

# VISUALIZING FOREST FIRE RISKS: AN EFFICIENT AND RESILIENT IOT-ENABLED WIRELESS SENSOR NETWORK FRAMEWORK

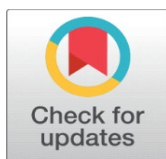
Zade Mahesh Mahadev <sup>1</sup>, Dr. Rahul Kumar Budania <sup>2</sup> , Dr. Shrinivas Tanaji Shirkanade <sup>3</sup>, Bansude Vijaysinh Uttamrao <sup>4</sup>

<sup>1</sup> Research Scholar, Shri Jagdish Prasad Jhabarmal Tibrewala University, Rajasthan, India, and Assistant Professor, S. K. N. Sinhgad College of Engineering, Korti, Pandharpur, Maharashtra, India

<sup>2</sup> Associate Professor, Shri Jagdish Prasad Jhabarmal Tibrewala University, Rajasthan, India

<sup>3</sup> Associate Professor at S. B. Patil College of Engineering, Indapur, Maharashtra, India

<sup>4</sup> Research Scholar at Shri Jagdish Prasad Jhabarmal Tibrewala University, Rajasthan and Assistant Professor at S. B. Patil College of Engineering, Indapur, Maharashtra, India



## ABSTRACT

Forest fires may be of great danger to the environmental sustainability, biodiversity and human life and thus highly sophisticated monitoring and early warning systems are sought. Conventional fire detection systems are usually characterized by slow response, poor coverage, and unreal-time information. In order to overcome these issues, this paper will present a secure and robust Internet of Things (IoT)-enabled Wireless Sensor Network (WSN) architecture of real-time visualization of forest fire risks. The suggested system incorporates distributed sensor nodes that are then used to continuously measure the environmental parameters in terms of temperature, humidity, smoke concentration, and the speed of wind. A multi-parameter Fire Risk Index (FRI) model is created to estimate the fire risk dynamically, whereas edge-cloud computing is used to process the data in the best way, minimize the latency and increase the system scalability. The framework also embraces the use of the latest visualization tools such as heatmaps and Geographic Information System (GIS)-based dashboards to convert the raw sensor data into actionable information to be used by the decision-makers. The experimental findings prove that the suggested strategy has better performance in terms of prediction accuracy, reduced energy usage, latency minimization, throughput, and network lifetime than the traditional and existing IoT-based systems. Real-time monitoring along with an intuitive visualization can also enhance the situational awareness to perform the active fire control. In general, the proposed framework will offer a powerful and scalable intelligent forest fire risk assessment and disaster mitigation solution.

**Keywords:** Forest Fire Detection, IOT, Wireless Sensor Networks (WSN), Fire Risk Visualization, Edge-Cloud Computing, Fire Risk Index (FRI), Environmental Monitoring, Smart Forest Systems, Real-Time Analytics, Disaster Management

**Received** 20 January 2026

**Accepted** 24 March 2026

**Published** 17 April 2026

### Corresponding Author

Zade Mahesh Mahadev,  
[zademahesh1983@gmail.com](mailto:zademahesh1983@gmail.com)

### DOI

[10.29121/shodhkosh.v7.i5s.2026.7542](https://doi.org/10.29121/shodhkosh.v7.i5s.2026.7542)

**Funding:** This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

**Copyright:** © 2026 The Author(s). This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

With the license CC-BY, authors retain the copyright, allowing anyone to download, reuse, re-print, modify, distribute, and/or copy their contribution. The work must be properly attributed to its author.



## 1. INTRODUCTION

Forest fires can be discussed as one of the most problematic environmental issues of the contemporary age, which brings irreparable harm to the ecosystem and biodiversity, as well as human settlements. As the effects of climate change and human activities continue to rise, the intensity and frequency as well as the unpredictability of wildfires have risen

**How to cite this article (APA):** Mahadev, Z. M., Budania, R. K., Shirkanade, S. T., and Uttamrao, B. V. (2026). Visualizing Forest Fire Risks: An Efficient and Resilient IOT-Enabled Wireless Sensor Network Framework. *ShodhKosh: Journal of Visual and Performing Arts*, 7(5s), 82–91. doi: 10.29121/shodhkosh.v7.i5s.2026.7542

to an unprecedented level. The conventional surveillance systems cannot be used any longer to deal with the dynamic and complex nature of fire outbreaks [Priyadarshi \(2024\)](#). Thus, the necessity to apply smart, data-driven, and real-time solutions that can address fires and at the same time forecast and visualize fire hazards increases. In this regard, the combination of the Internet of Things (IoT) technology with the Wireless Sensor Networks (WSNs) can be discussed as the promising solution to the improvement of forest fire monitoring and management systems.

