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Rain-Madems: Development of Rainfall Induced Mass Wasting Advance Early Warning and Monitoring System

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ABSTRACT

The study presented a quantitative study focused on developing an early advance warning system that mitigates risks in areas prone to rainfall induced mass wasting, utilizing vibration, moisture, and accelerometer sensors into a mobile robotic platform. Seeking to provide real-time data and predictive analysis to local authorities and communities. The system will use machine learning algorithms to enhance prediction accuracy, ensuring timely alerts and reducing potential damage. Employing an experimental research design, RAIN-MADEMS is compared with the standard equipment used by PHIVOLCS DYNASLOPE project that installs sensors under the ground to detect movement of the soil and alert communities of impending deep-seated landslides. This study contributes valuable insights into the development and assessment of RAIN-MADEMS, offering potential solutions to mitigate the impacts of heavy rainfall induced landslides on lives, infrastructure, and the environment.

Keywords: Landslide early *alert system, rainfall analysis, disaster management, mass wasting, moisture sensor, accelerometer, WiFi module, Node MCU, Arduino UNO*

1. INTRODUCTION

Mass wasting or landslides are a pressing concern due to their severe impact on lives and infrastructure, especially in regions prone to heavy rainfall or steep terrain. Recent events indicate an alarming rate of 50% more intense rainfall where the Philippine island faces worse landslides. Newest occurrence reported by PHILSTAR Global sait it happened at around 7:50 pm on February 6, 2024. With an estimated 9.8 hectares (24 acres) of land was buried by rocks, mud and trees that slid over 700 meters (2,300 ft) down a steep mountainside near the Apex Mining Co. concession in Zone 1 of Barangay Masara, Davao De Oro, Philippines. With at least 98 people reported dead and 9 missing persons The Chief Science Research Specialist at the University of the Philippines and a member of the WWA team, Richard Ybañez said "It's well known that Mindanao island is highly vulnerable to landslides due to high rainfall, frequent earthquakes and steep, hilly terrain along its eastern half".

Generally according to the published website of the National Park Service in September 2019, mass wasting is the movement of rock and soil down slope under the influence of gravity. Rock falls, slumps, and debris flows are all examples of mass wasting. Often lubricated by rainfall or agitated by seismic activity, these events may occur very rapidly and move as a flow. The Philippines is located near the equator that is why it is considered as a tropical country where it only experiences intense wet and dry seasons (Sunny Lin., 2021).

In recent years, advancements in sensor technology, robotics, and data analytics have opened new possibilities for early detection and warning systems (Luo et al., 2024). By integrating multiple types of sensors—such as seismic sensors to detect ground vibrations, moisture sensors to monitor soil water content, inclinometers to track ground tilt, and geophones to measure ground movement—into a unified system, we can obtain comprehensive data on environmental conditions that precede mudslides and landslides (Huang et al., 2022).

The RAIN-MADEMS project leverages these technological advancements to create a robust, real-time monitoring and warning system. This project aims to develop mobile robotic platforms equipped with various sensors, capable of continuous environmental monitoring and data transmission. By employing machine learning algorithms, the system will analyze collected data to identify patterns and predict potential landslide events, providing early warnings to local authorities and communities.

Gunawan et al. (2019) in their work "Design of Early Warning System Flood and Landslide Mitigation Sensor Based on Internet of Things" discuss how these systems can provide early warnings for floods and landslides by detecting environmental changes through sensors installed in disaster-prone areas. The system they describe integrates hardware, such as microchip controllers, with software applications leveraging the Internet of Things (IoT). This integration allows for real-time monitoring and data processing, essential for predicting potential disasters.

Seismic sensors, such as accelerometers and seismometers, are critical for detecting ground vibrations and seismic activity. According to Tian et al. (2023) in "Detecting the Unseen: Understanding the Mechanisms and Working Principles of Earthquake Sensors," these sensors are essential in monitoring earthquake-induced landslides. By detecting early ground movements, seismic sensors provide valuable data for predicting landslides and triggering early warnings. These sensors can be strategically placed in regions prone to seismic activity to continuously monitor the earth's movements, ensuring timely and accurate detection of any potential threats. This real-time monitoring is crucial for initiating preemptive measures to mitigate disaster impacts.

Soil moisture sensors, both capacitive and resistive, measure the volumetric water content in soil. Studies by Yu et al. (2021) in "Review of Research Progress on Soil Moisture Sensor Technology" highlight the importance of soil moisture in slope stability and the occurrence of landslides. High moisture content in soil can reduce its shear strength, making slopes more susceptible to failure. These sensors help in understanding water saturation levels that can lead to soil failure, providing critical data for assessing landslide risk. By continuously monitoring soil moisture levels, these sensors aid in predicting and preventing landslides, especially in regions with heavy rainfall or irrigation practices.

Artha and Julian (2018) with their research entitled "Landslide early warning system prototype with GIS analysis indicated by soil movement and rainfall" developed a landslide early warning system prototype incorporating accelerometers for ground movement detection and a water flow sensor for rainfall measurement. Their system uses a microcontroller to process these signals, triggering alarms and sending data to a monitoring center. An LCD displays acceleration data, and a telemetry system transmits information for remote monitoring, utilizing GIS spatial data for visualization. This approach aligns with Gunawan et al. (2019), who emphasize the importance of integrating sensor technology with IoT for real-time monitoring and early disaster prediction.

The system developed by Artha and Julian was tested in Kampung Gerendong, an area with a cumulative vulnerability score indicating a high risk of landslides. The results confirmed the system's effectiveness, demonstrating its ability to detect soil movement and rainfall exceeding 100 mm/day, and provide timely warnings. This practical application underscores the importance of sensor-based systems in landslide prediction and aligns with previous research on the effectiveness of sensor networks in landslide-prone areas (Yin et al., 2010).

This proactive approach is essential for improving disaster preparedness and response. With timely and accurate warnings, communities can evacuate areas at risk, and emergency services can take preventive measures, significantly reducing the loss of life and property. The integration of this system with local disaster response units ensures that the warnings are effectively communicated and acted upon.

OBJECTIVES

The study generally aims to develop an early warning system for the provinces of Mindanao islands that are highly susceptible for rainfall induced mass wasting or landslides.

Specifically, this study aims to:

1. Develop a landslide early warning device equipped with a capacitive soil moisture sensor , and find out the maximum water the soil can carry before collapsing.
2. Establish a landslide early warning device integrated with an accelerometer to measure the slope's average and maximum tilt before soil tumbles down. .
3. Design an application that integrates and utilizes real-time monitoring and an early alert system to reduce the possibility of rainfall-induced mass wasting.
4. Evaluate the accuracy of the gathered data on landslide occurrences to improve predictive models and enhance future warning systems.

