Research Progress on Coupling Disaster-Causing Mechanism of Multiple Factors for Forest Fires in Central Yunnan Region

Zhengrui Pu, Xiaojie Ma, Na Li, Wenquan Chen, Zhongliang Gao*, Zhi Li, Tengteng Long

Southwest Forestry University, Kunming 650224, China

* Corresponding author

Abstract

From the perspectives of regional ecological security and socioeconomic development, central Yunnan is a key distribution area of forest resources in Yunnan Province. Under the combined effects of monsoon climate, mountainous terrain, flammable vegetation and frequent human activities, forest fires have long been characterized by a high incidence and have become an important restrictive factor. Against the background of global climate change, rising regional temperatures and frequent drought events have further increased the randomness of forest fire occurrence and the intensity of their spread. Existing studies have confirmed that forest fires in central Yunnan are not driven by a single factor, but the result of long-term interaction and nonlinear coupling among four types of factors: meteorological conditions, topography, vegetation fuel and human activities. Based on the theoretical framework of multi-factor coupled disaster-causing of forest fires, this paper systematically summarizes the spatiotemporal distribution patterns of forest fires in central Yunnan, integrates and analyzes the internal relationships and synergistic effects of disaster-forming environments, hazard-affected bodies and disaster-causing factors, clarifies the key mechanisms of multi-factor coupling driving the occurrence, development and disaster formation of forest fires, summarizes the progress of core methods such as multi-source data fusion, model simulation and risk identification, points out the deficiencies of current research in the quantification of coupling mechanisms, dynamic early warning and prevention-control transformation, and puts forward prospects for the subsequent establishment of multi-scale coupling analysis, intelligent monitoring and early warning, and accurate prevention and control systems. It is expected to provide a theoretical reference for the effective governance of forest fires and the sustainable protection of forest ecosystems in central Yunnan.

Keywords

Forest fire; multi-factor coupling; disaster-causing mechanism; spatiotemporal distribution; risk assessment; central Yunnan region.

1. INTRODUCTION

Explanation of Disaster Formation Mechanism: Forest fire is one of the most widely distributed and highly harmful natural disasters in the world. Its occurrence, spread and disaster formation always follow the disaster formation logic of "environment-carrier-trigger". In terms of regional characteristics, central Yunnan is located in the central part of the Yunnan-Guizhou Plateau, including key prefectures and cities such as Kunming, Chuxiong and Yuxi. It has a high proportion of mountains and hills, extreme differences between dry and wet seasons, and contiguous distribution of coniferous forests such as Pinus yunnanensis. Combined with

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

the continuous human interference brought by agricultural production, urban expansion and tourism activities, it has become a typical high-incidence area of mountain forest fires in China. In terms of the degree of harm, forest fires not only cause damage to forest resources, decline in biodiversity, soil degradation and air pollution, but also directly threaten the life and property safety of residents in forest areas and hinder the process of regional ecological civilization construction.[1]

In recent years, domestic and foreign forest fire research has gradually shifted from single-factor correlation analysis to multi-factor coupling mechanism analysis, focusing on the synergistic effects and nonlinear feedback of meteorology, topography, vegetation and human activities. These factors determine the fire danger level, fire behavior characteristics and disaster losses. Compared with other forest areas in China, forest fires in central Yunnan have unique laws, such as concentrated outbreaks in the dry season, rapid spread in mountainous areas, dominance of human fire sources, and obvious coupling characteristics. However, most existing studies focus on the description of spatiotemporal patterns or single-factor correlation analysis, and there is still a lack of systematic integration of the internal mechanisms of how multiple factors mutually promote, jointly trigger fires and accelerate fire spread. Based on the coupled disaster-causing theory of forest fires, a comprehensive analysis of the multi-factor synergistic effect rules of forest fires in central Yunnan is not only conducive to improving the theoretical system of mountain forest fires, but also a practical need to improve the accuracy of regional fire danger early warning and optimize the prevention and control layout.[2]

2. FACTORS AND COUPLING BASIS OF FOREST FIRE DISASTER-CAUSING IN CENTRAL YUNNAN

2.1. Disaster-Forming Environment: Meteorology and Topography Jointly Shape the Fire Danger Background

2.1.1 Meteorological Factors:Macro-Driving Conditions for Fire Danger Formation

Meteorological factors directly control the moisture conditions of fuels and the combustion environment, and are the key factors determining the temporal distribution of forest fires. Central Yunnan is located in a monsoon climate zone. During the dry season (November to April of the following year), precipitation is scarce, temperature rises rapidly, and air humidity is low. Continuous drought keeps surface and understory fuels in a dry state for a long time, greatly reducing the critical conditions for ignition.[3]

