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Enhancing peatland fire prevention: an incremental LoRa and mobile-based early warning system

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Abstract

Peatland fires present a significant threat in Indonesia, arising from human activities or adverse weather conditions. An early warning system using long-range (LoRa) and mobile technology can help avert peatland fires through continuous environmental monitoring and rapid detection of fire risks. This study develops an incremental LoRa and mobile-based early warning system for peatlands. Temperature, humidity, and other environmental data are gathered by strategically placed node sensors and gateways in high-risk areas. The sensors transmit data to a cloud server for storage and analysis. Web and mobile platforms provide easy accessibility to view sensor readings and alerts. The system is designed using an incremental integration approach, seamlessly combining LoRa technology and mobile monitoring for enhanced real-time anomaly detection in peatlands. Telecommunication signal strength mapping and user testing help refine sensor placement and system usability. Evaluation of the mobile-based LoRa system demonstrates promising results. Users positively acknowledged the intuitiveness and utility of the web and mobile applications. The system achieved high task success rates exceeding 85%, low error rates under 15%, and reasonable task completion times during testing. This result indicates effectiveness in enabling early fire risk detection and response coordination. However, fluctuations in sensor reading accuracy compared to field measurements and limited telecommunication coverage in remote regions impacted system reliability. While significant progress has been made, challenges remain regarding consistent sensor accuracy and connectivity coverage. Future efforts should focus on integrating industrial-grade sensors and machine-learning techniques for improved data analytics and autonomous decision-making. Enhancing the system's accuracy and early detection capabilities will strengthen peatland fire prevention and mitigate risks from human activities and climate change impacts. With further development, the mobile-based LoRa system shows promise as an accessible, inexpensive, and scalable solution for early warning and coordinated action against peatland fires.

Keywords

Peatland fires, LoRa technology, Early warning system, Environmental monitoring, Mobile technology.

1.Introduction

Peatland is a unique and sensitive ecosystem that brings significant economic functions to the local community. As an essential natural resource, peatland provides vital environmental services such as flood control, water filtration, and carbon sequestration. At the same time, peatland supports the livelihoods of local communities through the cultivation of crops like sago, coconut, and fruit, as well as fishing and extraction of forest products. However, peatland is also highly vulnerable to degradation from deforestation, drainage, fire, and unsustainable agricultural practices [1].

However, recent reports reveal a concerning trend of forest fires in Indonesia, particularly on Sumatra island, predominantly caused by human errors and unsustainable practices. Sumatra has experienced widespread annual forest fires, with over 311,000 hectares burned in 2021 alone. The leading causes stem from slash-and-burn clearing of land for agriculture, negligence during land preparation, and drainage of peatland areas [2]. Prohibited farming practices aimed at converting peatland into palm oil areas have been identified as a significant catalyst for these fires. Draining peat swamps and using fire for land clearing are techniques illegally employed to convert forested peatlands into plantations for the lucrative palm oil industry [3]. This detrimental setting leads to frequent fire occurrences, especially during dry periods, resulting in haze and

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environmental repercussions [4], such as substantial carbon dioxide (CO_2) emissions [5], causing ecological damages, health issues, air degradation, water scarcity, and land erosion [6]. These circumstances are increasingly exacerbated by conflicting directives and bureaucratic lethargy among ministries and administrations that have hindered effective forest fire management [7].

While the challenges are immense, emerging technologies may offer solutions. Recognizing these challenges, researchers have explored innovative solutions, focusing on implementing internet of things (IoT) technologies for early warning systems. The IoT connects various physical items and devices through an internet connection [8, 9], with widespread applications in healthcare [10–13], intelligent cities, and environmental surveillance [14-16]. In our approach, we diverge from conventional methods by emphasizing the significance of long-range (LoRa) technology for long-distance sensor data transfer. Our research integrates temperature, soil moisture, and water level sensors to monitor the lower ground of peatlands efficiently. The LoRa allows data transmission across several kilometres from remote peatland areas to gateway nodes. Strategically placing LoRa sensor nodes in peatlands provides real-time monitoring of temperature fluctuations, soil moisture changes, and groundwater levels - critical indicators of fire risk conditions. Tailoring the sensor parameters specifically for peatlands enhances early detection capabilities.

Additionally, integrating LoRa with mobile platforms and web applications facilitates swift information dissemination to field personnel, ensuring a rapid response to any detected fire outbreaks. Personnel can access sensor data and risk alerts remotely via mobile apps instead of relying only on in-person data collection. The connections and mobile access offered by LoRa technology allow continuous peatland monitoring, automated risk identification, and prompt mitigation responses to avert fire incidents before escalation.

This study is motivated by the urgent need to mitigate the negative impacts of forest and land fires on peatlands in Indonesia, particularly Sumatra Island. Peatland fires have become an annual occurrence in Sumatra, also causing enormous environmental and economic damage. Our primary objective is to establish an effective and efficient early warning system for peatland fires using LoRa and sensors. Our research contributes by developing an integrated early warning system that combines LoRa technology and sensors for efficient detection and monitoring of land and forest fires in peatlands. We employ the incremental model method, enhance sensor capabilities, utilize mobile LoRa technology for real-time updates to field officers, and aim to mitigate the negative impacts of fires on peatland and local communities.

The remainder of this paper is organized as follows: Section 2 provides an exploration of the challenges identified in the existing literature, substantiated by pertinent citations. Section 3 outlines the methods employed in this research, followed by a discussion of the tools and materials utilized in developing LoRa. In section 4, we present the findings of this study and the contributions of our research, with concluding remarks presented in section 5.

2.Literature review

Although not all research outcomes have utilized mobile devices, the majority have employed LoRa to provide a way of communicating with users. Field personnel tasked with monitoring the condition of peatlands must be able to access information, which is made possible via mobile devices. By using keywords like LoRa architecture, sensors, mobile applications, and fire protection systems in credible journals, literature data was gathered. In addition, field officers from the local government, local volunteers, and regional disaster management boards were interviewed to gather narrative information.

Some previous research has been done regarding forest fire prevention. In [17], proposes a cost-effective solution to address forest fires in the Mediterranean using a low-cost LoRa-based network integrated with sensors for temperature, humidity, wind speed, and CO_2 measurement. The system assesses fire risk levels and detects forest fires by employing the 30-30-30 rule algorithm. Real-time data is made accessible to users through a website, demonstrating the capability to cover a circular area with a 1.1km radius in real-world tests. The advantages include affordability, LoRa communication, real-time monitoring, and comprehensive environmental data collection. However, limitations encompass sensor range constraints, reliance on LoRa network coverage, algorithmic simplification, and potential challenges during extreme weather conditions, offering a promising yet nuanced approach to forest fire prevention.

In [18], they addressed the increasing threat of forest fires in Serbia, particularly in the vulnerable Nature Park Golija. Utilizing geographic information system (GIS) and multi-criteria decision analysis, the research employs index-based and fuzzy analytic hierarchy process (AHP) methods along with the technique for order of preference by similarity to ideal solution (TOPSIS) method to create forest fire susceptibility zones. Results indicate very high and high susceptibility zones covering 26.85% and 25.75% of the area, respectively. An additional IoT-based sensor network collects local meteorological and environmental data, enabling real-time fire risk assessment and detection at a low cost. The combined approach facilitates improved long-term and short-term forest fire susceptibility assessment. While offering valuable insights into forest fire risk management and early warning systems in Serbia, the study emphasizes the importance of coordination among relevant authorities at national, regional, and local levels to respond to emergency events effectively.

The study from [19] focuses on leveraging the IoT and wireless sensor networks (WSN) to prevent forest fires proactively. Introducing a two-layer architecture, the sensor network at the bottom layer continuously monitors forest temperature and employs a two-step clustering algorithm to organize sensor nodes. The data is then transmitted in a bottom-up fashion to IoT-enabled unmanned aerial vehicles (UAV) in the upper layer. These UAVs interconnected with each other and a base station, take preventive measures like water sprinkling to mitigate fire risks. Comparative analysis against an existing WSN-assisted IoT clustering technique demonstrates superior performance in terms of reduced congestion at UAV stations, increased number of operational nodes, and enhanced network energy efficiency. While the method showcases advantages in proactive forest fire prevention, potential limitations may include the scalability of UAV deployment and the dependency on seamless communication between nodes and UAVs. The proposal from [20] introduces an innovative approach to forest fire prevention by integrating IoT and WSN with multi-hop routing in a real-time and dynamic monitoring system. The system focuses on gathering and analyzing meteorological conditions, pollutant concentrations, and oxygen levels in key forest areas. Unusual environmental measurements trigger a fuzzy logic-based forest fire risk controller, activating alerts through a web service and a mobile application. To ensure data integrity and confidentiality during transmission, security mechanisms employ Lamport's signature and a block cipher algorithm. While the method showcases the potential to enhance wildfire detection and prevention through advanced technology, limitations may include the complexity of implementation, potential resource requirements, and the need for robust cybersecurity measures. The paper from [21] addresses the crucial need for fire identification in homes to prevent property loss and safeguard lives. Emphasizing the rapid and unpredictable nature of fires, it argues that more than relying on the ability to smell smoke is required, given the short time frame for a building to burn down. Introducing an IoT-based solution, the method employs a variety of sensors to detect the presence of fire and promptly alert both the watchman and fire officials. Additionally, a preventive measure is implemented by integrating sprinklers that automatically activate when smoke sensors detect a fire. While the advantages include enhanced fire detection and a proactive solution with real-time alerts, potential limitations may involve the complexity of implementing an IoT-based system, cost considerations, and the need for reliable sensor technology to minimize false alarms.

