An IoT Based Landslide Monitoring and Early Warning System for Guwahati City

MADHUSHREE SHARMA, SHAKUNTALA LASKAR
Electrical and Electronics Engineering Department
Assam Don Bosco University
Azara, Guwahati, Assam
INDIA

Abstract: - Landslides pose a significant threat to regions with unstable terrain, particularly during monsoon seasons, with their frequency increasing due to climate change and unregulated urban development. Guwahati, a rapidly growing city in Assam, India, is particularly vulnerable, with several of its 18 surrounding hills prone to landslides. Given the rising number of landslide-related fatalities, an early warning system is crucial. Although landslide hazard zonation mapping for Guwahati city is available in the literature, it lacks the integration of an early warning system equipped with a decision-making framework. Such a system is necessary for timely responses, enabling the mitigation of risks to life and property. This paper presents an experimental model for a landslide early warning system in Guwahati, which utilizes soil moisture sensors integrated with an Internet of Things (IoT)-based platform to predict rainfall-induced landslide occurrences.

Key-Words: - Landslide, IoT, Early warning, ThingSpeak, Arduino, Soil Moisture, Fuzzy Logic

Received: April 29, 2024. Revised: March 9, 2025. Accepted: April 7, 2025. Published: May 8, 2025.

1 Introduction

Landslides occur every year during the monsoon season, but their frequency and likelihood have been increasing due to ongoing development and the escalating climate crisis. According to data available with the Ministry of Home Affairs' National Emergency Response Center until September 2022, 10 states recorded 182 landslide related fatalities across multiple areas during the monsoon in 2022[1]. Therefore, landslide early warning is very much necessary for landslide prone areas. Guwahati, a city in Assam, India, is surrounded by 18 hills, out of which 8 hills are landslide prone [2].

An experimental model for the city of Guwahati's landslide early warning system utilizing a soil moisture sensor and ThingSpeak has been described here. As landslides in Guwahati are primarily caused by rainfall, hence the most important factor to predict landslide occurrences is a change in the value of the soil moisture sensor [3]. ThingSpeak is a cloud-based Internet of Things (IoT) analytics platform service that facilitates the collection, visualization, and analysis of real-time data streams. ThingSpeak allows for the sending of data from devices, the instantaneous viewing of live data, and the sending of warnings [4].

In the literature several design of landslide disaster monitoring system, that embedded with IoT may be found. Several monitoring studies on landslide detection were carried out onto soil displacement caused by artificial rainfall and earthquake, in online and real time mode ([5][6][7][8][9][10]).

Monitoring of landslide is a method by which one can understand the mechanism of landslide and can adopt preventive measures to reduce casualties and infrastructure damage. A number of methods are found in literature that includes monitoring of landslide by using phase and amplitude based system, synthetic aperture radar (SAR) offset tracking method, remote sensing, precise point programming (PPP) algorithm, global positioning system (GPS) etc.

Further, we can harness the power of wireless sensor network technology for developing large scale systems for real time monitoring of landslide hazard.

In [11], to determine the critical values of the measured physical parameters or test the early warning system itself, a laboratory scale model of a rotational landslide was developed. This rotational landslide model had a size of 250×45×40 cm^3 and was equipped with soil moisture sensors, accelerometers, and automated measurement system.

The study in [12] presents a landslide disaster monitoring system utilizing IoT technology. It investigates soil displacement caused by artificial rainfall and earthquakes using three sensors: slope, humidity, and vibration. Sensor data highlight correlations between humidity and soil slope, demonstrating the system's potential for real-time, interactive landslide monitoring via cloud-based web services.

Further, a laboratory set-up was constructed to simulate landslide phenomenon and to record movement in [13]. The main aim of that proposed study is to construct an early warning system by using optical fibre technology. However, the adopted technology has not been used as an early warning system for a real monitoring case.