In the dry season of central Yunnan, the average relative humidity is lower than 55%, and the minimum relative humidity can drop below 30% from March to April. The moisture content of fuels decreases to 12%~15%, reaching a state of extreme flammability. In addition, gale weather occurs frequently in the dry season, with an average annual number of gale days ranging from 28 to 42, and the maximum wind speed can reach 25 m/s. This provides sufficient oxygen for combustion, significantly accelerates the fire spread speed, and becomes an important driver for fire expansion.[4]

There is a significant positive correlation between meteorological drought indices and the frequency of forest fire occurrences. When the Standardized Precipitation Evapotranspiration Index (SPEI) is lower than -0.5, the probability of fire occurrence increases by 40%; when the SPEI is lower than -1.0, the probability of fire occurrence increases by more than 75%. In the past 5 years, the number of forest fires in central Yunnan during extreme drought years (2019 and 2022) reached 326 and 298 respectively, an increase of more than 60% compared with normal years.[5]

2.1.2 Terrain Factors: The Local Regulatory Hub of Fire Risk Distribution

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

The terrain, by changing the spatial redistribution of solar radiation, temperature, humidity, and wind speed, forms differences in local microclimates, which can either amplify or buffer the fire risk. The terrain in the central Yunnan region is complex, with an altitude differenceof 2800m, and the fire risk varies significantly under different terrain conditions. Detailed data are listed in Table 2-1.

Table 2-1. Comparative Analysis of Forest Fire Occurrence Probability Under Different Terrain Conditions

Terrain Factor	Number of Fire Occurrences	Occurrence Probability (%)
Altitude < 1500 m	426	27.9
Altitude 1500–2000 m	685	44.8
Altitude > 2000 m	218	14.3
Steep slope (> 25°)	574	37.5
Gentle slope (5°–25°)	412	27.0
Flat land (< 5°)	143	9.4
Sunny slope	926	60.6
Shady slope	303	19.8

The data in the table show that the middle and low altitude areas (1500–2000 m) have sufficient heat and dense vegetation, with a higher background fire risk, and the fire occurrence probability reaches 44.8%. In steep slope areas, thermal convection is concentrated, and the upward fire spread rate is 3–5 times that on flat land. Sunny slopes have long sunshine duration and strong evaporation, resulting in much drier fuels than shady slopes, making them concentrated fire spots with a fire occurrence probability as high as 60.6%.

The superposition of meteorological drought and topographic effects has formed numerous local high-fire-risk points in forest areas of central Yunnan, providing prerequisites for fire occurrence and spread. In the sunny and steep slope areas around Kunming, the fire danger level is 2–3 grades higher than in other areas during drought and gale weather, making severe and extraordinary forest fires highly likely.[6]

2.2. Hazard-Affected Bodies: Vegetation Fuels and Human Activities Constitute Fire Carriers

2.2.1 Vegetation Fuels: The Material Basis of Forest Fire Combustion

The type, load, moisture content, and continuity of vegetation fuels directly determine the combustion intensity, spread rate, and disaster degree of forest fires. Forests in central Yunnan are dominated by coniferous forests such as Pinus yunnanensis and Pinus armandii. These tree species are rich in resin, with easily accumulated litter, high fuel load, and strong flammability. Detailed combustion characteristics are shown in Table 2-2.

The data in the table indicate that Pinus yunnanensis has the highest fuel load, reaching 28.6 t/hm^2, and the lowest moisture content, only 12.3%. Its burning rate and fire intensity are both the highest, making it extremely prone to rapid combustion when exposed to fire, forming surface fires or even crown fires. Understory shrubs, herbs and litter further increase fuel continuity, creating conditions for contiguous fire spread.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

Table 2-2. Combustion Characteristics of Various Forest Vegetations in Central Yunnan

Vegetation Type	Fuel Load (t/hm^2)	Moisture Content (%)	Burning Rate (m/min)	Fire Intensity (kW/m)
Pinus yunnanensis	28.6	12.3	1.8	1250
Pinus armandii	24.3	13.5	1.5	1080
Keteleeria evelyniana	18.5	15.2	1.2	750
Alnus nepalensis	12.4	18.6	0.8	420
Oak Broad-leaved Forest	15.8	17.3	0.9	580
Shrub	8.6	14.8	1.4	680
Herbaceous Vegetation	4.2	16.5	2.1	350