2. METHODOLOGY

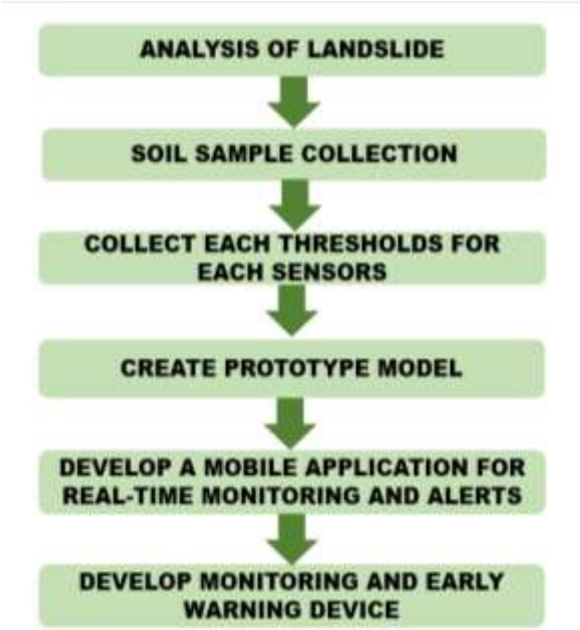

Figure 1. *Flow chart of methods to do*

The prototype integrated a quick landslide alert system with various employed innovative approaches to calculate predictive downslope motion of masses of land. Based on (Andrew Lees, 2021), landslides are commonly initiated by several factors, namely, slopes already on the verge of movement by rainfall, changes in water level, stream erosion, changes in groundwater, Earth vibrations such as earthquakes, volcanic activity, disturbance by human activities (mining or traffic), or any combination of these factors. The National Economic and Development Authority (NEDA) stated that Davao De Oro terrain of the provinces consists of flat, rolling, hilly, and mountainous portions, which are evenly distributed throughout the area. The highest elevation in the province reaches a height of more than 2,000 meters above sea level (MASL), and this is found in the municipalities of Maragusan, New Bataan, and Pantukan which has an aggregate area of 80.89 square kilometers or 1.73 percent of the total land area of the province. The lowest elevation is below 100 MASL with Laak having the widest area of 2.1537 sq. km., while New Bataan has the narrowest of 19.10 sq. km. Its mountain ranges and woods provide protection from typhoons. However, when heavy rains continue, some areas of the municipalities of Mawab, Monkayo, Montevista, and Nabunturan flood. The rainy season is most likely to occur between May and January of the following year, with the highest rainfall occurring from October to December. The dry season will most likely begin in February and last until April.

Figure 2. *Davao Region susceptibility to Rain-Induced Landslides Map Photo Source: Hazard Hunter PH*

Figure 3. *Davao De Oro Provinces susceptibility to Rain-Induced Landslides Map Photo Source: Hazard Hunter PH*

A study and implementation of IoT from India (Gupta,2024) used the flowing sensors to create an early warning system to mitigate the occurrence of landslides: Soil moisture sensor: It measures the moisture content of soil. Rain gauges: It measures the amount of rainfall an area receives in a particular time. Pore pressure sensor: It is a type of piezometer. It measures pressure of groundwater held within a Soil / Rock. Vibration sensor: It is a type of accelerometer that senses vibrations. It measures the Earth shaking effect. Additionally, an overview study of rainfall-triggered landslide early warning systems (LEWS) from (SHEAR Knowledge Brokers Team, 2021) stated that LOCAL LEWS can only provide warning information for the specific instrumented locations and only alerts when a specific threshold is at its limit.

According to a published article of (Current-Research-Ohlmacher-Page 7 of 9, n.d.) The average slope angle for landslides is 22.2 degrees with 75% of the landslides on slopes greater than 15 degrees. Furthermore, If the friction on a rock is greater than gravity for a certain slope, the rock material will most likely remain. However, if gravity is stronger, the slope will fail. The steeper the slope, the greater the friction or rock strength required to resist downward motion.The steepest angle a slope can be before the ground will slide is about 35 degrees, called the angle of repose. Moreover, Soil properties play a critical role in forming landslides, as cohesive soils such as clay and silt are more susceptible to landslides than granular soils such as sand and gravel (Batumalai et al., 2023). To add, vegetation helps bind material together; removing vegetation increases the chance of a landslide (British Geological Survey, 2021). According to J. Dou et al. (2015), shallow landslides are landslides having depth between 1.5 m and 10 m from the existing ground surface. Likewise, landslides originating from depths greater than 10 m are generally considered as deep landslides.

The researcher decided to use the accumulated published literature as a guide to create the RAIN-MADEMS prototype, including some of the ones discussed in this section. Using the different thresholds to categorize the susceptibility of an area to rain-induced mass wasting. Lastly, the data to be recorded will be sent through the app to be monitored and alert when certain thresholds are at its limit.

A plastic pipe, three feet long, was used as a body and protective suit for the sensors buried at least 3 feet below as a set up for data collection apparatus ensuring the safety of the wires and other components. Additionally, gathering the minimum and maximum numerical data for soil moisture sensor is required to keep track of the average moisture sensitivity of the sensor towards dry and wet soil while being buried together with the vibration sensor. Along with that, an accelerometer is strategically positioned inside the 3D printed canister to measure the tilting and the slope of the soil. After that, the researcher then merges all three data of each sensor onto the microcontroller which will then relay output of real-time monitoring of each sensor giving insights of different patterns.

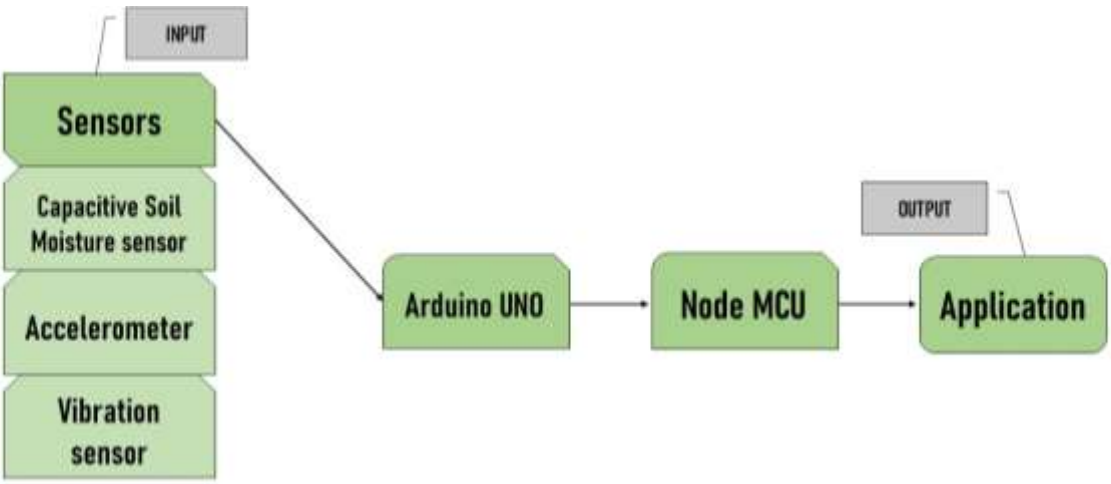

Figure 4. *A conceptual diagram of how the gathered data flows in RAIN-MADEM*

2.1 Preparation of Materials

A 3D model was made to create a canister solely for the non-waterproof components such as the micro controllers and battery supply making readings easier even in the presence of moisture. The researcher had installed waterproof sensors to detect the moisture level of the soil and ground vibration activity to record data during rainy seasons. In order to record data from the sensors without requiring physical contact, a WiFi module (Node MCU) was installed, increasing data collecting flexibility.