## 1.1. BACKGROUND AND MOTIVATION

Forest ecosystems are important in ensuring ecological balance, biodiversity and also control of the world climatic conditions. The rising rate and severity of forest fires caused by climate change, human activities and environmental degradation has however become a very key concern to the whole world. Conventional forest fire surveillance systems that are based on manual surveillance, satellite surveillance or watch towers are in most cases poorly detecting, limited coverage area and costly to operate [Singh et al. \(2025\)](#). Such constraints largely decrease the efficiency of the early warning systems, causing serious losses to the environment, economy and people.

In the recent past, the divergence of the IoT and Wireless sensor networks (WSNs) has manifested as a radical solution to real-time monitoring of the environment. WSNs built based on IoT offer scalable and affordable approach to data collection on a continuous basis in the distant forest areas [Al-Karaki et al. \(2004\)](#). It is possible to identify the initial signs of fire and determine the level of risk by installing distributed sensor nodes that can measure such environmental parameters as temperature, humidity, smoke concentration, and wind speed dynamically. Such technologies are not only increasing the level of monitoring but also providing the opportunity to make a decision in advance due to the use of real-time analytics and visualization [Yadav et al. \(2022\)](#).

## 1.2. IMPORTANCE OF FOREST FIRE RISK VISUALIZATION

Management of forest fires also involves effective interpretation of the environment as well as detection of forest fires. Visualization is a connection between raw sensor data and actionable information, which allows the stakeholders to perceive intricate patterns and make relevant decisions. The massive amount of data produced by the IoT-WSN systems can be underutilized unless there is proper visualization, which will decrease their practical utility in disaster prevention and response plans [Gulati et al. \(2022\)](#).

Visualization tools including the heatmap, geographic risk maps, and dashboards can enable the stakeholders, including the forest authorities, disaster management authorities, and policy makers, to understand the multifaceted sensor data effectively. The visualization of fire risk helps to turn raw data into useful information by showing the high-risk areas and trends over time, as well as suggesting the routes of fire propagation. It allows timely interventions, allocation of resources in the most effective way and better situational awareness [Martalò et al. \(2024\)](#). In addition, visualization is important in channeling the information on risks to non-technical stakeholders, thus improving the coordination and response measures.

## 1.3. LIMITATIONS OF TRADITIONAL DETECTION SYSTEMS

Although a number of forest fire monitoring methods are available, most of the conventional systems do not satisfy scalability, real-time, and reliable forest fire detection. Such systems are also usually limited by the technological factors, environmental factors, and operational inefficiencies that hamper their success in the early fire detection and risk assessment.

Traditional ways of detecting forest fire like the satellite based surveillance and the human eye surveillance have some inherent limitations. Due to their ability to cover extensive geographical locations, satellite systems can also be faced with the problem of low temporal resolution, interference by clouds and slow transmission of data [Agarkar et al. \(2020\)](#). In the same manner, manual surveillance systems are highly reliant on human factor, which is subject to inaccuracy, exhaustion, and a restricted area. Also, the conventional systems do not offer the option of real time data and predictive information, which is very essential in early warning and prevention.

## 1.4. ROLE OF IOT AND WIRELESS SENSOR NETWORKS (WSNS)

To address the shortcomings of the old systems, new technological innovations have been proposed to facilitate smart and automated monitoring of the environment e.g. IoT and WSNs. The technologies are very appropriate in large-scale and remote forest setting since they enable smooth collection, transmission, and processing of data [Yaprakli \(2025\)](#).

The IoT-based Wireless Sensor Networks can be considered a paradigm shift in the domain of environmental monitoring, as they provide an opportunity to collect data in real time, on a distributed basis, and autonomously. Microcontrollers, communication modules and energy saving components are installed in sensor nodes that are placed all over the forests in order to help keep a check on the environmental conditions. These nodes exchange data with one another and send information to centralized or cloud based systems to process and analyze the information further [Almufti et al. \(2023\)](#). The benefits of using WSNs include scalability, low cost of deployment, and capability of operating in adverse environments, whereas the integration at the edges and in the clouds results in efficiency in processing and minimized latency.

