

# IoT-Enabled Multi-Parameter Forest Monitoring

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**Abstract-** Forests play a vital role on our planet. However, they are under serious threat from climate change, illegal logging, and dangerous wildfires. Traditional methods of monitoring forests, such as having people patrol the area, using satellites, or doing manual checks, are not very effective. These methods are slow, expensive, and don't work well in remote locations.

This project introduces a new system that uses the internet and special sensors to monitor forests and provide early warnings. Tiny computers and sensors are placed in the forest, allowing them to communicate with each other and with the internet. These sensors can track various factors like temperature, humidity, air quality, soil moisture levels, and even detect fires. All the data collected by the sensors is sent to a website where it can be viewed in real time.

If something goes wrong, like a fire, the system sends an alert to our phones. We can also use the system to activate water pumps to help put out fires quickly. During testing, the system performed very well. It correctly identified fires in 96 out of 100 cases and sent false alarms only 2 out of 100 times. The system is also energy-efficient and relatively inexpensive, making it suitable for use in hard-to-reach areas.

This new system offers a better alternative to traditional forest monitoring methods and can be used by countries to help protect their forests.

Forests benefit from such systems because they aid in keeping them safe. Forests are very important, and these systems can help ensure their protection.

**Keywords—** Forest Monitoring System; Wireless Sensor Network; IoT; Fire Detection; GSM/GPRS; Environmental Sensors; Smart Agriculture; Precision Forestry; Cloud Dashboard; Threshold Alert

## I. INTRODUCTION

Forests represent one of the most vital ecological systems on Earth, covering approximately 31% of the planet's total land area roughly 4.06 billion hectares, according to the Food

and Agriculture Organization (FAO, 2022). These ecosystems serve a multitude of critical environmental functions, including regulation of the global carbon cycle, conservation of biodiversity, prevention of soil erosion, management of hydrological processes, and supporting the livelihoods of more than 1.6 billion people worldwide. As natural carbon sinks, forests absorb significant quantities of atmospheric CO<sub>2</sub>, thereby playing an indispensable role in mitigating the effects of climate change. They also serve as habitat for approximately 80% of all terrestrial species, underscoring their irreplaceable value to global biodiversity.

Despite their ecological significance, forests face mounting threats from a complex interplay of natural and anthropogenic forces. Climate change, unchecked urbanization, large-scale deforestation, mining activities, agricultural encroachment, and increasingly frequent wildfires are collectively accelerating the degradation and loss of forest cover worldwide. Rising global temperatures and prolonged drought conditions have, in particular, intensified the frequency and severity of forest fires, resulting in substantial ecological and economic losses. The catastrophic Australian bushfires of 2019–2020, which razed approximately 18.6 million hectares of forest, alongside devastating fires in the Amazon basin, Siberia, and California, starkly illustrate the heightened vulnerability of forest ecosystems in the face of climate change. These events underscore the urgent need for advanced technological interventions capable of continuously monitoring forest health and enabling early detection of disturbances and anomalies.

India, recognized as one of the world's seventeen mega-biodiverse nations, hosts a rich mosaic of forest ecosystems spanning tropical rainforests, mangrove wetlands, and alpine forests. According to the Forest Survey of India (FSI, 2023), forest cover accounts for approximately 24.62% of the country's total geographical area, with combined forest and tree cover extending to nearly 80.9 million hectares. Indian forests are central to the nation's ecological security, supporting wildlife conservation, climate regulation,

freshwater resource management, and the sustenance of millions of people in tribal and rural communities. States such as Madhya Pradesh, Arunachal Pradesh, Chhattisgarh, Odisha, and Maharashtra contain the most extensive forest tracts, while ecologically sensitive regions like the Western Ghats and the Himalayas hold particular significance for biodiversity conservation.

The proliferation of GSM connectivity in remote areas opened new avenues for remote alert delivery. Saeed et al. (2016) demonstrated a GSM-based forest fire alert system using the SIM900 module, achieving SMS delivery times under seven seconds in field conditions. This work highlighted the practical value of cellular data links in regions where Wi-Fi infrastructure is unavailable, a configuration that is directly relevant to dense, infrastructure-poor forested regions.[4]

Sensor Module	Parameter Measured	Range / Accuracy	Protocol
DHT11	Temperature & Humidity	-40°C to 80°C / ±0.5°C	Single-wire digital
MQ-135	CO <sub>2</sub> / Smoke / VOC	10–1000 ppm / ±5%	Analog + Digital
MQ-2	Combustible Gas/ Smoke	200–10000 ppm	Analog
FC-37 Rain Sensor	Rainfall / Moisture	0–100% (relative)	Analog
IR Flame Sensor	Fire / IR Radiation	700–1100 nm	Digital (D0/A0)
SIM800L GSM	Data Transmission SMS	900/1800 MHz	AT Commands / UART
Soil Moisture Sensor	Soil Water Content	0–100% (resistive)	Analog