The paper from [22] focuses on the early detection of house fires, recognizing the threats they pose to communities and property. Employing WSN, the system utilizes tiny, cost-effective, and low-power sensors for real-time fire detection with high accuracy. Multiple sensors are incorporated to enhance reliability, and the global system for mobile communications (GSM) is employed to mitigate false alarms. The system is designed to address sensor failures by ensuring early detection even when a sensor malfunctions while maintaining acceptable energy consumption levels. Simulation tests conducted in a smart home using the fire dynamics simulator (FDS) and a language program demonstrate the system's effectiveness in early fire detection. The advantages include robust early detection, energy efficiency, and false alarm prevention. However, potential limitations may involve the complexity of implementing WSN, cost considerations, and the need for ongoing maintenance to ensure sensor reliability.

The research from [23] aims to address the pervasive issue of land and forest fires in Riau Province, Indonesia, and their widespread impact on health, the environment, and economies in neighbouring countries. The proposed solution involves the development of an intelligent monitoring system using a LoRa wide area network (LoRa WAN) and IoT technology for early detection of fires. Leveraging LoRa's capability to transmit data up to 30 miles, sensors are strategically placed in locations previously affected by fires. The system provides a platform for efficient data communication and quick response to potential fire incidents. The method emphasizes early detection to enable timely prevention measures. While the advantages include the extensive coverage provided by LoRa, quick response capabilities, and potential mitigation of recurring fire disasters, limitations may involve the initial setup costs, maintenance requirements, and potential challenges in sensor reliability in harsh environmental conditions. The study from [24] focuses on improving the effectiveness and response time in emergencies by integrating IoT devices and sensors for real-time monitoring of environmental conditions. The system analyzes variables such as temperature, humidity, pressure, and pollutant gases, aiming to detect radical changes that could signal adverse weather events leading to emergencies like forest fires. Alerts are triggered when pollution levels rise excessively or specific conditions conducive to emergencies are detected. The developed system prioritizes communication security among IoT devices, web services, and mobile devices, implementing a secure data transmission protocol, a block cipher algorithm, and a secure authentication scheme. While the method offers advantages in proactive monitoring and early alerting, potential limitations may include the complexity of implementing secure communication protocols, initial setup costs, and the need for ongoing maintenance to ensure system reliability.

The paper from [25] addresses the inefficiency of traditional and satellite-based forest fire detection methods by proposing an early fire detection model leveraging IoT technology. The system utilizes Raspberry Pi microcontrollers and sensors for real-time monitoring. Data is stored and analyzed on a centralized server, and a feed-forward fully connected artificial neural network (ANN) is employed for predictive purposes. Upon fire detection, alert messages are sent to both administrators and individuals in proximity. The method aims to significantly reduce losses attributed to late fire detection, providing a more proactive approach to forest fire monitoring. While the advantages include improved efficiency, real-time monitoring, and timely alerts, potential limitations may involve the scalability of the system, initial setup costs, and the need for reliable sensor technology to minimize false alarms. The proposed architecture from [26] focuses on advancing the early detection of forest fires by integrating sensor networks and mobile (drone) technologies for efficient data collection and processing. The unmanned air vehicles (UAV) are employed to extend coverage over larger areas, enhancing the percentage of forest fire detections and monitoring regions with a high fire weather index or those already affected by fires. All collected information is transmitted to and stored in a cloud computing platform, enabling near real-time processing and alerting. The method emphasizes proactive monitoring and timely response to forest fires. The advantages include increased coverage, enhanced detection capabilities, and efficient cloud-based processing. However, potential limitations may involve the complexity of implementing and maintaining UAV systems, initial setup costs, and the need for robust cloud infrastructure for seamless data processing and storage.

In [27], The approach centres on addressing the escalating issue of forest fires, emphasizing the urgency to prevent their spread due to the devastating environmental and wildlife impact. Utilizing an ESP32 board and a combination of sensors, including rain sensors, sound sensors, digital humidity and temperature (DHT) sensors, and passive infrared (PIR) sensors, the method focuses on early detection as a crucial step in fire prevention. While the specific detection algorithm or methodology is not detailed, the overall aim is to create a system that senses key environmental indicators associated with fire risk. The advantages include the use of diverse sensors for comprehensive monitoring, potentially allowing for timely and accurate detection. However, the limitations may involve the need for further details on the detection algorithm, potential false alarms, and the scalability and reliability of the espressif32 (ESP32) board-based system in diverse environmental conditions.

In [28], The study harnesses the rapid development of IoT technology, specifically low-power wide area network (LPWAN) such as LoRa and narrowband-IoT (NB-IoT), for forestry management. It involves the transmission of sensing data related to forest information and employs various sensing technologies to survey forest resources and monitor microclimate changes. To validate the proposed LPWAN communication technology and sensor deployment, the researchers implemented LoRa and NB-IoT communication equipment, including repeater devices, along with diverse sensors in the challenging terrain of the Fushan Botanical Garden in Taiwan. The successful transmission of real-time sensing data from this diverse and complex environment demonstrates the viability of the communication devices and sensors. While the advantages encompass real-time data transmission and diverse sensing capabilities, potential limitations may include the need for extensive infrastructure deployment, initial setup costs, and potential challenges in maintaining network reliability in challenging terrains.

The study from [29] focuses on preventing forest fires in the peatlands of Siak regency, Riau Province, by developing an early warning system based on IoT using an incremental model. The peatlands' susceptibility to fires due to drying out from extreme weather and resident activities necessitates a proactive approach. The system involves node sensors and gateways deployed on specific peatland areas, periodically sending data to a cloud server for storage. The information is accessible through three platforms: web, mobile, and light-emitting diode (LED) board, enabling users to monitor and inspect the peatland. Test results indicate that all system components functioned as intended, with the platforms correctly displaying peatland data. The advantages include real-time monitoring and multiplatform accessibility, providing a comprehensive early warning system. However, potential limitations may involve the initial setup complexity, maintenance requirements, and the need for robust IoT infrastructure for seamless data transmission and storage.

The study from [30] focuses on the "Digitalization of Forests," integrating cutting-edge technologies like the IOT, WSN, internet of trees, and deep learning to enhance forest environment monitoring, data acquisition, and analysis. The exploration encompasses applications such as forest fire incidents, illegal logging, and poaching, with proposed generalized architectures for future research and development. The methods discussed include intelligent systems for sensing, monitoring, and analysis, addressing areas like flora analysis, forest fire predictions, and wildlife monitoring. The study also delves into enhancing tribal livelihoods and marketing minor forest products. Recommendations emphasize effective connectivity, sustained deployment of real-time sensing systems, and energy harvesting for optimal implementation of digital networks. While the advantages include improved ecosystem monitoring and conservation, potential limitations may involve the complexity of implementing and maintaining these technologies, initial setup costs, and ensuring the inclusivity and ethical considerations in technology interventions in natural ecosystems.

The study from [31] addresses fire safety concerns in complex and tall buildings, emphasizing the importance of acquiring real-time fire-ground information for effective firefighting, evacuation, and rescue operations. In the paper leveraging advancements in information technology, data analytics, and monitoring systems, they introduce the concept of IoT-aided building fire evacuation. The focus is on exploring the advantages and limitations of current intelligent building fire evacuation systems, presenting a conceptual design for an IoT-aided evacuation control system. The system's sequence covers information needs, sources, data transmission, and potential services and applications. While the advantages include improved evacuation processes and decision-making based on real-time information, potential limitations involve the complexity of implementing IoT technologies, data security concerns, and the need for robust 5th generation (5G) technologies for future advancements in building fire evacuations.

The paper from [32] introduces a novel, innovative automation system utilizing LoRa technology for remote monitoring and control of appliances in the era of Industry 4.0. The system employs a wireless communication system with various sensors, operated through a smartphone application and powered by a low-power battery, achieving an impressive operating range of 3–12 km. The LoRa-based architecture connects an Android phone to an ESP32 microprocessor, facilitating WAN communication with the LoRa module. Three real-life case studies evaluated the system's performance in measuring environmental temperature and humidity, detecting fire, and controlling appliance switching. The results demonstrated accurate environmental data acquisition, 90% accuracy in fire detection, and 92.33% accuracy in appliance switching functionality at distances up to 12 km. The modular design proved highly effective in achieving remote control and monitoring with lower power consumption, showcasing the system's potential advantages in IoT-based automation. However, potential limitations may include initial setup complexity, the need for robust network infrastructure, and potential challenges in handling diverse environmental conditions.

The research from [33] addresses the critical issue of forest fires in Indonesia, particularly in the peatland and forestry areas of Sumatera and Kalimantan Island, impacting the local economy, environment, and human health. The aim is to prevent casualties by developing an intelligent sensing system for ground-level monitoring and forecasting. Various sensors measuring parameters like temperature, humidity, gases, and carbon are integrated with an Arduino microcontroller and algorithm for intelligent monitoring and filtering noise data. Mathematical models and analysis are employed for forecasting hotspots in the Riau Province forest area. The system provides real-time information and forecasts to relevant institutions for timely action. While the advantages include proactive fire prevention and early warning capabilities, potential limitations may involve the need for robust infrastructure, data accuracy, and potential challenges in sensor reliability in harsh environmental conditions.

