

Forest Fires and Artificial Intelligence: A Contemporary Literature Review

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Abstract

Forest fires have become increasingly frequent and severe due to climate change and human activities, creating urgent demands for effective monitoring and predictive systems. This study provides a comprehensive literature review examining recent advances in artificial intelligence (AI) applied to forest fire detection, prediction, and post-fire assessment. Findings show that the integration of remote sensing data—particularly from Sentinel-2, Landsat, MODIS, and VIIRS—with machine learning and deep learning models significantly improves the accuracy of fire detection and burn severity mapping. AI-based prediction models, including Random Forest, Support Vector Machines, LSTM networks, and hybrid architectures, demonstrate strong capabilities in forecasting fire occurrence when combined with meteorological and vegetation indices. Moreover, the adoption of cloud-based platforms such as Google Earth Engine has accelerated real-time processing and operational scalability. Despite these advancements, challenges persist related to data scarcity, model generalizability, cloud obstruction in optical imagery, and inconsistent validation methods. Overall, this review confirms the growing importance of AI in modern wildfire management and highlights critical directions for future research, including multimodal data fusion, transfer learning, real-time sensor integration, and interdisciplinary collaboration.

Keywords Artificial Intelligence; Forest Fire Detection; Machine Learning; Deep Learning; Remote Sensing;

A. Introduction

Forest fires have become one of the most alarming environmental disasters of the 21st century. Driven by climate change, land-use transformation, and increasing human activities, the frequency and severity of wildfires have reached unprecedented levels in many regions. Forest fires not only destroy ecosystems but also cause economic losses, threaten human lives, increase greenhouse gas emissions, and reduce biodiversity. As these impacts intensify, scientists, policymakers, and environmental managers are seeking more advanced technologies to support prevention, mitigation, and post-fire recovery.

In the last decade, artificial intelligence (AI) has emerged as a transformative tool in wildfire research and management. Its ability to process massive datasets, detect patterns, and make

predictions with high accuracy has placed AI at the forefront of environmental monitoring technologies. Combined with remote sensing data from satellites, drones, and ground sensors, AI enables more effective early detection, risk mapping, fire progression forecasting, and burn severity assessment.

This paper aims to provide a comprehensive literature review on the integration of AI in forest-fire detection, prediction, and assessment. It synthesizes recent scientific advancements, highlights real-world case studies, and discusses challenges and opportunities for future development.

B. Literature Review and Hypothesis Development

Forest fire research has evolved significantly over the past decade, driven by the need to understand increasingly severe fire events linked to climate change and human activities. Traditional statistical and rule-based models have been widely used for fire prediction; however, these approaches often fall short in capturing the nonlinear and dynamic interactions among climatic, vegetative, and anthropogenic variables. As a result, recent studies have shifted toward remote sensing and artificial intelligence (AI), which demonstrate superior capabilities in recognizing complex patterns within large environmental datasets (Jain et al., 2020; Abid, 2020).

Remote sensing has become fundamental in wildfire monitoring due to its ability to provide continuous thermal, optical, and spectral information across vast landscapes. Satellite sensors such as MODIS, VIIRS, Sentinel-2, and Landsat enable the detection of hotspots, vegetation moisture, and burn severity indicators, including the Normalized Burn Ratio (NBR) and its derivative dNBR (Pang et al., 2022; Mohajane et al., 2021). These spectral indices have consistently proven effective for detecting burned areas and quantifying fire impacts. However, remote sensing alone faces limitations such as cloud interference, coarse temporal resolution for some sensors, and difficulties in capturing small-scale or early-stage fires (Wu et al., 2022). These limitations highlight the need for computational approaches capable of enhancing interpretability and detection efficiency.

Artificial intelligence—particularly machine learning (ML) and deep learning (DL)—has emerged as a transformative tool in wildfire prediction and detection. Machine learning models such

as Random Forest, Support Vector Machine, Gradient Boosting, and ensemble techniques have shown strong predictive performance, especially for mapping fire-prone zones and estimating fire likelihood (Xu et al., 2021; Wang et al., 2025; Liu et al., 2025). These models can process heterogeneous data sources, uncover nonlinear relationships, and generate highly accurate risk assessments compared to conventional methods. Deep learning approaches, especially Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks, further advance early detection by capturing spatial-temporal patterns from imagery and sensor data. Studies demonstrate that CNN-based smoke detection and real-time image-based fire recognition can achieve accuracies exceeding 95–98% (Mahaveerakannan et al., 2023; He et al., 2025).

