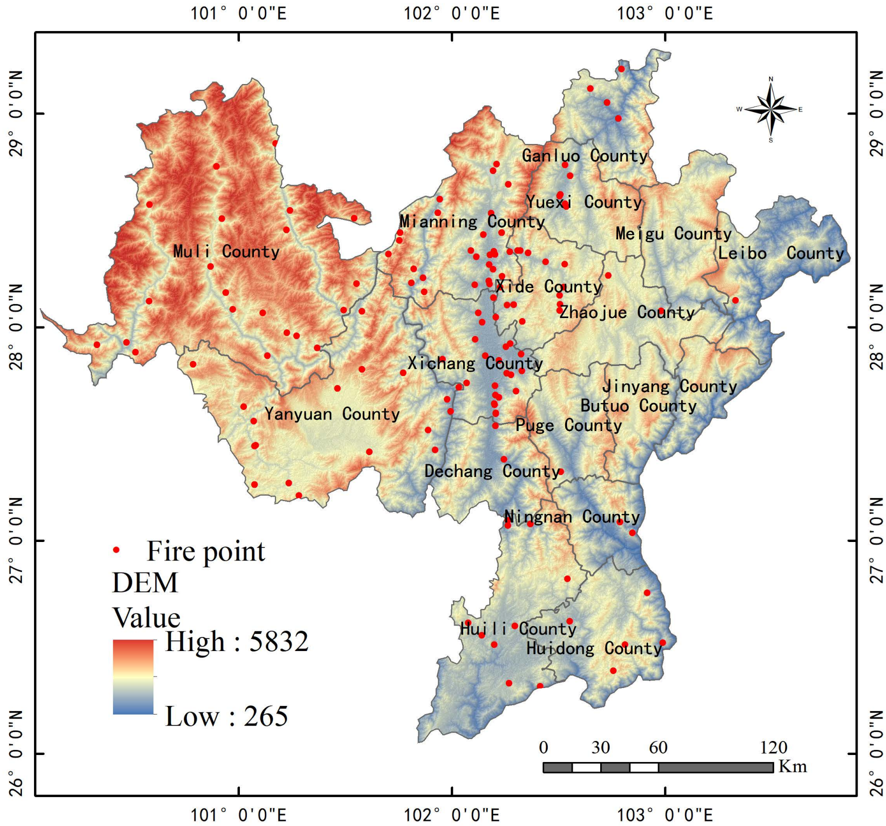


Figure 6. Spatial distribution of forest fire points in Liangshan prefecture, 2016-2024.

three factors account for 41% of all forest fires. In terms of natural causes, lightning strikes (12%) represent the primary and uncontrollable natural ignition source under Liangshan's unique topographic and climatic conditions. These typically occur at elevations of 1924 - 3010 meters, on slopes of 5˚ - 45˚, in areas with vegetation coverage no less than 0.44, and are concentrated between March and May. A significant proportion of fires (12%) remain undetermined due to technical and evidentiary challenges in fire investigation; these occur across a broad elevation range of 1405 - 2935 meters. Fires caused by minors playing with fire (10%) are also a notable issue, frequently observed at elevations of 1503 - 2588 meters, on slopes of 2˚ - 40˚, and in areas with vegetation coverage of 0.4 - 0.7. Electrical short circuits (10%) generally occur at elevations of 1493 - 2523 meters, on slopes of 6˚ - 28˚, in regions with vegetation coverage between 0.33 and 0.6, and are mainly recorded from January to March. The use of fire for outdoor living (6%) has emerged as a new risk factor, paralleling the rise in outdoor recreational activities. Among intentional human factors, arson (4%) and deliberate fire-setting (1%), though relatively low in proportion, are characterized by strong malicious intent and pose significant challenges for prevention. Regarding indirect human-related factors, fires spreading from adjacent provinces or counties (3%) underscore the cross-regional dynamics of forest fires and emphasize the necessity of establishing robust joint prevention and control mechanisms with neighboring regions.