The research from [34] addresses the recurring issue of forest fires in Riau Province, Indonesia, proposing the development of WSN for early detection. With the aim to mitigate the severe impact on human health and the environment, the WSN technology deploys sensors strategically in high-risk forest fire areas during the dry season. Mathematical analysis is applied for modelling the number of sensors required and determining the size of the forest area covering the entirety of Riau Province. The system provides an early indication of forest fires, enabling quick prevention measures before they escalate. The advantages include the feasibility of WSN for early warning, data collection from impacted areas, and alerting representative institutions for timely action. However, potential limitations may involve the initial setup complexity, maintenance requirements, and the need for continuous monitoring and improvement to ensure the system's effectiveness in diverse environmental conditions. In [35], The study focuses on addressing the challenge of forest fire detection by designing a monitoring system using LoRa technology. A microcontroller, fire sensor, and global positioning system (GPS) are employed to detect the presence of fire and transmit information across the forest. The experiment demonstrates the fire sensor's sensitivity in detecting fire within a range of 3 to 10 meters, detecting hotspots within the temperature range of 19.25 oC to 122.5 oC. The developed monitoring system showcases effective communication between sensor nodes and gateways up to 500 meters with a signal quality of -134 dBm. The optimal LoRa configuration for this communication capability is determined as a bandwidth of 250, a code rate of 4/5, and a spread factor of 10. The advantages include improved fire detection sensitivity and effective wireless communication for remote monitoring. However, potential limitations may involve initial setup complexity, maintenance requirements, and challenges in ensuring continuous and reliable communication in varied forest conditions. The study from [36] addresses the need for sustainable forest monitoring by proposing a hybrid architecture inspired by LoRa and edge computing for real-time tracking of tree health and growth. In this approach, sensor motes are deployed at trees to monitor soil moisture content, humidity, temperature, and air pressure. The collected sensor data is transmitted using 433 MHz LoRa and a Wi-Fi controller to record values in a cloud server, specifically the ThingSpeak server. The advantages include real-time monitoring capabilities and efficient data transmission using a hybrid architecture. However, potential limitations may involve the initial setup complexity, potential challenges in sensor maintenance and calibration, and considerations for scalability in large forest areas.

In [37], the study assesses the feasibility of an underground long-range wide area network (LoRaWAN) bushfire temperature sensing node in terms of survivability during a bushfire event. Thermal penetration into the soil is modelled analytically, considering dry soil conditions. A working prototype of the sensor unit is experimentally tested beneath a small timber fire, with a buried LoRa radio and a thermocouple monitoring temperatures from under the fire. The analysis reveals that the node's endurance under the fire is proportional to the square of the burial depth of electronic components and inversely proportional to the thermal diffusivity of the soil. The original contribution lies in practically demonstrating the durability of a LoRa sensing node beneath a fire front for bushfire sensing applications. Advantages include the ability to withstand fire exposure providing valuable data during bushfire events. However, potential limitations may involve challenges in real-world deployment, maintenance, and scalability for broader applications.

The study from [38] focuses on designing and implementing a LoRaWAN-based system for intelligent building fire detection and prevention independent of a Wi-Fi connection. Utilizing the IoT concept and LoRaWAN technology, a LoRa node with various sensors is developed to detect smoke, gas, Liquefied Gas, propane, methane, hydrogen, alcohol, temperature, and humidity. Real-world testing is conducted using Wi-Fi Lora 32 boards to evaluate performance in terms of response time and overall network delay. Tests cover different distances and heights in both open and indoor environments. The results indicate superior performance in sensing and data transfer from sensing nodes to controller boards. Advantages include the use of low-power devices, enabling long battery lifetimes and efficient data transmission over large distances. However, potential limitations may involve challenges in deployment, maintenance, and scalability for broader applications.

The article from [39] addresses the pressing issue of forest fires and their impact on ecosystems and resources. The proposed solution involves the development of an intelligent forest alert monitoring system within the IoT framework. The system integrates advanced sensors to detect critical parameters such as temperature, humidity, smoke, and unauthorized tree cutting, aiming to predict and prevent forest mishaps. Through automated decision-making processes, the system triggers alerts and implements harm mitigation actions based on the sensed data. A case study conducted in a natural forest zone environment validates the system's accuracy in predicting and ensuring forest safety. The advantages include early detection, prompt response, and potential harm mitigation, safeguarding both wildlife and human resources. However, potential limitations may involve challenges in sensor maintenance, algorithm refinement, and scalability for broader forest areas.

The study from [40] focuses on developing a monitoring and early warning system for forest fires using deep learning and the IoT. The system enhances forest fire recognition by integrating size, colour, and shape characteristics of flame, smoke, and area and employs an improved dynamic convolutional neural network for feature extraction and forest fire risk prediction. The proposed back propagation neural network fire (BPNNFire) algorithm demonstrates real-time accurate forest fire recognition with 84.37% accuracy, outperforming existing algorithms. The system also incorporates real-time online monitoring of forest environment indicators such as air temperature and humidity. The results indicate a maximum relative error of 5.75% and a packet loss rate of 5.99% at one forest farm and 2.22% at another, showcasing effective performance. Advantages include enhanced recognition accuracy and real-time monitoring, but potential limitations may involve algorithm complexity, maintenance challenges, and network packet loss rates in specific environments.

In [41], the study explores the implementation of a LoRa-based mesh network without relying on LoRaWAN, aiming for peer-to-peer communication between nodes without the need for gateways. The approach extends node reachability through multi-hop communication. The researchers present a hardware/software prototype based on low-power devices and provide a preliminary assessment of the proposed solution. The method involves configuring a mesh network using the LoRa technology, allowing nodes to communicate directly with each other in a decentralized manner. The advantages include reduced complexity compared to traditional LoRaWAN networks, potentially lower power consumption, and increased resilience. However, limitations may include challenges in managing network congestion, scalability concerns, and the need for careful optimization to ensure efficient multi-hop communication. Further testing and refinement of the prototype are likely needed to evaluate the feasibility and performance of the proposed solution fully. Based on the exposure of some of the previous research that has been described above, *Table 1* below presents an outline based on the features, LoRa utilization, and the availability of mobile technology.

Table 1 List of previous research

Research	LoRa	Early warning	Methods	Advantages	Limitation
[17]	√	Yes	Employing the 30-30-30 rule algorithm and several sensors	Cost-effectiveness, extended-distance communication, immediate monitoring, and thorough gathering of environmental data.	Restricted range of sensors, dependence on LoRa network availability, simplified algorithms, and possible difficulties in extreme weather conditions.
[18]	√	Yes	Utilizes index-based and	Enhances the evaluation of	Possibility of coordination

Research	LoRa	Early warning	Methods	Advantages	Limitation
			fuzzy AHP techniques in conjunction with the TOPSIS method.	forest fire susceptibility over both extended and short timeframes.	issues among authorities.
[19]	-	Yes	Using multi-layer structure: sensor network monitors forest temperature, two-step clustering algorithm for node organization, and IoT-enabled UAV.	Reduced congestion at UAV stations, more operational nodes, and improved network energy efficiency.	The scalability of UAV deployment and the reliance on continuous communication between nodes and UAV.
[20]	√	Yes	Incorporating IoT and WSN using multi-hop routing in a dynamic and real-time monitoring system.	Data integrity and confidentiality during transmission.	The necessity for solid cybersecurity measures
[21]	-	No	Utilizes diverse sensors for detecting fire occurrences and rapidly notifying both the watchman and fire officials.	Enhanced fire detection and a proactive solution with real-time notifications	The necessity of reliable sensors to minimize false detection.
[22]	-	Yes	Multiple Sensors implementation, enhanced with sensor failures and sensor malfunction mechanism.	Effective early identification, energy conservation, and prevention of false alarms.	Continuous maintenance is required to guarantee the reliability of the sensors.
[23]	√	Yes	Creating an intelligent monitoring system utilizing LoRa WAN and IoT technology to detect fires early in their development.	Leveraging the widespread reach of LoRa, swift response capabilities, and the possible alleviation of recurrent fire disasters.	The initial expenses for setup, ongoing maintenance needs, and potential issues in ensuring sensor reliability.
[24]	√	Yes	The system examines surrounding anomalies, including forest fires. It sends alerts when pollution reaches specific conditions. The system places a high emphasis on securing communication using a secure data transmission mechanism.	Proactive monitoring and early alerting, reinforced by security mechanism	Complexity of implementing secure communication protocols
[24]	√	Yes	The system uses microcontrollers and sensors for real-time monitoring. Data is stored and analyzed using feed-forward fully ANN.	Minimize losses associated with delayed fire detection, adopting a proactive strategy for monitoring forest fires.	Scalability of the system and initial setup costs.
[25]	√	No	Integrating sensor networks and drone technologies for efficient data collection and processing.	Expanded coverage, improved detection capabilities, and efficient processing in the cloud.	Implementing and sustaining UAV systems, initial setup expenses, and the necessity for a resilient cloud infrastructure.
[26]	-	Yes	To create a system that senses key environmental indicators	Employing various sensors for thorough monitoring, enabling timely and precise	More detail about the detection algorithm, possible false alarms, and the