Thus, a system may be developed using sensors that can detect, and data can be processed to be completed on the web server through cloud services for the city of Guwahati also. The system developed in this paper included soil moisture sensor as it has been demonstrated by various researcher that rainfall is one of the leading cause of landslide ([14],[15][16]). Further, by the method of regression analysis it was found that the soil moisture sensor value gives the highest R^2 value among all the parameters that are directly or indirectly related to landslide. Therefore, only by using the soil moisture sensor the early warning system can be developed by incorporating a fuzzy based decision system. Node MCU 8266 will record the moisture of the soil surface and the data can be uploaded to the cloud. The landslide alert can be broadcasted through smart phone application (using IFTTT ("If this than that") or Zapier platform) unlike other proposed system in the literature. Communities can receive the alert in real-time thereby potentially reduce the fatality risk.

ThingSpeak, an open-source IoT platform developed by MathWorks, enables real-time data collection, analysis, visualization, and action from various sensors and devices. The platform supports data storage in both private and public channels, real-time visualization through dynamic charts, data analysis using MATLAB code, and integration with other IoT services and platforms.

However, deploying the experimental landslide monitoring system at a large scale presents challenges across technical, environmental, financial, logistical, and social dimensions. Technical hurdles include sensor calibration, data integration, network connectivity, and real-time processing. Environmental factors like diverse terrains, extreme weather, and complex geology require region-specific customization. Financial constraints involve high costs and sustained funding, while logistical issues include accessibility, energy supply, and standardization. Social challenges encompass community involvement, land permissions, and policy barriers. Ensuring prediction accuracy, minimizing false alarms, and maintaining systems post-deployment are critical. A multidisciplinary approach, combining technical innovation, stakeholder collaboration, and long-term investment, is essential for effective implementation.

2 Methods

The block diagram of the proposed module is illustrated in Figure 1. The system is designed to monitor real-time environmental parameters critical for landslide prediction. Data are gathered from soil moisture sensor, rainfall intensity, and water seepage. These data are transmitted to the NodeMCU 8266 Module, which serves as the central processing unit for the collected data.

The NodeMCU 8266 features a built-in Wi-Fi module that facilitates seamless data transmission to a cloud platform. This integration enables continuous data storage and analysis in real-time. An IoT module is employed to manage the stored data efficiently, allowing for further processing. The processed data is then used to issue early warning alerts to individuals residing in landslide-prone areas. The IoT module ensures scalability, remote accessibility, and data integrity, making it an essential component of the landslide early warning system.

The experimental setup, illustrated in Figure 2**,** is a scaled-down physical model designed to replicate real-world conditions conducive to landslides. The setup consists of a 170 cm × 100 cm × 80 cm iron frame, which is enclosed with glass to provide a controlled environment for experimentation. The setup is strategically divided into three distinct compartments, each serving a specific purpose:

- Compartment 1 (Flat Section): This section contains porous buckets that facilitate the infiltration of water into the soil placed in the second compartment. The arrangement ensures that the amount of seepage water—an essential factor in landslide occurrence —is effectively monitored and controlled.

- Compartment 2 (Slope Area): The second compartment represents the sloped region where the primary experimental activities occur. Soil samples collected from the study area are placed here to simulate natural conditions. The slope angle in this compartment can be adjusted between 30° and 45°, mimicking real-life topographical variations in landslide-prone regions. A solar-powered sprinkler system is integrated to simulate artificial rainfall. The sprinkler system is equipped with adjustable flow rate and droplet size controls to replicate rainfall intensities typically observed in the study area. Rainfall simulation is a critical component, as landslides in this region are predominantly rainfall-induced.

- Compartment 3 (Lower Plain Area): The third compartment is located at the base of the slope and serves to collect residual water from the experiments. Two additional buckets are placed in this section to collect and measure the volume of water that percolates through the soil and flows downhill. This measurement provides insights into the water retention capacity of different soil samples, which is a key parameter in assessing landslide risk.