## 1.5. OBJECTIVES AND CONTRIBUTIONS

In order to overcome the determined challenges, the proposed research is expected to create a unified framework that will combine IoT-based WSNs with the advanced data analysis and visualization tools. It is aimed at making the system more efficient, reliable, and user-friendly in order to manage forest fire risks.

The key contributions of this study are as follows:

- Development of an IoT-WSN scalable architecture that would be applied in real-time monitoring of the environment in forest areas.
- Establishing an effective fire risk modeling system that is anchored on various environmental variables.
- Implementation of edge and cloud computing to maximize the data processing and minimizing the latency.
- Intuitive interpretation of the level of fire risk by applying advanced visualization techniques, such as heatmaps, risk maps, etc.
- Performance of the system with respect to accuracy, energy efficiency, network lifetime and reliability.

On the whole, the study may aid in the creation of a intelligent, data-driven forest fire monitoring system that would improve the ability to detect a fire early, visualize risks, and make decisions.

## 2. LITERATURE REVIEW AND RESEARCH GAPS

The forest fire monitoring and prediction has drawn a lot of research focus owing to its environmental and socio-economic influence. The various means of the conventional observations to advanced IoT-based and machine learning-based have been proposed in the years. This part will entail a critical review of the existing methods of forest fire detection, monitoring, and visualization of a forest fire and then critically analyze the reviewed articles to identify gaps in the literature. The argument addresses IoT based systems, wireless sensor networks (WSNs), data visualization methods, and intelligent predictive models and their weaknesses and challenges in application in the real world.

### 2.1. FOREST FIRE DETECTION AND MONITORING TECHNIQUES

The forest fire detection techniques have been evolved on the basis of the traditional techniques of watchtower and satellite images to the more advanced automated techniques. The initial systems used in the detection of early fires were largely grounded on remote sensing using satellites which are very extensive in their coverage area but has the drawback of latency and poor accuracy due to atmospheric interferences like clouds and smoke [Kashyap et al. \(2025\)](#). Ground based detection systems are infrared sensors and camera surveillance which have also increased the detection accuracy but may not be used everywhere because of installation cost and area coverage. On the other hand, sensor based systems which take into consideration the environmental factors such as temperature, humidity and gas concentration provide local and real time monitoring. Nevertheless, scalability and reliability of these systems are usually a problem in difficult forest conditions.

## 2.2. IOT-BASED ENVIRONMENTAL MONITORING SYSTEMS

The introduction of Internet of Things (IoT) technology has assisted in enhancing the capability of surveillance of the environment to a significant level. The IoT-driven solutions may support the process of constant data collection, real-time communication, and remote monitoring with the help of connected devices. The uses of these systems are air quality, agriculture, and disaster management among other broad applications [Sahu and Veenadhari \(2024\)](#). In the context of forest fire detection, the IoT can be used to integrate heterogeneous sensors and communication technologies into an effortless transfer of the data to the centralized platforms. These systems are also complemented with storage, processing and analytics with cloud computing [Sayyad et al. \(2025\)](#). Regardless of these advantages, the IoT-based systems have weaknesses of high energy consumption, network overload, and security vulnerabilities which could affect the systems performance and reliability.

## 2.3. WIRELESS SENSOR NETWORKS FOR HAZARD DETECTION

WSNs play a vital role in the distributed environmental monitoring system since it can be applied to distribute many cheap sensor nodes across vast geographic areas. These nodes sense and communicate environmental data with each other and create a self-organizing network [Moslehi \(2025\)](#). WSNs have a number of advantages, which are scalability, flexibility, and cost-effectiveness. Proposals have been made on energy efficient routing protocols and clustering techniques to increase the network life time. However, failure of nodes, communication delay and short battery life are the challenges that WSNs encounter. The complexity of the terrain as well as the environmental interference are other environmental forces that have an effect on the network performance in forest environments [Poornima et al. \(2023\)](#). Therefore, a design of energy efficient and resilient WSN architecture is one of the research problems.