Research	LoRa	Early warning	Methods	Advantages	Limitation
			associated with fire risk based on sensor reading.	detection.	adaptability of the ESP32 in different environmental conditions.
[27]	√	Yes	Applied LoRa and NB-IoT communication tools and various sensors in the complex terrain of Fushan Botanical Garden in Taiwan.	The real-time transmission of data and a wide range of sensing capabilities.	The necessity for widespread infrastructure deployment, initial setup expenses, and potential difficulties in maintaining network reliability in challenging terrains.
[28]	√	Yes	Applied LoRa and NB-IoT communication tools and various sensors in the complex terrain of Fushan Botanical Garden in Taiwan.	The real-time transmission of data and a wide range of sensing capabilities.	The necessity for widespread infrastructure deployment, initial setup expenses, and potential difficulties in maintaining network reliability in challenging terrains.
[29]	√	Yes	Developing an early warning system based on IoT, sensors and multiplatform information access.	Continuous monitoring in real-time and accessibility across multiple platforms, offering a thorough early warning system.	The complexity of the initial setup, ongoing maintenance needs, and the necessity for a robust IoT infrastructure to ensure smooth data transmission and storage.
[30]	√	Yes	Intelligent systems for sensing, monitoring, and analysis are implemented, focusing on areas such as analyzing flora, predicting forest fires, and monitoring wildlife.	Improved ecosystem monitoring and conservation	Ensuring that technology interventions in natural ecosystems are inclusive and adhere to ethical considerations.
[31]	√	No	Utilizing progress in Information Technology, Data Analytics, and monitoring systems.	Improved evacuation processes and decision-making based on real-time information	The need for robust 5G infrastructure for future advancements.
[32]	√	No	It utilizes wireless communication and diverse sensors, controlled by a smartphone app and powered by a low-energy battery. The LoRa-based system links an Android phone to a microprocessor for WAN communication.	Precise environmental data gathering, 90% correctness in spotting fires, and 92.33% precision in controlling appliance switches within a range of 12 km.	The complexity of the initial setup, ongoing maintenance needs, and the necessity for a robust IoT infrastructure to ensure smooth data transmission and storage
[33]	√	Yes	A microcontroller and algorithm are combined with diverse sensors to measure parameters, enabling intelligent monitoring and noise data filtration. The use of mathematical models and analysis also aids in predicting hotspots.	Proactive fire prevention and early warning capabilities	The importance of solid infrastructure, data precision, and possible issues with sensor dependability in challenging environmental conditions.
[34]	√	Yes	The WSN strategically places sensors in high-	The viability of WSN for early warning, collecting	Intricacies of the initial setup, ongoing maintenance

Research	LoRa	Early warning	Methods	Advantages	Limitation
			risk forest fire zones during the dry season. Mathematical analysis is used to model the necessary number of sensors and determine the size of the forest area, encompassing the entire region.	data from affected areas, and notifying relevant institutions for prompt action.	needs, and the necessity for constant monitoring and enhancements to guarantee the system's efficacy.
[35]	√	No	A microcontroller, fire sensor, and GPS are employed to identify the occurrence of fire and relay the information throughout the forest.	Enhanced sensitivity in detecting fires and efficient wireless communication for distant monitoring.	The complexity of the initial setup, ongoing maintenance needs, and ensuring consistent communication in diverse forest conditions.
[36]	√	Yes	The system places small sensors in trees to track soil moisture, humidity, temperature, and air pressure. These sensors use 433 MHz LoRa and a Wi-Fi controller to send the gathered data to a cloud server.	The system's ability to monitor in real-time and transmit data efficiently is enhanced through a hybrid architecture.	Challenges in maintaining and calibrating sensors, along with scalability considerations in extensive forest areas.
[37]	√	Yes	The research examines the viability of an underground LoRaWAN temperature sensing node for bushfires concerning its ability to survive during such an event.	The system incorporates resilience to fire exposure and offers valuable data during bushfire occurrences.	Obstacles in deploying, maintaining, and expanding the system for broader applications in real-world scenarios.
[38]	√	Yes	Designing and implementing a LoRaWAN-based system for intelligent building fire detection and prevention.	The use of low-power devices enables long battery lifetimes and efficient data transmission.	Obstacles in deploying, maintaining, and expanding the system for broader applications in real-world scenarios.
[39]	√	Yes	The system combines sophisticated sensors to identify crucial factors like temperature, humidity, smoke, and unauthorized tree cutting, with the goal of anticipating and averting forest incidents.	Swift identification, quick reaction, and possible reduction of harm, ensuring the protection of both wildlife and human resources.	Difficulties in maintaining sensors, refining algorithms, and achieving scalability for more significant forest regions.
[40]	√	Yes	Improves the detection by considering the fire and smoke signature. It uses an enhanced dynamic convolutional neural network for extracting features and predicting forest fire risk.	Enhanced recognition accuracy and real-time monitoring.	Algorithm complexity, maintenance challenges, and network packet loss rates in specific environments.
[41]	√	No	The approach includes setting up a mesh	Simplified structure compared to conventional	Addressing issues related to network congestion,

Research	LoRa	Early warning	Methods	Advantages	Limitation
			network utilizing LoRa technology, enabling nodes to communicate directly with one another in a decentralized manner.	LoRaWAN networks, potentially lower energy consumption, and enhanced robustness.	scalability challenges, and the necessity for meticulous optimization to ensure effective multi-hop communication.

3.Methods

3.1LoRa architecture

For effective IoT implementation, the sensors in LoRa can be connected to more than one gateway. A LoRa employs the protocol of LoRaWAN to deliver and receive data from LoRa sensors. Using LoRaWAN (nodes), we may control communication between devices and gateways. The foundation of LoRa nodes is asynchronous links, and they begin broadcasting as soon as they have data to send. As seen in *Figure 1*, gateways gather the data from the LoRa node and send them all to a server. The connected end nodes/smartphones, control panels, or other modules are then given access to this information by the server [42].

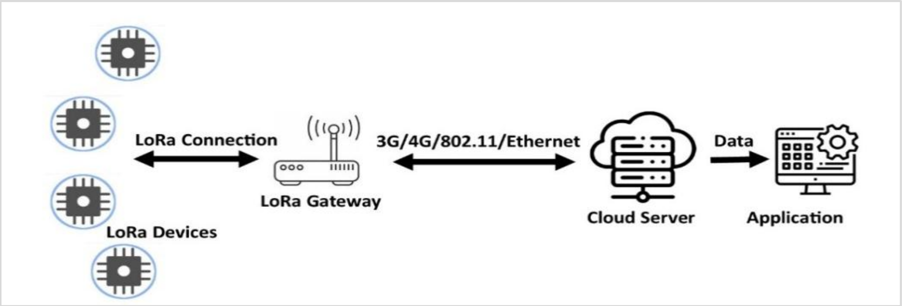


Figure 1 LoRa architecture

3.2System requirement and data collection

In *Table 2* below, we provide a comprehensive overview of the intricate hardware and software components meticulously employed in the construction of the robust monitoring system detailed extensively in the subsequent sections.

Table 2 List of requirements

Platforms	Hardware Specifications	Software Specifications
Nodes	Microcontroller, moisture sensor, humidity and temperature sensor, medium-sized solar panel, 12-volt accumulator battery, wireless transmitter/receiver module.	arduino integrated development environment (IDE) editor.
Gateway	Microcontroller, moisture sensor, humidity and temperature sensor, water indicator sensor, medium-sized solar panel, 12-volt accumulator battery, wireless transmitter/receiver module, serial communication module.	Arduino IDE editor.
IoT Server and Web Application	multi-core central processing unit (CPU), 8 giga bytes (GB) of random access memory (RAM), 20 GB of Storage, and unlimited bandwidth	Linux-based operating system (OS), web engine, database server, hypertext preprocessor (PHP) engine, and web framework.
Mobile Application	Android-based smartphone	Android Studio IDE.

The data collection process involves a systematic approach to gather, transmit, and manage information from the deployed sensors. Our data collection process unfolds in a systematic series of steps that ensure the efficient and accurate acquisition of environmental information. First and foremost, the operational foundation of our system relies on nodes and a gateway, each equipped with an array of sensors, including moisture sensors, humidity and temperature sensors, and water indicator sensors. These sensors play a pivotal role as the primary data acquisition units, capturing vital environmental parameters essential for comprehensive monitoring. In the subsequent stages, the collected data undergoes a meticulous process. Daily intervals govern the frequency of data collection, allowing us to capture dynamic changes in moisture levels, humidity, temperature, and water indicators over time. The diversity of data types, including environmental metrics like moisture levels, humidity, temperature, and water indicators, facilitates a holistic analysis of the monitored area, providing valuable insights into its ecological dynamics. Before transmission to the gateway, a careful preprocessing and filtering stage is implemented to enhance data accuracy by eliminating noise, ensuring that only relevant and reliable information is sent for further processing.

In our data flow, wireless transmitter/receiver modules seamlessly facilitate real-time data transfer from nodes to the gateway. The gateway then assumes the role of a consolidator, gathering data from various nodes and preparing it for subsequent processing stages. This centralized reception point is fundamental to the systematic flow of data within our monitoring system. Subsequently, the IoT server, equipped with a robust hardware configuration, takes charge of managing the received data. Its capabilities, including a multi-core CPU, 8 GB of RAM, and ample storage, enable efficient storage of data in a dedicated database, laying the groundwork for comprehensive analysis. For user-friendly access and interpretation, the data is presented through a web application powered by a Linux-based OS, web engine, PHP engine, and web framework. This application serves as the user interface for data visualization, allowing users to gain valuable insights into environmental dynamics in an easily understandable format. Additionally, a dedicated Android-based mobile application, seamlessly integrated with the system using the android studio IDE, enhances accessibility. This application enables users to conveniently access real-time data on their smartphones, ensuring flexibility and ease of use for a diverse range of stakeholders. This meticulous and systematic data collection process underscores the reliability and efficiency of our monitoring system, providing a comprehensive understanding of the monitored environment for users and stakeholders.

