

# Landslide Detection in Remote Areas Using LoRa and Sensor Networks

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**Abstract:** Landslides pose a significant threat to lives and infrastructure in hilly, remote regions, necessitating more proactive safety measures. This project introduces an intelligent IoT system that monitors environmental stability in real time by integrating a NodeMCU ESP8266 with soil moisture, tilt, and atmospheric sensors. By leveraging LoRa technology for long-range data transmission and Firebase for cloud storage, the system ensures that critical information is accessible even from isolated locations. An integrated AI model analyzes these data streams to predict landslide probabilities, triggering immediate alerts via a web dashboard, local buzzers, and LCD displays. This combination of smart sensing and predictive modeling creates a reliable, high-tech early warning system that empowers communities to manage disaster risks more effectively.

**Keywords:** Landslide, IoT, Sensor networks.

## 1. Introduction

Natural disasters consistently endanger both human lives and critical infrastructure, but their impact is magnified in rugged, challenging topographies. Among these, landslides stand out as one of nature's most destructive forces, often resulting in tragic loss of life and the catastrophic destruction of property. Recent shifts in global climate patterns have led to intensified rainfall, which, when combined with deforestation, unplanned urbanization, and global warming, has made these events increasingly frequent and unpredictable.

Traditional warning systems often fail in these environments due to inherent limitations, most notably a lack of reliable network coverage in remote areas. This creates an urgent need for innovative, resilient methods of disaster prediction. To address this gap, the current project, "Landslide Detection in Remote Areas using LoRa and Sensors," focuses on developing a robust solution that operates where conventional technology falls short.

### A. Background

Landslides occur when the structural stability of a slope is compromised by various natural and human-induced factors. Key triggers include intense rainfall that saturates the soil, seismic tremors, sudden heavy snowfall, and the destabilizing effects of deforestation and construction. According to the Geological Survey of India, nearly 15% of the country's landmass is landslide-prone, with the highest risks concentrated

in the North-Eastern states, the Himalayan regions of Himachal Pradesh and Uttarakhand, and the Western Ghats of Kerala. The devastating 2018 Kerala floods served as a grim reminder of this vulnerability, where numerous landslides wiped out entire villages and claimed many lives.

Despite these risks, traditional monitoring methods, such as manual inspections, satellite imagery, and GSM-based systems, often fall short due to several critical limitations:

- *Lack of Real-Time Detection:* They often fail to provide immediate data during the onset of a slide.
- *Network Dependency:* GSM systems rely on cellular coverage, which is frequently non-existent or destroyed during disasters in remote areas.
- *High Costs and Complexity:* Maintaining sophisticated equipment in rugged, rural terrains is often prohibitively expensive.

Modern advancements in the Internet of Things (IoT) and Wireless Sensor Networks (WSN) offer a more effective path forward. By continuously tracking environmental variables like rainfall intensity, soil moisture, and ground vibrations, we can gain a clearer picture of slope stability. Furthermore, the integration of LoRa (Long Range) technology ensures that this vital data can be transmitted across vast distances with minimal power consumption, making it the ideal communication backbone for remote disaster management.

### B. Relevance

The relevance of this project lies in its ability to safeguard lives and minimize the extensive property damage typically associated with landslides. Because these events often occur suddenly and without warning, the window for safety is narrow; by providing early alerts, this system grants communities the critical time needed to evacuate or relocate to safer ground.

Rather than merely reacting after a disaster has occurred, the system takes a proactive approach. It continuously monitors key environmental indicators, such as soil moisture, rainfall intensity, temperature, and ground movement, to identify high-risk scenarios before a slope fails.

A significant advantage of this design is its resilience in remote areas where traditional internet infrastructure is often unreliable or non-existent. By utilizing LoRa technology, the system can transmit vital data over long distances with minimal

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power consumption, ensuring a reliable and cost-effective solution for isolated regions. With immediate alerts delivered via local sound alarms and mobile notifications, the system ensures that warnings reach people quickly, turning data into life-saving action.