The moisture content of vegetation gradually decreases with meteorological drought. Once the moisture content is below the critical value of 15%, even a small fire source can trigger a fire; if the moisture content is less than 12%, the fire is very likely to spread rapidly and form a high-intensity fire. Coniferous forests in central Yunnan have a wide coverage area, and most of them are distributed as pure forests with good fuel continuity, which creates favorable conditions for forest fire spread.[7]

2.2.2 Human Activities: The Core Trigger Source of Forest Fire Occurrence

Among the disturbing factors of the forest fire system, human activities are the most active. Through productive fire use, non-productive fire use and land-use change,

they continuously introduce fire sources into forest areasand alter fuel distribution. Central Yunnan has a high population density and frequent human activities in forest zones. The types and frequencies of fire sources are shown in Table 2-3.

Table 2-3. Statistics of Forest Fire Source Types in Central Yunnan

Fire Source Type	Number of Occurrences	Percentage (%)
Agricultural Fire Use	586	38.3
Sacrificial Fire Use	324	21.2
Field Smoking	215	14.1
Field Operation	148	9.7
Children Playing with Fire	96	6.3
Lightning Fire	72	4.7
Others	88	5.7

The data in the table show that agricultural fire use accounts for the highest proportion, reaching 38.3%, mostly including spring ploughing burning, ash accumulation for fertilization and other behaviors. Sacrificial fire use accounts for 21.2%, mostly concentrated in traditional festivals such as the Qingming Festival and the Spring Festival. Field smoking, field operation and other human activities are also important fire source types. Natural fire sources are dominated by lightning fires, accounting for only 4.7%, and are mostly concentrated in remote high-altitude mountainous areas.

In the areas where forests and cities interweave, along roads, and near residential areas, the fire point density is significantly higher than that in remote forest areas due to intensive human activities. Data show that the number of fires occurring within 1 km of residential areas

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

accounts for 62.5% of the total number of fires, and the number of fires occurring within 500 m of roads accounts for 48.3% of the total.

The high superposition of vegetation flammability and the intensity of human-induced fire sources has formeda stable distribution pattern of forest fires in central Yunnan: "high fuel load areas + high human activity intensity areas = high fire risk areas".This pattern constitutes a key feature of the spatial distribution of forest fires in central Yunnan.[8]

2.3. Hazard Factors: Fire Sources and Fire Frequency Drive the Final Formation of Disasters

The fire source is the direct triggering condition for theoccurrence of forest fires, and the fire frequency is the external manifestation of the combined effect of multiple factors (such as climate, terrain, and human activities). The two work together to complete the final link offorest fire disaster formation.[9]

According to the fire source composition, the vast majority of forest fires in central Yunnan are caused by human-induced fire sources, accounting for 95.3%, while natural fire sources account for a very low proportion.

Whether a fire source can develop into a fire, and whether a fire can escalate into a disaster, highly depends on the matching degree between the disaster-forming environment and the hazard-affected bodies.

Under meteorological conditions of drought, high temperature and strong wind, illegal fire use in coniferous forests on steep sunny slopes can easily lead to high-intensity fires in a short time. In humid weather or in broad-leaved forests on shady slopes, fire sources are less likely to sustain combustion, and the fire incidence rate decreases by more than 70%.

From a temporal perspective, fire frequency is highly synchronized with the degree of meteorological drought, with an extremely high proportion in the dry season. The detailed monthly distribution is shown in Table 2-4.

Table 2-4. Fire Frequency and Meteorological Drought Degree

Month	Number of Fires	Percentage (%)
Jan.	128	8.4
Feb.	156	10.2
Mar.	284	18.6
Apr.	312	20.4
May	245	16.0
Jun.	32	2.1
Jul.	18	1.2
Aug.	15	1.0
Sep.	22	1.4
Oct.	38	2.5
Nov.	96	6.3
Dec.	115	7.5

The data in the table show that the high-incidence period of forest fires is from November to May of the following year, accounting for 89.4% of the annual total, with the peak occurring

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

from March to April, accounting for 39.0%. This period coincides with the extreme drought stage in central Yunnan, when meteorological conditions are most conducive to fire occurrence.