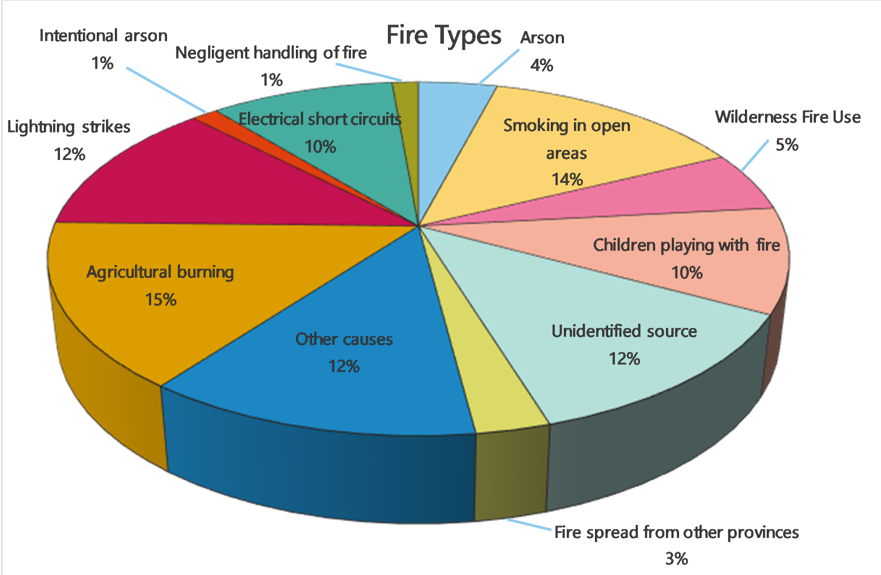


Figure 7. Causes of forest fires in Liangshan prefecture, 2016-2024.

6. Driving Factor Analysis

6.1. Topographical Factors

The distribution of forest fires in Liangshan Prefecture by elevation from 2016 to 2024 is shown in **Figure 8**. The majority of fires (132 incidents, 92.31%) occurred at elevations between 1500 and 3000 m. The highest frequency was at 1501 - 2000 m (63 fires, 44.06%); only 4 fires (2.80%) occurred at 3000 - 3201 m; no fires occurred above 3201 m.

The slope of forest fires in Liangshan Prefecture from 2016 to 2024 is shown in **Figure 9**. Forest fires predominantly occurred on slopes of 5˚ - 25˚ (81 incidents, 56.65%). The highest concentration was on slopes of 5˚ - 15˚ (46 incidents, 32.17%). Fires occurred equally on slopes of 0˚ - 5˚ and 35˚ - 45˚ (16 incidents each, 11.19%); only 3 fires occurred on slopes >45˚ (max 57˚). No fires occurred on slopes steeper than 60˚.

The distribution of forest fires in Liangshan Prefecture on uphill slopes from 2016 to 2024 is shown in **Figure 10**. Northwest, west, and southwest slopes each experienced over 20 fires (average 24 per aspect), collectively accounting for 53.14% of all fires. Southeast, east, and northeast slopes each recorded fewer than 15 fires (average 12 per aspect), collectively accounting for 23.83%. Fire frequency on west-facing slopes was twice that on east-facing slopes.

6.2. Vegetation Factors

The distribution of forest fires in Liangshan Prefecture by vegetation coverage from 2016 to 2024 is shown in **Figure 11**. The highest number of fires occurred in areas with NDVI 0.51 - 0.8 (79 incidents, 55.24%), followed by NDVI 0.21 - 0.5 (55 fires, 38.46%). The lowest frequency was in NDVI 0.81 - 1.0 (1 fire); fires in areas with NDVI <0.2 were scarce (8 incidents, 5.6%).