## 2. Literature Analysis

[1] The proposed system offers an IoT-based method for monitoring areas that are prone to landslides. It collects environmental data like rainfall, soil moisture, and vibrations. The system uses LoRa communication to send data over long distances, which makes it suitable for remote areas with poor connectivity. There is a mobile app included that gives users real-time alerts. Experimental results indicate that the system successfully monitors environmental conditions and provides reliable data transmission. However, the system could be improved by adding more sensors and better prediction models.

[2] An IoT-based landslide detection system uses sensors such as accelerometers, soil moisture sensors, vibration sensors, and rainfall sensors. These sensors connect to microcontrollers like Arduino or NodeMCU. The system analyzes the collected data to identify possible landslide conditions. Alerts are sent out when specific thresholds are exceeded. This system allows for early detection and cuts down the need for manual monitoring. However, relying on threshold-based analysis can reduce its accuracy in complex environmental conditions.

[3] A real-time landslide monitoring and user notification system is proposed using IoT technology to continuously track environmental factors such as rainfall, vibration, and slope movement. The system provides alerts through local methods like a buzzer and LCD, as well as remote communication via Wi-Fi-based mobile apps. The results show effective real-time monitoring and prompt alert generation. However, the system relies on stable internet connectivity, which limits its use in remote areas.

[4] A self-sustaining rainfall monitoring system is created for reducing landslide risk. It uses solar-powered sensors and microcontrollers. The system tracks rainfall levels and spots potential landslide risks based on set threshold values. Using renewable energy allows it to operate continuously without needing outside power. It works well in detecting heavy rainfall events, but it does not link with other environmental factors like soil moisture and slope movement for a complete analysis.

[5] A LoRaWAN-based landslide early warning system has been suggested in order to solve communication problems in remote areas. The system has a microcontroller combined with soil moisture sensors, GPS, and accelerometers to measure the state of the slope. The data is sent by means of the LoRaWAN and is presented in a mobile application. The system proves that it can communicate over long distances reliably and that it can also monitor efficiently. However, the system only covers a few parameters, and it needs to be improved with predictive analytics for higher accuracy.

[6] An IoT-enabled landslide detection system mainly focuses on monitoring different environmental factors such as rainfall, soil moisture, vibration, and slope movement. Alerts are generated by the system once sensor values go beyond

threshold limits. Also, it utilizes wireless communication to transmit data. The findings suggest that the system is capable of real-time monitoring very efficiently and has also enhanced community awareness. Nevertheless, the system does not have the capability of employing advanced machine learning techniques for making predictions.

[7] Remote sensing imagery and Convolutional Neural Networks (CNN) form the concept of a deep learning-based landslide detection system. It is a model that, by training on satellite images and ground truth data, classifies areas as landslide or non-landslide zones. The implementation of this method results in high accuracy in the detection and mapping of landslides on a large scale. On the downside, this is mostly an offline analysis method, and it does not provide real-time monitoring.

[8] To better protect communities in hilly regions, this new IoT system uses a network of sensors—tracking everything from soil moisture to ground vibrations—to detect potential landslides. It effectively sorts risk into three clear categories: safe, alert, and high alert. While the current detection is highly effective, the next evolution of this project involves integrating cloud monitoring and sophisticated machine learning to provide even more reliable early warnings.

### A. Research Gaps

Despite the development of various landslide detection technologies, several deficiencies persist in current models. Many existing systems still rely on manual inspections or rudimentary monitoring conditions, which leads to a lack of precision and significant delays in reporting. This lag in data processing often renders the information outdated by the time it reaches stakeholders, undermining the goal of immediate safety.

A major technical hurdle is the heavy dependence on conventional internet or cellular connectivity. In remote, mountainous, or disaster-prone regions, these networks are often unreliable or entirely absent, making it nearly impossible to maintain consistent surveillance or deliver timely alerts when they are needed most.