Below are some of the specifications of the solar powered sprinkler system:

- Solar Panel: A 100-watt mono crystalline solar panel with a 12V output provides power for the entire system.
- Water Pump: Equipped with a DC submersible pump that has a flow rate of 3 liters per minute and operates on 12V DC, consuming 60 watts.

- Battery: A 12V, 20Ah lithium-ion battery stores energy to ensure the system can function continuously, even during periods of low sunlight.

- Sprinkler Heads: Features adjustable spray pattern heads that can cover an area of up to 15 square meters, allowing for customizable experiments.

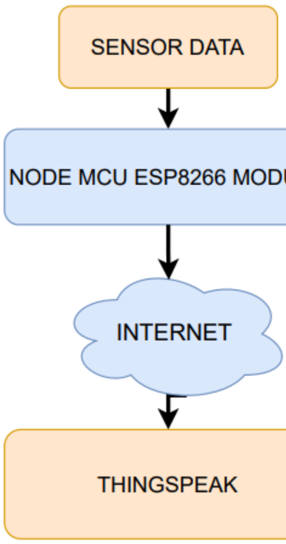

Figure1: Basic block diagram for IoT based landslide early warning

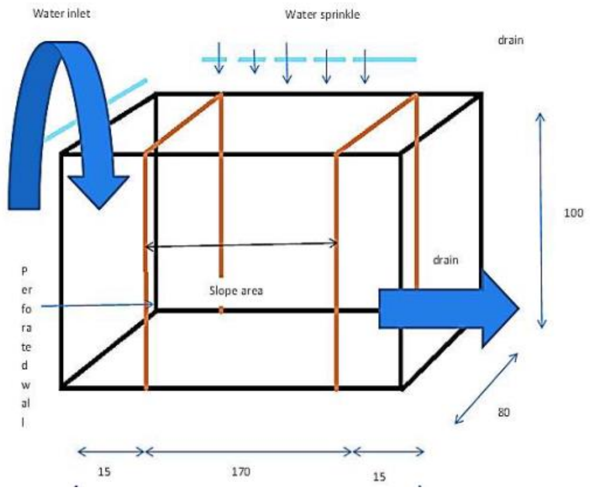

Figure2: Experimental set up

3 Experimental Observations

In this experiment, YL38 soil moisture sensors were strategically positioned at multiple locations within the slope area to monitor variations in soil moisture content. Artificial rainfall was simulated using a solar-powered sprinkler system, the specifications of which have been detailed in a prior section. The entire setup was integrated with a laptop running a program on the Arduino platform, which enabled data collection and transmission from the soil moisture sensors. The gathered data was stored in the cloud using the ThingSpeak platform for subsequent analysis and providing early warning for better response in critical conditions.

Soil collected from the landslide prone area was packed in the ramp section of the experimental set up. The set up was elevated at an angle slightly less than the soil's critical angle. The critical angle is the minimum angle calculated from soil properties at which soil movement would occur due to the gravitational force without the addition of moisture.

Figures 3 and Figure 4 illustrate the soil conditions at different stages of the experimental setup. Figure 3 presents the initial state of the soil prior to the introduction of artificial rainfall. In this figure, the soil appears undisturbed, with moisture content at baseline levels as recorded by the YL38 sensors. This serves as a control for the subsequent observations.

Figure 4, on the other hand, depicts the soil condition after the artificial rainfall was introduced through the solar-powered sprinkler system. The impact of rainfall on the soil's surface and subsurface layers can be observed, with changes in soil moisture content evident from the sensor readings. These figures collectively provide a visual comparison of the soil's response to rainfall, illustrating the transition from its initial dry state to a moisture-saturated condition, which is crucial for understanding the hydrological behavior within the slope area.