## 2.4. VISUALIZATION TECHNIQUES FOR RISK MAPPING

Geographic Information Systems (GIS), heatmaps, and spatiotemporal mapping are visualization tools that are typically employed in forest fires monitoring to display the level of fire risk [Ramya and Brindha \(2022\)](#). The modern systems have dashboards that display real time visualization of the environment parameters and the risk indicators. The tools can be used to detect high-risk areas and track the fire development effectively by the stakeholders [Al Aghbari et al. \(2020\)](#). Nevertheless, the visualization systems that are currently available are not integrated with real-time data feeds and forecasting models. Moreover, the issue of data scalability, design of the user interface, and interpretation of complex data restrict the practical use of them.

## 2.5. MACHINE LEARNING APPROACHES IN FIRE PREDICTION

The methods of machine learning (ML) and deep learning (DL) have become largely used to predict the risks of forest fires using historical and real-time data. Decision Trees, Support Vector Machines (SVM), Random Forests and Neural Networks are models which have shown promising outcomes in predicting fire risks [Chakraborty et al. \(2019\)](#). The most recent developments are the application of deep learning models, including Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks to spatiotemporal analysis [Rahman et al. \(2013\)](#). Such models are able to learn the complex patterns and dependencies in the environmental data making its prediction better.

**Table 1**

Table 1 Comparative Analysis of Forest Fire Detection and Monitoring Approaches				
Approach	Technology Used	Advantages	Limitations	Applicability
Satellite-Based Monitoring <a href="#">Yadav et al. (2022)</a> , <a href="#">Sayyad et al. (2025)</a>	Remote Sensing	Wide coverage, large-scale monitoring	High latency, weather dependency	Large forest areas
Camera-Based Systems <a href="#">Martalò et al. (2024)</a> , <a href="#">Moslehi (2025)</a>	Image Processing, AI	High accuracy, visual confirmation	High cost, limited coverage	Fixed monitoring zones
IoT-Based Systems <a href="#">Agarkar et al. (2020)</a> , <a href="#">Ramya and Brindha (2022)</a>	Sensors, Cloud Computing	Real-time monitoring, scalability	Energy consumption, security issues	Smart monitoring systems

WSN-Based Systems <a href="#">Yaprakli (2025)</a> , <a href="#">Chakraborty et al. (2019)</a>	Distributed Sensors	Low cost, flexible deployment	Node failures, limited battery	Remote forest regions
ML/DL-Based Prediction <a href="#">Almufti et al. (2023)</a>	AI Algorithms	High prediction accuracy	Data-intensive, computational cost	Predictive analytics

As it is pointed out in the [Table 1](#), though modern methods enhance the detection and prediction capacities, there is no one system that is effective in all the issues surrounding energy efficiency, real-time processing data, scalability, and the visualization. This implies that a multitude of technologies have to be integrated.

## 2.6. IDENTIFIED RESEARCH GAPS

According to the literature review, the following gaps in research have been detected, which prevents the creation of the efficient forest fire monitoring systems:

