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# LandsiTrack: IoT-Based Real-Time Landslide Risk Detection and Early Warning System using Soil Movement and Slope Monitoring at Barangay Cantao-an, City of Naga

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**Abstract -** *Purpose - This study aimed to develop LandsITrack, an IoT-based real-time landslide risk detection and early warning system for Barangay Cantao-an, City of Naga, Cebu. The system monitors slope instability using soil moisture and tilt sensors and provides automated SMS alerts and dashboard monitoring. Methodology - The study utilized developmental, descriptive, and experimental research methods in designing and evaluating LandsITrack. The system integrated tilt and soil moisture sensors, Arduino microcontrollers, GSM modules, and IoT platforms to monitor slope conditions, transmit real-time data, and provide automated SMS alerts and dashboard monitoring. Results - The developed system successfully monitored slope conditions and transmitted real-time alerts during testing and deployment. The inclinometer achieved an average error rate of 2.98%, while SMS notification response times under stable network conditions averaged 23.09 to 31.77 seconds across all alert levels. User Acceptance Testing also showed highly positive feedback in usability, accessibility, and effectiveness, with an overall evaluation interpreted as "Strongly Agree." Conclusion - LandsITrack successfully demonstrated the feasibility of a low-cost IoT-based landslide monitoring and early warning system capable of detecting slope instability through soil moisture and tilt monitoring. The system provided real-time monitoring and timely SMS alerts, showing strong potential in improving disaster preparedness in landslide-prone communities. Recommendation - Future improvements to LandsITrack may include integrating rainfall monitoring, expanding sensor coverage, and implementing more reliable communication technologies for long-term deployment. Continuous calibration and testing are also recommended to improve system accuracy and reliability. Implication - The successful implementation of LandsITrack demonstrates that affordable IoT-based technologies can strengthen community-level disaster preparedness and early warning capabilities in landslide-prone areas. The system may help local authorities and residents make faster and more informed decisions, potentially reducing casualties, property damage, and response delays during landslide-related incidents.*

**Keywords -** *IoT, Landslide Monitoring, Early Warning System, Soil Moisture Sensor, Inclinometer, LandsITrack, SIM800L, ThingSpeak, Disaster Risk Reduction*

## I. INTRODUCTION

Landslides are among the most destructive natural hazards affecting mountainous and hilly regions. These events can result in casualties, infrastructure destruction, environmental damage, and displacement of communities. In the Philippines, landslides frequently occur due to intense rainfall, unstable terrain, deforestation, slope excavation, and rapid urban development. Jones et al. (2023) reported that although the Philippines covers only around 6% of the land area in Southeast Asia, 46% of rainfall-induced landslide events in Southeast Asia occur in the Philippines, and 42% are typhoon-induced [1].

Barangay Cantao-an in the City of Naga, Cebu, has been identified as a landslide-prone area based on geohazard assessments conducted by the Mines and Geosciences Bureau Region VII (MGB-7), classifying the barangay as having very high landslide susceptibility [2]. In October 2023, 35 families from Purok Riverside were evacuated after large cracks appeared on a nearby mountainside [3]. The 2018 Naga City landslide further demonstrated the deadly gap between hazard recognition and timely response, where significant pre-failure fractures were visible on the slope but did not translate into protective action for downslope communities (Lagmay et al., 2020) [4].

Traditional landslide monitoring methods such as geohazard mapping and manual field inspections remain useful for hazard assessment; however, these methods provide limited real-time monitoring and warning capabilities. Recent technological developments in Internet of Things (IoT) systems provide opportunities for community-level disaster monitoring through the integration of sensors, cloud communication, and automated notification systems that can continuously collect environmental data and distribute alerts to both authorities and residents [5], [6].