Table 1 represents the experimental observations recorded during the study. These observations are displayed in real time on both the serial monitor and the LCD (Liquid Crystal Display) integrated with the Arduino system. The rainfall amount is determined by calculating the volume of induced rainfall over the defined area of the experimental setup. This method ensures precise measurement of rainfall intensity, which is a critical factor in the analysis of landslide-prone conditions.

The ThingSpeak platform displayed output at intervals of 20 seconds. Figures 5 through 9 illustrate five such outputs, corresponding to varied rainfall intensities at time intervals T1, T2, T3, T4, and T5. The observation period spans from 10:50:00 hours to 10:58:00 hours. These outputs capture the recorded soil moisture sensor readings under different levels of artificial rainfall. The figures provide a detailed representation of the variations in soil moisture content in response to varying rainfall intensities. Additionally, real-time data monitoring was performed using the Arduino serial monitor, which confirmed identical values to those transmitted to the cloud platform.

Once the artificial rainfall system was activated, the soil moisture readings began to fluctuate, reflecting the dynamic changes in the soil's water content. To ensure accuracy and consistency in the recorded data, the system was programmed with a 20-second buffer time. This buffer allowed the soil moisture readings to stabilize before data transmission. At 20-second intervals, the sensor data were automatically sent to the ThingSpeak platform, where they were logged and visualized for subsequent analysis. This approach provided a reliable means to monitor and record the soil moisture response to different rainfall events in near real-time.

Figure 3: Initial condition

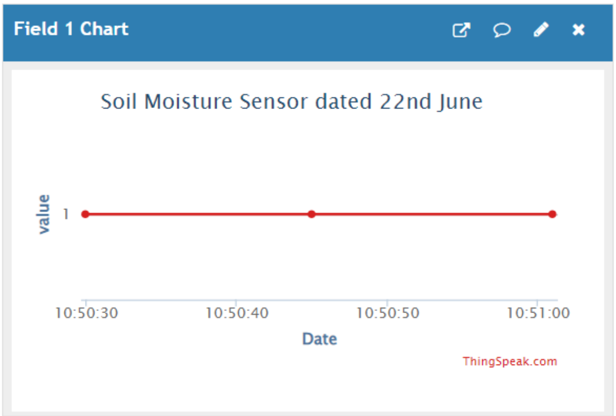

Figure 5: ThingSpeak output (at time T1, initial condition)

Figure 4: Occurrence of landslide

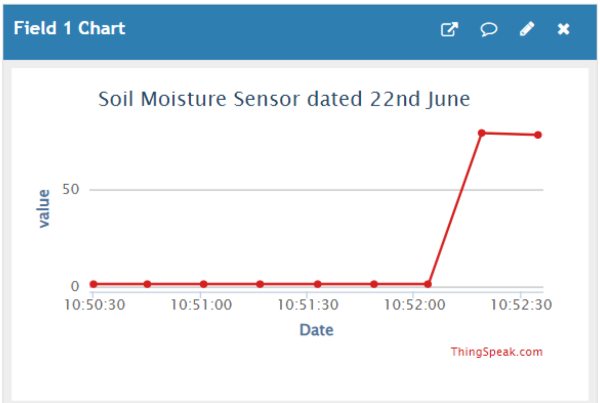

Figure 6: ThingSpeak output (at time T2)

Sl No	Time	Rainfall amount (in cm)	Soil Moisture value in percentage(in the LCD display)
1	T	0	1
2	T+1	29	49
3	T+2	59	63
4	T+3	71	74
5	T+4	82	76
6	T+5	94	79

Table1: Experimental observations

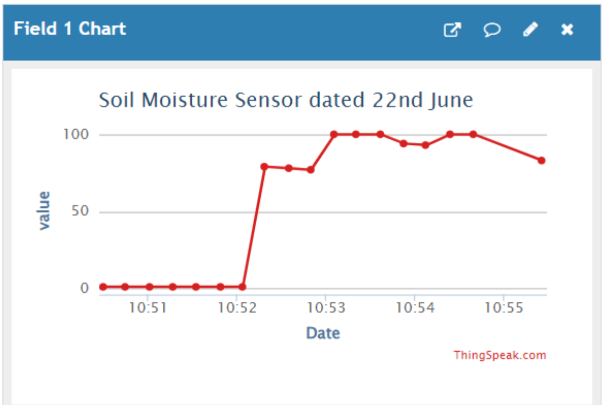

Figure 7: ThingSpeak output (at time T3)