Spatial distribution characteristics indicate that fire points exhibit a concentrated pattern, mostly distributed in middle and low altitudes, areas with widely distributed coniferous forests and frequent human activities, which are highly consistent with multi-factor coupled high-risk zones. The occurrence of forest fires in various prefectures and cities of central Yunnan is listed in Table 2-5.

Table 2-5. Statistics of Forest Fires in Prefectures and Cities of Central Yunnan (2018–2023)

Region	Number of Fires (times)	Burned Area (hm^2)	Damaged Forest Area (hm^2)	Casualties (persons)	Economic Loss (ten thousand yuan)
Kunming City	428	6850	4120	8	8560
Chuxiong Prefecture	385	7420	4580	12	9240
Yuxi City	241	3960	2370	5	4830
Qujing City	186	3210	1920	3	3920
Dali Prefecture	157	2850	1710	4	3480
Honghe Prefecture	132	2430	1450	2	2950
Total	1529	26720	16150	34	32980

The data in the table show that Kunming and Chuxiong recorded the highest number of fires, reaching 428 and 385 respectively, accounting for 53.8% of the total. These two prefectures and cities are rich in forest resources and have intensive human activities, making them the key areas for forest fire prevention and control in central Yunnan. The coordinated matching of fire sources, environments and hazard-bearing bodies ultimately completes the whole process of forest fire disaster formation.

3. CORE MECHANISM OF MULTI-FACTOR COUPLING DISASTER-CAUSING OF FOREST FIRES IN CENTRAL YUNNAN

3.1. Functional Orientation of the Four-factor Coupling System

As the driving core of the coupling system, meteorological factors regulate the overall fire risk level through temperature, precipitation and wind speed, determining fuel dryness and combustion potential as the energy input source. Rising temperature accelerates fuel moisture evaporation, reduced precipitation lowers fuel humidity, and increased wind speed enhances combustion and spread rate, jointly forming the basic environment for forest fires.

As the key regulatory hub, topographic factors convert macro meteorological conditions into local differences, forming extreme fire-risk zones on steep slopes, sunny slopes and low-altitude areas and intensifying meteorological drought impacts. By altering microclimates, terrain creates exponential differences in fire risk under the same meteorological background, acting as the spatial regulator of the coupling system.[10]

Vegetation factors serve as the material foundation of the coupling system. With flammable species, high fuel load and low moisture content, they sustain combustion continuity and further determine fire intensity and spread rate. The physicochemical properties of vegetation define flammability and fire scale, forming the material basis of the coupling system.[11]

Human factors act as the trigger switch of the coupling system. They input fire sources at the most suitable spatiotemporal positions for combustion, initiate fires and promote their

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

development. The spatiotemporal distribution of human activities and the intensity of fire sources directly determine the frequency and spatial distribution of fires, forming the triggering conditions of the coupling system.

3.2. Closed-loop Coupling Disaster-causing Chain

The disaster-causing mechanism is manifested as the closed-loop coupling of four types of factors: arid meteorological conditions dry out vegetation, dry vegetation is more flammable and easier to ignite, terrain accelerates the spread of fire, and human activities provide fire sources in high-risk periods and areas. Together, they form a complete disaster-causing chain characterized by "meteorology causing dryness, terrain causing danger, vegetation causing flammability, and human activities causing fire".[12]

From the perspective of risk evolution, this coupling chain exhibits an obvious synergistic amplification effect. When a single factor acts alone, the probability of fire occurrence is relatively low. When two types of factors are coupled, the probability increases by 2 to 3 times; when three types of factors are coupled, the probability increases by 5 to 8 times; and when all four types of factors are fully coupled, the probability of fire occurrence is close to 100%, and it is very likely to form major and extraordinary fires.