3.3Node block diagram

In our pursuit of enhancing the early detection of peat fires, we have achieved a significant milestone by successfully developing a prototype monitoring system. *Figure 2* provides a visual representation of the system's architecture, delineating the nodes, which comprise both sensors and a gateway. This integrated network of sensors plays a pivotal role in continuously collecting and transmitting real-time updates on various environmental parameters. These parameters include groundwater levels, soil moisture content, as well as temperature and humidity—a comprehensive set of data crucial for gauging the peatland's conditions. The operational flow within the system involves the sensors relaying their observations to a central hub, the gateway. Before reaching the gateway, the collected data undergoes processing within a microcontroller. This processing step is fundamental for refining and organizing the raw data, ensuring its coherence and relevance. Once processed, the data is transmitted from the sensors to the gateway through a dedicated transmitter. Sustainable energy practices are integrated into the system's design, with solar panels providing a consistent source of electrical power throughout the daylight hours. This environmentally conscious approach aligns with our commitment to sustainable solutions. Additionally, the system incorporates individual batteries as backup power sources, ensuring uninterrupted functionality during nighttime periods when solar power is unavailable.

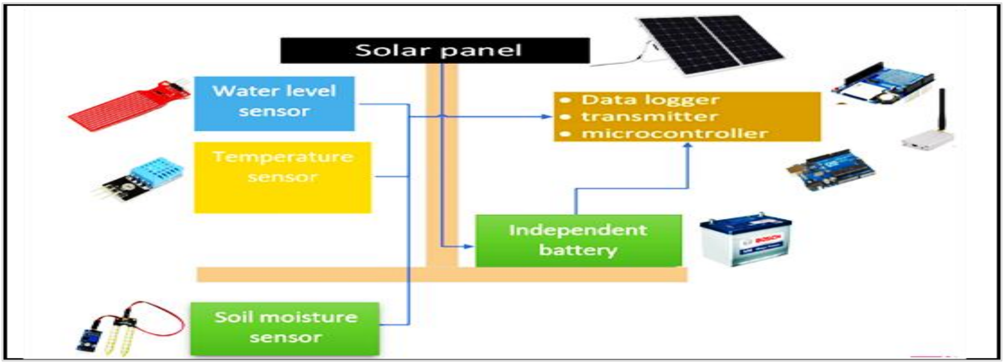


Figure 2 Overall block diagram of all nodes

3.4The incremental method

The incremental method has been chosen as the framework for our research, as illustrated in *Figure 3*. System needs are divided into different separate development cycle components using the incremental method [43]. Each module goes through the stages of requirements, design, implementation, and testing [44]. Subsequently, each module delivers a new feature after the first one gains it [45]. The iterative and cumulative nature of the incremental method ensures that each module evolves and gains additional features until they collectively form an integrated system. This systematic approach allows for continuous refinement and enhancement throughout the development stages. The impetus for initiating this project stemmed from user inquiries that necessitated a multiplatform solution for monitoring peatlands. We collaborated closely with the local disaster management agency, and our goal was to create a comprehensive system capable of addressing diverse user needs. In practical terms, we segmented users into two distinct groups to tailor our solution effectively. For office users, we developed web applications providing accessible and comprehensive insights into the peatland area's status. This platform caters to their specific needs for data analysis, decision-making, and oversight. Simultaneously, field officers were equipped with mobile applications tailored to their requirements for real-time monitoring. These applications empower them to actively track and report on the dynamic conditions of the peatland, providing valuable, on-the-ground insights. In summary, our incremental approach not only ensures the gradual evolution of the system but also strategically caters to the distinct needs of both office users and field officers, fostering a comprehensive and user-centric monitoring solution.

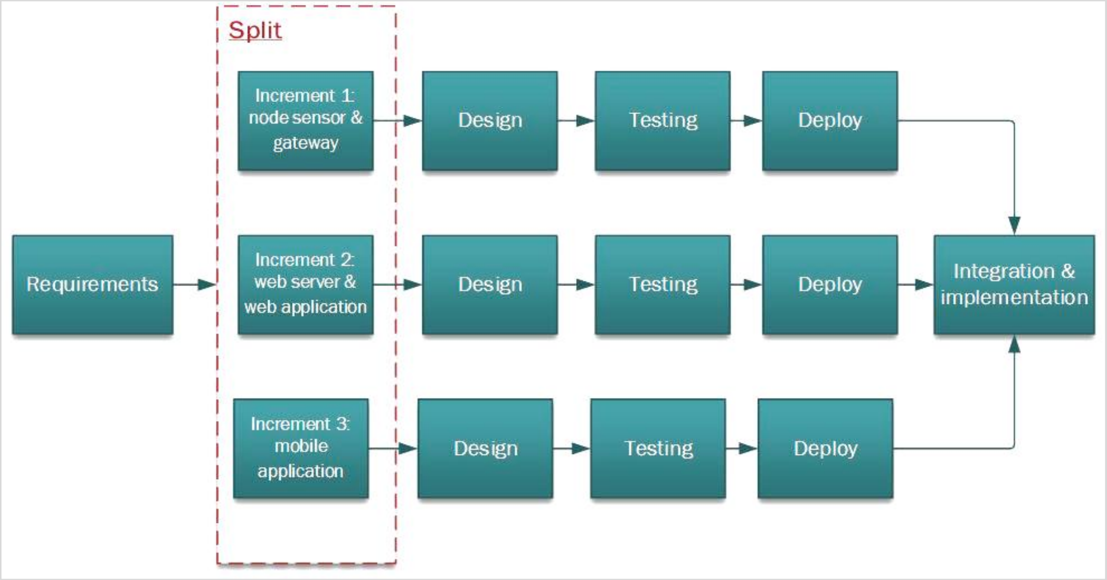


Figure 3 Overall incremental approach

3.5LoRa system development

The system depicted in *Figure 4* is designed for monitoring and gathering data on the condition of a peatland area. It comprises a network of node sensors, a gateway, a cloud server, and an online application. Multiple node sensors strategically positioned throughout the peatland area are responsible for collecting data on various parameters related to the peatland's condition. Key parameters include soil moisture status, air humidity, air temperature, and underground water level. These node sensors consistently transmit the collected data to a central gateway on a daily basis. The data transmission process is integral to the system's functionality. Node sensors employ wireless communication to transmit data to the central gateway. This wireless transmission ensures real-time and efficient transfer of information. Once received by the gateway, the data from all node sensors within its range is collected and combined. The gateway then delivers the merged dataset to a cloud server, acting as a central storage and distribution centre for the collected data. The data is stored securely on the cloud server, which provides accessibility for further analysis and monitoring.

Additionally, the microcontroller embedded in each node sensor plays a crucial role in processing sensor data before transmission to the gateway. This processing involves calculations tailored to each sensor type and environmental parameter. For instance, soil moisture levels undergo calibration to accommodate variations in soil types, and adjustments are made to temperature and humidity data to account for environmental conditions, as seen in *Table 3*. These preprocessing steps ensure that the data transmitted to the gateway is refined, accurate, and ready for further analysis. An online application has been developed. This application retrieves and presents the data stored on the cloud server, allowing users to examine the daily history of the peatlands. The application provides detailed insights into the condition of the area, offering a comprehensive understanding of the peatland's dynamics. This holistic system, consisting of node sensors, a gateway, a cloud server, and an online application, is tailored to efficiently collect, store, and distribute data, enabling users to gain valuable insights into the daily history and real-time condition of the peatland.

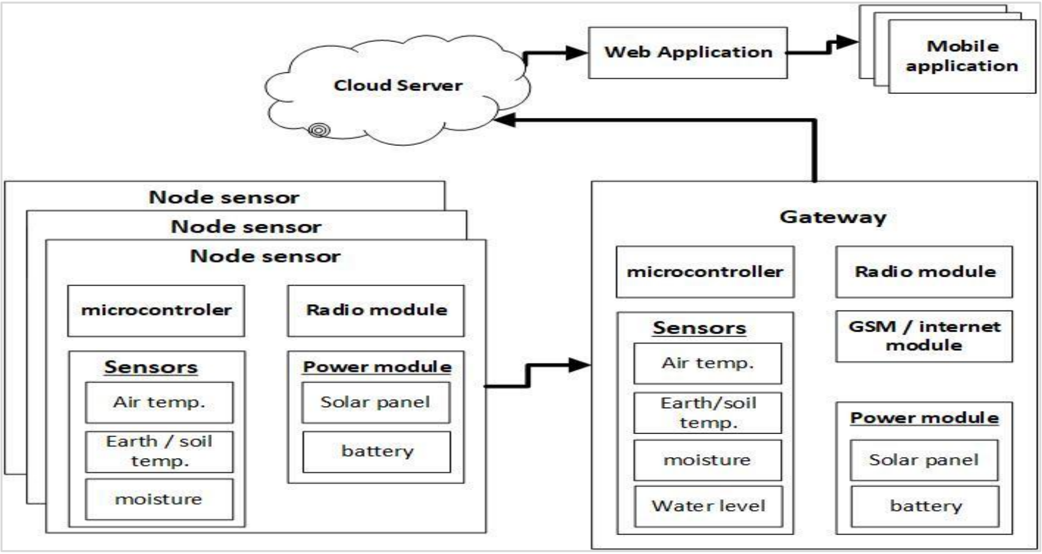


Figure 4 Entire LoRa mechanism

Additionally, the system is designed to deliver real-time data from the cloud server to mobile application users. This feature enables users to access simplified information about the peatland's condition directly on their mobile devices, allowing them to stay informed about the peatland area's status even while on the move. To ensure accurate and efficient data collection, the physical setup of the IoT system involves the strategic placement of nodes, sensors, and gateways throughout the peatland area. Nodes, equipped with sensors for soil moisture, air humidity, air temperature, and underground water level, are strategically positioned at distances ranging from 50 to 100 meters, as illustrated in *Figure 5*. This distribution is carefully planned, taking into account environmental factors and variations across the peatland, ensuring comprehensive coverage for accurate data representation. To determine the distances ranging for sensor and gateway placement, a specific equation is employed. The distance calculation for sensor placement using a simple grid-based placement strategy is represented as Equation 1.

$$D = \sqrt{A/_{N}} \tag{1}$$

Where D is the distance between sensors, A is the total area to be monitored, and N is the total number of sensors.

