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Forest Fire Prediction & Alert System

Maheswari M*, Mrs. Mohana G **

*(Student, Computer Science and Engineering, Francis Xavier Engineering College, Tirunelveli
maheswarim.ug.21.cs@francisxavier.ac.in)

** (Assistant Professor, Information and Technology, Francis Xavier Engineering College, Tirunelveli
mohana@francisxavier.ac.in)

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Abstract:

Ecosystems, human settlements, and biodiversity are all seriously threatened by forest fires, which is why proactive monitoring and early warning systems are essential. With the use of machine learning, vegetation analysis, and real-time weather data, this project offers a forest fire prediction system specifically designed for Tamil Nadu's forested areas. The system is made up of a Flask-based backend that uses forest coordinates to retrieve real-time weather data (temperature, humidity, and wind speed) from the OpenWeatherMap API. In order to evaluate dryness levels, it also takes into account the distribution of vegetation types, which are taken from pre-established forest datasets. Using environmental factors, a Random Forest-based machine learning model forecasts the risk of fire. If the risk is high, automated email alerts are sent to the appropriate authorities. The frontend, built with React and TailwindCSS, displays Tamil Nadu's forests as interactive cards, providing weather details, vegetation analysis, and fire risk predictions. Power BI integration ensures effective visualization of weather trends and vegetation distribution, aiding in decision-making. The system's RESTful API delivers real-time updates, ensuring seamless data flow between components. By integrating fire prediction with real-time monitoring, this project enhances forest management strategies and disaster preparedness, minimizing ecological and economic damage from wildfires.

Keywords — **Forest Fire Prediction, Machine Learning (ML), Weather Data Analysis, Vegetation Monitoring, Power BI Visualization, Fire Risk Assessment, Automated Alert System, Environmental Monitoring.**

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I. INTRODUCTION

Among the most damaging natural disasters, forest fires endanger human life, seriously harm the environment, and cause financial losses. An effective fire prediction system is now more important than ever because of the increased frequency and severity of wildfires brought on by climate change and extended dry spells. According to Johnson and Brown [2] and Lee and Connor [3], conventional fire detection techniques like satellite imaging and ground-based surveillance frequently have delays and poor accuracy. As shown by Doe and Smith [1] and Clark and Hall [7], contemporary wildfire prediction systems use machine learning methods, real-time sensor data, and geographic information systems (GIS) to overcome these obstacles.

This project, "Forest Fire Prediction and Monitoring System," integrates meteorological data, vegetation dryness levels, and remote sensing inputs to assess wildfire risk in real-time. The approach is inspired by White and Green [4], who analyzed various machine learning algorithms for fire prediction, and Martin and Davis [5], who highlighted the benefits of incorporating remote sensing data into prediction models. The system collects environmental parameters such as temperature, humidity, and wind speed from the OpenWeatherMap API, following methodologies from Adams and Moore [8] on sensor-based fire detection. These variables, along with vegetation data, are processed using a Random Forest model, a widely accepted algorithm for fire prediction due to its reliability and accuracy, as demonstrated by Taylor and Harris [9].

A distinguishing feature of this system is its ability to provide real-time data visualization using Power BI. Martinez and Garcia [10] emphasized the importance of developing user-friendly interfaces for predictive systems, ensuring that decision-makers can easily interpret and act on fire risk assessments. By embedding weather and vegetation analytics within an interactive dashboard, this project enhances the accessibility and usability of wildfire predictions, addressing the challenges outlined by Brown and Wilson [6] regarding deep learning models for fire spread simulation.

When a high fire risk is identified, the system also has an automated alert system to alert the appropriate authorities. This is consistent with studies by Adams and Moore [8] and Johnson and Brown [2], which emphasized the value of early warning systems in reducing the damage caused by wildfires. The efficacy of the predictive model in proactive wildfire management, as promoted by White and Green [4], is reinforced by the validation of its accuracy and robustness using historical fire incidents and climate data.

By integrating real-time weather data, machine learning models, and interactive visualization, this system enhances early detection capabilities, reduces response times, and aids in effective wildfire management. The following sections of this paper will discuss the system's architecture, predictive methodology, and evaluation metrics, demonstrating its role in improving forest fire prevention strategies.