Furthermore, many current systems operate on single-parameter analysis. Because landslides are complex events triggered by the interplay of multiple environmental factors, such as soil saturation, slope inclination, and seismic activity, relying on a single metric reduces the overall reliability of risk assessments. Most of these solutions also tend to be reactive, triggering alarms only when conditions have already reached a critical state, which leaves little to no time for preventative action.

Finally, the high cost and technical complexity of advanced monitoring equipment often make them impractical for deployment in rural or underserved areas. There is, therefore, a clear and urgent need for a cost-effective, multi-parameter system that can operate autonomously in remote environments without the need for traditional internet infrastructure.

### B. Motivation

The primary driving force behind this project is the

devastating impact landslides have on both human life and the environment. In high-risk regions specifically hill states like Kerala—recurring landslides have caused immense suffering, destroying homes, severing vital road networks, and claiming the lives of innocent people. The danger is compounded by the fact that many of these events occur without any formal warning to the local population, leaving them completely vulnerable to nature's unpredictability.

Recognizing this gap, it became clear that a solution capable of providing advance notice was not just a technical goal, but a humanitarian necessity. While existing disaster management strategies exist, they are often too complex, prohibitively expensive, or physically impossible to deploy in the very remote areas that need them most. We were motivated to bridge this gap by developing a more accessible and resilient alternative.

Furthermore, we are inspired by the potential of modern technology to serve a greater social purpose. By integrating the latest advancements in Internet of Things (IoT) and Machine Learning, we aim to transform raw environmental data into a protective shield, utilizing cutting-edge science to save lives and make everyday living safer for those in high-risk terrains.

### 3. Problem Identification and Objectives

#### A. System Study

The system analysis in this study evaluates the performance of current landslide monitoring strategies, identifying their inherent flaws and proposing a sophisticated AI-driven IoT solution as a more capable alternative. Current methodologies often rely on a mix of manual observations and basic automated tools that are frequently inefficient, prone to error, and incapable of providing the real-time data flow necessary for remote mountainous regions. Major technical bottlenecks include restricted communication ranges and the absence of a localized, high-speed warning mechanism.

To overcome these obstacles, our approach integrates a multi-sensor array, comprising soil moisture, rainfall, temperature, and tilt sensors, interfaced with the NodeMCU (ESP8266) microcontroller. This configuration allows for the continuous monitoring of environmental variables. By utilizing a LoRa communication module, the system can transmit this data over vast distances, ensuring operational stability in areas where traditional internet or cellular access is non-existent.

Once transmitted, the data is processed through a Random Forest Classifier. This machine learning model analyzes the multi-parameter input to calculate the probability of a landslide with high precision. If a risk is detected, the system triggers a multi-channel alert protocol, delivering immediate warnings via an on-site buzzer, an LCD interface, and a dedicated mobile application. This integrated design offers several key advantages, including real-time responsiveness, long-range reliability, low power consumption, and a cost-effective implementation strategy.

#### B. Problem Definition

Despite the existence of various monitoring tools, many

high-risk regions remain vulnerable due to a lack of affordable, real-time, and scalable detection mechanisms. Existing techniques are often prohibitively expensive and provide only infrequent data updates, making them difficult to scale across vast, remote terrains. These delays in detection significantly increase the threat to both human life and essential infrastructure.

Key challenges identified in current practices include:

- *Geographic and Temporal Barriers:* Constant monitoring is physically difficult in rugged terrains, and traditional methods, such as manual inspections or satellite imagery, often suffer from significant time lags between data collection and alert generation.
- *Economic Constraints:* The high capital and operational costs of sophisticated monitoring equipment make it inaccessible for many local governments and rural communities.
- *Data Fragmentation:* Many existing tools fail to synthesize multiple environmental variables, leading to a less accurate understanding of slope stability.

These gaps underscore the urgent need for a specialized tool capable of synchronized, real-time tracking of various environmental parameters. Crucially, such a system must be able to maintain robust point-to-point communication without relying on conventional, often fragile, network infrastructures.