COSTING:

ITEMS	QUANTITY	PRICE	TOTAL
wires	15 m	Php 2.50	Php 37.50
PVC pipe #2	1 pc	Php 88.00	Php 88.00
Wheels	1 set	Php 308.50	Php 308.50
Spray Paint	1 pc	Php 115.00	Php 115.00
Capacitive Soil Moisture	1 pc	Php 69.00	Php 69.00
8” Jumper wire	1 set	Php 17.00	Php 17.00
12” Jumper wire	1 set	Php 18.00	Php 18.00
Electrical Tape	1 pc	Php 20.00	Php 20.00
Rechargeable LI-ON Battery 3.7V	3 pc	Php 95.00	Php 285.00
DC cord	1 pc	Php 20.00	Php 20.00
Vibration Sensor	1 pc	Php 135.00	Php 135.00
BMS Module	1 pc	Php 180.00	Php 180.00
Arduino UNO w/ cable	1 pc	Php 459.00	Php 459.00
Accelerometer	1 pc	Php 385.00	Php 385.00
Solar Panel 12V	1 pc	Php 580.00	Php 580.00
3D printed box	1 pc	Php 2,800.00	Php 2,800.00
USB cord	1 pc	Php 65.00	Php 65.00
Micro USB cord	1 pc	Php 99.00	Php 99.00
Plywood	1 pc	Php 390.00	Php 390.00

Plastic Cover	1 pc	Php 165.00	Php 165.00
		GRAND TOTAL	Php 6,235.00

2.2 Software Development

Using Arduino UNO and Node MCU, the researcher created and manually wrote codes with the help of the conceptual diagram and the corresponding list of guide sensors listed above. C++ was utilized for development because it is compatible with the microcontroller and sensors. C++ is an object-oriented programming (OOP) language that many see as the ideal language for developing large-scale programs. It can be utilized in sectors such as system software, game development, embedded systems, scientific computing, and high-performance applications. The C++ standard library includes a variety of coding conveniences and functions, making it simple to create complicated software systems. C++ may operate on a variety of platforms, including Linux, Mac, and Windows. (Barney, 2023).

SW-420 vibration sensor is a module that can detect vibrations or shocks on a surface. It can be used for various purposes, such as detecting door knocks, machine malfunctions, car collisions, or alarm systems. In addition, there is a potentiometer that can be further used to control the threshold point of the vibration or its sensitivity. There isn't any need to recalibrate the programming because it uses constant data of 0-1, with 0 indicating no vibration detection and 1 indicating vibration detection. To set the sensitivity for vibration detection, the researcher can twist the potentiometer from 1 to 3.

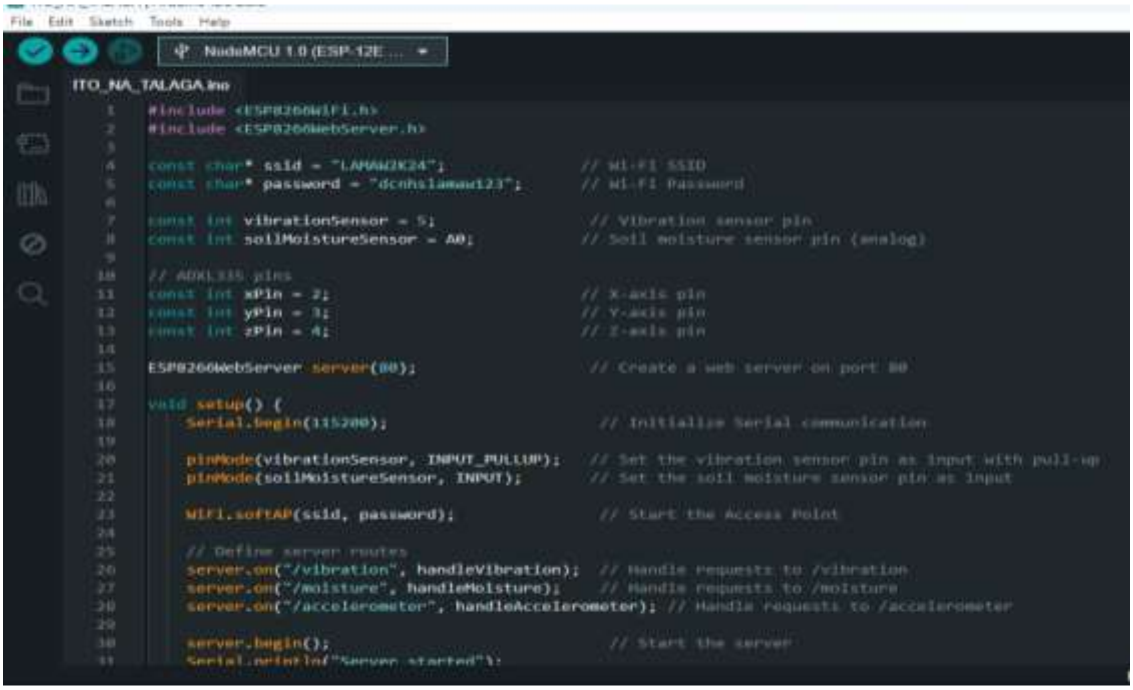

Figure 5. *Coding vibration sensor using Arduino Uno & Node MCU*

Capacitive Soil Moisture V 1.2 is a soil moisture sensor that measures soil moisture levels by capacitive sensing rather than resistive sensing like other sensors on the market. The Soil Moisture sensor is made of corrosion-resistant material which gives it excellent service life. The researcher matched its data to soil moisture percentages to make data collection easier when determining soil moisture levels.