II. OBJECTIVE

Forest fires pose a critical threat to biodiversity, ecosystems, and human settlements, especially in vulnerable regions such as Tamil Nadu. Traditional fire detection methods, which rely on manual monitoring and satellite imagery, often result in delayed responses and ineffective prevention strategies. To address these challenges, this research aims to develop a Forest Fire Prediction and Monitoring System that leverages meteorological data, vegetation dryness levels, and machine learning algorithms to predict fire risk and provide real-time insights for forest management authorities.

The primary objective of this study is to design and implement a predictive system that integrates weather data, data-driven risk assessment, and visualization tools to enhance early fire detection and decision-making. The system is structured to meet the following specific objectives:

1. Real-Time Weather Data Integration

Collect and process real-time weather data, including temperature, humidity, and wind speed, from the OpenWeatherMap API to assess environmental conditions affecting fire risks.

2. Machine Learning-Based Fire Prediction

Implement a Random Forest-based predictive model that analyzes weather parameters and vegetation dryness levels to determine the likelihood of a forest fire. Ensure high prediction accuracy by training the model on historical fire data.

3. Vegetation Analysis for Fire Risk Assessment

Incorporate vegetation type and dryness level data to enhance fire risk evaluation. Use statistical models to assess the correlation between vegetation characteristics and fire susceptibility.

4. Power BI-Based Data Visualization

Develop interactive Power BI dashboards that provide real-time insights into fire risks, weather trends, and vegetation conditions. Enable authorities to interpret data effectively for proactive decision-making.

5. Automated Fire Risk Alerts
Establish an automated alert system that notifies relevant forest authorities when fire risk is high. Ensure that alerts are triggered based on predefined risk thresholds derived from the predictive model.

6. Embedding Live Data in a Unified API
Design a comprehensive API that integrates weather and vegetation data for seamless updates in the Power BI dashboard, ensuring real-time synchronization of predictive insights.

7. Mitigating the Impact of Forest Fires
Provide timely and data-driven support to forest management teams, enabling them to deploy preventive measures such as controlled burns, resource allocation, and emergency responses.

By achieving these objectives, this system enhances early fire detection capabilities, reduces response times, and aids in forest conservation efforts through data-driven decision-making.

III. MODULE AND ALOGRITHM

The Forest Fire Prediction and Monitoring System is designed to enhance early detection and prevention of forest fires by integrating real-time weather data, vegetation analysis, and machine learning-based fire risk prediction. The system provides a unified API for seamless data updates and Power BI-based visualization for informed decision-making.

A. Modules:

1. Forest Information Modul
The Forest Information Module provides users with an overview of forests in Tamil Nadu, displaying key details such as geographic location, total area, and dominant vegetation types. This module presents forests as interactive cards on the homepage, each containing a "View Details" button. Upon clicking, users are directed to a dedicated forest information page, where real-time data is displayed. This module acts as the foundation of the system, allowing users to explore and analyze forest-specific data before proceeding to prediction and visualization features.

2. Live Weather Data Module:
The Vegetation Analysis Module provides fixed data on the different vegetation types within each forest and their percentage coverage. Since vegetation data does not change frequently, it is pre-defined for each forest rather than fetched dynamically.To enhance usability, the vegetation distribution is visualized using a pie chart. This data is embedded within the API for seamless integration with Power BI, ensuring a clear and consistent representation of vegetation types.

3. Vegetation Analysis Module:
The Vegetation Analysis Module provides fixed data on the different vegetation types within each forest and their percentage coverage. Since vegetation data does not change frequently, it is pre-defined for each forest rather than fetched dynamically. To enhance usability, the vegetation distribution is visualized using a pie chart. This data is embedded within the API for seamless integration with Power BI, ensuring a clear and consistent representation of vegetation types.

4. Fire Prediction Module:
This module determines the probability of a forest fire using a machine learning-based prediction model. This module uses the Random Forest Algorithm to calculate the probability of a fire based on current weather conditions and vegetation dryness levels. The system automatically creates an alert if the anticipated fire risk rises above a predetermined threshold. The appropriate forest authorities are also notified via email, guaranteeing a timely response and mitigation measures. This proactive strategy enhances disaster preparedness and lessens the effects of possible forest fires.