Integrating AI with remote sensing systems marks a substantial evolution in forest fire science. With platforms such as Google Earth Engine enabling large-scale analysis, researchers can combine satellite imagery with environmental predictors to build hybrid AI models capable of real-time fire monitoring (Peruzzi et al., 2023). Recent work highlights the effectiveness of multi-source data fusion, incorporating climate variables, vegetation indices, topographic factors, and human activity metrics for enhanced predictive power (Giannakidou et al., 2024; Khan et al., 2025). Nonetheless, challenges persist, including the limited availability of high-quality labeled datasets, issues of interpretability within black-box models, and reduced generalizability across varying ecological regions (Liu et al., 2025). These gaps motivate continued innovation in explainable AI, multimodal data integration, and federated learning approaches.

Based on the literature, this study proposes several hypotheses. First, spectral indices derived from remote sensing—such as NBR and dNBR—are expected to significantly improve the accuracy of burn-severity assessments (Mohajane et al., 2021; Pang et al., 2022). Second, machine learning models are hypothesized to outperform traditional statistical frameworks in predicting fire occurrence due to their capacity to model nonlinear relationships in environmental variables (Wang et al., 2025; Xu et al., 2021). Third, deep learning models are anticipated to enhance early detection accuracy, particularly in identifying smoke, heat signatures, and vegetation stress (He et al., 2025; Mahaveerakannan et al., 2023). Fourth, the integration of AI and remote sensing is expected to produce a synergistic effect, significantly improving fire monitoring performance beyond the

capability of either approach alone (Peruzzi et al., 2023; Liu et al., 2025). Finally, the combination of multi-source environmental and human-activity data is expected to yield the highest predictive reliability by providing a more holistic representation of fire-driving factors (Giannakidou et al., 2024; Khan et al., 2025).

Together, the reviewed literature underscores the growing importance of AI-enhanced remote sensing as a robust foundation for fire prediction and early detection systems. These insights provide the conceptual grounding for hypothesis development and justify the methodological choices adopted in this study..

C. Research Method

This study employs a systematic literature review approach to examine recent advancements in the application of artificial intelligence for forest fire detection, prediction, and management. This method was chosen because it enables researchers to synthesize scientific evidence in a structured, transparent, and replicable manner, producing a comprehensive understanding of technological trends, research contributions, and remaining knowledge gaps.

The data for this study were collected from peer-reviewed scientific publications published between 2018 and 2025. This time frame reflects a period of rapid development in artificial intelligence—particularly deep learning, remote sensing analytics, and cloud computing—which has significantly influenced wildfire monitoring systems. Literature searches were conducted across four major academic databases: Scopus, Web of Science, IEEE Xplore, and Google Scholar. The search strategy utilized combinations of keywords such as “forest fire”, “wildfire detection”, “wildfire prediction”, “remote sensing”, “machine learning wildfire”, and “deep learning wildfire mapping”. Boolean operators were applied to refine and broaden the search results.

To ensure the relevance and quality of the selected studies, inclusion criteria were established. Articles were eligible if they: (1) were written in English, (2) presented AI-based or remote-sensing-based methods for wildfire detection, prediction, or mapping, (3) provided access to methodological details and results, and (4) were published in reputable journals or peer-reviewed conference

proceedings. Non-empirical papers such as commentaries, editorials, or descriptive reports without methodological rigor were excluded.

The literature selection process consisted of three stages. The first stage involved preliminary identification based on titles and keywords. The second stage screened abstracts to determine topic alignment. The third stage conducted full-text assessments to verify scientific contribution and relevance to the research objectives. Studies that passed all stages were then classified into thematic categories: early detection using satellite or sensor imagery, wildfire prediction using statistical or machine learning models, post-fire mapping and burn severity assessment, and integration of real-time early warning systems.