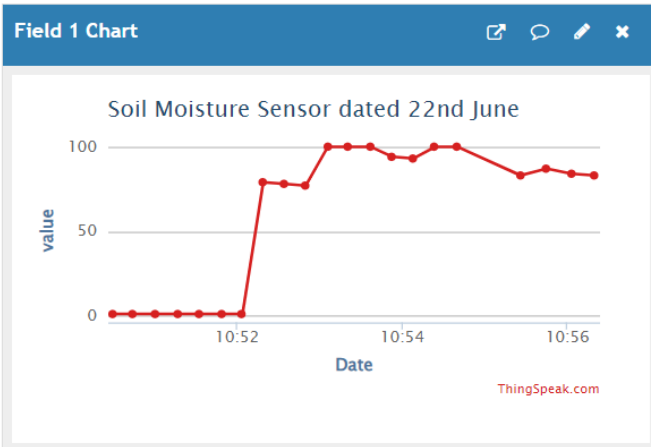

Figure 8: ThingSpeak output (at time T4)

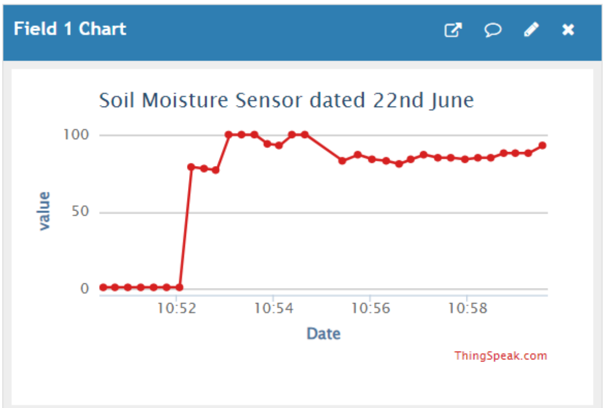

Figure 9: ThingSpeak output (at time T5)

4 Fuzzy Logic Based Landslide Early Warning system

Fuzzy logic is particularly suitable for landslide prediction due to its ability to handle uncertainty and imprecision, which are inherent in natural systems. Landslides are influenced by a combination of complex, interdependent factors such as rainfall, soil moisture, slope stability, and geological conditions. These factors often lack precise thresholds or clear relationships, making conventional models less effective.

Fuzzy logic allows for the modeling of these vague and uncertain relationships by using linguistic variables and rules, such as "high rainfall" or "moderate soil moisture," instead of rigid numerical values. This flexibility enables the system to integrate diverse inputs, account for overlapping conditions, and provide more nuanced predictions. Moreover, fuzzy logic systems can incorporate expert knowledge and adapt to varying environmental conditions, making them a robust tool for developing early warning systems and managing landslide risks effectively. Fuzzy logic-based landslide monitoring is an advanced approach used to assess the risk of landslides by dealing with uncertainties and imprecise data, which are common in natural phenomena like slope instability ([17],[18],19]. Unlike traditional binary systems, fuzzy logic allows for partial truth values between 0 and 1, enabling a more flexible and nuanced analysis of factors contributing to landslides, such as soil moisture, rainfall, slope angle, and ground movement.