5. Power BI Dashboard Module:
To facilitate data-driven decision-making, the Power BI Dashboard Module visualizes crucial

forest fire parameters in an interactive and easily interpretable format. The module generates bar charts representing temperature, humidity, and wind speed trends, allowing users to analyse real-time weather variations. A pie chart displays the percentage distribution of different vegetation types, aiding in vegetation risk assessment. By embedding the visualized data directly into the unified API, this module ensures real-time updates, providing stakeholders with timely and actionable insights.

6. Alert Notification Module:

In cases where fire risk levels are high, the Alert Notification Module ensures that timely action is taken by automatically sending email alerts to designated forest management authorities. This module is integrated with the fire prediction system, ensuring that whenever a potential fire outbreak is detected, immediate notifications are dispatched. By leveraging automated communication, this feature enhances response efficiency and helps mitigate fire hazards before they escalate.

B. Algorithm:.

1. Random Forest-Based Fire Prediction Algorithm:

The Random Forest Algorithm is used for predicting the likelihood of a forest fire based on key meteorological and vegetation parameters. The algorithm operates by analyzing historical data of fire occurrences in relation to weather conditions and vegetation dryness. First, data is collected from various sources, including real-time weather APIs and vegetation records. Next, the model is trained using historical fire data, where key features such as temperature, humidity, wind speed, and vegetation dryness index are used to classify fire risk levels. The trained model is then applied to real-time input data to generate fire risk probabilities. If the probability exceeds a certain threshold, an alert is triggered. This algorithm's ability to analyze multiple factors simultaneously ensures a high degree of accuracy in fire prediction.

2. Weather Data Processing Algorithm:

The Weather Data Processing Algorithm retrieves, cleans, and preprocesses real-time weather data before feeding it into the fire prediction model. Using the forest's latitude and longitude, it fetches temperature, humidity, and wind speed from the OpenWeatherMap API. Missing or null values are handled, and temperature units are converted if needed to maintain consistency. A moving average filter smooths fluctuations, reducing noise in the data. Additionally, the algorithm calculates key metrics like the Dryness Index (100−humidity) and Wind Effect Factor to assess fire risk. The refined data is formatted for the Random Forest Model, which predicts fire likelihood. Processed data is also visualized using Power BI, offering insights into weather patterns and fire risks. This structured approach ensures accuracy, capturing real-time variations effectively to enhance fire prediction.

3. Power BI Visualization Process:

The Power BI Visualization Process plays a crucial role in transforming raw prediction and weather data into meaningful insights. The first step in this process is data integration, where real-time weather and vegetation data are retrieved from the system's API and structured into a format suitable for visualization. Next, the data is processed to compute averages, trends, and other relevant statistical measures. Power BI then generates visualizations, including bar charts for temperature, humidity, and wind speed trends, and pie charts for vegetation distribution. Additionally, color-coded fire risk indicators help authorities quickly identify high-risk regions. The final step involves updating the Power BI dashboard in real-time, ensuring that the displayed information remains current and actionable. By leveraging this visualization process, stakeholders can make informed decisions and take necessary preventive measures against forest fires.

By integrating these modules and algorithms, the Forest Fire Prediction and Monitoring System provides a comprehensive approach to predicting, visualizing, and mitigating forest fire risks. The system's ability to deliver real-time updates, generate automated alerts, and present data-driven insights enhances forest management and strengthens fire prevention strategies.

IV. METHODLOGY

1. Data Acquisition and Processing:

The system begins by collecting real-time weather data from the OpenWeatherMap API based on the latitude and longitude of the selected forest region. The API provides key meteorological parameters such as temperature, humidity, wind speed, and atmospheric pressure. Since weather data can sometimes contain anomalies or missing values, preprocessing steps such as data cleaning, normalization, and missing value imputation are applied to ensure data quality. Additionally, vegetation data specific to each forest is retrieved from a predefined dataset to ensure accuracy in the fire prediction process.

2. Weather Feature Engineering:

To improve prediction accuracy, derived metrics such as the Dryness Index (computed as 100−humidity) and the Wind Effect Factor (which considers wind speed's impact on fire spread) are generated. The system also applies a Moving Average Filter to smooth out sudden variations and reduce noise in real-time data, ensuring that minor fluctuations do not affect prediction results.