#### C. Objectives

The key objective of the proposed project is designing and developing a landslide detection and early warning system based on IoT sensors and LoRa. The project's main objective is to develop a multi-sensor network which will continually monitor environmental parameters, including moisture in the soil, rainfall, temperature, and slope condition. The next important objective is the development of LoRa-based communication system capable of sending low power consumption data over the distances, where it is difficult to access the Internet connectivity. The project is supposed to develop data analysis methods for predicting landslides using a random classifier model.

The data is transmitted to the Firebase database where users can observe live readings using the application on their smartphone or laptop. Firebase service is useful not only for storing but also provides instant notifications, allowing users to access the application even from remote places. The system provides the users with real-time notification about potential landslides using a buzzer, LCD display, and application notifications.

### 4. Problem Analysis and Methodology

The strategy for designing and implementing this landslide detection solution focuses on building a highly efficient and dependable framework for monitoring high-risk environments, specifically those in geographically isolated regions. Traditional monitoring methods have frequently proven to be too slow, costly, and technically limited to provide the continuous oversight necessary for effective disaster prevention. Consequently, these legacy systems often struggle

to offer the proactive warnings needed to stay ahead of geological failures.

To address these challenges, the proposed solution integrates a sophisticated blend of IoT sensors, LoRa technology, and cloud-based monitoring platforms. By simultaneously tracking a diverse set of critical indicators, including soil moisture saturation, slope inclination, ground vibrations, precipitation intensity, and ambient temperature, the system can pinpoint the earliest signs of slope instability. This multi-layered data approach ensures a more comprehensive and resilient response than conventional methods, transforming reactive observation into real-time preventative action.

### A. High Level Design

The system is structured in a multi-layered architecture designed to streamline the transition from raw environmental data to actionable safety alerts. This hierarchical approach ensures that each stage of the landslide detection process—from the initial physical trigger to the final user notification—is both efficient and resilient.

- **Sensing Layer:** At the core of the system is a suite of specialized sensors. These components are responsible for the high-precision detection of environmental shifts, such as changes in soil moisture saturation, ambient temperature fluctuations, and minute ground displacements or slope movements.
- **Processing & Communication Layer:** All data captured by the sensing layer is aggregated and managed by the NodeMCU (ESP8266) microcontroller. To ensure the system remains functional in remote terrains, this layer utilizes the LoRa wireless protocol, which facilitates long-range data transmission with minimal power requirements.
- **Cloud & Analytical Layer:** The transmitted information is securely archived in a cloud server, creating a centralized database for real-time monitoring. Within this layer, a Machine Learning model analyzes the incoming data streams to assess landslide probability and risk levels.
- **Interface & Alert Layer:** The final layer focuses on accessibility and immediate response. Users can monitor live conditions through dedicated web or mobile applications. In the event of a high-risk detection, the system triggers localized alerts via integrated buzzer and LCD display components, ensuring those on the ground are warned instantly.

### B. High Level Architecture

The system is organized into six functional layers that work in tandem to ensure reliable landslide detection and communication:

1. **Sensing Layer:** This foundational layer is responsible for real-time data acquisition. It utilizes high-precision sensors to monitor critical environmental triggers, including soil moisture saturation, precipitation levels, ambient temperature, and minute shifts or vibrations within the slope's structure.

2. **Processing & Control Layer:** Acting as the system's brain, this layer utilizes the NodeMCU (ESP8266) to aggregate raw sensor signals. Before transmission, the data undergoes localized processing to filter out electronic noise and ensure the integrity of the information being sent.
3. **Communication Layer:** To overcome the challenges of remote deployment, this layer employs LoRa (Long Range) wireless technology. This enables the system to maintain stable, long-distance data links while operating on extremely low power, making it ideal for areas without traditional cellular coverage.
4. **Cloud & Monitoring Layer:** All processed data is transmitted to the Firebase Cloud platform. This layer provides a secure, centralized repository where historical and real-time data can be accessed and visualized from anywhere in the world via web or mobile interfaces.
5. **AI Prediction Layer:** This intelligence layer applies advanced machine learning, specifically the Random Forest algorithm, to the incoming data streams. By recognizing complex patterns in the environmental metrics, the AI can predict potential landslide events with a higher degree of accuracy than simple threshold-based systems.
6. **Alert & Display Layer:** The final layer focuses on immediate hazard communication. When the AI detects a high-risk scenario, the system triggers localized warning mechanisms, including audible buzzer alarms and visual LCD readouts, to ensure that individuals on-site receive instantaneous life-saving information.