Figure 6. *Coding soil moisture sensor using Arduino Uno & Node MCU*

The ADXL335 accelerometer is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The sensor measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. The researcher calibrates its data to degrees. By collecting the raw X, Y, and Z values from the accelerometer, the researcher used the following formulas to get its angle:

1. Determining the calibrated value

$$\text{Calibrated Value} = \text{Raw Value} - \text{Offset}$$

2. Converting to Tilt Angles

Pitch (rotation around Y-axis):

$$\text{Pitch} = \arctan\left(\frac{X}{\sqrt{Y^2 + Z^2}}\right)$$

Roll (rotation around X-axis):

$$\text{Roll} = \arctan\left(\frac{Y}{\sqrt{X^2 + Z^2}}\right)$$

3. Converting Radians to Degrees

$$\text{Angle in degrees} = \text{Angle in radians} \times \left(\frac{180}{\pi}\right)$$

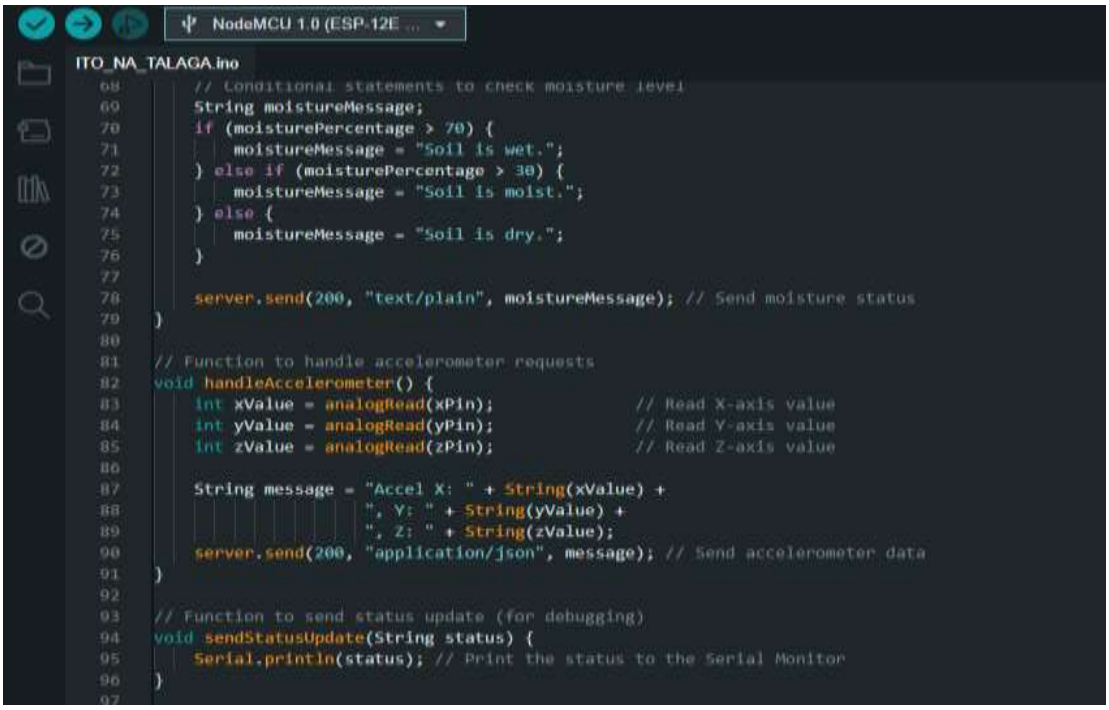

Figure 7. *Coding accelerometer using Arduino Uno & Node MCU*

2.3 Prototype Making

During prototyping, the researcher opted for utilizing the schematic diagram to connect the wirings. Making the workflow significantly faster.

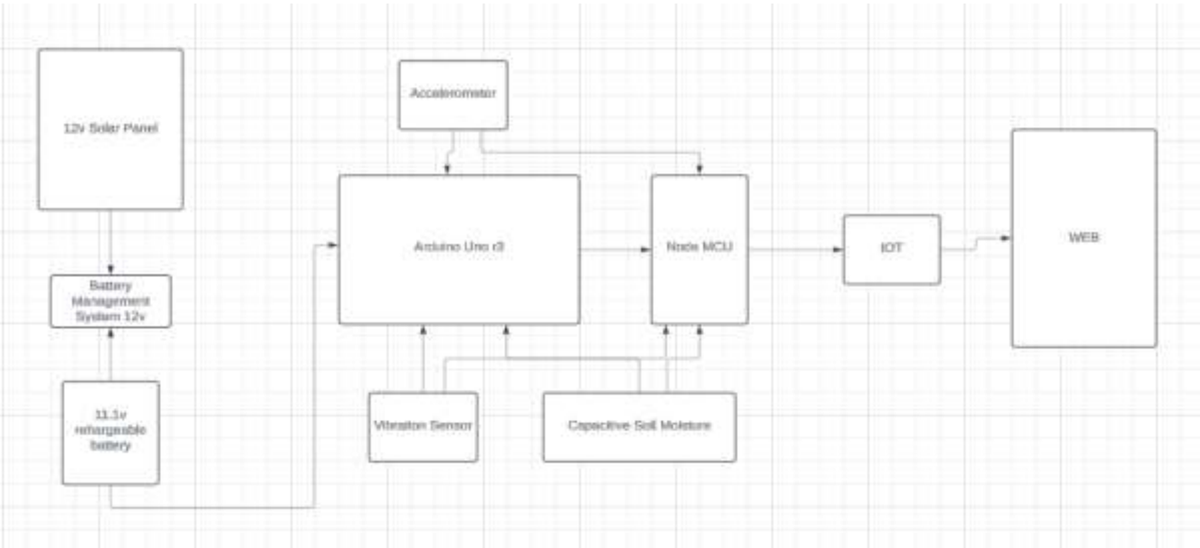

Figure 8. *A conceptual framework for RAIN-MADEMS*

<u>OPERATING VOLTAGE AND CURRENT DRAW</u>:

Arduino UNO: 5V/50mA

Node MCU: 3V/300mA (during WiFi transmission)

Vibration sensor: 5V/10mA

Capacitive Soil Moisture sensor: 5V/22mA

Accelerometer: 3.5mA

Arduino UNO Input Voltage: 5V

Arduino UNO current output: 800mA

CONNECTION OF SENSORS TO MICROCONTROLLER:

Soil Moisture:

VCC to 5V (Arduino UNO Board)

AOUT to D6 (MCU V3 ESP8266)

GND to GND (MCU V3 ESP8266)

Vibration sensor:

VCC to 5V (Arduino UNO Board)

DO to D5 (MCU V3 ESP8266)

GND to GND (MCU V3 ESP8266)

Accelerometer:

VCC to 5V (Arduino UNO Board)

X-OUT to D2 (MCU V3 ESP8266)

Y-OUT to D3 (MCU V3 ESP8266)

Z-OUT to D4 (MCU V3 ESP8266)

GND to GND (MCU V3 ESP8266

To evaluate the accuracy of the RAIN-MADEMS prototype, the researcher made the choice to build a four by three feet simulator capable of handling 25 kilograms of clay soil. In this case, the simulator will be subjected to significant rainfall and external forces that may cause movement within the soil.