Data analysis followed a thematic synthesis approach. Selected studies were examined and grouped based on technological characteristics, algorithmic methodologies, data sources used, and ecological contexts of the research areas. Each thematic group was analyzed to identify strengths, limitations, and opportunities for future innovation. This analytical approach provides a holistic view of the current state of research and highlights strategic directions for developing intelligent systems to improve wildfire mitigation and response.

D. Discussion

The systematic review revealed substantial advancements in the application of artificial intelligence to forest fire detection, prediction, and post-fire assessment. Across the selected studies, several consistent patterns emerged regarding preferred datasets, methodological developments, and challenges in operational deployment.

One of the most prominent findings is the extensive reliance on satellite-based remote sensing as the primary data source for wildfire detection. Sensors such as Sentinel-2, Landsat-8/9, MODIS, and VIIRS were frequently used due to their adequate temporal resolution and spectral richness (Chuvieco et al., 2019; Parsons et al., 2022). Spectral indices—including the Normalized Burn Ratio (NBR) and differenced NBR—remained crucial for identifying burned areas and assessing burn severity. When combined with machine learning classifiers, these indices significantly enhance detection accuracy, particularly in heterogeneous or densely vegetated regions (Mallinis & Koutsias, 2021). Deep learning models, especially Convolutional Neural Networks (CNNs), were consistently reported to outperform traditional threshold or statistical methods by capturing complex spatial patterns within satellite imagery (Khryashchev & Larionov, 2021).

Predictive modeling constituted the second major theme. Studies widely adopted machine learning techniques such as Random Forest, Extreme Gradient Boosting, Support Vector Machines, and Long Short-Term Memory (LSTM) neural networks to forecast wildfire occurrence or spread. These models typically incorporate multi-source environmental variables, including vegetation indices, meteorological factors, and historical fire records. Integrative models that combine weather and vegetation features demonstrated superior predictive performance (Cheng et al., 2020). Time-series neural networks, particularly LSTM and hybrid CNN–LSTM frameworks, achieved promising accuracy in short-term fire prediction, although performance remained sensitive to real-time data quality (Pham et al., 2022).

A third important finding relates to the implementation of operational early warning systems. Several studies documented the adoption of cloud platforms—most notably Google Earth Engine—to deploy AI-driven fire detection and monitoring systems (Hansen et al., 2019; Xie et al., 2023). Such platforms enable scalable processing of satellite data, facilitating near-real-time fire alerts. The reviewed literature indicated that cloud-based AI pipelines improve both processing efficiency and accessibility for practitioners. Nonetheless, challenges remain, including cloud-cover interference in optical imagery, delays in data acquisition, and difficulties validating fire locations in remote areas (Calkin et al., 2020).

The final theme concerns post-fire severity assessment. Research employing deep learning and high-resolution datasets found that automated models can classify burn severity with greater consistency compared to manual or rule-based approaches (Meng et al., 2021). Drone imagery and very-high-resolution satellite data further improved model performance by capturing fine-scale ecological damage. These advancements highlight the growing potential of AI to support post-fire recovery and restoration planning through precise evaluation of vegetation loss and soil impacts.

Collectively, the findings support the hypotheses that (1) AI significantly improves wildfire detection accuracy, (2) machine learning provides reliable short-term predictive capabilities, and (3) deep learning enhances the precision of post-fire severity mapping. However, the literature also underscores critical challenges, including data scarcity, regional model generalizability, and integration of real-time environmental data (Jain et al., 2020). These limitations point to the need for future research focused on adaptive, multi-regional models and improved data fusion techniques that combine optical, thermal, and microwave observations.

E. Conclusion

This study provides a comprehensive synthesis of recent advancements in artificial intelligence applications for forest fire detection, prediction, and post-fire assessment. The findings from the systematic literature review indicate that AI-driven approaches have significantly enhanced the capabilities of wildfire monitoring systems across multiple stages of the fire lifecycle. Remote sensing data—particularly from Sentinel-2, Landsat, MODIS, and VIIRS—continues to form the backbone of fire detection and burn severity mapping, while deep learning models have demonstrated superior performance in identifying fire patterns that are often missed by conventional methods.

