Proceedings of CONF-MCEE 2026 Symposium: Advances in Sustainable Aviation and Aerospace Vehicle Automation
DOI: 10.54254/2755-2721/2026.KA27052

A Review of Forest Fire Monitoring Research in China Based on GIS and Remote Sensing

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Abstract. Once a forest fire occurs, it can cause severe atmospheric pollution and significant economic and ecological losses. Therefore, conducting research on pre-disaster early warning and risk monitoring of forest fires holds great practical significance. This paper aims to review the current state of forest fire monitoring research in China based on Geographic Information System (GIS) and remote sensing technologies, with the goal of providing references for related studies and practical applications. Using keywords such as "forest fire," "fire monitoring," "GIS," and "remote sensing," a literature search was conducted on the China National Knowledge Infrastructure (CNKI) database. A total of 12 academic journal articles that met the criteria were selected for review. The findings indicate that remote sensing data sources have become increasingly diversified. MODIS, Sentinel-2 satellites, and unmanned aerial vehicles (UAVs) each have distinct advantages and limitations at different monitoring scales. The fusion of multi-source data enables multidimensional analysis of fire causes, although it presents technical challenges. ArcGIS-related methodologies, when integrated with various models, have shown significant effectiveness—for example, statistical models improve prediction accuracy, and the Analytic Hierarchy Process (AHP) is applied in risk assessment. However, issues such as insufficient model generalizability persist. The study regions covered are broad, and the number of publications shows an upward trend. Nonetheless, challenges remain in terms of technological integration and the translation of research outcomes into practical applications. Moving forward, it is necessary to optimize technical approaches to better address forest fire prevention and control, and to provide a scientific basis for forest resource protection and policy formulation.

Keywords: forest fire, fire monitoring, GIS, remote sensing, risk assessment

1. Introduction

Forests contain numerous resources essential for human survival and are of great value to humankind. However, once a forest fire occurs, if it is not extinguished promptly, it can lead to severe pollution and significant losses. According to data from the National Forestry and Grassland Administration, during the 40-year period from 1950 to 1989, an average of approximately 16,000 forest fires occurred annually. This number decreased to about 6,000 per year between 1990 and 2020, and since 2021, the annual figure has fallen below 1,000. Meanwhile, over 90% of forest and

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DOI: 10.54254/2755-2721/2026.KA27052

grassland fires have been caused by human activities [1]. Forest fires are among the most frequent, difficult to manage, and destructive natural disasters, posing one of the greatest threats to forest resource security. In light of the severe fire prevention situation, conducting research on early warning and risk monitoring of forest fires before they occur is of particular importance. To address this issue, China issued the Forest Law of the People's Republic of China on September 20, 1984, and subsequently promulgated the Regulations on Forest Fire Prevention on January 16, 1988, to reduce the occurrence of forest fires through legal means. Despite this, domestic research on forest fire monitoring remains relatively limited. Developing algorithms capable of deeply analyzing image data, accurately extracting flame and smoke features, and achieving real-time and precise monitoring is crucial for supporting fire prevention and disaster management. Understanding the mechanisms of forest fire occurrences in different regions, as well as the spatiotemporal distribution patterns of forest fires, can provide references for forecasting future fire dynamics under the influence of global climate change. It also offers valuable insights for formulating future forest vegetation management policies and fire control strategies. This paper collects and analyzes relevant literature from the China National Knowledge Infrastructure (CNKI) database. Through examination of publication trends, research institutions, keywords, and citation metrics, this study summarizes various algorithms used in forest fire monitoring and management, aiming to provide scientific and practical guidance for local forest fire management.

2. Methods

This review aims to comprehensively understand the current application status, existing challenges, and future development trends of ArcGIS in forest fire detection, with the goal of informing relevant research and practice. Literature was retrieved from the CNKI database using keywords such as “forest fire,” “fire monitoring,” “ArcGIS,” and “remote sensing.” Boolean operators were applied to combine search terms, and the search was limited to academic journal articles of research type.