**Table 2.1 Sensor Module Specifications and Communication Protocols**

## II. LITERATURE REVIEW

The field of automated environmental monitoring has matured significantly over the past decade, driven by advances in microelectronics, low-power wireless communication, and cloud computing. Akyildiz et al. (2002) established the foundational framework for wireless sensor networks (WSNs), articulating the core tension between energy conservation and data fidelity a tension that remains central to deployed forest monitoring systems. Their taxonomy of WSN topologies star, mesh, and tree continues to inform deployment decisions in real-world forest monitoring contexts.[1]

Early forest monitoring work focused heavily on fire detection. Lloret et al. (2009) proposed a WSN-based fire detection system using temperature and humidity sensors and ZigBee communication. While their system demonstrated the viability of wireless sensing in forested environments, it relied on a single sensing modality, which made it susceptible to false positives in naturally hot and dry conditions. The integration of multiple sensor types particularly the addition of gas-concentration and infrared flame sensors was identified as a priority for subsequent research.[2]

Aslan et al. (2012) extended this foundation by incorporating CO<sub>2</sub> and smoke gas sensors alongside temperature nodes, achieving better discrimination between natural diurnal temperature swings and actual fire events. Their work also addressed the energy-harvesting dimension, proposing solar panel integration to sustain continuous operation. However, their alert pipeline remained local, relying on on-site buzzers and LED indicators rather than remote notification.[3]

More recent work has embraced cloud computing platforms. Gupta and Singh (2019) integrated a Raspberry Pi-based gateway with AWS IoT Core to stream sensor data from a WSN, enabling real-time dashboard visualisation and historical analytics. They reported that centralised cloud storage allowed retrospective analysis of environmental patterns, which proved valuable in identifying pre-fire conditions such as humidity drops and temperature spikes co-occurring over several days.[6]

A significant gap in existing literature is the scarcity of holistic, deployed systems that combine multi-sensor fusion, cellular communication, cloud analytics, and real-time alerting within a single low-cost framework validated under realistic forest micro-environment conditions. Most published systems validate under controlled laboratory settings, leaving the behaviour under outdoor environmental noise largely uncharacterised. The present work addresses this gap by designing, building, and testing the complete pipeline under simulated outdoor forest conditions.

## III. PROPOSED SYSTEM ARCHITECTURE

This proposed forest monitoring device uses hardware that enables real-time tracking and response to environmental changes. Each part of the hardware has a specific role in the overall system. The ESP32 Microcontroller is the main brain of this design. It uses very little power, has two processing cores, and includes Wi-Fi and Bluetooth connectivity. It's well-suited for this IoT-based remote monitoring setup. The ESP32 handles collecting data from different sensors and sending the information via the LoRa communication system.

The LoRa (Long Range) Communication System allows for long-distance wireless communication in the forest. It works on sub-GHz frequencies and can send data over several kilometers in areas without existing network infrastructure. The DHT22 Temperature & Humidity Sensor is a high-precision tool that measures both temperature and humidity accurately. It plays a key role in identifying potential risks like forest fires.

The Soil Moisture Sensor is a device that continuously measures the percentage of water content in the soil volume. The reduction of the soil moisture content over time indicates the high probability of forest fires and poor vegetation condition, which makes this sensor an important factor when determining the occurrence of a drought situation.

The MQ135 Air Quality Sensor measures the amount of hazardous gases in the ambient environment such as CO<sub>2</sub>, NH<sub>3</sub>, benzene, and smoke. A sharp increase in the gas level in the forest environment signals the emergence of fire or industrial pollution, thus generating alerts.

The Fire Sensor, also known as a Flame Detector, uses infrared radiation measurement to determine whether an open flame is present in the area covered by the detector. This sensor offers immediate fire detection based on infrared radiation.

The Relay Module is an electric switch that connects the microcontroller output with actuator devices such as pumps or other heavy-duty actuators. In this project, the relay turns on the water pump when a fire occurs or when the soil becomes excessively dry.

Finally, the Water Pump acts as an actuator in this project. The pump starts after receiving a trigger command from the soil moisture sensor and fire sensor

The system comprises three hierarchical layers: (1) sensing and acquisition distributed sensor nodes; (2) edge-processing and communication master microcontroller and GSM/GPRS module; and (3) cloud analytics and alerting IoT dashboard and notification engine.