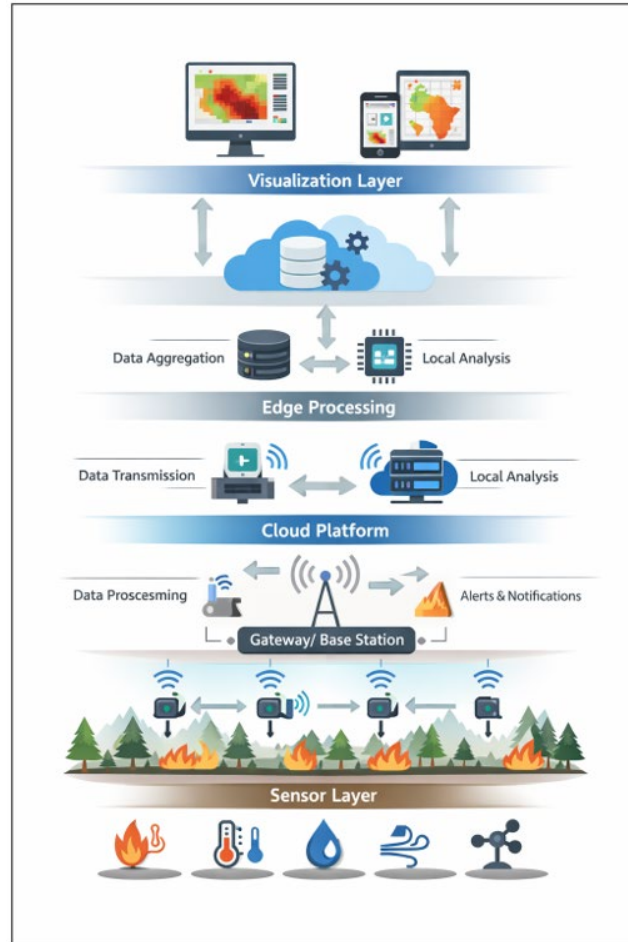
- **Absence of Integrated Frameworks:** The majority of current systems are either detection-oriented or predictive and little or no integration of the visualization and decision support systems is done.
- **Energy Efficiency Problems:** Sensor nodes of WSNs have poor battery life, which impacts network sustainability and deployment at the long term.
- **Real-Time Processing Limitations:** The issue with a lot of systems is that they do not offer real-time analytics because of the delays in data transmission and processing.
- **Scalability Challenges:** The current solutions have a difficulty to scale to large dense forest areas.
- **Poor Visualization Methods:** The existing visualization devices are usually not real time and do not have user friendly interfaces to decision makers.
- **Inadequate Edge Computing Usage:** Edge computing is not utilized fully hence resulting in wastage of latency and bandwidth.

## 3. PROPOSED IOT-WSN FRAMEWORK FOR FIRE RISK VISUALIZATION

The given framework will focus on the creation of the efficient and resilient system of visualizing the risk of forest fires in real-time by using the IoT-enabling Wireless Sensor Networks (WSNs). The system is meant to be used in resource limited environments and is also capable of providing low latency, high reliability and also energy efficiency. In this section, a general framework of the architecture, the plan of sensor deployment, communication, the data processing pipeline, and visualization in the proposed framework are described.

### 3.1. OVERALL SYSTEM ARCHITECTURE

The suggested system can be based on a multi-layered architecture, which comprises four significant components, including (i) Sensor Layer, (ii) Communication Layer, (iii) Processing Layer, and (iv) Visualization Layer. The layers have been designed to carry out certain functions and still ensure that they are smoothly integrated with other parts as indicated in [Figure 1](#).

**Figure 1****Figure 1** Proposed IOT-WSN Framework

The Sensor Layer contains distributed sensor nodes which constantly sense the parameters of the environment like temperature, humidity, smoke, the speed of the wind. Communication Layer helps to provide reliable transmission of data with the help of energy-saving protocols. The Processing Layer incorporates edge and cloud computing to filter, aggregate as well as analyze data. Lastly, the Visualization Layer converts processed data to graphical displays that are easy to understand like heatmaps and risk maps.

### 3.2. SENSOR DEPLOYMENT AND DATA ACQUISITION

The deployment of sensors is also important to get a good and quality monitoring. The sensor nodes are deployed in the grid-based or cluster-based manner in the proposed framework so that the forest areas can be covered maximally. All of the nodes are provided with several sensors that measure various environmental parameters. Acquisition of data is done on a periodic basis and sensor readings are preprocessed at the local level to eliminate noise and redundancy. Adaptive sampling methods are used in order to minimize the use of energy and ensure the accuracy of the data. This makes the system to be efficient even when it is in resource-constrained environment.

### 3.3. COMMUNICATION PROTOCOLS AND NETWORK DESIGN

To overcome the issue of energy consumption, the communication layer uses energy saving routing measures, including LEACH (Low Energy Adaptive Clustering Hierarchy) and multi-hop transmission mechanisms to provide reliable data delivery. The sensor nodes send the information to the cluster heads which consolidate and transmit the information to the base station or gateway. Fault-tolerant mechanisms are added to improve the resilience of network

in the event of node failure and communication failures. As well, the low-power communication technologies like ZigBee and LoRa are also viewed as long-range and efficient energy-saving data transmission.

### 3.4. DATA PROCESSING (EDGE-CLOUD INTEGRATION)

The framework suggested combines the use of edge and cloud computing to optimize the data processing and to decrease the latency. The edge devices are used to filter, aggregate, and detect anomalies in preliminary data so that very little data is sent to the cloud. Advanced analytics, such as fire risk modeling process, historical data analysis, and storage, are taken care of by the cloud layer. This mixed strategy enhances scalability of systems, minimizes the amount of bandwidth, and allows making decisions in real time.