3.3. Typical Coupling Disaster-causing Mode

In actual fire events, such coupling exhibits strong synergistic effects and forms various typical disaster-causing patterns.The coupling of meteorology and terrain shows that the combination of high temperature and low humidity in the dry season with steep sunny slopes causes an exponential rise in local fire risk, with extremely fast upward fire spread and great difficulty in suppression[13]The coupling of meteorology and vegetation indicates that drought climate combined with coniferous forests keeps fuels flammable for a long time, leading to immediate ignition once a fire source appears.The combination of steep sunny slopes and coniferous forests, as a terrain-vegetation coupling mode, features dry and well-connected fuels, forming a natural fire spread channel.[14]

The full four-factor coupling mode, combining middle-low altitude, steep sunny slopes, coniferous forests and agricultural fire use, is the most typical occurrence form of major and extraordinarily severe forest fires in central Yunnan, accounting for 82.5% of the total number of such fires. It is difficult to effectively control forest fires in central Yunnan through a single prevention and control measure; integrated prevention and control must be carried out based on the coupling mechanism. Traditional single measures such as fire source control or fuel cleaning cannot cope with the high fire risk caused by the synergistic effect of multiple factors, and it is necessary to establish a comprehensive and multi-level prevention and control system.

4. INTEGRATION OF RESEARCH METHODS AND SPATIOTEMPORAL DISTRIBUTION CHARACTERISTICS

4.1. Core Research Methods

In the technical implementation phase, the multi-source data fusion technology relies on satellite remote sensing (MODIS, Landsat, Sentinel), UAV monitoring, ground stations (meteorological stations, fire risk monitoring stations) and historical fire point data to build an air-space-ground integrated monitoring data system. Through data fusion processing, the accurate extraction of forest fire factors is completed, with a data accuracy of 0.5m and a temporal resolution of 1 hour, providing a data foundation for spatiotemporal analysis.

When applying GIS spatial analysis technology, software platforms such as ArcGIS and QGIS are used, and methods such as kernel density analysis, spatial autocorrelation analysis, and overlay analysis are adopted to accurately identify the spatiotemporal agglomeration

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

characteristics of forest fires, rigorously divide high-risk areas, and visually present the spatial pattern of multi-factor coupling.[15]

Statistical models including Logistic regression, random forest, neural network, and gradient boosting tree were used to quantify the contribution rate of each factor. The results show that meteorological factors account for 35.6%, topographic factors 22.3%, vegetation factors 24.8%, and human factors 17.3%, clarifying the weight of each factor in the coupling system.

Physical spread models such as FARSITE, cellular automata, and BEHAVE were applied to simulate the fire spread process and predict fire development trends, with an accuracy of over 85%, providing technical support for fire suppression.[16]

For multi-factor coupling risk research, tools including the N-K coupling model, entropy weight method, and fuzzy fusion evaluation method were adopted to enhance the systematicness and objectivity of the study and achieve accurate fire risk zoning.[17][18]

4.2. Integration of Spatiotemporal Distribution Characteristics

4.2.1 Temporal Distribution Characteristics

In terms of seasonal distribution, fires are concentrated in the dry season (from November to April of the following year), accounting for 74.5% of the annual total. The wet season (May–October) has abundant precipitation, with very few fires, accounting for only 25.5%. According to monthly statistics, March–April is the peak fire period, accounting for 39.0% of the annual total; January–February and November–December are secondary high-incidence periods, while June–September is a low-incidence period.In terms of interannual distribution, fires are significantly driven by precipitation and temperature. In drought years, both fire frequency and burned area increase markedly, with strong interannual fluctuations. Over the past 10 years, fire frequency has fluctuated within a range of 186 to 326 events.

4.2.2 Spatial Distribution Characteristics

High fire risk zones are mostly distributed in middle and low altitude areas around Kunming and the mountainous regions of Chuxiong. These areas are densely covered with coniferous forests and have frequent human activities, with fires concentrated mainly along roads, residential areas, steep slopes and sunny slopes.Regions at an altitude of 1500–2000 m, with slopes >25° and sunny aspects, have the highest fire risk, accounting for 68.2% of total fire points. Fire points in coniferous forest areas account for 72.6%, broad-leaved forest areas 15.3%, and shrub-grass areas 12.1%, showing significant differences in fire point proportions among different vegetation types.Regarding human activity distribution, fire point density in forest-urban interfaces, tourist scenic areas and agricultural cultivation zones is 8–10 times higher than that in remote forest areas.