A set of detailed inclusion and exclusion criteria was developed: Inclusion criteria: (1) Studies involving the application of ArcGIS, remote sensing, or model algorithms in forest fire detection; (2) Empirical research studies; (3) Studies of high quality that employ scientifically sound research methods. Exclusion criteria: (1) Duplicate publications; (2) Studies unrelated to forest fire detection; (3) Studies of low quality with evident methodological flaws.

From the included literature, the following information was extracted: (1) Basic information: authors, year of publication, journal name, and study location; (2) Research methodology: types of data and data collection methods; (3) Research findings: primary outcome indicators (e.g., diagnostic accuracy, sensitivity, specificity) and their values, as well as statistical analysis results; (4) Conclusions: interpretation of results and recommendations by the authors.

The quality of the literature was evaluated based on relevance, methodological innovation, accuracy of research results, and overall research impact. Subsequently, the literature was categorized and summarized. The review presents an overview of forest fire detection methods based on ArcGIS, and analyzes the current application status, advantages, challenges, and future prospects of ArcGIS and remote sensing technologies in forest fire detection.

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3. Results

3.1. Overview of included literature

Based on the established evaluation criteria, a total of 12 academic journal articles were selected for inclusion. Among them, the earliest publication was in March 2008 and the most recent in March 2025. The distribution of publication years shows a gradually increasing trend, indicating growing academic attention to this research field. All selected publications are from peer-reviewed academic journals. Journals with a higher number of relevant articles include Forest Fire Prevention and Acta Ecologica Sinica, which are mainly categorized under disciplines such as geography and forestry. The selected studies can be roughly classified into two categories: Six papers focused on forest fire analysis based on remote sensing imagery; Six papers focused on forest fire analysis based on GIS.

The included references are summarized in Table 1.

Table 1. Included references

No.	Title	Year	Method	Study Area
1	Temporal and Spatial Characteristics of Forest Fires and Fire Source in Sichuan Province in the Past 20 Years	2025	Remote sensing analysis of fire spatiotemporal distribution using MODIS data	Sichuan Province
2	Forest Fire Monitoring and Application in Chongqing Based on MODIS	2008	Forest fire monitoring using four MODIS spectral bands (NIR, MIR, TIR); proposed a direct discrimination method based on Band 7 and a comprehensive threshold method for non-high-temperature fire points	Chongqing City
3	Research on Forest Burnt Area Monitoring Based on Multispectral Remote Sensing Images	2025	Image acquisition, data preprocessing, fire information extraction using NDVI (based on red and near-infrared bands); comparative analysis of burned area monitoring	Dayandong Forest Area, Yunnan Province
4	Application of UAV Remote Sensing in Forest Fire Early Warning Systems	2025	Utilized infrared thermal imaging, multispectral sensing, image processing; simulation based on Stefan–Boltzmann Law, Lambert–Beer Law, and Rothermel model	----
5	Monitoring and Mechanism Analysis of Forest Fires Using Multi-Source Meteorological Data	2024	Analyzed weather background, satellite cloud images, ground observation, wind vector–potential temperature diagrams, vertical methane distribution via satellite, and ERA5 vertical airflows	Sichuan–Yunnan Region
6	Estimation of fine dead fuel load based on Random Forest Model	2025	Estimation of surface fine dead fuel load using remote sensing data and field survey data; applied random forest model to 172 forest and bamboo plots; analyzed variable importance	Anhua County, Hunan Province
7	Forest Fires occurrence in Heilongjiang Province Based on Spatial Generalized Additive Models	2025	Used forest fire data (2006–2020), with meteorological, topographic, and vegetation factors; evaluated logistic regression and spatial GAMs with four different basis functions	Heilongjiang Province
8	Study on Forest Fire Risk Assessment and Division in Shenzhen Based on AHP	2025	Applied AHP, expert scoring, and judgment matrix to calculate indicator weights; used forest resource maps and national risk survey data; zoned fire risk into five levels using ArcGIS natural break method	Shenzhen City
9	Application of GIS Fuzzy Analytic Hierarchy Process for Forest Fire Risk Zoning Study: A Case Study of Ningyuan County, Hunan Province	2024	Combined fuzzy logic and AHP in ArcGIS to evaluate forest fire risk; considered environmental, anthropogenic, and topographic factors	Ningyuan County, Hunan Province
10	Study on Evaluation Model of Forest Fire Emergency Monitoring Index Based on Analytic Hierarchy Process	2025	Constructed AHP-based evaluation model for emergency fire monitoring; analyzed early warning indicators and quantified model results	----
11	Study on Evaluation Model of Forest Fire Emergency Monitoring Index Based on Analytic Hierarchy Process	2025	System composed of fire data collection nodes, gateway nodes, and monitoring nodes; used various sensors and improved DV-Hop algorithm for localization; transmitted data via 4G to remote monitoring center	----
12	Dynamic Forest Fire Early Warning in Yunnan Based on 3D Temporal Pyramid Convolutional Neural Network	2025	Proposed a dynamic fire early warning model (M) using 3D temporal pyramid CNN; conducted sparse, multi-scale convolution on consecutive frames to extract temporal features at different scales	Yunnan Province