This study developed LandsITrack, an IoT-based real-time landslide risk detection and early warning system that integrates tilt monitoring, soil moisture sensing, cloud-based monitoring, and automated SMS alerting. The system is grounded in the Information Systems Success Model (DeLone & McLean, 2003) [7], the Integrated Early Warning Systems framework (Basher, 2006; UNDRR, 2015) [8], [16], Slope Stability Theory (Duncan, 1996; Iverson, 2000) [5], [3], and the Technology Acceptance Model (Davis, 1989) [6].

## II. STATEMENT OF THE PROBLEM

This study designed and developed an IoT-based real-time Landslide Risk Detection and Early Warning System that uses soil movement and slope monitoring to minimize the risks and damage caused by landslides. Specifically, this study sought

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to address the following:

- Identify the critical factors contributing to landslides and determine appropriate soil movement and slope monitoring parameters.
- Develop a prototype system that integrates IoT-enabled sensors for soil movement, slope angle, and soil moisture monitoring, designed to collect real-time data, analyze hazard thresholds, and automatically send early warning alerts via SMS notifications and user dashboard monitoring whenever potentially dangerous slope instability is detected.
- Evaluate the performance of the developed system in terms of: (3.1) accuracy of soil movement detection, (3.2) reliability of slope angle monitoring, (3.3) response time of data transmission and the alert system, and (3.4) efficiency of the early warning notifications sent to end-users.
- Conduct user acceptance testing of the system in terms of: (4.1) Usability, (4.2) Accessibility, and (4.3) Overall effectiveness.

## III. METHODOLOGY

This study used a combination of developmental, descriptive, and experimental research methods to create and evaluate the LandsITrack IoT-based early warning system. The developmental method guided the design and creation of the system, including hardware assembly, sensor integration, and software programming. The descriptive method was utilized to gather information from residents and barangay officials regarding landslide awareness, preparedness, and evaluation of the system's usability and usefulness. The experimental method was applied during prototype testing, where the tilt and soil moisture sensors underwent controlled and field tests to assess accuracy, response time, reliability, and stability.

### A. *Research Environment*

The research was conducted in Barangay Cantao-an, City of Naga, Cebu, an area identified as landslide-prone due to steep topography, unstable soil composition, and previous slope failure incidents. The location provided a suitable and realistic environment for prototype testing and data collection, enabling the researchers to evaluate the LandsITrack system under conditions that closely simulate actual landslide scenarios.

### *B. Research Respondents and Instrument*

Nine respondents were selected through purposive sampling from residents and barangay officials of Barangay Cantao-an who are directly affected by potential landslide hazards. The main data collection instrument was a structured survey questionnaire with three parts: respondent profile, landslide awareness and preparedness, and system evaluation. A four-point Likert scale was applied (1 = Strongly Disagree, 4 = Strongly Agree), and Weighted Mean Scores (WMS) were calculated and interpreted using the ranges: 3.50–4.00 = Strongly Agree, 2.50–3.49 = Agree, 1.50–2.49 = Disagree, 1.00–1.49 = Strongly Disagree.

### *C. System Architecture*

The developed system consisted of dual field monitoring nodes equipped with MPU6050 MEMS tilt sensors (dual-depth: 0.60 m and 0.75 m per node) and capacitive soil moisture sensors integrated with Arduino ATmega328 microcontrollers. ESP32-WROOM-32 modules handled IoT communication with ThingSpeak, while SIM800L GSM modules managed SMS alert dissemination. Each node was powered by a 6W solar panel and a YTX4L-BS 12V 3Ah AGM battery, with the ESP32 operating in light-sleep mode to maintain a monitoring interval of 28 seconds to 1 minute and 7 seconds.

The main system, powered by a 60W solar panel and AGM battery, received GSM transmissions from the field nodes and coordinated alert dissemination to recipients. Sensor readings were transmitted to ThingSpeak and Firebase platforms and displayed through a Progressive Web Application (PWA) dashboard hosted on GitHub Pages, providing real-time monitoring, historical data visualization, and administrative management.