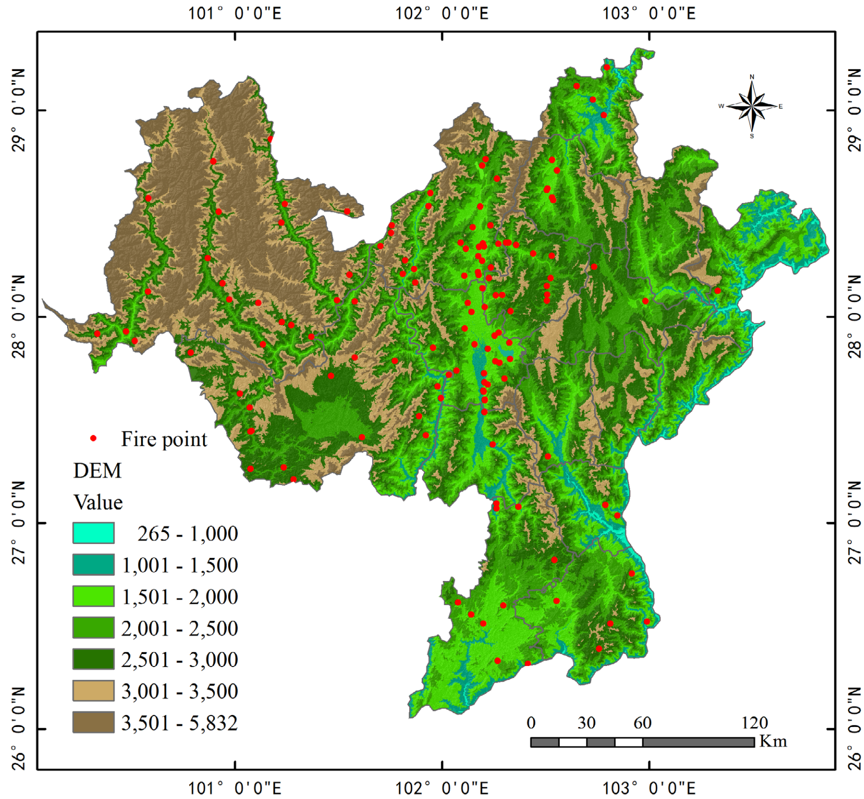


Figure 8. Altitudinal distribution of forest fires in Liangshan prefecture, 2016-2024.

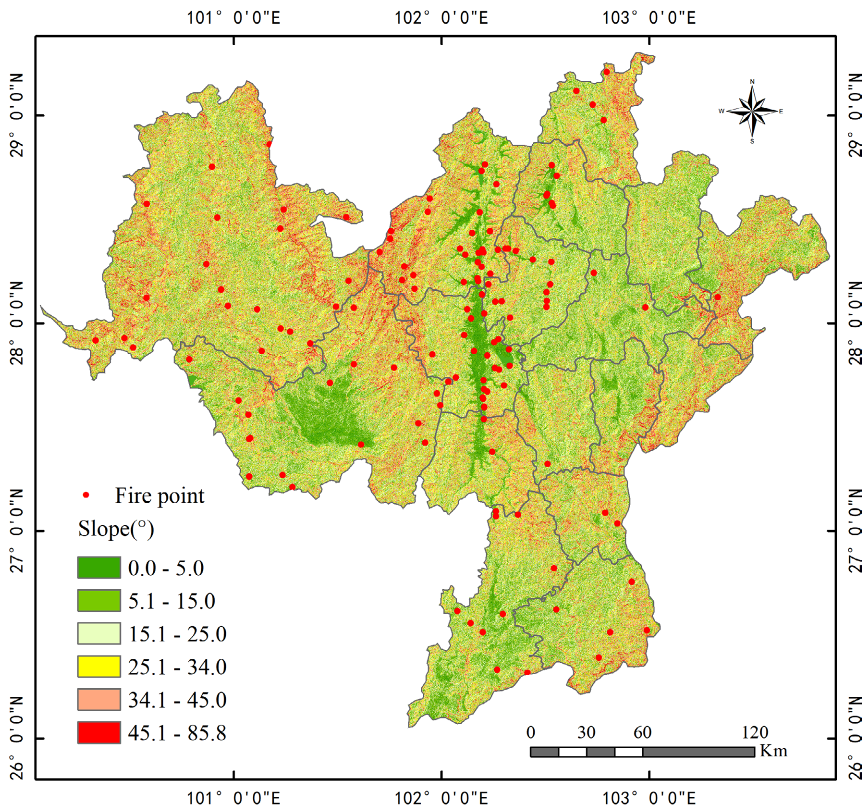


Figure 9. Distribution of forest fires in Liangshan prefecture by slope gradient, 2016-2024.