Figure 9. *Building a simulator box*

2.4 Data Collection

The RAIN-MADEMS system collected real-time environmental data using a combination of sensors to monitor soil moisture, tilt angle, and ground vibrations. A capacitive soil moisture sensor was embedded in the ground at three feet to continuously measure moisture levels, particularly during simulated rainfall, and flagged critical thresholds when moisture levels exceeded 50%, indicating potential soil liquefaction. The system also employed an ADXL335 accelerometer to track changes in tilt angle, detecting early signs of instability at 22 degrees and significant movement at 30 degrees or higher. Additionally, a SW420 vibration sensor was used to monitor ground vibrations, providing binary data to identify whether movement was occurring. The collected data from these sensors was processed by an Arduino Uno and transmitted wirelessly through the NodeMCU ESP8266, enabling continuous real-time monitoring and instant alerts when critical thresholds were reached. This integrated data collection approach ensured accurate predictions of potential landslides across all ten tests.

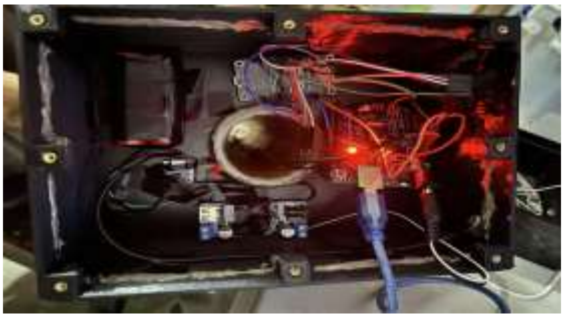

Figure 10. Testing of the prototype

Soil Moisture (%)	Alert Level
Below>30-40	Low
41-55	Moderate
56-65	High
66- 70<Above	Very High

Moisture below 30% was labeled Low Risk, indicating stable soil conditions, while levels between 30% and 40% were classified as Moderate Risk, signaling increased moisture but still manageable stability. When moisture reached 56% to 65%, it was flagged as High Risk, indicating potential instability. Lastly, levels above 66% were marked as Very High Risk, reflecting a strong likelihood of soil liquefaction and mass wasting.

Angle/Tilt of Slope (°)	Alert Level
18-22	Normal
23-26	Caution
27-29	Warning
30-34	Critical

The accelerometer was classified into four alert levels to assess slope stability. Tilt angles between 18° and 22° were considered Normal, indicating stable slope conditions. Angles from 23° to 26° triggered a Caution alert, signaling the early stages of potential instability. When the tilt reached 27° to 29°, a Warning was issued, reflecting increased slope movement and a higher risk of mass wasting. Finally, angles from 30° to 34° were categorized as Critical, indicating severe instability and a high likelihood of slope failure. These classifications enabled the system to provide timely alerts as the tilt angle increased, ensuring that escalating risks were effectively monitored.

The following table illustrates the RAIN-MADEMS system's performance in monitoring environment-related variables, specifically soil angle, moisture levels, and ground movement, in order to predict the risk of rain-induced mass wasting events like landslides. The system collected data from ten tests, each concentrating on tilt angle, moisture content, and movement detection, with corresponding alarm levels determined by these factors and prescribed limitations.

Test no.	Angle (°)	Moisture (%)	Movement (yes/no)	Alert Level
1	22	30%	No	Safe
2	23	35%	No	Stable
3	24	40%	No	Stable
4	25	50%	Yes	Warning
5	26	55%	Yes	Critical
6	27	60%	Yes	Critical
7	28	65%	Yes	Critical
8	29	68%	Yes	High Risk
9	30	70%	Yes	Mass Wasting Likely
10	33	72%	Yes	Mass Wasting Imminent

3. RESULTS AND DISCUSSION

This section will present the results and discussion that will answer the research questions and accomplish the research objectives.

The researcher took three sensors in total to create the RAIN-MADEMS prototype. One, capacitive soil moisture sensor was used because rainfall is commonly a lubricant to soil making it easy to erode and maneuver and cause a debris flow. Through trial and testing the researcher gathered that about 30% and below is when the capacitive soil moisture sensor indicates that the soil is dry. And when it is buried under wet soil it starts to increase about 30% to 40% as our average moist and wet soil while, 50% to 70% level is when the soil starts to liquify and become muddy that can start mass wasting.

DRY SOIL	30%< below
WET SOIL	30% to 40% (considered wet but not detrimental) 50% to 70% (soil starts to liquify and becomes muddy. Issues a warning that can cause possible landslide)

Second, the vibration sensor has a constant reading of 0 to 1 where 0 indicates that there is no underground vibration and 1 denotes that there is possible movement whether from a natural seismic activity or manmade oscillation. Therefore, there is no need for calibration of its code because of its constant data of 0-1. Adjusting the sensitivity through twisting the potentiometer from 1-3 to acclimate its detection for vibration.

Third, an accelerometer was strategically placed inside the 3D canister to detect tilting. It is found that within 22 degrees of inclination, soil starts to fall out in small particles. At 35 degrees of inclination it is considered to be the maximum inclination of a slope before it starts to topple down and create mass wasting without the help of rainwater as a lubricant.

To test the accuracy of this threshold, the researcher tested RAIN-MADEMS ten times each time, the sensors provided accurate readings within the set thresholds for soil moisture, vibration, and tilt. These findings demonstrate that the system can accurately monitor and predict landslide conditions based on environmental change.

Test no. (°)	Angle (°)	Moisture (%)	Movement (yes/no)	Alert Level	Correct Prediction (yes/no)
1	22	30%	No	Safe	Yes
2	23	35%	No	Stable	Yes
3	24	40%	No	Stable	Yes
4	25	50%	Yes	Warning	Yes
5	26	55%	Yes	Critical	Yes
6	27	60%	Yes	Critical	Yes
7	28	65%	Yes	Critical	Yes
8	29	68%	Yes	High Risk	Yes
9	30	70%	Yes	Mass Wasting Likely	Yes
10	33	72%	Yes	Mass Wasting Imminent	Yes

The table shows the results of the RAIN-MADEMS system's performance in monitoring environmental conditions, specifically soil angle, moisture levels, and ground movement, to predict the likelihood of mass wasting events such as landslides. The system gathered data from 10 tests, each focusing on the tilt angle, moisture content, and movement detection, with the corresponding alert levels based on these factors.

Accuracy Calculation

The system's accuracy is determined by comparing the number of correct predictions made by the system to the total number of tests. The accuracy formula is:

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Total Tests}} \times 100$$

In this case, the system made **10 correct predictions** out of **10 tests**. Therefore, the calculation is:

$$\text{Accuracy} = \frac{10}{10} \times 100 = 100\%$$

This result indicates that the RAIN-MADEMS system performed with **100% accuracy** in detecting and correctly predicting soil conditions and movement based on the data from the sensors.