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3.2. Research on forest fire analysis based on remote sensing data

An analysis of the selected literature reveals that forest fire studies based on remote sensing imagery primarily employ the following methodological approaches:

3.2.1. Application of MODIS data

MODIS (Moderate Resolution Imaging Spectroradiometer), with its high temporal resolution (1–2 day revisit cycle) and global coverage, has become a crucial data source for dynamic forest fire monitoring. In a study on forest fires in Sichuan Province, researchers processed nearly 20 years of MODIS data, integrating spatial analysis and statistical modeling to systematically uncover the spatiotemporal distribution patterns of forest fires in the region. The findings indicated that fire incidents predominantly occur during the dry winter and spring seasons and are more frequent in mountainous areas with dense vegetation and limited accessibility [2,3]. In a study focusing on urban forest fire detection in Chongqing, the research team utilized MODIS data and proposed two identification methods: a direct high-temperature fire point detection method based primarily on Band 7, and a composite threshold method for identifying non-high-temperature fire points [4]. The former leverages the high thermal sensitivity of Band 7 to directly identify flaming fire zones, while the latter constructs a multi-band threshold model incorporating near-infrared, shortwave infrared, and other spectral bands to effectively detect low-temperature potential fire points, enabling early warning for urban forest fires. However, the relatively coarse spatial resolution of MODIS (250–1000 meters) limits its accuracy in complex terrains, leading to potential omission of fire points. Moreover, cloud and fog interference can significantly reduce monitoring precision.

3.2.2. Application of Sentinel-2 and UAV technologies

Sentinel-2's high spatial resolution (10–60 meters) and multispectral imaging capabilities provide strong technical support for precise monitoring of burned forest areas [5]. In a study conducted in the Dayandong forest area of Yunnan Province, researchers used Sentinel-2's infrared and near-infrared band data to compute indices such as the Normalized Difference Vegetation Index (NDVI) and Burned Area Index (BAI). They then conducted comparative analyses using various classification algorithms (e.g., Support Vector Machines, Random Forests) to assess the accuracy of burned area detection, offering quantitative support for post-disaster damage assessment [6]. In addition, UAV (Unmanned Aerial Vehicle) remote sensing—integrating infrared thermal imaging, multispectral sensors, and image processing—has demonstrated unique advantages in high-resolution, localized monitoring. This approach incorporates physical models such as the Stefan–Boltzmann Law (for temperature inversion), Lambert–Beer Law (for spectral absorption analysis), and the Rothermel model (for simulating fire spread) [7]. For instance, UAV-mounted thermal infrared cameras can capture real-time temperature distributions of fire zones. Combined with the Rothermel model, this enables prediction of fire spread pathways, providing on-site emergency commanders with critical decision-making support [8]. Nonetheless, UAVs are limited by short flight durations (typically under 1 hour) and small monitoring ranges (only a few square kilometers per flight), constraining their applicability in large-scale wildfire events.