### *D. Alert Mechanism*

A four-level alert mechanism was implemented: Level 1 – Low Risk Movement Detected (5° tilt / 60% moisture), Level 2 – Moderate Risk Elevated Movement Detected (10° / 75%), Level 3 – High Risk (15° / 85%), and Level 4 – Critical – Evacuate Now. Level 4 required simultaneous validation from both sensor nodes within a five-minute rolling window before issuing evacuation warnings, minimizing false alarms. Tilt thresholds were established based on conservative margin-setting informed by Uchimura et al. (2015) [11], while soil moisture thresholds were derived from Wicki et al. (2020) [21]. SMS alerts were written in the Bisaya language, with content tailored per alert level and recipient group.

## IV. RESULTS AND FINDINGS

### *A. System Functionality*

The developed LandsITrack system successfully demonstrated real-time monitoring and automated warning capabilities during controlled and field testing. Sensor nodes continuously collected tilt and soil moisture readings and transmitted data to the cloud platform. The PWA dashboard displayed sensor values, alert levels, historical records, and system health indicators. SMS alerts were successfully delivered to designated recipients according to the triggered alert level. The dual-node validation mechanism effectively minimized false evacuation alerts by requiring simultaneous critical detection from both nodes before issuing Level 4 warnings.

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*B. System Performance*

Table I presents the key performance metrics recorded during testing and field deployment.

Table 1. System Performance Summary

| Metric | Result |
|---|---|
| Tilt Sensor Avg. Error Rate | 2.98% |
| SMS Response – Level 1 (Stable Network) | 23.09 s (avg) |
| SMS Response – Level 2 (Stable Network) | 26.07 s (avg) |
| SMS Response – Level 3 (Stable Network) | 28.95 s (avg) |
| SMS Response – Level 4 (Stable Network) | 31.77 s (avg) |
| Overall Avg. SMS Response (Stable) | 27.47 s |
| SMS Response – Level 1 (Unstable Network) | 51.39 s (avg) |
| SMS Response – Level 4 (Unstable Network) | 1 min 32.58 s (avg) |
| Dashboard Update Interval | ~27.8 s |
| Node Monitoring Cycle Interval | 28 s – 1 min 7 s |
| Node Standalone Battery Runtime | ~50 hours |
| Node Solar Panel Net Surplus (6W) | 3.6 Wh/day |
| Main System Solar Net Surplus (60W) | 51.8 Wh/day |
| Slope Monitoring Pass Rate (Simulated L4) | 7/10 trials |

The MPU6050 inclinometer achieved an average error rate of 2.98% across ten trials, with individual errors ranging from 0.13% at 15° to 6.65% at 20°, confirming reliable angular measurement for slope-tilt monitoring. This aligns with findings by Artese et al. (2015) [7] that low-cost MEMS tilt sensors can detect meaningful precursory angular changes when properly calibrated. SMS response times under stable conditions averaged 27.47 seconds overall, with longer times at higher alert levels attributable to the SIM800L's sequential delivery architecture. Under unstable network conditions, times increased significantly and delivery failures were observed, confirming GSM signal quality as the primary external variable affecting alert reliability [9].

Slope monitoring reliability testing yielded a 7/10 pass rate under simulated collapse conditions, with three failures recorded when only one node sent an alert. The solar energy configuration confirmed sustainable off-grid operation, with the 6W node panel producing a 3.6 Wh daily surplus and the 60W main system panel producing 51.8 Wh surplus.

*C. User Acceptance Testing – Usability*

Table II presents UAT results for Part I: Usability (n = 9).

| Statement | WMS | Interpretation |
|---|---|---|
| 1. The system is easy to learn and operate. | 3.44 | Agree |
| 2. The interface is clear and understandable. | 3.67 | Strongly Agree |
| 3. The dashboard layout is organized and user-friendly. | 3.33 | Agree |
| 4. Navigating the system features is simple and intuitive. | 3.56 | Strongly Agree |
| 5. The alert messages are clear and easy to understand. | 3.56 | Strongly Agree |
| **Overall WMS** | **3.51** | **Strongly Agree** |

Usability obtained a WMS of 3.51 (Strongly Agree), indicating that respondents found the system user-friendly and easy to operate. The dashboard interface and SMS notification format were perceived as clear and understandable, even for users with limited technical experience. This finding aligns with the Technology Acceptance Model [6], wherein perceived ease of use is a primary determinant of user adoption.