Interpretation of Test Results

1. **Soil Angle and Moisture Levels:**

As the angle of the slope increased, so did the soil moisture percentage. This increase corresponds to the system's thresholds for different alert levels: At lower angles (22°–24°), moisture levels remained under 40%, and no movement was detected, indicating stable conditions. As the angle approached and exceeded 25°, moisture levels crossed the 50% threshold, signaling a warning, with the system detecting ground movement starting at 25° and above. Moisture levels of 55%–72% (from 26° to 33° angles) indicated critical conditions, with increasing severity leading to "Mass Wasting Imminent" alerts as the tilt and moisture levels reached higher values.

2. **Movement Detection:**

The vibration sensor (SW420) accurately detected ground movement starting at a tilt of 25°, coinciding with increasing moisture levels. This threshold aligns with the typical onset of landslide risks due to soil liquefaction and instability. The system's ability to consistently detect movement at critical angles and moisture levels demonstrates its reliability in early landslide detection.

System Performance and Early Warning

The system's performance aligns with the expectations of providing early warnings for mass wasting events. Critical thresholds of **50% soil moisture** and **25° slope tilt** were key indicators for issuing warnings and critical alerts, ensuring timely detection of potentially hazardous conditions. The system escalated alert levels as conditions worsened, providing a full range of responses from "Safe" to "Mass Wasting Imminent."

Key Findings:

- The system was able to distinguish between stable and hazardous conditions based on real-time sensor data.
- The integration of tilt angle, soil moisture, and vibration data ensured a comprehensive approach to monitoring soil stability.
- The 100% accuracy in these trials shows the system's potential for effective early detection, though more extensive testing under varied conditions would further validate its performance.

4. CONCLUSION

The RAIN-MADEMS prototype demonstrated strong potential in predicting rainfall-induced landslides by monitoring key environmental factors such as soil moisture, tilt angle, and ground vibrations in real time. Using integrated sensors, the system effectively tracked changes in soil conditions, providing timely alerts as tilt angles increased and moisture levels reached critical thresholds. Early signs of instability were detected at a tilt of 22 degrees, with significant movement observed beyond 30 degrees when moisture levels surpassed 50%. This allowed the system to issue warnings before conditions became dangerous.

Over the course of ten tests, RAIN-MADEMS consistently delivered accurate results, with an impressive 100% accuracy rate in identifying conditions conducive to rain-induced mass wasting. The wireless transmission of data ensured timely updates for users, enhancing its value as an early warning tool. By effectively correlating tilt angles and moisture levels, the system proved to be a reliable resource for mitigating landslide risks, meeting all project objectives.This level of precision confirms that the RAIN-MADEMS system is not only capable of monitoring environmental conditions but also provides a vital resource for risk mitigation strategies in landslide-prone regions. Overall, the RAIN-MADEMS system stands as a vital innovation in environmental monitoring, offering a proactive solution to safeguard communities against the devastating impacts of rain-induced mass wasting events.

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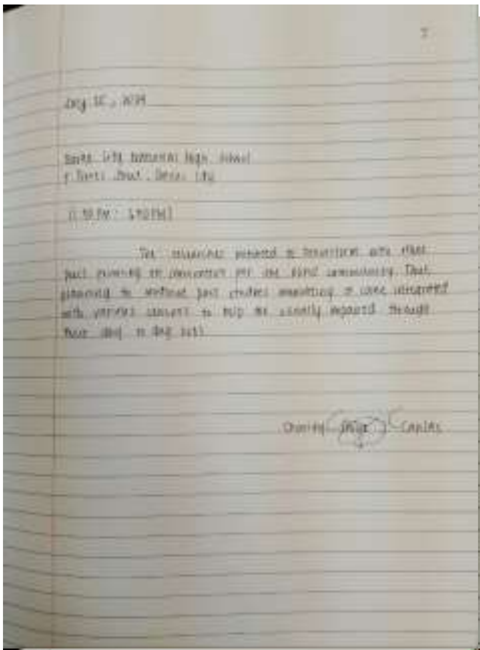
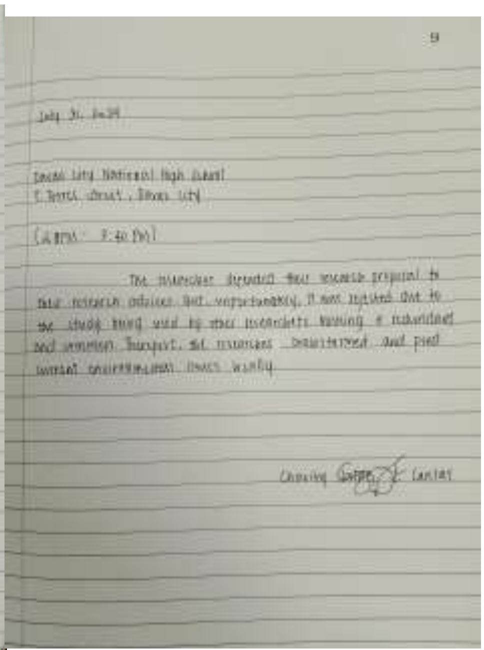
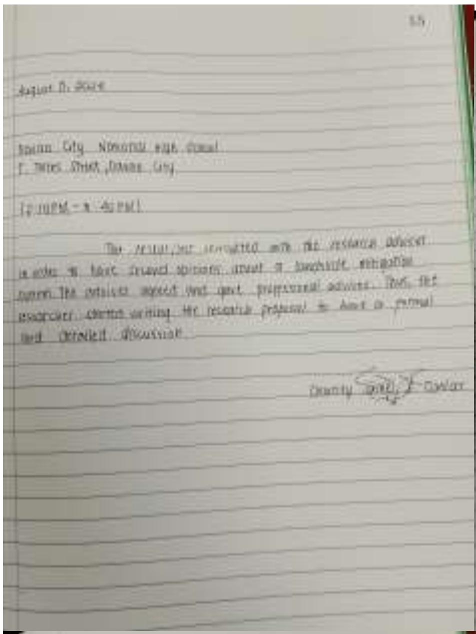
Appendices