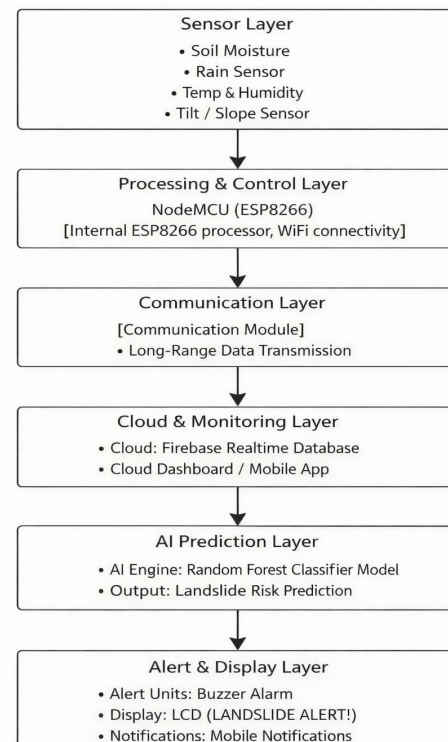


Fig. 1. High level architecture

### C. Technologies Proposed

#### 1) Internet of Things (IoT)

The Internet of Things (IoT) serves as the central nervous system of this project, linking a diverse array of physical sensors to a digital network. By integrating soil moisture, rainfall, temperature, vibration, and tilt sensors, the system creates a comprehensive digital twin of the environment. Managed by the NodeMCU (ESP8266) board, this setup automates the entire monitoring cycle—from data capture to transmission—eliminating the need for dangerous and inconsistent manual field observations.

#### 2) Machine Learning: Random Forest Classifier

Unlike traditional detection systems that rely on rigid "threshold values" (which can trigger false alarms), this study employs the Random Forest Classifier. This machine learning algorithm evaluates the complex, non-linear relationships between different environmental factors. By processing data through multiple "decision trees," the model provides a more nuanced risk assessment, classifying the probability of a landslide into four distinct categories: Low, Medium, High, and Very High. This predictive approach significantly enhances the accuracy of early warnings.

#### 3) Frontend Development: React.js

To ensure that complex technical data is accessible to stakeholders, React.js is used to build a dynamic web dashboard. This framework allows for the creation of an intuitive, interactive interface where users can monitor real-time environmental conditions. Through the use of live data feeds, historical graphs, and clear status updates, the React-based dashboard transforms raw sensor numbers into a visual format that is easy to interpret during a crisis.

#### 4) Backend and Data Management: Firebase

Firebase acts as the robust backbone for data storage and management. Its real-time database capabilities ensure that as soon as a sensor records a change, it is reflected on the user's dashboard without delay. Beyond storage, Firebase handles critical notification services and provides a centralized, scalable environment. This scalability is essential, as it allows the system to easily expand and incorporate data from additional sensor nodes across a wider geographic area without compromising performance.

### D. Hardware Requirements

#### 1) NodeMCU (ESP8266)

The NodeMCU ESP8266 serves as the central processing unit and primary controller for this project. It is a cost-effective, open-source IoT development board specifically designed with integrated Wi-Fi capabilities, which simplifies the process of connecting physical hardware to the digital world.

Key features that make it essential for this system include:

- **Integrated Processing:** It manages the simultaneous data acquisition from the entire sensor array, acting as the bridge between raw electrical signals and digital data.
- **Ease of Development:** The board is fully compatible with the Arduino IDE, allowing for efficient code deployment and rapid prototyping of the control logic.