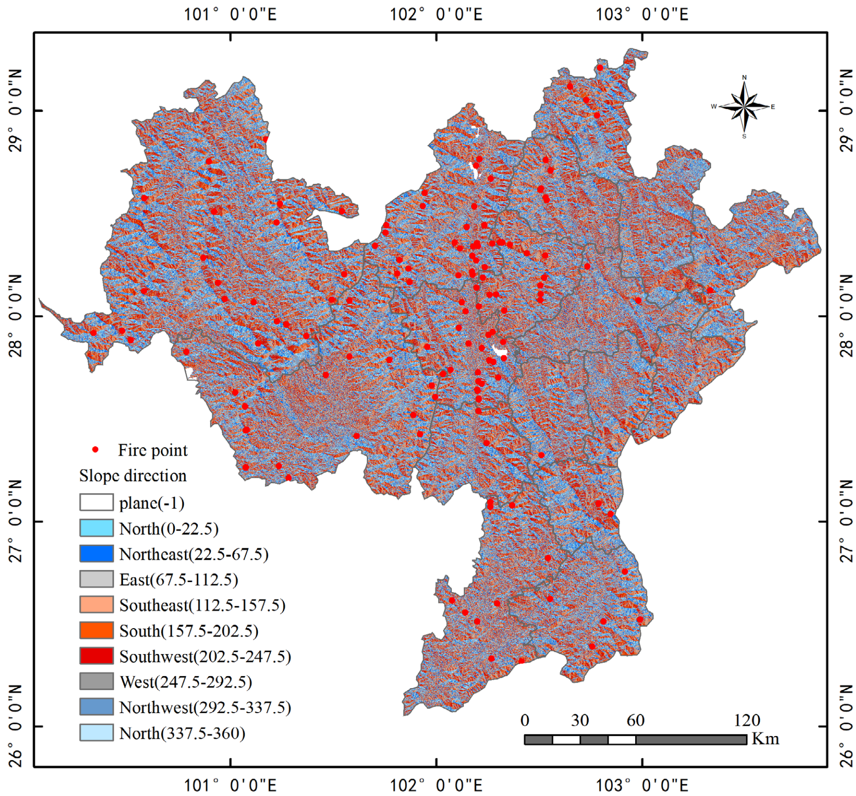


Figure 10. Distribution of forest fires on uphill slopes in Liangshan prefecture, 2016-2024.

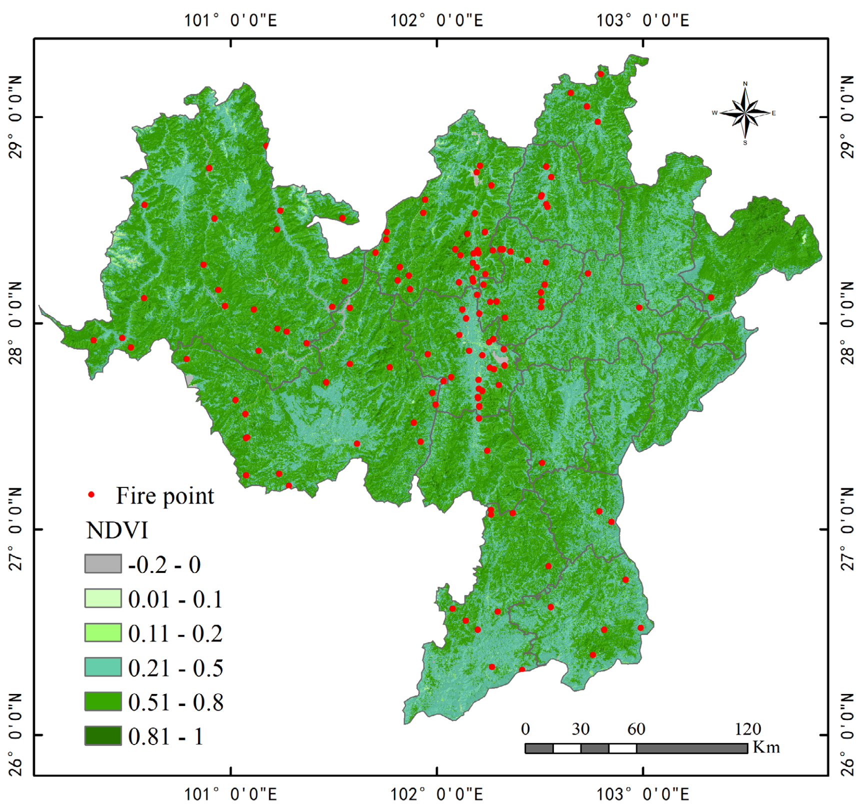


Figure 11. Distribution of forest fires in Liangshan prefecture by vegetation cover, 2016-2024.