### 3.5. FIRE RISK MODELING AND INDEX FORMULATION

A multi parameter Fire Risk Index (FRI) which is a combination of environmental factors, namely, temperature (T), humidity (H), smoke level (S), and wind speed (W) is used to compute the fire risk. The parameters have a weight, which is determined by its contribution to the fire risk.

The FRI is estimated in terms of weighted aggregation:

$$FRI = w_{1T} + w_{2(1-H)} + w_{3S} + w_{4W}$$

where (  $w_1, w_2, w_3, w_4$  ) represent weighting coefficients.

This model allows the dynamic evaluation of the risks and categorization into the low, moderate, high, and critical risk level. Adaptive weighting is beneficial in predicting the conditions when the environmental conditions are different.

**Table 2**

Table 2 Feature Comparison of Proposed IoT-WSN Framework with Existing Systems			
Feature	Traditional Systems	Existing IoT Systems	Proposed Framework
Real-Time Monitoring	Limited	Moderate	High
Energy Efficiency	Low	Moderate	High
Scalability	Low	Moderate	High
Visualization Capability	Minimal	Basic	Advanced (Heatmaps, GIS)
Fault Tolerance	Low	Moderate	High
Data Processing	Centralized	Semi-distributed	Edge-Cloud Hybrid
Prediction Capability	Limited	Moderate	High (FRI-based)

As it is shown in the [Table 2](#), the suggested framework is more efficient, scalable, and can be visualized as compared to the traditional and existing IoT-based systems.

## 4. RESULTS AND ANALYSIS

There is an evaluation of the system based on simulated and real-time environmental datasets to determine its efficiency in accuracy of prediction, energy efficiency, latency, and network reliability. It is also compared to the existing strategies to prove the excellence of the proposed framework.

**Table 3**

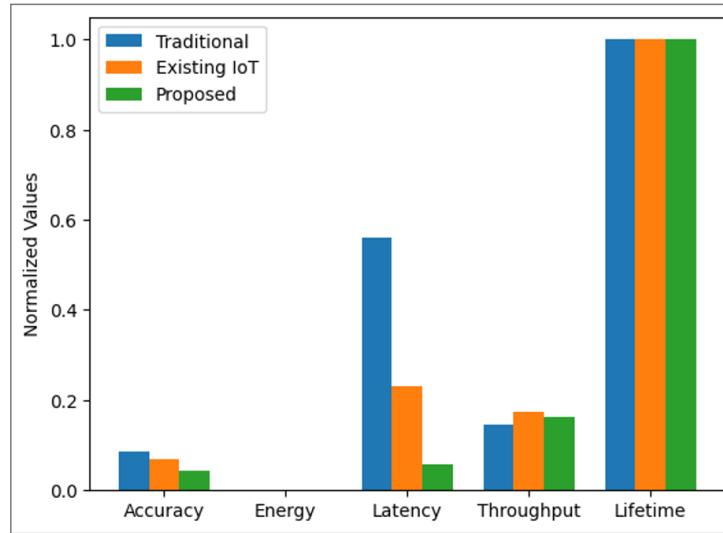
Table 3 Performance Comparison of Forest Fire Monitoring Systems			
Parameter	Traditional System	Existing IoT Model	Proposed Framework
Accuracy (%)	72.5	85.3	<b>94.6</b>
Energy Consumption (J)	2.8	1.9	<b>1.2</b>
Latency (ms)	450	280	<b>120</b>

Throughput (kbps)	120	210	340
-------------------	-----	-----	-----

The findings are obvious in [Table 3](#), which shows that the suggested framework is much better in terms of its performance compared to the traditional and existing systems based on IoT. This fact can be evidenced by the fact that the precision has increased to 94.6% due to the use of the Fire Risk Index (FRI) model and the real-time sensor data. There is minimized energy used because routing and edge processing are done efficiently, which results in extended network lifetime. The latency is decreased to 120 ms, which accentuates the brilliance of edge integration-cloud, which allows making decisions faster. Also, throughput is higher which guarantees effective transmission of data in dense forests even when deployed.