- **Optimized for Remote Use:** Its compact form factor and low power requirements are ideal for deployment in the field, where space and energy efficiency are critical.
- **Versatile Interfacing:** With multiple GPIO (General Purpose Input/Output) pins, the NodeMCU can communicate with various sensors, such as soil moisture and tilt sensors, at the same time, ensuring a holistic view of the environment.

By facilitating direct communication with cloud platforms and web dashboards, the NodeMCU ensures that landslide conditions can be monitored from any location in real time.



Fig. 2. NodeMCU

#### 2) LoRa Module

It is a wireless communication system designed for transmitting small data packets over vast distances such as over mountains or rural areas by consuming so little energy that a single battery can last several years. Unlike normal internet, which may not function in remote locations, LoRa excels in these conditions because it operates on lower radio frequencies that can effortlessly penetrate forests, concrete structures, and long stretches of air. Although it cannot be used to access the internet, LoRa is ideal for creating a connection between sensors and a control center from afar, revolutionizing life in distant locales.



Fig. 3. LoRa

#### 3) Soil Moisture Sensor

This machine functions similar to an earth "monitoring device," detecting the amount of moisture absorbed by the earth in order to predict the possibility of landslides. The machine monitors changes in electricity in the earth's surface, either in terms of resistance or capacitance, depending on the level of saturation of the soil. If this machine determines the presence of excessive moisture content in the earth's surface, especially during rains, it becomes an indication of instability in the earth's surface, being "heavy" enough to slide down.



Fig. 4. Soil moisture sensor

#### 4) Temperature and Humidity Sensor (DHT11/DHT22)

The DHT11/DHT22 sensors are used for reading temperature and humidity from the surrounding area. The capacitor and thermistor play an essential role when it comes to the detection of changes in temperature and humidity levels in the air. These two factors will assist us in determining climate conditions, which may lead to landslide conditions. In case of changes in humidity and temperature levels in the environment, there will be rainfall. This sensor has a digital output that will assist us in connecting it to the microcontroller such as NodeMCU.



Fig. 5. Temperature and humidity sensor

#### 5) Tilt Sensor

The tilt sensor works as a "level" for the earth by consistently monitoring the degree of inclination of the terrain. This is probably the most important component because it detects the earliest signs of an approaching landslide, which is when the terrain starts to move or tilt. Through the use of microelectromechanical systems (MEMS) accelerometers, even the slightest angle change that cannot be seen by the naked eye can be detected. Once the earth has exceeded its "critical angle," it will trigger an alarm. As the earth usually moves or leans before a landslide occurs, the tilt sensor provides an important early warning system.



Fig. 6. Tilt sensor

#### 6) Vibration Sensor

This kind of sensor is used in measuring vibrations on the earth's surface as a result of any shaking or vibration of the ground or any external forces. This sensor uses either MEMS to convert vibrations into electric signals, which are then analyzed to determine the magnitude of vibrations. It is useful in sensing micro-seismic activities that are not easily detected but may point out the possibility of landslide.



Fig. 7. Vibration sensor

#### 7) Buzzer

Buzzer is an electronic component used to produce sounds upon its operation. The basic concept behind the working of a buzzer is that electrical energy is converted into sound energy. Buzzer is used in this circuit as a local alarm system. In case of any landslide threat detected by sensors, buzzer will beep as a warning signal for people around it.



Fig. 8. Buzzer

#### E. Software Requirements

1. *Arduino IDE*: To develop, compile, and upload the program code onto the ESP8266 (NodeMCU). IDE can also be used for tracking the data sent by the sensors in a serial manner.
2. *Embedded C/Arduino Code*: To write code in Node MCU for receiving sensor data, analyzing sensor data, and transmitting data using LoRa Module.
3. *Firebase Real-Time Database*: Online database for storing and managing data in real-time that is sent from sensors. It helps to synchronize the hardware and interface system instantly.
4. *Web/Mobile App Interface*: To design an online application interface that provides users with the live data regarding the environment and alerting them about landslides.
5. *Python*: Programming language required for implementing Random Forest classifier for landslides prediction using the sensor data provided as input.