6.3. Proximity to Residential Areas and Roads

Forest fires primarily occurred within 500 - 2000 m of residential buffers (141 incidents, 98.60%). The highest frequency was within 500 - 1000 m (48 incidents, 33.57%); the lowest was within 2000 - 2500 m (2 incidents, 1.40%). No fires occurred beyond 2500 m. The highest number of fires occurred within 500 m of road buffers (103 incidents, 72.03%), followed by 500 - 1000 m (34 incidents, 23.78%). The 1000 - 2000 m range recorded only 6 fires (4.20%); no fires occurred beyond 2000 m.

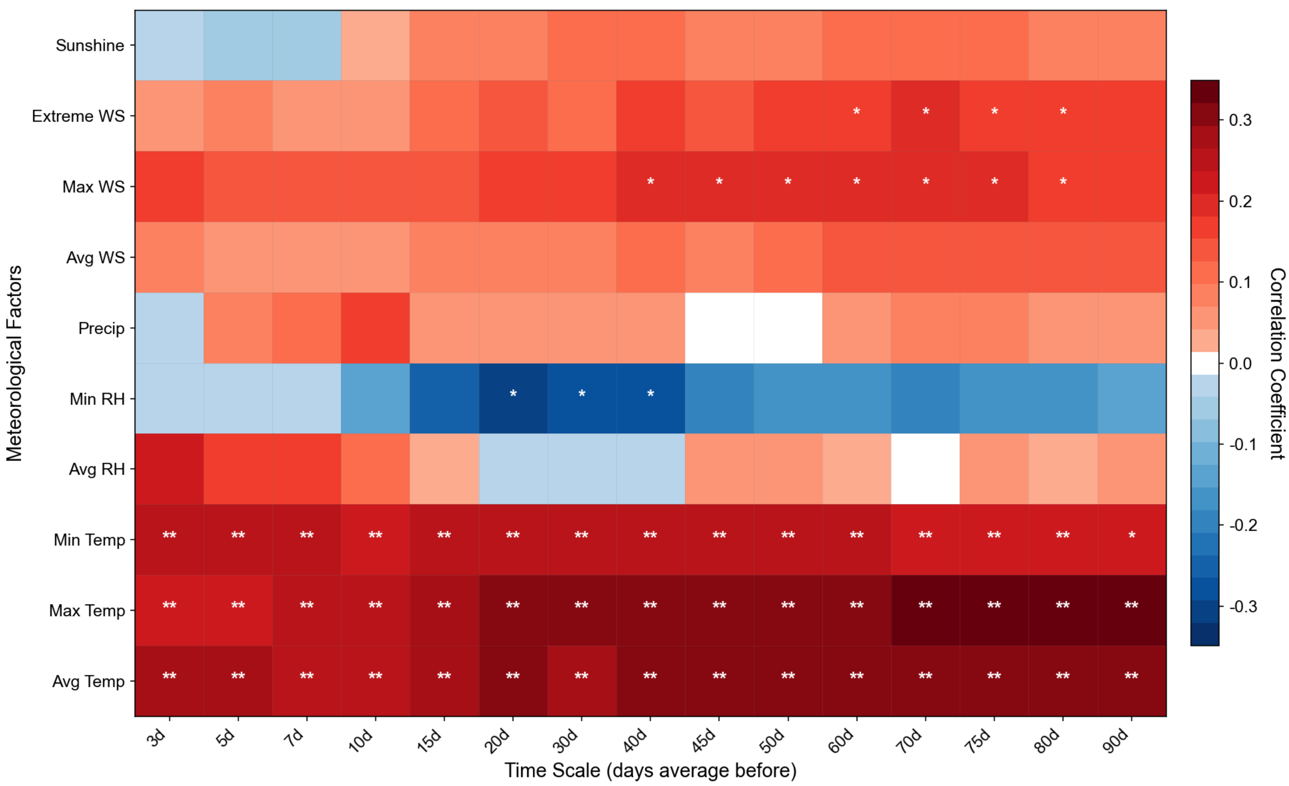
6.4. Analysis of Meteorological Drivers for Forest Fires in Liangshan Prefecture