*D. User Acceptance Testing – Accessibility*

Table III presents UAT results for Part II: Accessibility (n = 9).

Table III. User Acceptance Testing – Accessibility

| Statement | WMS | Interpretation |
|---|---|---|
| 1. The system is accessible whenever it is needed. | 3.89 | Strongly Agree |
| 2. The system works on commonly used devices. | 3.67 | Strongly Agree |
| 3. The dashboard loads within an acceptable time. | 3.22 | Agree |
| 4. I can access the system without significant delays. | 3.44 | Agree |
| 5. I can access the system at any time (24/7). | 3.56 | Strongly Agree |
| **Overall WMS** | **3.56** | **Strongly Agree** |

Accessibility achieved a WMS of 3.56 (Strongly Agree). The dual-access design — web-based dashboard and SMS alerts — ensured information availability regardless of device type or internet connectivity, which is particularly important in community-based deployments. Luht-Kallas et al. (2023) [19] demonstrated that SMS remains a practical and widely

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accessible channel for early warning in communities with varying levels of digital access.

*E. User Acceptance Testing – Overall Effectiveness*

Table IV presents UAT results for Part III: Overall Effectiveness (n = 9).

| Statement | WMS | Interpretation |
|---|---|---|
| 1. The system provides timely warnings of potential landslides. | 3.89 | Strongly Agree |
| 2. The alerts help me take appropriate action for safety. | 3.89 | Strongly Agree |
| 3. The system increases my awareness of landslide risks. | 3.78 | Strongly Agree |
| 4. The system can help reduce possible damage and casualties. | 4.00 | Strongly Agree |
| 5. I trust the warnings provided by the system. | 3.56 | Strongly Agree |
| **Overall WMS** | **3.82** | **Strongly Agree** |

Overall Effectiveness achieved the highest WMS of 3.82 (Strongly Agree). The item "The system can help reduce possible damage and casualties" received a perfect score of 4.00, reflecting strong community confidence in LandsITrack's potential impact on disaster preparedness. Mowbray et al. (2024) [20] found through a systematic review that mobile warnings consistently increase the likelihood that people receive hazard information and improve stated intentions to take protective action.

*F. Summary of User Acceptance Testing*

Table V summarizes the overall UAT results across all three evaluation dimensions.

Table V. Summary of User Acceptance Testing

| Section | WMS | Interpretation | n |
|---|---|---|---|
| Part I – Usability | 3.51 | Strongly Agree | 9 |
| Part II – Accessibility | 3.56 | Strongly Agree | 9 |
| Part III – Overall Effectiveness | 3.82 | Strongly Agree | 9 |
| **Overall Weighted Mean Score** | **3.63** | **Strongly Agree** | |

The overall Weighted Mean Score of 3.63 (Strongly Agree) confirms strong community acceptance of LandsITrack across all dimensions. The findings indicate that respondents considered the system easy to use, accessible, and effective in improving landslide preparedness, consistent with the Information Systems Success Model [7] wherein user satisfaction is jointly driven by system quality, information quality, and service quality.