Areas with weak human disturbance and high vegetation moisture, such as high-altitude primitive forests and nature reserves, have long maintained a low fire risk level, with fire occurrences accounting for only 5.8% of the total. This spatiotemporal pattern is highly consistent with the spatial coupling of meteorological drought, topographic differences, vegetation distribution, and human activities.[19][20]

5. RESEARCH LIMITATIONS AND FUTURE PROSPECTS

5.1. Research Limitations

The current status of forest fire research in central Yunnan shows that although considerable achievements have been made in spatiotemporal patterns, single-factor effects and risk zoning, obvious deficiencies still exist. There is a certain gap compared with developed forestry countries, which cannot meet the requirements for accurate forest fire prevention and control in the new era.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

From the perspective of quantitative analysis, the quantitative analysis of multi-factor nonlinear coupling is insufficient, dominated by qualitative descriptions and lacking a unified coupling measurement system. It is difficult to accurately quantify the intensity of synergistic interactions among various factors and their feedback mechanisms. In terms of dynamic monitoring and prediction capacity, research on long-term sequence dynamic monitoring and climate change response is weak with short data series, which hardly supports long-term fire risk trend prediction. Research on the evolution of forest fire regimes under climate change is also inadequate.[18]

An analysis of the application of intelligent early warning technology shows that the application of multi-source data fusion and intelligent early warning technology lacks depth. The accuracy and timeliness of early warning models need to be improved, and traditional early warning systems struggle to meet the requirements of accurate early warning in complex mountainous environments.The transformation of research findings into prevention and control decisions is ineffective. Accurate prevention and control measures targeting coupling mechanisms still need optimization. Theoretical research and practical prevention and control are not closely integrated, and feasible integrated prevention and control schemes are lacking.

5.2. Future Outlook

In accordance with the research plan, the multi-factor coupling mechanism should be taken as the focus, efforts should be made to break through four directions, and a complete forest fire scientific research and prevention and control system should be established. Centering on multi-scale coupling analysis, a four-dimensional coupling model of meteorology-topography-vegetation-human factors will be established to quantify the synergistic effects and feedback mechanisms, establish a unified coupling measurement system, and achieve the leap from qualitative to quantitative analysis.Technological integration will be relied on to promote intelligent monitoring and early warning. By integrating remote sensing, the Internet of Things, big data and machine learning technologies, a high-precision dynamic fire risk early warning system will be established to achieve minute-level and grid-based fire risk prediction, and improve the accuracy and timeliness of early warning.

At the level of prevention, control, transformation and application, targeted measures shall be adopted based on coupling risk zoning, and accurate approaches shall be developed to improve fire source control, combustible material removal, and the layout of fire suppression forces. Differentiated prevention and control plans shall be formulated to promote the in-depth integration of theoretical research and practical prevention and control.

Multidisciplinary cross-research relies on the integration of theories and methods from meteorology, forestry, geography, sociology, computer science and other disciplines, which enhances the systematicness and practicality of forest fire research and establishes an interdisciplinary research system.

6. CONCLUSION

Forest fires in the central Yunnan region are typical multi-factor coupled disasters. Meteorological conditions drive fire risk, topography regulates local differences, vegetation fuels form the material basis, and human activities act as ignition sources. The synergistic interaction of these four factors determines the spatiotemporal distribution, occurrence probability and disaster intensity of forest fires. Statistics from 2018 to 2023 show that a total of 1,529 forest fires occurred in central Yunnan, covering a burned area of 26,720 hm^2 and causing economic losses of 329.8 million yuan. The situation of forest fire prevention and control is severe. With the continuous intensification of climate change and human activities, forest fire management in central Yunnan needs to shift from single-factor management to

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

coupled system governance, breaking the limitations of traditional prevention and control models.

Integrating long-term development requirements, it is necessary to take the coupled disaster-causing mechanism as the theoretical focus, rely on multi-source data and intelligent models as technical support, and establish an integrated system of "mechanism analysis – risk assessment – dynamic early warning – precise prevention and control". This will comprehensively enhance the integrated prevention and control capacity of forest fires and reduce fire occurrences.

ACKNOWLEDGEMENTS

This work is supported by the National Nature Science Foundation of China(32360396), the Joint Agricultural Project of Yunnan Province (202301BD070001-037, 202301BD070001-248), the Science and Technology Innovation Project for University Students of Yunnan Education Department (S202410677007 S202410677044).

REFERENCES

[1] Rui Huang, Zhuotai Wang. Spatial-temporal Distribution Patterns of Forest Fires in China from 2010 to 2022[J]. Journal of Northeast Forestry University, 2025, 53(09): 20-25.

[2] Min Tao. Analysis of Spatial-Temporal Changes in Burned Areas and Vegetation in Ganzi Prefecture from 2010 to 2024[D]. Sichuan Normal University, 2025.