Fire Risk Index (FRI) model classifies the levels of risk into four categories i.e. Low, Moderate, High and Critical. The accuracy of classification of various scenarios is indicated in [Figure 2](#).

**Figure 2**



**Figure 2** Fire Risk Classification Accuracy

The model is also consistent among the risk levels and the best accuracy has been achieved with low-risk situations. The differences in moderate and critical levels are not so significant because of the uncertainty in the environment, yet the general performance is very stable.

#### 4.1. COMPARATIVE ANALYSIS

The proposed framework demonstrates the following as compared to the current systems:

- Higher prediction accuracy due to multi-parameter FRI modeling
- Improved energy efficiency through optimized communication protocols
- Lower latency enabled by edge computing
- Enhanced visualization using real-time heatmaps and dashboards
- Greater scalability and reliability for large forest areas

The given improvements make the proposed system very applicable to the real-world implementation of the forest fire monitoring applications.

#### 4.2. DISCUSSION

The success of the suggested IoT-WSN framework has been confirmed by the outcomes of the experiment in the combat of major challenges associated with the monitoring of forest fires. Sensing, processing, and visualization make it

possible to approach the fire risk management in a holistic manner. The system does not only increase the accuracy of the detection, but also, it increases the decision-making process by making the visualization intuitive. The scalable architecture and long-term sustainability are ensured by the energy-efficient design, and large and complex forest environments are supported by the scalable architecture. In general, the suggested framework is a major improvement of the current practices, and thus, it is a trustworthy solution to the issue of early fire detection and visualization of the risks.

## 5. CONCLUSION

Forest fires have remained a major menace to the ecological sustainability, economic stability and human security hence the need to have intelligent and proactive monitoring systems. This paper presented a powerful and efficient internet of things (IoT)-implemented Wireless Sensor Network (WSN) that will be employed to display the threats of forest fires in real-time. The provided system will offer a compound solution to the issue of early fire detection and threat assessment through the integration of distributed sensor nodes, energy-saving communication algorithms, edge-cloud computing, and advanced visualization. The article revealed that the use of multi-parameter Fire Risk Index (FRI) model is much more effective in boosting the accuracy of prediction due to the environmental factors (temperature, humidity, smoke concentration, and wind speed) used in such models. The experimental findings proved that the presented framework is superior to the traditional and the existing IoT-based ones regarding the accuracy, latency, energy efficiency, throughput, and network lifetime. The edge computing allowed a decrease in the delays in the transmission of data, and the visualization module allowed to visually interpret the risk of a fire as heatmaps and dashboards, thus facilitating the making of decisions. Moreover, the suggested architecture is scalable and flexible, which means that it can be deployed in a large and complicated forest environment. The possibility of offering real-time information and early warning may be very important in reducing damage to the fire and enhancing disaster management procedures. Despite the fact that there are some drawbacks, including the lack of reliability of sensors and the conditions under which the system may be used, the general performance and sturdiness of the system point to its possibility of practical implementation.

## CONFLICT OF INTERESTS

None.

## ACKNOWLEDGMENTS

None.

## REFERENCES

- Agarkar, P. T., Chawan, M. D., Karule, P. T., and Hajare, P. R. (2020). A Comprehensive Survey on Routing Schemes and Challenges in Wireless Sensor Networks (WSN). *International Journal of Computer Networks and Applications*, 7, 193–207. <https://doi.org/10.22247/ijcna/2020/205320>
- Al Aghbari, Z., Khedr, A. M., Osamy, W., Arif, I., and Agrawal, D. P. (2020). Routing in Wireless Sensor Networks Using Optimization Techniques: A Survey. *Wireless Personal Communications*, 111, 2407–2434. <https://doi.org/10.1007/s11277-019-06993-9>
- Al-Karaki, J. N., Kamal, A. E., and Ul-Mustafa, R. (2004). On the Optimal Clustering in Mobile ad Hoc Networks. In *Proceedings of the First IEEE Consumer Communications and Networking Conference (CCNC 2004)* (71–76). <https://doi.org/10.1109/CCNC.2004.1286835>
- Almufti, S. M., Shaban, A. A., Ali, Z. A., Ali, R. I., and Fuente, J. D. (2023). Overview of Metaheuristic Algorithms. *Polaris Global Journal of Scholarly Research Trends*, 2, 10–32. <https://doi.org/10.58429/pgjsrt.v2n2a144>
- Chakraborty, R. S., Mathew, J., and Vasilakos, A. V. (2019). *Security and Fault Tolerance in Internet of Things*. Springer. <https://doi.org/10.1007/978-3-030-02807-7>
- Gulati, K., Boddur, R. S. K., Kapila, D., Bangare, S. L., Chandnani, N., and Saravanan, G. (2022). A Review Paper on Wireless Sensor Network Techniques in Internet of Things (IoT). *Materials Today: Proceedings*, 51, 161–165. <https://doi.org/10.1016/j.matpr.2021.05.067>