To investigate the persistent and lagged effects of meteorological factors on forest fire occurrence, this study spatially matched forest fire locations with the nearest regional meteorological stations using the Haversine formula. Meteorological factors observed at the corresponding regional automatic stations were then selected, including temperature variables (mean, maximum, and minimum temperature), air humidity (mean and minimum relative humidity), precipitation, and wind speed (mean two-minute wind speed, peak wind speed, and maximum wind speed). On the temporal scale, 14 time windows spanning from 3 to 90 days prior to fire occurrence (i.e., 3, 7, 10, 15, 20, 30, 40, 45, 50, 60, 70, 75, 80, and 90 days) were analyzed. The average value of each meteorological factor within each time window was calculated.

Given that the burned area of forest fires and some meteorological variables did not follow a normal distribution, Spearman's rank correlation coefficient (ρ) was used for nonparametric correlation analysis to identify monotonic relationships between burned area and the average values of meteorological factors across different time scales. By comparing the Spearman correlation coefficients between meteorological factors and burned area across the different time windows, this study identified the meteorological factors most strongly correlated with burned area and their corresponding time scales. These factors were thus considered the primary meteorological drivers influencing forest fire occurrence.

Figure 12 shows the correlations between burned area and meteorological factors from 2016 to 2024. The results indicate: 1) The average values of mean, maximum, and minimum temperature across all time windows (3 – 90 days prior) were positively correlated with burned area, with p-values below 0.01. The highest correlation coefficients were observed for the 20-day average mean temperature (0.3041), the 80-day average maximum temperature (0.3487), and the 20-day average minimum temperature (0.2594). 2) The average minimum relative humidity over the preceding 20, 30, and 40 days showed negative correlations with burned area, with the strongest correlation observed for the 20-day average (approximately −0.3132). 3) The average maximum wind speed over the preceding 60, 70, 75, and 80 days was positively correlated with burned area, with the highest correlation coefficient for the 70-day average (0.1885). Similarly, the average peak wind speed over the preceding 40 - 80 days showed positive correlations, with the strongest association also for the 70-day average (0.1965). 4) The Meteorological Drought Index (MCI) on the day of the fire showed a positive correlation with burned area, with a correlation coefficient of 0.1990. 5) At the studied time scales, no significant correlations were found between burned area and average relative humidity, precipitation (20:00 - 20:00), average two-minute wind speed, or sunshine duration.

In summary, the meteorological factors most strongly correlated with forest fire burned area were the 20-day average temperature, 80-day maximum temperature, 20-day minimum temperature, 20-day minimum relative humidity, 70-day average peak wind speed, and 70-day average maximum wind speed. These findings indicate that the influence of meteorological conditions on forest fire occurrence in Liangshan Prefecture arises from synergistic interactions among multiple factors, reflecting cumulative effects across long-, medium-, and short-term time scales.



(*Indicates significance at the 95% confidence level; ** indicates significance at the 99% confidence level).

Figure 12. Correlation between forest fire burn area and meteorological factors, 2016-2024.

7. Discussion

This study reveals that forest fires in Liangshan Prefecture occur most frequently between January and May, predominantly concentrated in central and western counties such as Xichang, Muli, and Yanyuan. This spatiotemporal clustering pattern aligns with the findings of previous research (Deng, 2023), providing a scientific basis for the precise allocation of firefighting resources. Notably, fires exhibited a distinct bimodal daily pattern, with the period from noon to 9 PM (totaling 113 incidents) being the peak occurrence time. Particularly, the proportion of burned area at 16:00 and 17:00 was exceptionally high, collectively accounting for 64.33%. Furthermore, 72.03% of fires originated within a 500-meter buffer zone of roads. These two patterns hold direct implications for fire management practices: patrol schedules and public awareness resources should be prioritized during the high-risk afternoon-to-evening hours, and key monitoring areas and fire prevention points should be established along major roads to efficiently intercept and provide early warnings for human-ignited fire sources.