3.2.3. Multi-source data integration and analysis

Multi-source data fusion techniques, which integrate meteorological, remote sensing, and ground observation data, offer new perspectives for uncovering the mechanisms behind forest fire

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outbreaks. In a study of the Sichuan–Yunnan region, researchers combined weather background variables (e.g., wind speed, humidity, temperature), satellite cloud imagery, ground meteorological station observations, wind vector–potential temperature diagrams, vertical methane distribution from satellite remote sensing, and vertical airflow data from ERA5 (Fifth Generation ECMWF Atmospheric Reanalysis of the Global Climate). The study revealed a significant correlation between wildfire flashovers and geological degassing activity, and proposed a "gas-fueled, thermally driven" theoretical framework for fire outbreak mechanisms [9]. This approach overcomes the limitations of single-source data by enabling multi-dimensional analysis of fire causation from meteorological, vegetative, and geophysical perspectives. However, the high heterogeneity of data sources poses technical challenges, such as achieving spatiotemporal alignment and developing effective data fusion algorithms.

3.2.4. Data-driven model construction

Building machine learning models based on multi-source data has become an important method for quantitatively assessing forest fire risks. In a study in Anhua County, Hunan Province, researchers constructed a Random Forest model to estimate the surface fine dead fuel load. The model was built using spectral index variables derived from Sentinel-2A satellite imagery, combined with field survey data, including topographic factors (slope, aspect), stand structure (canopy closure, tree height), and vegetation types. The model achieved a high coefficient of determination ($R^2 = 0.82$) on the test dataset, with spectral indices and slope contributing most significantly to the estimation accuracy [10]. This method effectively leverages the complementary strengths of multi-source data. However, it requires a large number of annotated training samples, and is sensitive to the temporal and spatial consistency of input data.

3.3. Gis-based forest fire analysis

3.3.1. Integration of statistical models and spatial analysis

The powerful spatial analysis capabilities of ArcGIS, when combined with traditional statistical models, provide a scientifically grounded approach to regional forest fire prediction. In a study conducted in Heilongjiang Province, researchers integrated forest fire records, meteorological variables (e.g., precipitation, temperature), topographic data (elevation, slope), and vegetation information within the ArcGIS platform. They evaluated the performance of a Logistic Regression Model and four variations of the Spatial Generalized Additive Model (SGAM) employing different basis functions. The results showed that the SGAM model incorporating thin-plate spline basis functions achieved the highest predictive accuracy (AUC = 0.87). This model effectively captured the nonlinear relationships between fire occurrence and environmental variables by adaptively fitting spatial non-stationarity [11]. However, the effectiveness of such models is contingent upon access to long-term, high-quality datasets, and the parameter optimization process can be computationally complex.

3.3.2. Diversified applications of the Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP), combined with ArcGIS spatial analysis, is widely used in forest fire risk assessment and zoning. In a case study from Shenzhen City, researchers employed AHP, expert scoring, and judgment matrix methods to assign weights to indicators such as meteorological conditions, topography, vegetation, and human activities. The Natural Breaks

DOI: 10.54254/2755-2721/2026.KA27052

Method in ArcGIS was used to classify the forest fire risk index into five levels, resulting in a comprehensive risk zoning map for the entire city [12]. In another study in Ningyuan County, Hunan Province, scholars incorporated fuzzy logic into the AHP to handle the uncertainty in expert scoring by constructing a fuzzy judgment matrix. Using ArcGIS spatial interpolation techniques, they generated a detailed forest fire risk zoning map [13]. Furthermore, other research efforts have constructed emergency monitoring evaluation models for forest fires based on AHP, establishing quantitative indicator systems from dimensions such as response speed and monitoring accuracy [14]. Nonetheless, the subjectivity involved in assigning weights in AHP may affect the objectivity and reliability of risk assessment results.

3.3.3. Integration of Wireless sensor Networks (WSNs) with arcgis

The integration of Wireless Sensor Networks (WSNs) with ArcGIS has facilitated the development of real-time forest fire monitoring and geovisualization systems. These systems consist of fire detection nodes (equipped with temperature, smoke, and humidity sensors), gateway nodes, and a central monitoring station. An improved DV-Hop localization algorithm—which enhances anchor node deployment and corrects distance estimation errors—was applied to improve fire localization accuracy. In practical applications, sensor nodes transmit monitoring data to gateway nodes, which then send the information to the monitoring center via a 4G network. The ArcGIS platform is employed for real-time fire point mapping, visualizing risk levels, and querying historical fire records [15]. However, current implementations face challenges such as high sensor energy consumption and limited network coverage, necessitating further optimization of node deployment strategies and communication protocols.