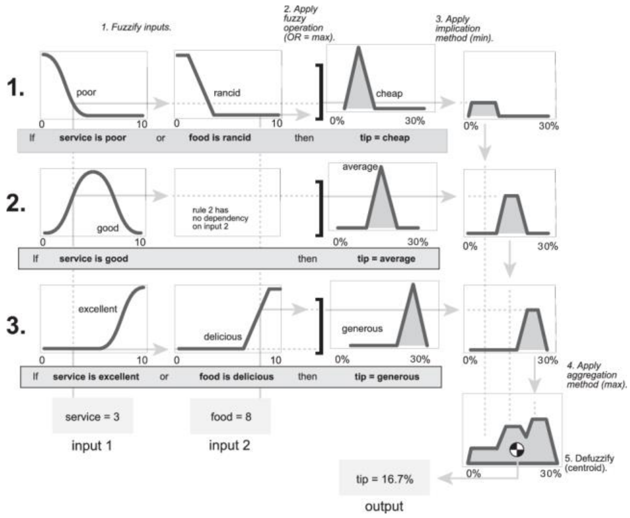

Figure 10: Some specific rules and cases processed by Mamdani fuzzy interference system

Mamdani systems offer several advantages, including their intuitive nature, making them easy to understand and implement. They are well-suited to incorporating human input, allowing for a more natural and flexible approach to decision-making. Additionally, Mamdani systems provide a more interpretable rule base, which enhances clarity and transparency in their operations. These features, combined with their widespread acceptance, make Mamdani systems a popular choice in various applications.

In this system, input parameters—such as soil moisture levels, rainfall intensity, and ground vibrations—are processed through fuzzy logic rules that mimic human reasoning. These inputs are classified into fuzzy sets (e.g., "low," "moderate," "high") and processed using a set of predefined rules. The output, which indicates the likelihood or severity of a landslide, is also expressed in degrees (e.g., "possible," "probable," or "imminent"), rather than in strict true/false terms. By integrating sensor data in real time and applying fuzzy logic, landslide monitoring systems can provide early warnings, helping to mitigate risks in vulnerable areas.

Figure 11: Fuzzy logic block diagram

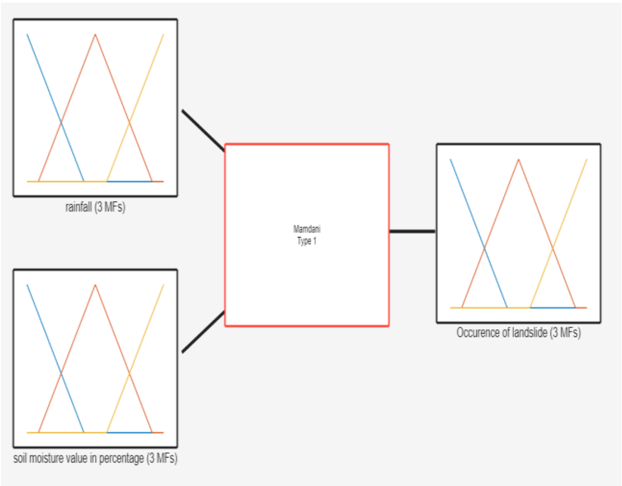

Figure 12: Fuzzy logic designer in Matlab

In this study, a real-time monitoring system has been developed to assess the risk of landslide occurrences by integrating soil moisture sensor data with artificially induced rainfall data. These two environmental parameters—real-time soil moisture levels and rainfall intensity—are utilized as the primary inputs for a fuzzy logic-based prediction model. The system is designed using the Mamdani-I type fuzzy inference system (FIS), which is one of the most widely used fuzzy logic systems for decision-making processes due to its intuitive rule-based approach.

These two inputs are processed within the fuzzy inference system, which translates the numerical sensor data into linguistic terms, such as "low", "moderate" and "high" for soil moisture and rainfall intensity. The system's outputs are observed and analyzed within MATLAB, where the fuzzy logic rules and system parameters are implemented and executed.