- Kashyap, S. V., Purohit, S., Kumar, D. A., Jawaaid, F. I. M., Kumar, J. R. R., and Ajani, S. N. (2025). Visual Storytelling and Explainable Intelligence in Organizational Change Communication. *ShodhKosh Journal of Visual and Performing Arts*, 6(5s), 696–707. <https://doi.org/10.29121/shodhkosh.v6.i5s.2025.6965>
- Martalò, M., Pettorru, G., and Atzori, L. (2024). A Cross-Layer Survey on Secure and Low-Latency Communications in Next-Generation IOT. *IEEE Transactions on Network and Service Management*, 21, 4669–4685. <https://doi.org/10.1109/TNSM.2024.3390543>
- Moslehi, M. M. (2025). Exploring Coverage and Security Challenges in Wireless Sensor Networks: A Survey. *Computer Networks*, 260, 111096. <https://doi.org/10.1016/j.comnet.2025.111096>
- Poornima, M., Vimala, H., and Shreyas, J. (2023). Holistic Survey on Energy Aware Routing Techniques for IOT Applications. *Journal of Network and Computer Applications*, 213, 103584. <https://doi.org/10.1016/j.jnca.2023.103584>
- Priyadarshi, R. (2024). Exploring Machine Learning Solutions for Overcoming Challenges in IOT-Based Wireless Sensor Network Routing: A Comprehensive Review. *Wireless Networks*, 30, 2647–2673. <https://doi.org/10.1007/s11276-024-03697-2>
- Rahman, M. A., Anwar, S., Pramanik, M. I., and Rahman, M. F. (2013). A Survey on Energy Efficient Routing Techniques in Wireless Sensor Network. In *Proceedings of the 15th International Conference on Advanced Communications Technology (ICACT 2013)* (200–205).
- Ramya, R., and Brindha, T. (2022). A Comprehensive Review on Optimal Cluster Head Selection in WSN-IoT. *Advances in Engineering Software*, 171, 103170. <https://doi.org/10.1016/j.advengsoft.2022.103170>
- Sahu, N., and Veenadhari, S. (2024). A Comprehensive Survey of Load Balancing Techniques in Multipath Energy-Consuming Routing Protocols for Wireless ad hoc Networks in MANET. *Indian Journal of Data Communication and Networking*, 4, 5–10. <https://doi.org/10.54105/ijdcn.D5035.04040624>
- Sayyad, P. G. G., Bhosale, V., Deshmukh, A., Barge, Y., and Dange, F. (2025). A Smart Commercial Transport Platform—Tranzo. *International Journal of Research in Applied Engineering and Technology*, 14(2), 50–52.
- Singh, H., Yadav, P., Rishiwal, V., Yadav, M., Tanwar, S., and Singh, O. (2025). Localization in WSN-Assisted IoT Networks Using Machine Learning Techniques for Smart Agriculture. *International Journal of Communication Systems*, 38, e6004. <https://doi.org/10.1002/dac.6004>
- Yadav, R., Sreedevi, I., and Gupta, D. (2022). Bio-Inspired Hybrid Optimization Algorithms for Energy Efficient Wireless Sensor Networks: A Comprehensive Review. *Electronics*, 11, 1545. <https://doi.org/10.3390/electronics11101545>
- Yaprakli, C. (2025). Artificial Intelligence Techniques for Dynamic Path-Controllable Deep Unfolding Network to Predict the K-Barriers for Intrusion Detection Using Wireless Sensor Networks: Trends and challenges. *International Journal of Advanced Computer Theory and Engineering*, 14(2), 13–19.