3.3.4. Application of deep learning models

The integration of deep learning with ArcGIS offers intelligent solutions for dynamic forest fire early warning systems. In a study on forest fire forecasting in Yunnan Province, researchers proposed an early warning model based on a 3D Temporal Pyramid Convolutional Neural Network (3D-TPCNN). This model applies multi-scale convolution operations on sequential video frames to automatically extract spatiotemporal features of fire ignition and propagation. Experimental results showed that the model achieved an early warning accuracy of 91.2% on the test dataset, representing a 23% improvement over traditional methods [16]. When integrated with the ArcGIS platform, the model's output can be spatially visualized, enabling real-time fire risk mapping. However, training such models demands substantial computational resources and relies heavily on high-quality annotated fire video datasets.

4. Discussion

Based on the analysis of the 12 selected studies, research on forest fire monitoring in China using GIS and remote sensing technologies has evolved into a multi-dimensional and multi-method integrative approach. Significant progress has been made in terms of technological application, model development, and practical guidance. However, several key challenges remain.

In terms of data acquisition, the diversification of remote sensing data sources supports fire monitoring at various spatial scales. MODIS data, with its high temporal resolution and global coverage, plays a crucial role in regional-scale dynamic monitoring and spatiotemporal pattern analysis of forest fires. However, its spatial resolution is limited, particularly in complex terrains

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[9,13]. Sentinel-2 satellites and UAV technologies offer advantages for high-resolution, fine-scale monitoring, but the limited flight endurance and coverage area of drones restrict their wider application [5,7,10,15]. Multi-source data fusion has overcome the limitations of relying on single data sources by integrating meteorological, remote sensing, and ground observation data to analyze fire causes from multiple dimensions. Nevertheless, the heterogeneity of these data sources presents significant challenges for data fusion, particularly in achieving spatiotemporal consistency and algorithmic integration [1].

In terms of methodological applications, the combination of statistical models and spatial analysis has greatly improved the scientific basis for forest fire prediction. Models such as the Spatial Generalized Additive Model (SGAM) enhance prediction accuracy by capturing the nonlinear relationships between environmental factors and fire occurrence [6]. The Analytic Hierarchy Process (AHP) integrated with GIS has been widely adopted for fire risk assessment and zoning, while improved versions—such as fuzzy AHP—have helped reduce subjectivity in weight assignment [3,4,11]. The integration of Wireless Sensor Networks (WSNs) and GIS enables real-time fire monitoring and spatial visualization, and improvements in localization algorithms have enhanced fire point accuracy. However, issues such as high sensor energy consumption and limited network coverage remain [8]. Finally, deep learning models such as the 3D Temporal Pyramid Convolutional Neural Network (3D-TPCNN) have significantly improved early warning accuracy by extracting spatiotemporal features. Yet, the high demand for computational resources and data labeling quality limits their widespread deployment [17].

5. Conclusion

The studies reviewed span a wide range of geographic regions, covering provinces and cities such as Sichuan, Chongqing, Yunnan, Heilongjiang, Hunan, and Shenzhen. This broad spatial coverage reflects increasing national attention to forest fire research. The upward trend in scholarly publications and the application of innovative models and algorithms indicate growing interest and technological advancement in this field. These innovations provide more precise and quantitative tools for forest fire monitoring. However, existing research still faces several clear limitations. There is a lack of effective coordination mechanisms among different data sources and technical methods; the technical barriers in multi-source data fusion remain unresolved; and the generalization and practical applicability of some models require further improvement. Moreover, challenges persist in translating advanced research outcomes into grassroots-level applications.

In summary, forest fire monitoring research based on GIS and remote sensing has already provided crucial support for fire prevention and management in China. Nonetheless, addressing current challenges with targeted solutions and continuously refining and innovating technologies and methodologies is essential. Only through these efforts can we better respond to the increasingly severe threat of forest fires under global climate change and provide a more robust scientific basis for forest resource protection and fire management policy development in China.

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