5 Discussions

Based on the experimental observations, it is evident that the soil moisture sensor values exhibit a rapid increase during the initial phases of rainfall. This sharp rise indicates a swift uptake of water by the soil, as it transitions from a relatively dry state to one that can accommodate a significant influx of moisture. However, as the soil continues to absorb water, a notable trend emerges: once the soil moisture content reaches approximately 70% of its maximum capacity, the rate of increase begins to slow. At this point, the soil moisture values stabilize, indicating that the soil has reached a near-saturation state where further absorption of water becomes minimal.

This steady-state behavior suggests that the pore spaces within the soil have filled to a critical threshold, limiting the capacity of the soil to retain additional moisture. The stabilization of soil moisture values reflects a balance between the incoming water from rainfall and the soil's ability to absorb and retain that water, providing important insights into the hydrological response of the slope under artificial rainfall conditions. A detailed comparison between the proposed experimental model with traditional methods are listed below:

ThingSpeak based LEWS (Landslide Early Warning System) provides real-time data visualization and analysis on a cloud-based platform. However, the traditional method often relies on manual data collection and offline processing.

Proposed method is highly scalable with minimal hardware upgrades due to cloud integration.

Low cost of ThingSpeak and Fuzzy Logic soft ware due to the open-source nature of ThingSpeak and inexpensive hardware.

6 Conclusions

Through MATLAB simulation, the system produces real-time predictions of landslide risks under different environmental conditions. This fuzzy logic-based model provides a valuable tool for early warning systems in regions prone to landslides by offering real-time, adaptive risk assessments based on changing soil and weather conditions. The results demonstrate the potential of combining real-time sensor data and fuzzy logic for effective landslide prediction and prevention.

Further, the experiment successfully demonstrated how real-time soil moisture monitoring, coupled with IoT technology, can provide valuable insights into slope stability under varying rainfall conditions. The use of ThingSpeak and Arduino proved effective for data collection, analysis, and visualization, highlighting the potential of such technologies in environmental monitoring and disaster management. The setup can be integrated with IFTTT or Zapier to send bulk messages or emails, providing warnings to residents in landslide-prone areas throughout the city of Guwahati. Lastly, the proposed model also provides a simple and cost effective alternative than the cases as discussed in the literature review.

The experiment opens avenues for future research, including integrating additional environmental factors like vegetation cover, soil composition, and seismic activity to enhance landslide prediction accuracy. Improving sensor precision and durability to withstand extreme weather conditions can further refine data reliability. Exploring advanced data analytics and machine learning models could enhance real-time prediction capabilities. Additionally, scaling up the system to cover larger geographic areas and optimizing network connectivity in remote locations are critical. Incorporating alternative power sources like solar energy and evaluating the potential of integrating other IoT platforms for automated alerts can also advance disaster management practices.

Network issues can significantly impact a landslide early warning system (LEWS) using ThingSpeak, causing data transmission delays, disrupted notifications, reduced accuracy, and integration failures, compromising timely and reliable warnings. To address these challenges, sensors can store data locally and upload it when connectivity is restored. Integrating ThingSpeak with local alarm systems, such as sirens or LEDs, ensures immediate alerts in low-connectivity areas. Continuous monitoring of the network performance will also help maintaining system robustness and reliability in delivering critical early warnings.

The experimental findings can be generalized to other landslide-prone areas, as landslides in these regions are predominantly rainfall-induced, and the soil composition is typically consistent across the hills within the city. This commonality in causal factors and geological characteristics enhances the applicability of the results, providing a basis for broader implementation of the proposed methodologies.

Acknowledgement:

Authors are thankful to all the staff and faculty members of the Department of Electrical and Electronics Engineering and Department of Civil Engineering of Assam Don Bosco University, Guwahati, Assam, India.

References:

[1] Annual Report 2022-23, Ministry of Home Affairs, Government of India.