## V. FINDINGS

Based on the development, deployment, and evaluation of the LandsITrack system, the following findings were identified:

- The developed dual-node monitoring architecture successfully collected and transmitted real-time tilt and soil moisture data from the monitored slope area. Both nodes operated consistently within the expected monitoring cycle and uploaded data reliably to the cloud platform.
- The system effectively implemented a four-level alert mechanism capable of automatically disseminating SMS notifications to designated recipients according to detected risk levels, with content appropriately tailored per recipient group.
- The use of dual-node validation for Level 4 alerts minimized the occurrence of false evacuation warnings by requiring confirmation from both sensor nodes before issuing critical alerts.
- The Progressive Web Application dashboard successfully provided real-time visualization, historical monitoring, and administrative management features, installable on both Android and iOS devices without requiring an app store download.
- Remote threshold configuration through ThingSpeak allowed administrators to update alert parameters without requiring physical access to the deployed hardware.
- The solar-powered configuration provided a net daily energy surplus for both the field nodes and the main system, confirming sustainable off-grid operation throughout the deployment period.
- Under unstable cellular network conditions, SMS delivery failures and significantly longer response times were observed, identifying GSM signal quality as the primary external variable affecting alert reliability.
- User Acceptance Testing results indicated strong respondent agreement regarding the usability, accessibility, and effectiveness of the developed system, obtaining an overall Weighted Mean Score of 3.63 interpreted as "Strongly Agree."

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## V. CONCLUSION

The study successfully developed LandsITrack, an IoT-based real-time landslide risk detection and early warning system capable of monitoring slope tilt and soil moisture conditions while automatically disseminating alerts through SMS notifications and dashboard monitoring.

The results demonstrated that the system effectively collected and transmitted real-time environmental data, implemented reliable multi-level warning mechanisms, and reduced false alarms through dual-node validation. User evaluations further showed strong acceptance in terms of usability, accessibility, and effectiveness, with an overall WMS of 3.63 (Strongly Agree).

The study highlights the potential of low-cost IoT technologies in strengthening community-based disaster risk reduction and improving preparedness in landslide-prone areas such as Barangay Cantao-an, City of Naga, Cebu. The system does not predict landslides but detects precursor indicators of slope instability consistent with established early warning principles [11], [17], [21].

## VII. RECOMMENDATIONS

Based on the study's findings, the following improvements are recommended:

- Integrating a rainfall intensity sensor to capture the primary hydrological trigger of slope failure alongside existing tilt and moisture parameters.
- Expanding the number of sensor nodes across the monitored slope to improve spatial coverage and data reliability.
- Adopting LoRaWAN or other LPWAN communication protocols to reduce dependency on GSM cellular signal quality in remote deployments [14].
- Replacing the cranking-type AGM battery with a deep-cycle variant to improve long-term energy storage reliability.
- Conducting extended deployment across at least one full wet season to enable data-driven refinement of tilt and soil moisture alert thresholds [11].
- Implementing a bulk SMS gateway to enable simultaneous multi-recipient delivery and reduce response time at higher alert levels.
- Enhancing enclosure weatherproofing to improve hardware durability under sustained tropical field conditions.

## AUTHOR CONTRIBUTIONS

**Author 1:** Conceptualization, Methodology; Data curation, Writing-Original, draft preparation, Reviewing; **Author 2**: Investigation, Validation, Visualization, draft preparation, Writing- Reviewing

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## GENERATIVE AI STATEMENT

The authors used ChatGPT (Open AI) solely as a language-support tool to improve the clarity, coherence, and grammatical accuracy of the manuscript. All AI-assisted outputs were critically reviewed, revised, and validated by the authors to ensure the accuracy, integrity, and originality of the content. The authors accept full responsibility for the final version of the manuscript and its published content.

## ETHICAL CONSIDERATIONS

Prior to the data gathering, ethical approval was obtained from the University of Cebu Academic Research Ethics Committee (UCAREC). The approved protocol ensured adherence to the principles of respect for persons, beneficence, justice, voluntary participation, informed consent, confidentiality, and anonymity, and compliance with the Data Privacy Act throughout the research process.

## DECLARATION OF INTEREST

The authors declare that they have no competing financial, professional, or personal interests that could have influenced the conduct, findings, or publication of this study.

## DATA AVAILABILITY

Data will be made available by the corresponding author on request.

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