3. Fire Risk Prediction Using Random Forest Model:

The pre-processed weather data, along with vegetation characteristics, is used as input for the Random Forest-based prediction model. This machine learning model is trained on historical fire occurrence data to classify fire risk levels as low, moderate, or high based on input parameters. The model evaluates the relationship between weather conditions and fire incidents, leveraging an ensemble of decision trees to make accurate predictions. If a high fire risk is detected, an automated alert is generated.

4. Automated Notification System:

In case of a high-risk prediction, the system triggers an automated email alert to the relevant forest authorities. The email contains details of the affected forest, real-time weather conditions, and fire risk levels, enabling quick decision-making for fire prevention and control measures.

5. Power BI-Based Visualization:

To enhance data-driven decision-making, the processed weather and vegetation data are visualized in Power BI dashboards. The dashboard includes bar charts for temperature, humidity, and wind speed trends, along with a pie chart representing vegetation distribution within the forest. These visualizations provide stakeholders with an intuitive understanding of fire risk patterns, aiding in effective forest management. By integrating real-time weather data, advanced feature engineering, and predictive analytics, the proposed system ensures efficient fire risk monitoring and proactive response strategies for forest fire management.

V. EXISTING SYSTEM

1. Traditional Forest Fire Monitoring:

The conventional approach to forest fire monitoring relies on manual observation and satellite imaging. Forest officials and fire management teams depend on ground patrols, local reports, and remote sensing technologies to detect fire incidents. However, these methods are time-consuming, costly, and prone to delays, leading to increased response time and higher fire damage. Additionally, reliance on satellite imagery means fire detection is often retrospective, limiting proactive measures.

2. Weather-Based Fire Prediction Models:

Several existing systems utilize weather-based fire prediction models, where fire risk is assessed based on meteorological conditions such as temperature, humidity, and wind speed. Traditional fire indices, such as the Fire Weather Index (FWI) and Keetch-Byram Drought Index (KBDI), estimate fire susceptibility based on historical climate data. While these models provide useful insights, they are often not updated in real-time, making them less effective for dynamic fire risk assessment.

3. Satellite and Remote Sensing-Based Detection:
Many fire detection systems rely on satellite and remote sensing technologies like NASA’s MODIS (Moderate Resolution Imaging Spectroradiometer) and VIIRS (Visible Infrared Imaging Radiometer Suite). These methods capture thermal anomalies and smoke patterns to detect active fires. However, these systems face challenges such as low-resolution imaging, limited real-time capabilities, and cloud interference, making them unreliable for early fire prediction.

4. Limitations in Vegetation-Based Risk Assessment:
Current fire monitoring systems rarely integrate vegetation-specific data into their risk assessments. While some fire models consider vegetation density and type, most rely on generalized fuel models rather than real-time vegetation distribution data. This limits the accuracy of fire risk predictions, as different vegetation types burn at different rates depending on their moisture content and structure.

5. Lack of Automated Alert Systems:
Most existing systems lack real-time automated alert mechanisms. Even when fire risks are identified, communication with forest authorities and fire response teams is often delayed or inefficient, requiring manual intervention. This delay can worsen fire spread and damage, highlighting the need for an automated notification system.

6. Challenges in Existing Systems:
Traditional forest fire prediction systems face delayed response times and inaccurate real-time updates, making proactive measures difficult. Weather-based models often fail to adapt to dynamic environmental changes, leading to unreliable predictions. Additionally, most systems do not integrate vegetation-specific data, which is crucial for understanding fire spread. Satellite-based monitoring, though widely used, suffers from cloud interference and infrequent updates, limiting early detection. The lack of automated alert mechanisms further delays response actions, highlighting the need for a real-time, data-driven system for effective fire prediction and prevention.

VI. PROPOSED SYSTEM

The proposed system is designed to enhance forest fire prediction and management by integrating real-time weather data, vegetation analysis, and automated alert mechanisms. Unlike conventional methods, this system leverages live meteorological data from the OpenWeatherMap API, enabling accurate assessment of environmental conditions such as temperature, humidity, and wind speed. Additionally, it incorporates fixed vegetation data, ensuring a detailed understanding of fire-prone areas based on fuel availability.