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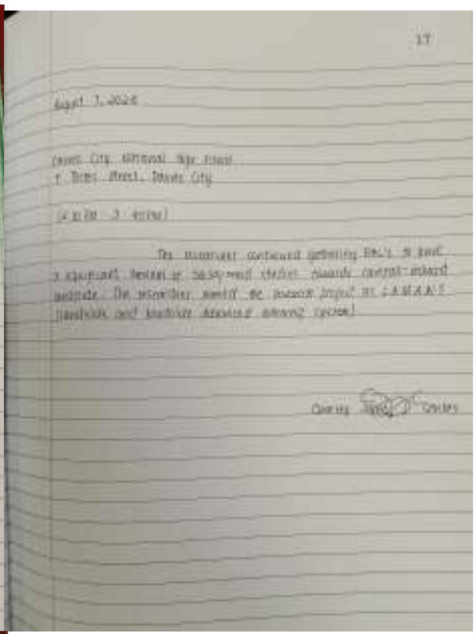
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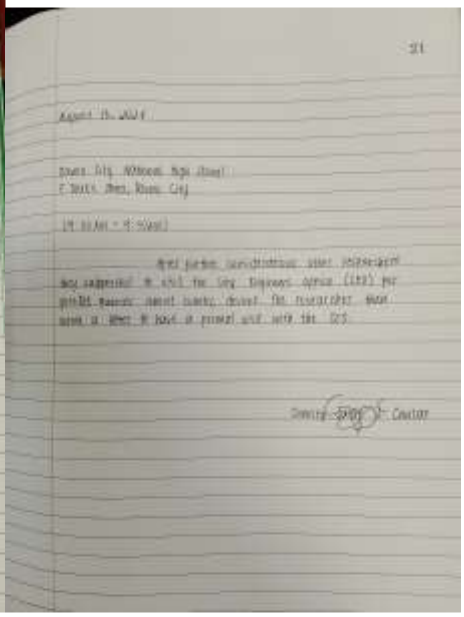
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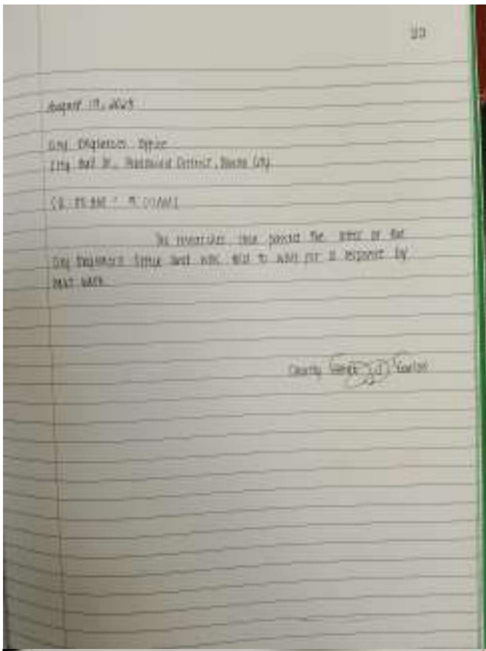