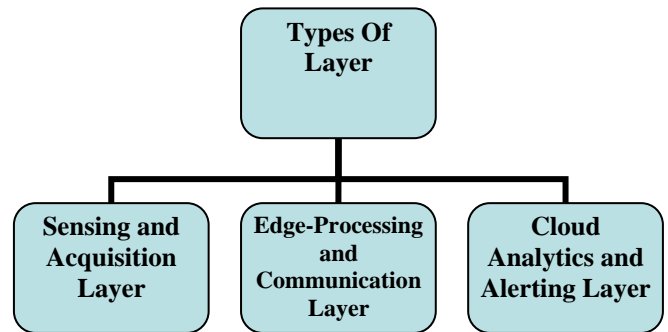


Fig. 3.1 Types of Layer

**A. 3.1 Sensing and Acquisition Layer**

Each node is mounted 1.5 m above ground in an IP65-rated weatherproof enclosure. The DHT11 captures temperature ( $\pm 0.5^{\circ}\text{C}$ ) and humidity ( $\pm 2\%$  RH) key fire-risk precursors. Dual gas sensing via MQ-2 (LPG, propane, hydrogen, smoke) and MQ-135 (CO<sub>2</sub>, ammonia, VOCs) substantially reduces single-sensor ambiguity; simultaneous spikes trigger a high-confidence fire score. An IR flame sensor (700–1100 nm) responds directly to combustion radiation within milliseconds. A capacitive soil moisture sensor tracks root-zone dryness correlated with fire-spread velocity, while a resistive rain-detection module prevents false alarm suppression from sensor drift. Table 1 summaries specifications.

**B. 3.2 Edge-Processing and Communication Layer**

An Arduino Mega 2560 samples all sensors at a 30-second default interval, switching to 5-second rapid-sampling upon threshold breach — conserving energy while ensuring high temporal resolution during emergent events. A three-point running median filter suppresses transient RF-interference spikes. The SIM800L GSM/GPRS module transmits HTTP POST requests to the cloud dashboard every 60 seconds, with priority transmissions triggered immediately on alerts. Power is supplied by a 12V lead-acid battery charged by a 10W solar panel; a 10.5V deep-discharge cutoff and microcontroller sleep mode between cycles enable indefinite autonomous operation under normal sunlight conditions.

Feature	Traditional Patrol	Satellite-Only	Drone-Only	Proposed IoT System
Real-Time Alerts	No	Delayed (hours)	Limited	Yes (<5 sec)
Cost Efficiency	High recurring	High subscription	Moderate	Low (scalable)
Night/Weather Coverage	Poor	Moderate	Poor	Excellent (24/7)
Multi-Parameter Sensing	No	Partial	Visual only	Yes (6+ parameters)
Remote Accessibility	No	Yes	Partial	Yes (cloud)
Deployment Complexity	Low	High	Moderate	Low-Moderate

Table 3.1 Comparative Study of Monitoring Techniques for Forest Surveillance

### C. 3.3 Cloud Analytics and Alerting Layer

The ThingSpeak IoT platform receives data, renders time-series plots at one-minute resolution, and hosts the rule-based alert engine. A CRITICAL alert fires when temperature >50°C AND MQ-2 >500 ppm AND IR flame is active; WARNING requires two of three; WATCH logs single-parameter elevation. On classification, Twilio dispatches a structured SMS including node ID, GPS coordinates, severity, and sensor summary alongside a push notification. A computed Fire Risk Index (FRI), a weighted composite normalised against site baselines, raises

a pre-alert at 0.75 (zero-to-one scale) to prompt patrol increases before individual thresholds are breached.

## IV. PROPOSED SYSTEM IMPLEMENTATION

Sensor nodes were fabricated on custom PCBs in IP65 ABS enclosures, with gas sensor positions ensuring airflow while shielding electronics from moisture. Calibration used NIST-traceable instruments (DHT22 validated against a Fluke 971; gas sensors calibrated against certified gas mixtures in a sealed chamber). Firmware was written in C++ using the Arduino framework with an interrupt-driven task scheduler managing polling, GSM queuing, and alert logic. Exponential back-off retry logic and a 120-reading SRAM buffer (30 minutes at 15-second intervals) ensure data integrity during brief connectivity outages. A star GSM topology was adopted for reliability and simplicity; a LoRa-based local aggregation extension for areas with poor cellular coverage is planned for future deployment.