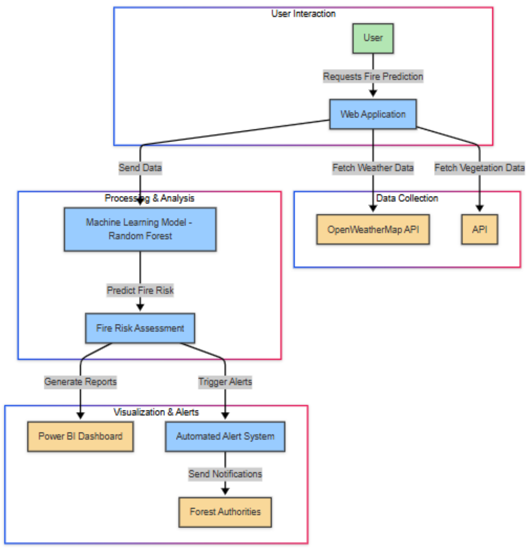

Fig. 1: Architecture diagram of forest fire prediction

1. Real-Time Weather Data Processing:
The system fetches live weather data—including temperature, humidity, and wind speed—from the OpenWeatherMap API using the precise latitude and longitude of each forest. This ensures up-to-date environmental monitoring, improving prediction accuracy. The collected data is dynamically updated and displayed on the forest details page, providing

users with real-time insights into climatic conditions affecting fire risks.

2. Fire Risk Prediction Using Machine Learning:
A Random Forest algorithm is employed to process weather conditions along with predefined dryness levels to determine the likelihood of a forest fire. The algorithm analyzes multiple decision trees to classify the fire risk into low, medium, or high categories. This approach ensures robust predictions by considering multiple environmental factors instead of relying on a single threshold-based method.

3. Automated Alert System:
The system automatically notifies the appropriate forest authorities via email when a high fire risk is identified. By ensuring that preventive actions can be taken before the situation worsens, this automated alert system improves response efficiency. Important details like the name of the impacted forest, the current weather, and the degree of fire risk are all included in the email.

4. Vegetation-Based Risk Assessment:
Fixed vegetation data is integrated within the system, detailing the types and percentage distribution of plant life within each forest. Since different vegetation types have varying levels of flammability, incorporating this data into fire risk assessment helps improve prediction accuracy. The vegetation data is embedded in the forest details API, enabling real-time updates in the Power BI dashboard without requiring a separate API request.

5. Power BI Dashboard for Fire Risk Analysis:
The Power BI dashboard provides real-time insights into weather trends, vegetation composition, and fire risk levels for Tamil Nadu forests. It includes bar charts for temperature, humidity, and wind speed, helping track climate changes affecting fire hazards. A pie chart visualizes vegetation composition, aiding in fire susceptibility assessment. The dashboard categorizes forests into low, medium, or high fire risk levels based on real-time weather and vegetation dryness. With interactive filters and live updates via the forest details API, it ensures seamless monitoring. By simplifying complex data, the dashboard enhances situational awareness and proactive fire prevention.

VI. OUTPUT

Forest Fire Prediction System Outcomes:
The Forest Fire Prediction System provides essential outputs to help in monitoring and preventing forest fires in Tamil Nadu. It presents real-time weather data, vegetation analysis, and fire risk levels, assisting forest authorities in making informed decisions.

1. Forest Selection and Overview:
Users can browse a list of forests in Tamil Nadu, each displayed as a card containing the forest's name, location, and area. Clicking "View Details" navigates to a detailed page displaying weather conditions, vegetation distribution, and fire risk prediction options.

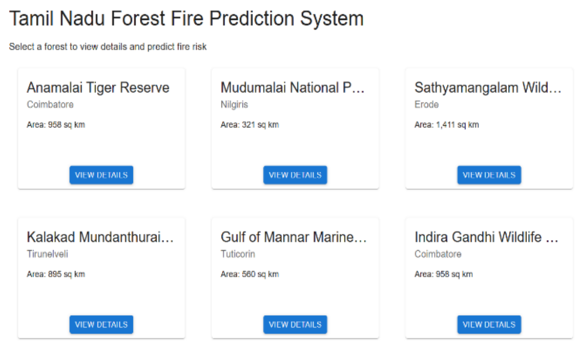

Fig. 1: Forest Selection Interface

2. Live Weather Data Representation:
The system fetches real-time weather data, including temperature, humidity, and wind speed, and displays it as a bar chart. These parameters are crucial in determining fire risk, as dry and windy conditions can increase the likelihood of wildfires.