#### F. Feasibility

##### 1) Technical Feasibility

It consists of components that are easily accessible, including NodeMCU, sensors, and LoRa modules. They are

programmable and can be integrated into the system. The system collects data from the surroundings, analyzes using the Random Forest algorithm and predicts landslides. Cloud and dashboards are used by the system for convenience in monitoring purposes.

#### 2) *Economic Feasibility*

It is economically viable due to its use of inexpensive hardware and software parts. It requires very little maintenance and energy; therefore, it incurs small operating costs. It costs much less compared to losses caused by landslides.

#### 3) *Operational Feasibility*

It operates automatically and does not require human involvement. It produces alerts through visual and audio alarms and reports its findings using dashboards. This makes it easy for users.

#### 4) *Environmental Feasibility*

It saves energy and does not pose any harm to the environment. It facilitates environmental preservation by predicting and mitigating the impacts of landslides.

#### 5) *Social Feasibility*

The system ensures the well-being of the society in landslide prone areas. It provides effective alerts and helps people take precautions.

### 5. Results and Discussion

The process of implementation involves the configuration of hardware parts first. Firstly, soil moisture, rain fall, temperature, and tilt sensors will be connected to the NodeMCU (ESP8266). This node receives information about the landslides environments. Sensor calibration will be done to ensure accuracy of results. Afterward, NodeMCU processes information received from sensors by interpreting the signal into values and checking if it is safe enough. Lastly, the data is prepared for transmission.

The LoRa technology will be applied in the system as a medium of communication. Information collected by the NodeMCU will be transmitted through the LoRa transmitter and received by LoRa receiver. It allows sending information for a long distance even when internet connection is not available. After all this, information gathered is stored in a cloud database called Firebase. Real-time storage of data is done here and it can be accessed anytime. In addition, a web interface is developed using React.js.

In the end, the implementation of the warning system becomes feasible. This happens in situations whereby the analysis shows that the probability of danger is relatively high or any of the sensors goes past its threshold limit.

### 6. Conclusion

The AI-based Landslide Detection and Early Warning System efficiently combines elements such as environmental sensors, Internet of Things (IoT), LoRa wireless communication technology, and the Random Forest algorithm to create an effective system for landslide monitoring. It continuously collects various data related to soil moisture level, rain, temperature, humidity, vibration, and changes in slope,

analyses it using the Random Forest algorithm to detect any cases of future landslides. The presented technology offers better efficiency, low power consumption, and application in remote, mountainous areas where there is no proper internet connectivity compared to traditional methods of detection. The LoRa technology allows sending data over longer distances while consuming less power, thus being appropriate for remote areas. Linking to cloud platforms such as Firebase and applications for smartphones or web browsers makes it even more convenient to access and analyze data collected by the system.

To conclude, it can be said that IoT, machine learning (Random Forest), and proper data communication technology are promising technologies for improving efficiency of early warning systems.

### 7. Scope of Future Study

The proposed Landslide Detection and Early Warning System would provide an excellent basis for further research into the field of landslide detection and prediction, however, there are certain improvements that can be made to the model to enhance its efficiency. Firstly, the existing Random Forest model used in the study can be further optimized by optimizing the hyper parameters of the algorithm. Moreover, larger volumes of data can be used to train the model in order to improve its efficiency. Secondly, other machine learning algorithms such as SVM, Gradient Boosting, or even Neural Networks can be used to enhance the accuracy of prediction. Some modifications that can be made to improve the system will be the addition of different kinds of sensors such as sensors for groundwater levels, GPS sensors to detect land displacement, and the use of advanced equipment to measure rainfall. This is bound to increase the level of data collected in terms of its accuracy and precision, thereby increasing prediction and analysis. Some other future improvements will be the integration of data from satellite technology and geographical information systems that will be used to map out areas susceptible to landslides. Also, an advanced application based on web/mobile phone technology providing real-time alerts, warnings about the occurrence of landslides in near future, and instructions on what to do during emergencies will be created. Linking this system to disaster management systems of the government will help in ensuring rapid response. Other improvements in the future can include the development of a system that is energy efficient due to solar power in the sensor nodes. Mesh networks can be put into place with several LoRa gateways being installed to increase the range of the network.