[2] Persihillo P.,Dutta P., Bordoni M., Cevasco A., Non Linear Regression Technique to assess the Landslide Susceptibility of the Kalapahar Hill, Guwahati, Assam, State (India), *Rend. Online Soc. Geol. In.*, Vol 41, No 2, 2016, pp 179-182

[3] Ray R., Jacobs J., Relationship among Remotely Sensed Soil Moisture, Precipitation and landslide Events, *National Hazards*, Vol 43, No 1, 2007, pp 211-222

[4] Abdullah D., Zeebaree S., Comprehensive Survey of IoT based Arduino Applications in Healthcare Monitoring, *International Journal of Health Science*, Vol 6, No 3, 2022, pp 6871-6892

[5] Pawar P., Rathod H., Hadale R., Kharche S., IoT based Landslide Detection and Monitoring, *IJRAR*, Vol 6, No 2, 2018, pp-53-59

[6] Bhangale K, Mane A., Patil Y., Mapari R., Bhosale H., IoT based Landslide Detection in Hilly Area, *6th International Conference on Computing, Communication, Control and Automation(ICCUBEA 2022)*, Pune, India, 26-27 August ,2022

[7] Harinarthini S., Reddy U., IoT Enabled Landslide Detection Mitigating Environmental Impacts, *ICFTEST 2024*.

[8] Amune A., Patil S., Ushir D., Nangare A., IoT based Smart Landslide Detection System (S-LDS), *International Conference on Emerging Smart Computing and Informatics (ESCI 2023),* Pune, India, 1-3March 2023.

[9] Zohari M., Hassan O., Landslide Monitoring System Based on Internet of Things (IoT), *International Journal of Science and Engineering Applications*, 2024, Vol 13, No 4, pp 27 – 29

[10] Eknath K., Nalegaonkar A., Salunke V., IoT Based Landslide Detection & Prevention System, *IJARIIE 2018*, Vol 4 No 2, 2018, pp 692-696

[11] Atmajati E., Yuliza E., Habil H., Sadisun I., Munir M., "A simple landslide model at a laboratory scale", *AIP Conference Proceedings* 1857, 060002 2017, doi: 10.1063/1.4987085

[12]Susanto E.,Budiman F., Mukhtar D. and Latief M., "Slope, Humidity and Vibration Sensors Performance for Landslide Monitoring System", *IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob),* 2019

[13]Arzu A., Abdullah K., Mert E., Haluk A., and Kerem K., Optical Fiber Technology to Monitor Slope Movement, *Engineering Geology for Society and Territory* , 2016, Vol 2, No 4, pp 114-118

[14] E Yuliza, Study of Soil Moisture Sensor for Landslide Early Warning System: Experiment in Laboratory Scale, *Journal of Physics: Conference Series,* 2016, Vol 3, No 4, pp 30-37

[15] Roshan T., Alvin J., Raniya J., Sara M., Landslide Early Warning System by Analyzing Soil Moisture and Land Movement, *International Journal of Novel Research and Development*, 2023, Vol 8, No 5, pp 48-54

[16] Prakasham C., Aravith R., Design and Development of Real-time Landslide Early Warning System through Low Cost Soil and Rainfall Sensors, *Materials today Proceedings*, 2021, Vol 45, No 6, 2021, pp 5649-5654.

[17] Wardhana M. et al., Logic Method Design for Landslide Vulnerability, *ICENIS 2019*, pp 1-6

[18] Basofi A., Fariza A., and Dzulkarnain M., Landslides Susceptibility Mapping using Fuzzy Logic: A case study in Ponorogo, East Java, Indonesia, Proc. 2016 *Int. Conf. Data Softw. Eng. ICoDSE*, 2016, pp 0-6

[19] Femandez C., Mendoza K., and Jude A., Development of Microcontroller-based Landslide Early Warning System. *IEEE Region 10 Conference*, 2016, pp 3000-3005

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

The study was supported by Assam Science Technology and Environment Council, Department of Science, Technology and Climate Change, Government of Assam, under Student Science Scheme Vide No ASTEC/S&T/206/2019-2020/1243-1287 dated 05-05-2020

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.