In the analysis of meteorological factors, the burned area of forest fires showed a significant positive correlation with prior-period (e.g., preceding 20 days, preceding 80 days) average and maximum temperatures, and a significant negative correlation with minimum relative humidity. This finding usefully supplements the conclusions of earlier studies focusing on concurrent meteorological conditions (Zhang et al., 2024a), by revealing the lagged effects of meteorological influences. A key discovery is that while daily-scale meteorological variables (such as average relative humidity, precipitation, and wind speed) showed no significant statistical association with burned area, the Meteorological Drought Composite Index (MCI) demonstrated a stable positive correlation (correlation coefficient 0.1990). As MCI is a composite index representing medium to long-term moisture deficit, its correlation with burned area indicates that forest fires in Liangshan Prefecture, particularly large-scale ones, are driven more substantially by prolonged, cumulative drought stress. Consequently, compared to single daily weather indicators, MCI could serve as a more robust warning indicator for predicting high fire danger and potential major fire incidents, and it is recommended for integration into Liangshan Prefecture's forest fire danger rating forecast system.

This study has certain limitations regarding data and methodology. Although regional station meteorological data were used to enhance spatial matching accuracy, missing and incomplete data from some stations may still affect the robustness of the results. Future work could address this through methods like data interpolation or fusion with reanalysis data. Analytically, this study primarily relied on Spearman correlation analysis. While this method effectively identifies monotonic relationships between variables, it cannot establish causality or elucidate interactions among multiple driving factors. To gain a deeper understanding of the complex mechanisms underlying fire occurrence, future research should employ more advanced statistical modeling techniques, such as multiple regression models, structural equation modeling, or machine learning algorithms. These approaches can quantify the independent contributions and interactions of various factors, thereby enabling the construction of more predictive and explanatory fire risk models.

8. Conclusion

This study systematically reveals the spatiotemporal patterns and primary driving factors of forest fires in Liangshan Prefecture. The key findings are summarized as follows:

Forest fires in Liangshan Prefecture exhibit high temporal concentration, with the high-occurrence period from January to May accounting for 97.90% of the total fire incidents. March represents the annual peak in both fire frequency and burned area. Diurnally, fires occur primarily between 12:00 and 21:00, a period characterized by high fire frequency and significantly larger burned areas. Spatially, the distribution shows distinct regionalization, with high-incidence areas concentrated in Mianning County in the north, Xichang City in the central region, and Muli and Yanyuan Counties in the west. Human activities are the dominant ignition source: anthropogenic fires, including agricultural fire use and outdoor smoking, are the primary causes (collectively 41%). These predominantly occur at elevations of 1500 - 2000 meters and within proximity to residential areas (500 - 2000 meter buffer) and roads (500 meter buffer), highlighting the urgency of strengthening human fire source management. Topography and vegetation are key environmental contexts: fires mainly occur in areas with elevations of 1500 - 3000 meters and slopes of 5˚ - 25˚. Furthermore, fire frequency on west-facing slopes (northwest, west, southwest) was twice as high as on east-facing slopes. Forests with medium to high vegetation coverage (0.21 - 0.8) constitute the primary setting for fire occurrence. Long-term meteorological drought is a significant natural driver: Preceding temperature conditions (e.g., mean air temperature of the preceding 20 days, maximum temperature of the preceding 80 days) and humidity (minimum relative humidity of the preceding 20 days) showed relatively strong correlations with burned area. Wind speed and the MCI index also exhibited certain positive correlations, whereas factors like precipitation and average wind speed showed no significant correlation. More importantly, a positive correlation exists between the composite Meteorological Drought Composite Index (MCI) and burned area, indicating that accumulated long-term drought is a key natural factor leading to large-area fires.

In summary, forest fire prevention efforts in Liangshan Prefecture should be based on these patterns to implement targeted management strategies: intensify patrols and fire source control during critical periods (winter-spring, afternoon) and in key areas (western and central counties, areas along roads), and utilize medium to long-term drought indicators like the MCI to enhance early warning and forecasting capabilities for fire risk. This approach will enable the efficient allocation of fire prevention resources and facilitate the proactive management of fire risks.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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