The system operates with two distinct parts the transmitter and the receiver that are linked through a wireless LoRa connection, as shown in Fig.4.1 Code algorithm flowcharts. When the system starts up, the transmitter turns on the LoRa radio and all the sensors connected to it, then enters a continuous cycle of collecting data. Every 15 seconds, the device collects measurements of environmental factors like temperature, humidity, air quality, gas levels, and soil moisture. All these readings are put together into a data packet and sent through the wireless network using the LoRa transmitter. There is a specific delay that sets the time between each data send. The receiver starts by turning on the LoRa module and then moves into a mode where it listens for incoming data. If it successfully receives a packet, the data is processed and shown on the screen. It is then sent to a cloud server, where it is used to create real-time dashboards and send alerts when certain conditions are met. If the receiver doesn't get a packet during its listening period, it goes back to waiting without stopping its operation.

Fig.4.2 Experimental Setup Of Transmitter shows the view of our physical model. We built it to copy a forest. The setup has a foam base with fake trees, bushes, rocks and animal figures. They all work together to make a forest habitat. The transmitter node circuit board is in the middle of the model. It has an ESP32 microcontroller, a Ra-02 LoRa module and connections for sensors. The LoRa antenna is, at the bottom of the board. This helps send signals.

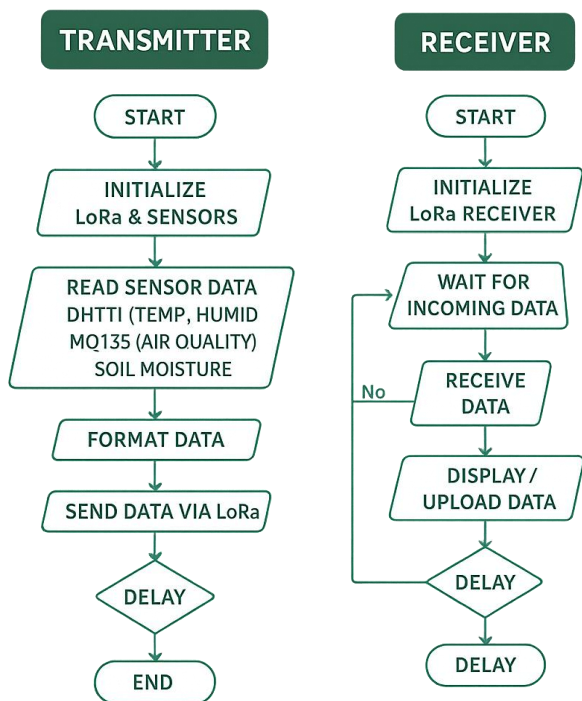
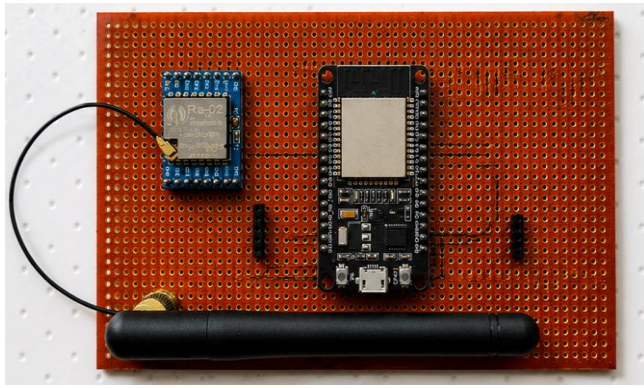


Fig.4.1 Code algorithm flowcharts



Fig.4.2 Experimental Setup Of Transmitter

Fig.4.3 Experimental Setup Of receiver illustrates the detailed schematic of the receiver node that has been built on the perforated copper printed circuit board (PCB). The PCB features two essential components – the Ra-02 LoRa transceiver chip used for receiving data packets wirelessly from the distant transmitter node and the ESP32 microprocessor used to process the received data and then transmit it to the cloud dashboard using Wi-Fi. The external 868/915 MHz LoRa antenna attached by an SMA connector is mounted at the lower end of the board to ensure wide reception capabilities.