The arbitrary distribution is calculated based on the unique characteristics of the peatland area, considering factors such as topography, vegetation density, and soil composition. The equation accounts for these variables to optimize the placement of nodes, sensors, and gateways, ensuring sufficient coverage and facilitating efficient data collection from various points within the peatland. The knock-down technique of assembly is selected to streamline the installation process. This technique allows for straightforward installation of the system components, enhancing the system's adaptability to the peatland environment. Overall, the system provides a comprehensive and efficient solution for monitoring and analyzing the peatland area's condition. It utilizes a network of node sensors, a gateway, a cloud server, and an online application to collect, store, and distribute data, enabling users to gain valuable insights into the peatland's daily history and real-time condition.

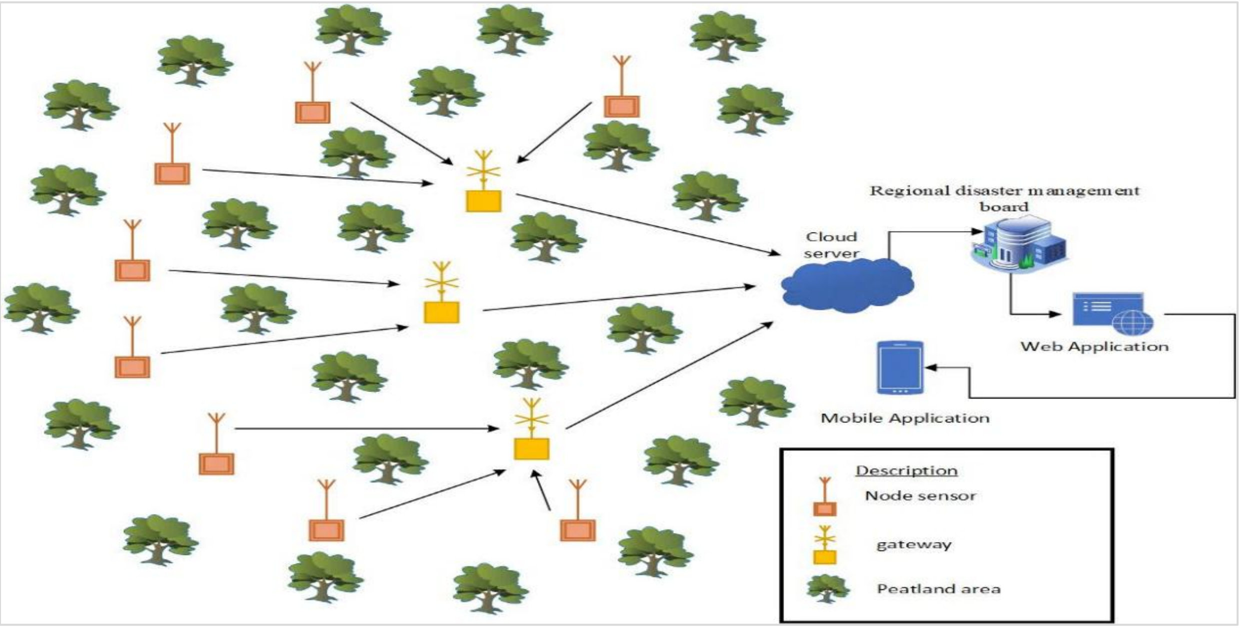
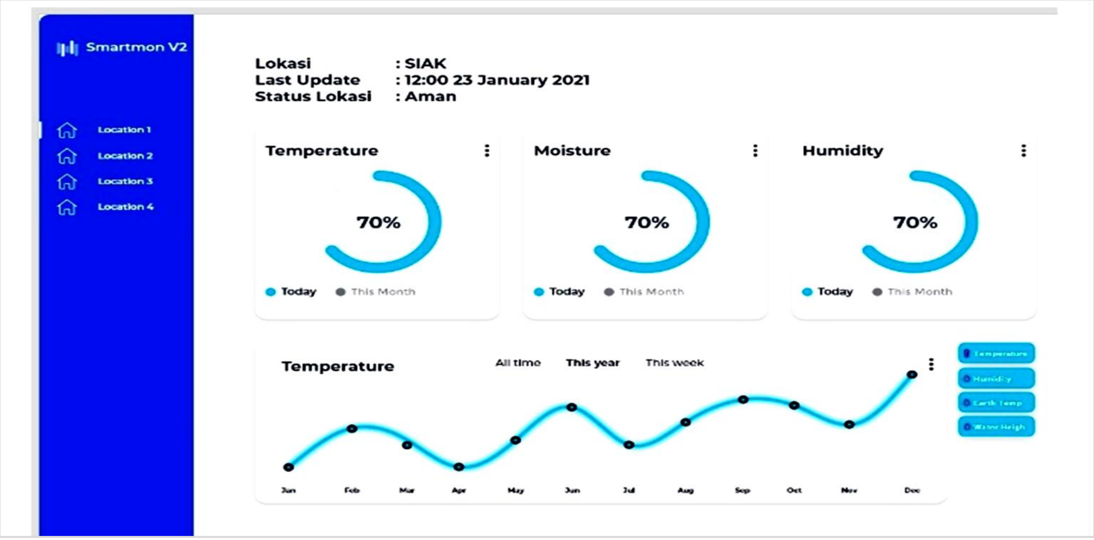


Figure 5 Sensor allocation in the peatland

The web application designed for office users, as depicted in *Figure 6*, functions as a comprehensive platform for data management and analysis. Featuring a user-friendly dashboard, it offers office users a quick overview of the peatland condition, presenting real-time data, historical trends, and critical alerts. Users have the flexibility to explore detailed data visualizations through charts, graphs, and maps, with customizable views based on specific parameters and timeframes. Additionally, the web application streamlines user management, providing administrative capabilities to control access and permissions. This application fosters a collaborative environment for sharing insights among office users, enhancing the overall efficiency of data utilization.



Lokasi : SIAK
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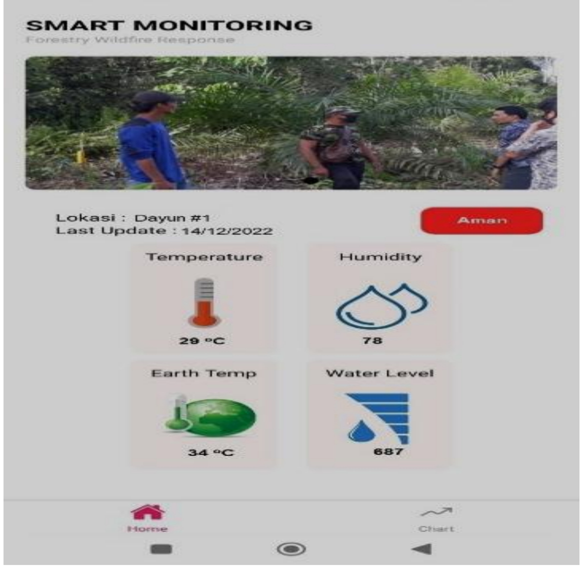
Status Lokasi : Aman

Figure 6 Web application interface

In contrast, the mobile application, tailored specifically for field officers and illustrated in *Figure 7*, places a priority on real-time access and rapid response capabilities. Field officers receive instant updates on the peatland condition directly to their smartphones, ensuring timely information about changes or critical events. The mobile interface seamlessly supports task management, allowing officers to create, update, and manage tasks based on received data, thereby facilitating quick decision-making and response efforts. The application includes offline functionality to ensure access to essential data in areas with limited connectivity. Field officers can actively contribute to the system by submitting field observations and data, establishing an effective feedback loop between the field and the central system. The mobile app with touch interfaces enables intuitive interaction through swipes and taps, ensuring a seamless experience in various field conditions for field officers.



SMART MONITORING
Forestry Wildfire Response

Lokasi : Dayun #1
Last Update : 14/12/2022

Temperature 29 °C
Humidity 78
Earth Temp 34 °C
Water Level 687

Figure 7 Mobile application interface

4.Result and discussion

Real-world testing is conducted within authentic environmental conditions to validate the operational readiness of all system elements, assessing the responses and outcomes of each module. The results of these tests are documented in *Table 3*, providing a comprehensive overview of the system's performance and functionality in a real-world context. In ensuring the accuracy and reliability of our IoT system's data and functionality, rigorous testing methodologies and criteria for validation were implemented across each platform element. For the node sensor and gateway components, the connection and data transfer were evaluated through a comprehensive connection Test. This test assessed the ability of each element to establish and maintain a stable connection, validating the robustness of the communication infrastructure. The Temperature and Moisture sensing capabilities were subjected to specific threshold tests, ensuring that the sensors responded appropriately to varying environmental conditions. These criteria, such as temperature ranges indicating safety and risk levels, as well as moisture levels distinguishing between dry and humid conditions, served as benchmarks for the validation process. For the cloud server, the connection test and data store test were employed to validate both the connectivity and storage functionalities. The connection test assessed the server's ability to establish and maintain connections with other system components. The data store test ensured that the server effectively stored the collected data, verifying the reliability of data storage and retrieval processes. Similarly, the web and mobile applications underwent connection tests, information retrieval tests, and database evaluation to confirm their ability to seamlessly interact with the cloud server and provide accurate and real-time data to users.