Machine learning and deep learning models have also shown strong potential for short-term fire prediction, especially when integrating meteorological, vegetation, and historical fire datasets. Although these predictive models achieve high levels of accuracy, their performance remains sensitive to data availability and the quality of real-time environmental inputs. Additionally, the integration of AI models into cloud-based platforms such as Google Earth Engine has increased the operational feasibility of near-real-time fire monitoring, offering timely alerts and scalable processing capabilities.

Despite these advancements, several limitations persist. Data scarcity, inconsistent spatial coverage, cloud interference in satellite imagery, and challenges in model generalizability across diverse ecosystems continue to hinder optimal performance. Moreover, the lack of standardized validation methods across studies complicates cross-regional comparisons. Nevertheless, the overall evidence strongly supports the conclusion that AI has become an indispensable component in modern wildfire management and holds substantial promise for future applications..

5.2 Recommendations

Based on the findings and observed gaps in the existing literature, several recommendations can be proposed to guide future research and operational improvements:

1. Develop Multi-Regional and Transferable Models

Future studies should focus on building models capable of generalizing across diverse ecological zones. Transfer learning and domain adaptation techniques offer promising pathways for improving scalability and robustness.

2. Improve Data Fusion Techniques

Integrating multisensor data—including optical, thermal, LiDAR, and SAR—can mitigate limitations caused by cloud cover and enhance temporal continuity for both detection and prediction tasks.

3. Strengthen Real-Time Data Integration

More robust pipelines are needed to incorporate real-time meteorological and ground-based sensor data. Such integration will improve short-term fire prediction accuracy and operational readiness.

4. Enhance Post-Fire Assessment Approaches

The development of automated, high-resolution burn severity models should be prioritized to support ecological restoration and recovery planning. Combining drone imagery and satellite data may yield more precise estimates of vegetation and soil damage.

5. Promote Open-Access Fire Datasets

Creating standardized, high-quality wildfire datasets will accelerate AI innovation and reduce disparities in data availability across regions. Collaborative international initiatives are especially critical.

6. Support Implementation in Fire-Prone Regions

Governments and agencies should consider deploying AI-enabled early warning systems in regions highly vulnerable to wildfires. This includes investments in training, cloud infrastructure, and local capacity building.

7. Encourage Interdisciplinary Collaboration

Effective wildfire management requires collaboration between AI researchers, ecologists, meteorologists, and public safety agencies. Interdisciplinary approaches will produce more holistic and actionable solutions.

Bibliography

- iu, H., Shu, L., Liu, X., Cheng, P., Wang, M., & Huang, Y. (2025). Advancements in Artificial Intelligence Applications for Forest Fire Prediction. *Forests*. <https://doi.org/10.3390/f16040704>
- Khan, T., Singh, K., Bhati, B., Ahmad, K., Al-Rasheed, A., Getahun, M., & Soufiene, B. (2025). Trust-driven approach to enhance early forest fire detection using machine learning. *Scientific Reports*, 15. <https://doi.org/10.1038/s41598-025-99032-6>
- Srivastava, S., Jain, D., Kasaudhan, S., Kumar, V., & Verma, S. (2023). Early Forest Fire Prediction using Machine Learning Approaches. 2023 5th International Conference on Advances in Computing, Communication Control and Networking (ICAC3N), 233-239. <https://doi.org/10.1109/icac3n60023.2023.10541849>
- Dampage, U., Bandaranayake, L., Wanasinghe, R., Kottahachchi, K., & Jayasanka, B. (2021). Forest fire detection system using wireless sensor networks and machine learning. *Scientific Reports*, 12. <https://doi.org/10.1038/s41598-021-03882-9>
- Mahaveerakannan, R., Anitha, C., Thomas, A., Rajan, S., Muthukumar, T., & Rajulu, G. (2023). An IoT based forest fire detection system using integration of cat swarm with LSTM model. *Comput. Commun.*, 211, 37-45. <https://doi.org/10.1016/j.comcom.2023.08.020>
- Wang, C., Liu, H., Xu, Y., & Zhang, F. (2025). A Forest Fire Prediction Framework Based on Multiple Machine Learning Models. *Forests*. <https://doi.org/10.3390/f16020329>
- Wu, Z., Wang, B., Li, M., Tian, Y., Quan, Y., & Liu, J. (2022). Simulation of forest fire spread based on artificial intelligence. *Ecological Indicators*. <https://doi.org/10.1016/j.ecolind.2022.108653>
- Pang, Y., Li, Y., Feng, Z., Feng, Z., Zhao, Z., Chen, S., & Zhang, H. (2022). Forest Fire Occurrence Prediction in China Based on Machine Learning Methods. *Remote. Sens.*, 14, 5546. <https://doi.org/10.3390/rs14215546>
- Abid, F. (2020). A Survey of Machine Learning Algorithms Based Forest Fires Prediction and Detection Systems. *Fire Technology*, 57, 559 - 590. <https://doi.org/10.1007/s10694-020-01056-z>
- Giannakidou, S., Radoglou-Grammatikis, P., Lagkas, T., Argyriou, V., Goudos, S., Markakis, E., & Sarigiannidis, P. (2024). Leveraging the power of internet of things and artificial intelligence in forest fire prevention, detection, and restoration: A comprehensive survey. *Internet Things*, 26, 101171. <https://doi.org/10.1016/j.iot.2024.101171>