Generally, future work could focus on enhancing the accuracy of the model, expanding its scope, improving the design of the user interface, and using innovative technologies that will further enhance the robustness, intelligence, and practicality of the system.

### References

- [1] V. A. Patole and G. S. Pingale, "System for monitoring slopes and landslide detection using IoT."

- [2] N. Kumar, S. Govindan, S. A. Kiran, and R. Pawar, "IoT-based landslide detection system," *Int. J. Sci. Technol. (IJST)*.
- [3] L. Abinesh, G. Krithiga, and A. Magdaline, "Real-time hill station landslide monitoring and user notification system using IoT."
- [4] R. Poovarasan, K. Meiarasan, G. Vimalraj, and C. Selvi, "Self-sustaining rainfall monitoring system for landslide risk mitigation."
- [5] M. Muladi, S. Y. Amarda, A. K. Mahamad, S. D. Prasetyo, and C. Harsito, "LoRaWAN and IoT based landslide early warning system," *Acadlore Trans. Geosci.*, vol. 3, no. 2, pp. 106–122, 2024.
- [6] Y. Wang, H. Gao, S. Liu, D. Yang, A. Liu, and G. Mei, "Landslide detection using deep learning and remote sensing imagery: A case study of Linzhi."
- [7] K. B. Bhangale, R. G. Mapari, A. Mane, and H. Bhosale, "IoT-based landslide detection in hilly area."
- [8] A. Sharma *et al.*, "Artificial intelligence techniques for landslides prediction using satellite imagery," *IEEE Access*, vol. 12, 2024.
- [9] P. K. Indukala, U. G. Gosh, and M. V. Ramesh, "IoT-driven microseismic sensing system and monitoring platform for landslide detection," *IEEE Access*, vol. 12, 2024.
- [10] M. Jawalkar, N. Malviya, P. Hage, S. Chakule, and P. Pattewar, "IoT-based landslide detection and monitoring system," *Int. J. Res. Appl. Sci. Eng. Technol.*, 2022.
- [11] V. A. Patole *et al.*, "System for monitoring slopes and landslides detection based on IoT."
- [12] N. Casagli, E. Intriери, V. Tofani, and G. Gigli, "Landslide detection, monitoring and prediction with remote sensing techniques," *Nat. Rev. Earth Environ.*, vol. 4, pp. 51–64, 2023.
- [13] K. Karthikeyan, G. Gowri, K. Hariharan, and M. Guruprasath, "Landslides detection system."
- [14] C. Kharkar, N. Pawar, S. Kosambe, and J. A. Desai, "Landslide detection system using WSN."
- [15] P. Gupta, "IoT-based landslide monitoring system," *Int. J. Adv. Res. Sci.*, 2021.
- [16] S. Chakraborty, "Blockchain in cloud-based landslide monitoring," *Secure Comput. J.*, 2022.
- [17] B. Mahathi, S. S. Kirthika, and K. Balaji, "Smart landslide detection: A real-time monitoring and alert system for disaster prevention," *Int. J. Res. Appl. Sci. Eng. Technol.*, 2025.
- [18] B. V. Gowda, B. N. Sindhu, S. Tanuja, and M. Tejashwini, "Early landslide detection using IoT," *Int. J. Adv. Res. Comput. Commun. Eng.*, 2024.
- [19] R. L. Ray and M. Lazzari, *Landslides: Investigation and Monitoring*. Springer, 2020.
- [20] P. S. Rawat, "Landslide monitoring using IoT system with cloud support," in *Proc. 10th IEEE Uttar Pradesh Section Int. Conf.*, 2023.