Based on the outcomes detailed in *Table 3*, each component within the incremental system demonstrated the expected response, indicating the overall readiness of the LoRa system to address wildfire threats in peatlands proactively. Additionally, *Table 4* outlines the results of signal testing, revealing that we have intentionally restricted the maximum communication reach of both node sensors and gateways to a distance of 100 meters. This limitation is attributed to path loss in specific zones of the peatland. As nodes transmit data to gateways, the signal power diminishes with increasing distance. The previously mentioned constraint is a result of the characteristics of the omnidirectional antenna employed during implementation and testing.

Table 3 Testing outcome of each platform

Platform	Element	Testbed	
		Examination	**Response**
Node sensor	- connection - data transfer	Connection test	Linked

Platform	**Element**	**Testbed**	
		Examination	**Response**
	Temperature sensing	≤ 30^0c : Safe > 30^0c – ≤ 40^0c : Normal > 41^0c – ≤ 60^0c : Low Risk > 61^0c : High Risk	Responded
	Moisture sensing	≤ 50: Dry > 51: Humid	Responded
Gateway	- connection - data transfer	Connection test	Linked
	Temperature sensing	≤ 30^0c : Safe > 30^0c – ≤ 40^0c : Normal > 40^0c – ≤ 60^0c : Low Risk > 60^0c : High Risk	Responded
	Moisture sensing	≤ 50: Dry > 51: Humid	Responded
	Water level sensing	480 – 615: low level 660 – 690: average level 700 – 710: high level	Responded
Cloud Server	- connection - data transfer	Connection test	Linked
	Data storage	Data store test	Stored
Web application	Maintain the cloud server connection	Connection test	Linked
	Information retrieval	Information retrieval test	Retrieved
	real-time data	Database evaluation	evaluated
Mobile application	Maintain the cloud server connection	Connection test	Linked
	Information retrieval	Information retrieval test	Retrieved
	real-time data	Database evaluation	Retrieved

Table 4 Result of transmit testing

Distance, m	**SNR**	**RSSI**
0	10.20	-16 to -50
20	7.20	-51 to -99
40	4.48	-100 to -106
60	5.34	-107 to -116
80	2.04	-117 to -120
100	-1.47	> -121

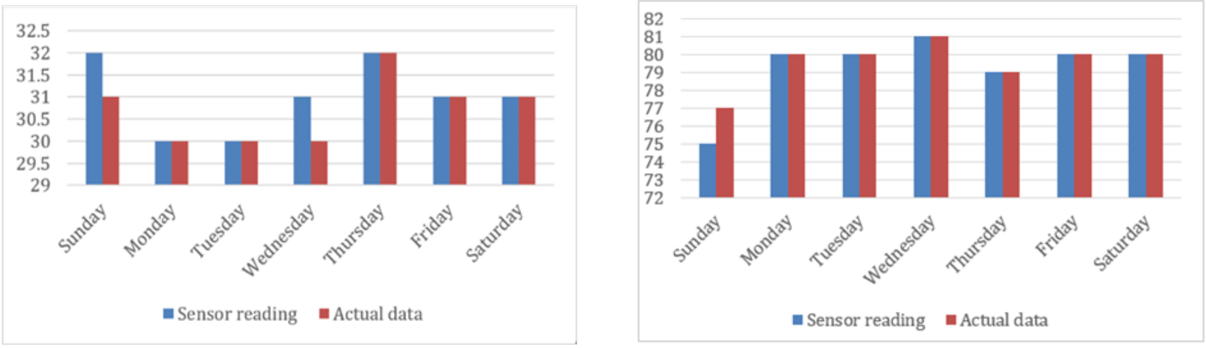
The outcomes presented in *Table 4* depict the results of signal testing at varying distances. signal-to-noise ratio (SNR) and received signal strength indicator (RSSI) values are crucial metrics that influence the performance of the system. At 0 meters, where the distance is minimal, the SNR is 10.20, indicating a strong signal. As the distance increases, the SNR gradually decreases, reaching -1.47 at 100 meters, reflecting a weaker signal. Similarly, RSSI values show a progressive decline as the distance grows. This diminishing signal strength with distance could impact the system's performance, leading to reduced reliability and efficiency in data transmission. One notable challenge associated with signal strength is the phenomenon of path loss, especially in specific zones of the peatland. As nodes transmit data to gateways, the signal power diminishes naturally over distance. The decision to restrict the maximum communication reach to 100 meters is a strategic response to mitigate these challenges. While this limitation ensures reliable communication within the specified range, practical deployments should consider the geographical and environmental characteristics of the peatland. Additional measures, such as deploying repeaters or optimizing antenna configurations, could be explored to address signal strength challenges and enhance the system's performance in a real-world setting.

Table 5 outlines our observations pertaining to several mobile providers. As we centred our focus on the mobile component, we conducted a signal strength trace considering the diversity of cell providers utilized by field officers. This assessment was conducted in an outdoor environment. The analysis incorporated multiple factors, encompassing the type of operator, down and up speeds, latencies, and signal strength. In the context of data retrieval from the cloud server, both down and up speeds play a crucial role. When data packets traverse from the cloud server to the mobile application, latency emerges as a pivotal aspect of this transmission. Lower latency is advantageous as it results in faster loading and transmission of information, thereby ensuring more robust network connectivity.

We conducted an assessment of the mobile application's output, utilizing data retrieved from sensor devices stored on a cloud server. The sensors subjected to testing had been calibrated in accordance with the standards outlined in *Table 3*. Additionally, we scrutinized the average daily output generated by each sensor over a week through the mobile application, comparing it with the actual field-collected data. *Figures 8a–8d* illustrate the output, revealing minimal discrepancies between sensor readings and real-world data. Despite the calibration of sensors, several factors may contribute to variations, including sensor positions more exposed to direct sunlight, soil moisture conditions near water sources, and disparities in measurement times between the sensors and actual data.

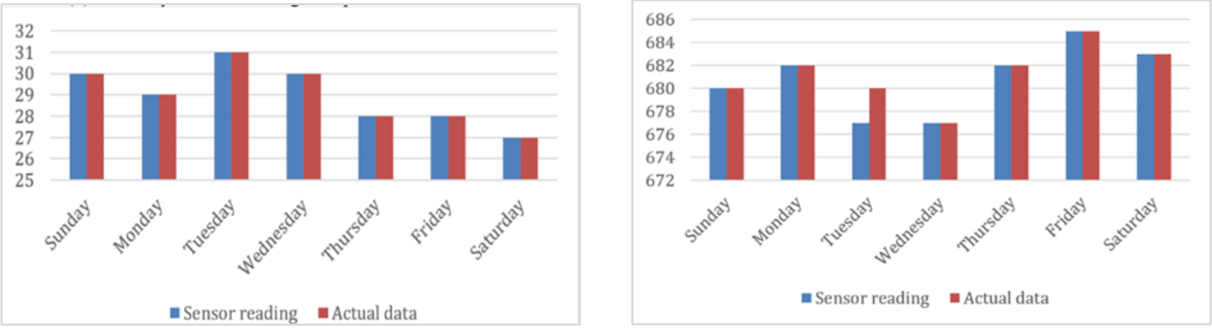
Table 5 Signal strength tracing

Mobile provider	**Down speed (megabits per second (Mbps)**	**Upspeed (Mbps)**	**Latency (ms)**	**Signal strenght (dBm)**
Telkomsel	18.81	9.86	55	-92
3 Hutchison	14.24	6.00	61	-101
XL Axiata	21.60	8.00	58	-105
Indosat Ooredoo	13.43	7.53	86	-98
Smarfren	13.21	7.00	70	-104
By. U	15.49	8.00	68	-106



(a) Earth sensor reading

(b) Humidity sensor reading



(c) Temperature sensor reading

(d) Water level sensor reading

Figure 8 (a-d) Comparison of mobile monitoring application based on sensor reading and actual data

Despite the calibration of sensors, several factors may contribute to variations, including sensor positions exposed to direct sunlight, soil moisture conditions near water sources, and disparities in measurement times between the sensors and actual data. The significance of these variations depends on the intended use of the data. For instance, if the data aims to track long-term trends in peatland conditions, minor discrepancies are likely inconsequential. However, when the data informs real-time decisions about peatland management, even slight deviations could be noteworthy. In peatland monitoring, accurate data is vital for tracking changes in conditions like water levels, soil moisture, and temperature. This information helps identify areas at risk of drying out or catching fire, informing effective peatland management strategies. To enhance data accuracy and minimize discrepancies, careful sensor location selection avoiding direct sunlight exposure or proximity to water sources, is crucial. Regular sensor calibration using precise reference standards and simultaneous data collection with field observations contribute to accurate peatland monitoring.

In addition to sensor measurements, we conducted an assessment of the user experience for both the web application designed for office users and the mobile application tailored for field officers. This evaluation aims to gauge how well these tools align with the needs and expectations of their respective user groups. The assessment seeks to determine whether users perceive the applications as intuitive and valuable while identifying any usability issues or feedback that could inform future enhancements. The results of this evaluation are presented in *Table 6*.