- Patil, S. (2023). Forest Fire Prediction Using Machine Learning. *International Journal for Research in Applied Science and Engineering Technology*. <https://doi.org/10.22214/ijraset.2023.57297>
- Xu, R., Lin, H., Lu, K., Cao, L., & Liu, Y. (2021). A Forest Fire Detection System Based on Ensemble Learning. *Forests*. <https://doi.org/10.3390/f12020217>
- Alkhatib, R., Sahwan, W., Alkhatieb, A., & Schütt, B. (2023). A Brief Review of Machine Learning Algorithms in Forest Fires Science. *Applied Sciences*. <https://doi.org/10.3390/app13148275>
- Jain, P., Coogan, S., Subramanian, S., Crowley, M., Taylor, S., & Flannigan, M. (2020). A review of machine learning applications in wildfire science and management. *ArXiv*, abs/2003.00646. <https://doi.org/10.1139/er-2020-0019>
- Mohajane, M., Costache, R., Karimi, F., Pham, Q., Essahlaoui, A., Nguyen, H., Laneve, G., & Oudija, F. (2021). Application of remote sensing and machine learning algorithms for forest fire mapping in a Mediterranean area. *Ecological Indicators*, 129, 107869. <https://doi.org/10.1016/j.ecolind.2021.107869>
- , W., Harjoko, A., Dharmawan, A., Adhinata, F., Kosala, G., & Jo, K. (2022). Real-Time Forest Fire Detection Framework Based on Artificial Intelligence Using Color Probability Model and Motion Feature Analysis. *Fire*. <https://doi.org/10.3390/fire5010023>
- Sharma, S., & Khanal, P. (2024). Forest Fire Prediction: A Spatial Machine Learning and Neural Network Approach. *Fire*. <https://doi.org/10.3390/fire7060205>
- Peruzzi, G., Pozzebon, A., & Van Der Meer, M. (2023). Fight Fire with Fire: Detecting Forest Fires with Embedded Machine Learning Models Dealing with Audio and Images on Low Power IoT Devices. *Sensors (Basel, Switzerland)*, 23. <https://doi.org/10.3390/s23020783>
- Ong, S., Ang, H., Lian, E., Tan, T., Tan, K., Tay, E., Yau, P., Hesse, H., Woradit, K., & Bhatia, D. (2025). FIREfly project: forest fire monitoring and prediction using machine learning. **, 13635, 1363502 - 1363502-10. <https://doi.org/10.1117/12.3056811>
- He, L., Zhou, Y., Liu, L., Zhang, Y., & , J. (2025). Research and application of deep learning object detection methods for forest fire smoke recognition. *Scientific Reports*, 15. <https://doi.org/10.1038/s41598-025-98086-w>