[3] Yingtang Zhang, Xu Duan, Junfeng Li. Climatic Regionalization of Forest Fires in the Central Yunnan Region[J]. Journal of Southwest Forestry University, 1994, 14(03): 172-176.

[4] Xuemei Wang, Yuxin Hu, Ying Chen, et al. Comparative Analysis of Forest Fire Driving Factors in Different Forest Regions of China Based on Geodetector[J]. Acta Ecologica Sinica, 2025, 45(01): 227-238.

[5] Xiaoqing Liu, Fu Ren, Weiting Yue, et al. Driving Forces and Spatial Heterogeneity of Forest Fires in China[J]. Journal of Geo-information Science, 2025, 27(05): 1214-1227.

[6] Yu Gao, Aoli Suo, Min Gao, et al. Effects of Different Fire Intensities on Soil Organic Carbon Components of Pinus yunnanensis Forest in Lushan Forest Farm, Sichuan Province[J]. Acta Ecologica Sinica, 2023, 43(22): 9281-9293.

[7] Chao Yue, Caifang Luo, Lifu Shu, et al. Research Progress of Wildfires under the Background of Global Change[J]. Acta Ecologica Sinica, 2020, 40(02): 385-401.

[8] Haiqing Hu, Yunmin Wei, Long Sun, et al. Effects of Climate, Vegetation and Topography on the Spatial Pattern of Forest Fire Severity in the Greater Khingan Mountains[J]. Acta Ecologica Sinica, 2020, 40(05): 1642-1652.

[9] Lifu Shu, Qiuhua Wang, Long Jin, et al. Comprehensive Analysis of Driving Factors for Lightning Fire Occurrence in the Tahe Area of the Greater Khingan Mountains[J]. Acta Ecologica Sinica, 2014, 34(12): 3365-3373.

[10] Qiuhua Wang, Lifu Shu, Fengjun Zhao, et al. Study on Comprehensive Risk Assessment and Spatial Pattern of Forest Fires in Yunnan Province[J]. China Safety Science Journal, 2021, 31(09): 186-193.

[11] Shuai Li, Wenjuan Zhao, Ruliang Zhou. Analysis of Influencing Factors on Forest Fire Vulnerability in Central Yunnan Based on VSD Model[J]. Forest Inventory and Planning, 2021, 46(01): 52-57.

[12] Ruliang Zhou, Shuai Li, Wenjuan Zhao. Dynamic Changes of Restoration Rate and Its Impact Factors in Typical Burned Areas of Central Yunnan[J]. Resources Science, 2021, 43(12): 2506-2516.

[13] Rui Huang, Zhuotai Wang. Spatial and Temporal Distribution Patterns of Forest Fires in China from 2010 to 2022[J]. Journal of Northeast Forestry University, 2025, 53(09): 20-25.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202605_12(5).0008

[14] Tao Min. Analysis of Spatial-Temporal Changes in Burned Areas and Vegetation in Garzê Prefecture (2010–2024)[D]. Chengdu: Sichuan Normal University, 2025.

[15] Zhiwei Wu, Hongshi He, Yu Liang. Research progress on multi-factor coupling driving mechanism of forest fires[J]. Chinese Journal of Applied Ecology, 2022, 33(07): 1981-1990.

[16] Xiaorui Tian, Lifu Shu, Mingyu Wang. Research Progress and Trend of Forest Fire Models[J]. World Forestry Research, 2020, 33(02): 1-7.

[17] Fengjun Zhao, Lifu Shu, Qiuhua Wang. Combustion Characteristics of Forest Fuels and Fire Risk Assessment in Central Yunnan[J]. Forest Research, 2021, 34(03): 102-109.

[18] ZhouJ, FengB, WuH, et. al. Spatio-temporal distribution characteristics and driving factors of forestland in the Da-XiaoLiangshan mountains based on to pographic gradient [J]. Scientific Reports, 2025, 15(1):7501-7501.

[19] TalukdarRN, AhmadF, GoparajuL, etal. Forest fire in Thailand: Spatio-temporal distribution and future risk assessment [J]. Natural Hazards Research, 2024, 4(1): 87-96.

[20] AbhinavS, ShuchitaS, DebashishM, et al. Spatiotemporal distribution of air pollutants during a heatwave-induced forest fire event in Uttarakhand. [J]. Environmental science and pollution research international, 2023, 30(51): 110133-110160.