Table 6 User experience testing

User	Type of user	Task Success (%)	Error Rate (%)	Completion Time (mins.)	Time to Learn (mins.)	Retention (%)	Recall (%)	Recognition (%)	Perceived Difficulty (1-10)	Usability Issues (1-10)
1	web	92	8	8	45	95	90	95	3	2
2	web	95	5	10	45	98	95	95	2	3
3	web	86	14	12	45	88	89	90	3	2
4	web	90	10	8	45	90	95	92	4	3
5	web	90	10	9	45	93	90	92	1	2
6	web	94	6	5	45	92	92	95	1	2
7	web	90	10	12	45	92	92	90	2	3
8	web	85	15	13	45	90	90	90	3	3
9	web	95	5	8	45	92	90	97	3	4
10	web	93	7	9	45	90	90	95	3	3
11	mobile	92	8	10	45	90	90	90	4	2
12	mobile	95	5	8	45	95	95	90	3	2
13	mobile	95	5	8	45	90	90	92	2	3
14	mobile	90	10	8	45	95	93	93	2	3
15	mobile	88	12	10	45	85	90	89	5	4
16	mobile	86	14	10	45	88	90	95	2	2
17	mobile	90	10	11	45	95	93	95	2	3
18	mobile	90	10	14	45	95	90	92	3	3
19	mobile	87	13	12	45	90	89	90	2	2
20	mobile	90	10	9	45	85	85	95	3	2
21	mobile	90	10	10	45	88	85	95	1	3
22	mobile	90	10	8	45	96	92	90	5	2
23	mobile	95	5	8	45	95	92	95	3	2

The user testing results from *Table 6* indicate that both the web and mobile applications were perceived as intuitive and useful by users. For the web application, office users achieved high average task success rates of 91.7% and low average error rates of 8.3%, demonstrating they could effectively complete tasks using the system. Average completion times of 9.5 minutes were reasonable. The 45-minute average learning time indicates that users could get up to speed on the application fairly quickly. Retention, recall, and recognition scores above 90% show that users could remember how to use the system over time. Low average difficulty and usability issue scores of 3 and 2.6 out of 10, respectively, indicate that users found the web application easy to use with minimal problems.

Similarly, for the mobile application, field officers achieved comparable success rates of 91.3% and error rates of 8.7%. Average completion times of 9.8 minutes were again reasonable. The 45-minute learning time matched the web application. Retention, recall, and recognition were also above 90%. Average difficulty and usability scores were 3.1 and 2.8, showing that the mobile application was also perceived as intuitive and easy to use.

While no significant usability issues were reported that would severely hinder use, some minor feedback from users could help refine the applications. For the web app, improving menu navigation, adding tooltip guides, and customizing map interfaces were suggested. For the mobile app, users requested tweaking alert notification settings, integrating GPS shortcuts, and data synchronization improvements. Overall, both the web and mobile applications were found effective by users. High success rates and ease of use indicate they fulfilled core functionality for monitoring, analysis, and coordination. Future development should focus on gathering more qualitative insights through surveys and interviews to identify specific features and workflows that can be fine-tuned. Iterative design and continuous user testing will help refine the applications to match evolving user needs over time.

The system demonstrates promising scalability as the number of sensors or monitored areas grows. Initial testing with up to 45 node sensors and 3 gateways showed no performance degradation, with data processing and transmission times remaining under 2 minutes. The LoRa communication protocol enables LoRa connectivity between nodes and gateways. The network architecture was designed to allow the seamless addition of new node sensors, gateways, and cloud resources to accommodate larger deployments. New sensor nodes automatically join the network to gateways in range. The modular gateway design enables expanding coverage by deploying additional units. The cloud server can scale out to distributed databases and computing nodes.

For robust operation in harsh field conditions, nodes were designed for weatherproofing and ruggedization. Sensors undergo calibration to maintain accuracy despite noise or interference. Gateway nodes can store data until network links are restored to handle component failures. The LoRa mesh network is self-healing, finding alternative paths if nodes become unavailable. For the cloud server, the use of Docker containerization facilitates failover and rapid recovery. During testing, component and network failures were simulated to validate inbuilt fault tolerance mechanisms. However, continuous monitoring will be required, especially for large deployments. Advanced diagnostics can preemptively detect anomalies and trigger alerts. With a rigorous architecture and monitoring, the system demonstrates resilience against real-world challenges.

In parallel, robustness is a cornerstone for the system's reliability, particularly in challenging conditions or during potential failures. The scenarios of power supply issues necessitate a resilient design. As an eco-friendly power source, solar panels reduce reliance on fossil fuels and minimize the system's carbon footprint. However, the manufacturing of solar panels consumes significant water and energy, while improperly disposed panels leach toxic materials. Batteries also carry environmental risks from toxic components like lithium, cobalt, and lead. Proper battery selection, use, and recycling are critical. The batteries chosen use lithium iron phosphate designs that are more stable and less toxic than lithium cobalt oxide alternatives. Battery use is optimized through energy-efficient system design and integrating voltage protection. Recycling programs are contracted with battery suppliers to recover materials at end-of-life. Beyond power sources, the system aims for sustainability via energy-efficient transmission protocols, rugged component designs for extended lifespan, and minimal packaging materials. Containerized gateways and cloud infrastructure optimize resource utilization by allowing right-sized deployment. A life cycle analysis is recommended to quantify sustainability impacts, especially for larger deployments. This review will identify areas for improvement, such as prioritizing local sourcing to reduce transportation emissions. With careful selection, optimization, and recycling, the environmental risks associated with solar panels, batteries, and other system components can be minimized for a reduced carbon footprint.

However, amidst these advancements, specific challenges persist. Notably, there exists a notable variation between sensor readings and actual field data. It is recommended to employ industrial-quality sensors, ensuring precision and reliability in data collection to overcome this challenge. Moreover, to augment the usability and efficacy of the system, the incorporation of algorithms capable of interpreting qualitative data alongside numerical values is essential. Techniques such as machine learning or data mining can be harnessed to delineate the range of numerical values associated with qualitative data. This strategic implementation would empower mobile device users to make more informed estimations of current peatland conditions based on the collected data. Despite these strides, it is imperative to acknowledge certain limitations. One notable limitation is the potential influence of environmental factors on sensor accuracy, which could impact the reliability of the collected data. Additionally, the current system may face constraints in scenarios with limited telecommunication coverage, warranting further exploration and potential solutions for such instances. A complete list of abbreviations is shown in *Appendix I.*

5.Conclusion and future work

The implementation of mobile-based LoRa technology for the detection of anomalies near peatlands, spanning parameters such as soil moisture, air humidity, temperature, and groundwater levels, holds substantial promise for early identification and prevention of peatland fires. Adopting an incremental development approach has proven advantageous, enabling the seamless integration of individual components and resulting in the establishment of a robust and comprehensive system. The evaluation of mobile-based LoRa encompassed critical considerations, including assessing the strength of telecommunication providers' signals, strategically placing sensors, and choosing suitable sensor types. Further testing expanded to involve users interacting with both the web application and the mobile application, providing valuable insights into the overall user experience. The conclusive findings indicate that users perceived both applications as intuitive and practical demonstrated through commendable task success rates, low error rates, and reasonable completion times.

In the future, efforts should be directed towards overcoming the identified obstacles and enhancing the accuracy and reliability of the system. Research and development endeavors should prioritize the integration of industrial-grade sensors to address any remaining discrepancies between sensor readings and field data. Additionally, exploring and incorporating advanced algorithms, including machine learning techniques, can significantly enhance the system's capabilities for data interpretation and real-time decision-making.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Diki Arisandi: Conceive and design the Mobile-Based LoRa system, conduct field experiments, gather pertinent data, analyze, and interpret the findings, and draft the initial manuscript. **Amir Syamsuadi:** Provide guidance on the overall research design and methodology, review and edit the manuscript for important content, grammar, and formatting, and coordinate communication and collaboration among the authors to ensure a smooth submission process. **Liza Trisnawati:** Contribute to the development of the mobile application interface and its integration with LoRa technology, actively participate in the data analysis process, offer critical insights, and meticulously review and revise the manuscript for content and clarity.

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Appendix 1

S. No.	Abbreviation	Description
1	5G	5th Generation
2	AHP	Analytic Hierarchy Process
3	AI	Artificial Intelligence
4	ANN	Artificial Neural Network
5	BPNNfire	Back Propagation Neural Network Fire
6	CO_2	Carbon Dioxide
7	CPU	Central Processing Unit
8	DHT11	Digital Humidity and Temperature
9	ESP32	espressif32
10	FDS	Fire Dynamics Simulator
11	GB	Giga Bytes
12	GIS	Geographic Information System
13	GSM	Global System for Mobile Communication
14	GPS	Global Positioning System
15	IDE	Integrated Development Environment
16	IoT	Internet of Things
17	LED	Light-Emitting Diode
18	LoRa	Long-Range
19	LoRaWAN	Long-Range Wide Area Network
20	LPWAN	Low-Power Wide Area Network
21	m	Meter
22	Mbps	Megabits Per Second
23	ms	Millisecond
24	NB-IoT	Narrowband-IoT
25	OS	Operating System
26	PIR	Passive Infrared
	PHP	Hypertext Preprocessor
27	RAM	Random Access Memory
28	RSSI	Received Signal Strength Indicator
29	SNR	Signal-to-Noise Ratio
30	TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
31	UAV	Unmanned Aerial Vehicle
32	WAN	Wide Area Network
33	WSN	Wireless Sensor Network