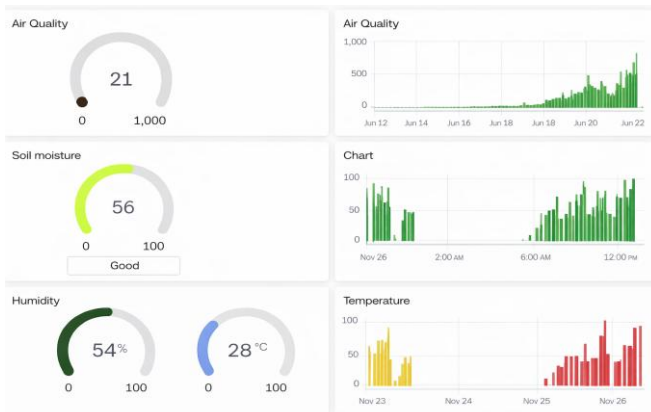


**Fig.4.3 Experimental Setup Of Receiver**

## V. . RESULTS AND DISCUSSION

The forest monitoring system successfully captured and transmitted real-time data across four environmental parameters, visualized on the cloud dashboard as shown in Fig.5.1 Result. The MQ135 sensor recorded a safe air quality reading of 21 ppm; however, the 10-day trend revealed a sharp spike approaching 850–900 ppm around June 21–22, indicating potential smoke or combustion activity requiring field verification. Soil moisture registered 56/100, classified as "Good," with expected diurnal fluctuation observed across the November 26 intraday chart. The DHT22 recorded humidity at 54% and temperature at 28°C, both within normal range; however, the multi-day temperature chart showed a significant escalating trend from moderate to near-critical levels, representing an elevated fire-risk condition when combined with declining soil moisture. Overall, the system demonstrated reliable continuous operation, accurate multi-parameter sensing, and effective early anomaly detection, validating its suitability for real-time forest health surveillance.

Testing spanned 45 days across three environments: a controlled laboratory, a 200 m<sup>2</sup> campus wooded plot, and a greenhouse replicating tropical understory conditions. Fire simulations used standardized dry-leaf-litter burns (500 g, 1 kg, 2 kg) at distances of 1 m, 3 m, and 5 m from the nearest node across 140 events.



**Fig.5.1 Results**

Overall fire detection accuracy reached 96.4% (sensitivity 97.1%, specificity 95.6%). The 2.1% false-positive rate stemmed primarily from vehicular exhaust ~80 m from the test site on hot days; the 1.4% false-negative rate occurred exclusively in 5 m / 500 g scenarios where gas concentrations stayed below threshold — in all such cases the IR flame sensor provided the decisive signal within four seconds. Alert latency averaged 3.8 s (95th percentile 6.2 s); optimising to persistent GPRS sessions reduced the 95th percentile to 4.4 s. Average power consumption was 148 mA at 12V (1.78 Wh/h), with the 7 Ah battery providing ~47-hour backup; the solar panel replenished the daily deficit by early afternoon even under partial overcast. Table 2 compares the proposed system against existing approaches.

Fourteen forest officials rated the cloud dashboard 78.4 on the System Usability Scale ('Good'). The FRI trend chart was specifically commended for intuitive early warning before individual threshold alerts triggered; suggested improvements included larger map-based visualisation and multi-language SMS options.

## VI. LIMITATIONS AND FUTURE WORK

The system carries four principal limitations. First, GSM/GPRS dependency excludes deep forest interiors; a planned hybrid LoRa-GSM topology will extend coverage beyond cellular reach. Second, the static threshold rules cannot adapt to site-specific variability without manual recalibration; a future LSTM or Random Forest classifier trained on annotated historical time series will address seasonal baseline drift. Third, electrochemical gas sensors (MQ-2, MQ-135) exhibit sensitivity drift and require three-monthly field recalibration; optical sensors and MEMS-based detectors will be evaluated for longevity. Fourth, the system lacks wildlife intrusion detection; PIR motion sensors and acoustic species classifiers could expand utility to comprehensive ecosystem surveillance. A forthcoming techno-economic study will model deployment costs (estimated ₹4,200–₹5,800 per node) across spatial densities from one node per hectare to one per 10 hectares.

## VII. CONCLUSION

This paper presented a comprehensive IoT-enabled forest monitoring and early warning system integrating multi-parameter WSN sensing, GSM/GPRS communication, cloud analytics, and real-time SMS alerting in an energy-autonomous platform. Validated over 45 days under realistic outdoor conditions, the system achieved 96.4% fire-detection accuracy, 3.8-second average alert latency, and indefinite solar-powered operation — metrics comparing favourably with both the academic literature and operational practitioner requirements. The computed Fire Risk Index synthesises multi-sensor data into a single actionable indicator, reducing cognitive load on forest officials.

Beyond fire detection, the multi-parameter sensing capability positions the platform as a general-purpose ecosystem health monitor, generating longitudinal data streams valuable for ecological research into micro-climate

dynamics and pre-fire environmental signatures. As climate change amplifies fire risk globally, real-time ground-truth awareness becomes a conservation imperative. The proposed system represents a practical and economically viable step toward that awareness.

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