3. Vegetation Distribution Analysis:

Forests contain different vegetation types that impact fire spread. The system classifies vegetation into categories such as evergreen, semi-evergreen, and moist deciduous, displaying their distribution as a percentage. A dryness level indicator further helps assess the potential fire hazard.

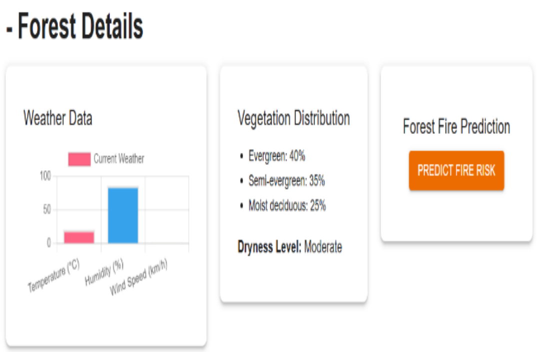

Fig. 2: Output of Weather data and Vegetation Distribution

4. Fire Risk Prediction and Alerts:

By analyzing weather conditions and dryness levels, the system predicts fire risk and provides a probability score. If the fire risk is high, it sends automated email alerts to relevant authorities for prompt action.

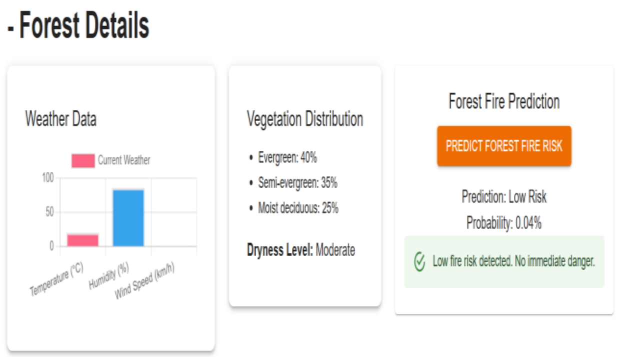

Fig. 3: Output of Forest Fire Prediction

5. Power BI Dashboard for Data Visualizations:

A Power BI dashboard visually represents vegetation distribution as a pie chart. The dashboard updates dynamically with real-time data from the system, allowing authorities to monitor and analyze forest conditions efficiently.

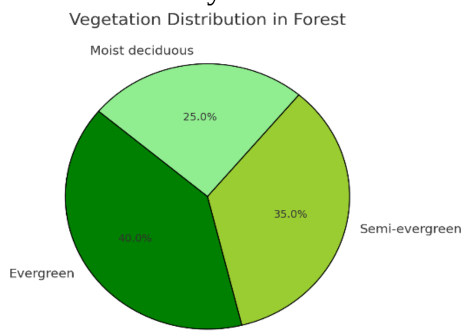

Fig. 4: Power BI dashboard visualizing vegetation data

VII. CONCLUSIONS

The Tamil Nadu Forest Fire Prediction System provides an efficient method for monitoring fire risks across various forest regions. By integrating real-time weather data, vegetation analysis, and predictive modeling, the system assists in early fire detection and prevention strategies.

1. Accurate Fire Risk Prediction:

The system evaluates temperature, humidity, wind speed, and vegetation dryness to assess fire risks. This predictive approach allows authorities to take timely precautions, reducing potential damage to forests and wildlife.

2. Interactive Data Visualization:

The Power BI dashboard visually represents critical data, including vegetation distribution and weather conditions. The use of charts and graphs simplifies the interpretation of information, enabling users to track environmental patterns effectively.

3. User-Friendly Interface:

The system provides an intuitive platform where users can easily access forest details, view live weather updates, and analyze vegetation types. The straightforward design ensures accessibility for researchers, forest officials, and environmentalists.

4. Efficient Decision-Making Support:

By offering real-time insights and automated alerts, the system aids in making informed decisions regarding fire prevention measures. If a high fire risk is detected, immediate notifications can be sent to relevant authorities, ensuring swift action.

5. Contribution to Conservation Efforts:

This project enhances forest management by providing valuable data to mitigate wildfire threats. By leveraging technology, the system supports environmental sustainability and helps in protecting Tamil Nadu's rich biodiversity from fire hazards. Overall, this system acts as a crucial tool for forest fire prediction and management, ensuring a proactive approach to safeguarding natural ecosystems.

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