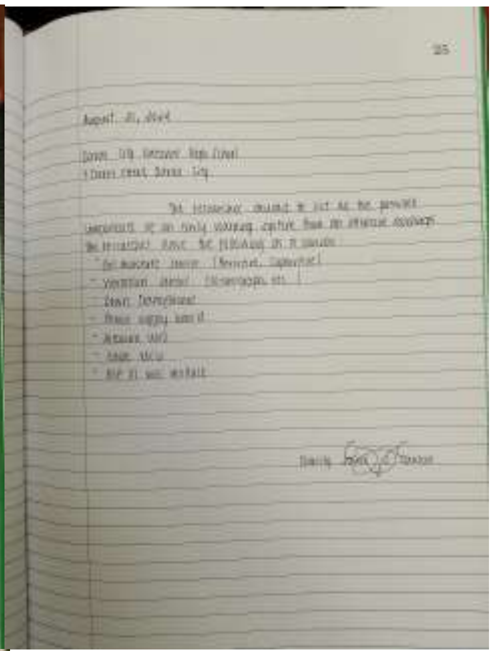

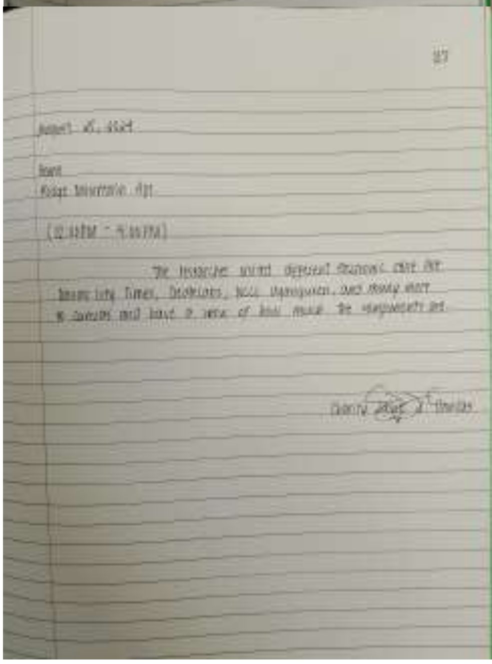

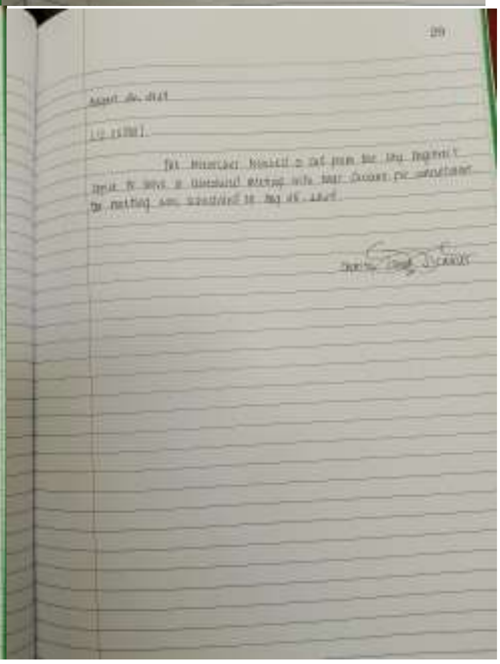

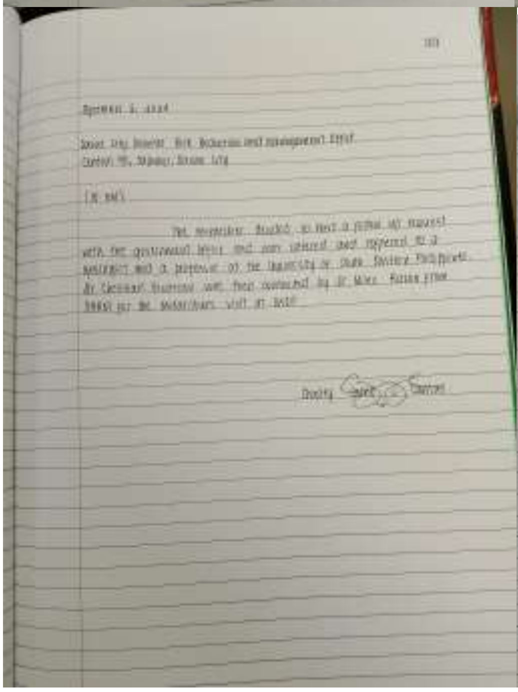

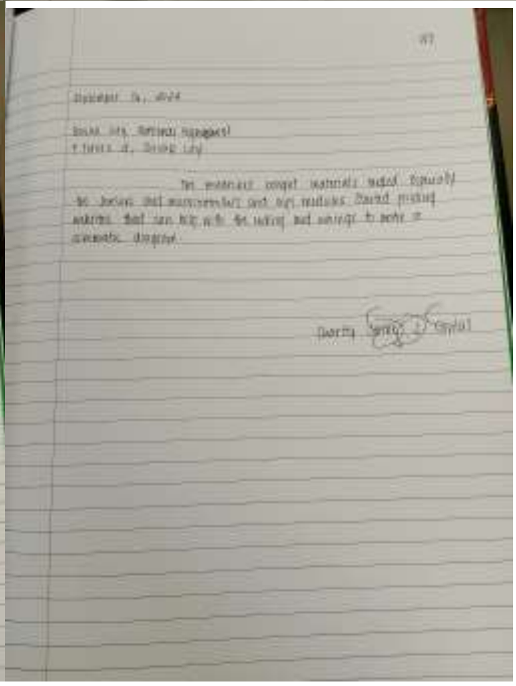

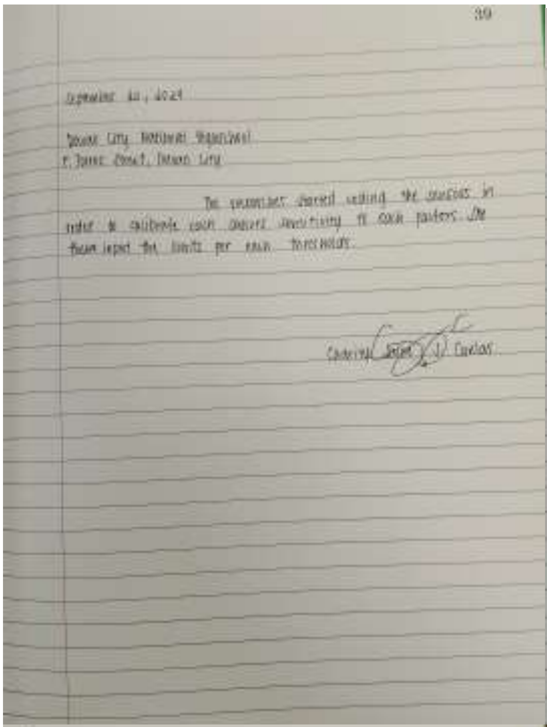
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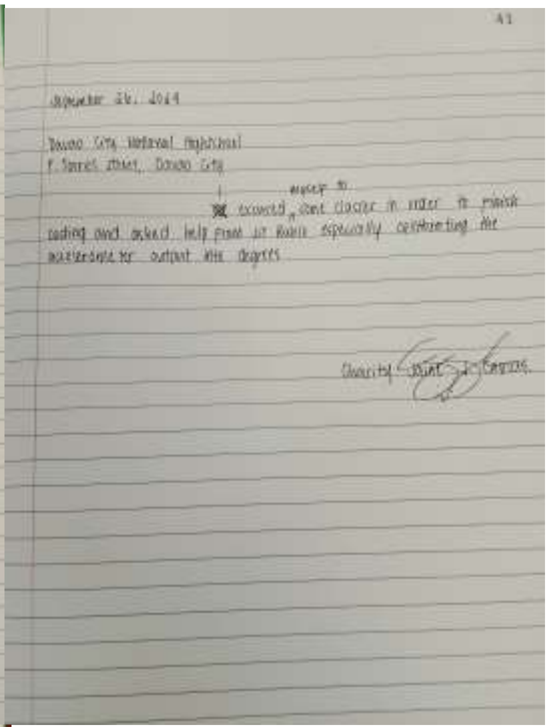
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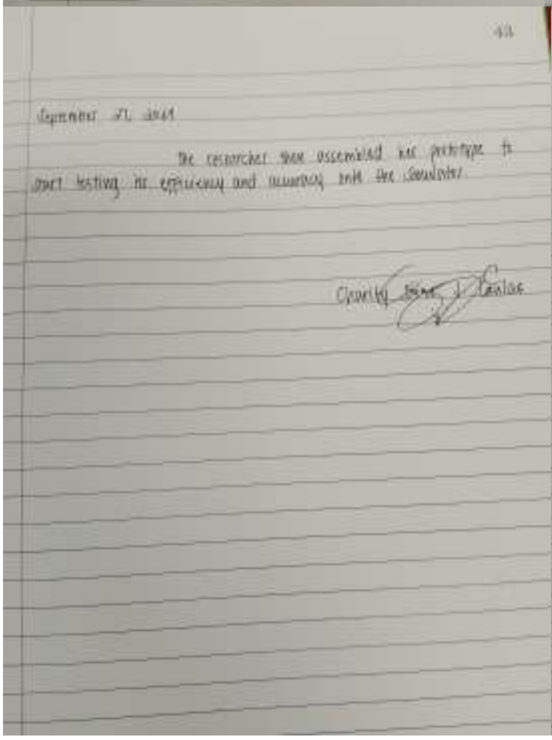
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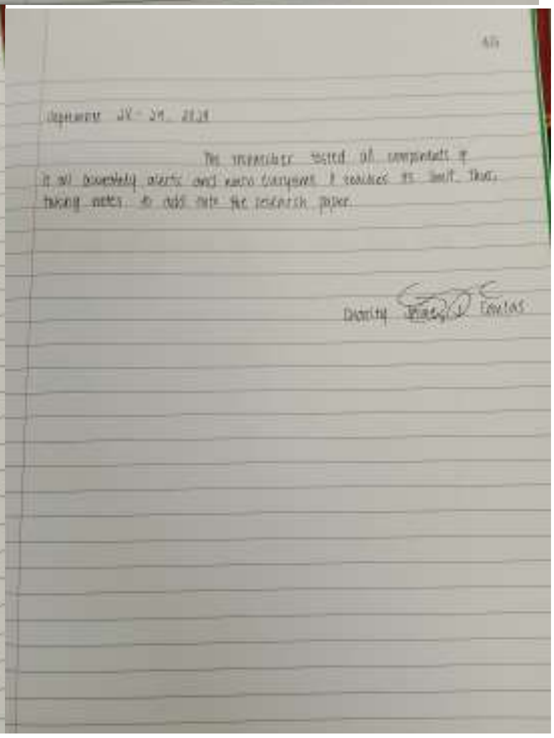
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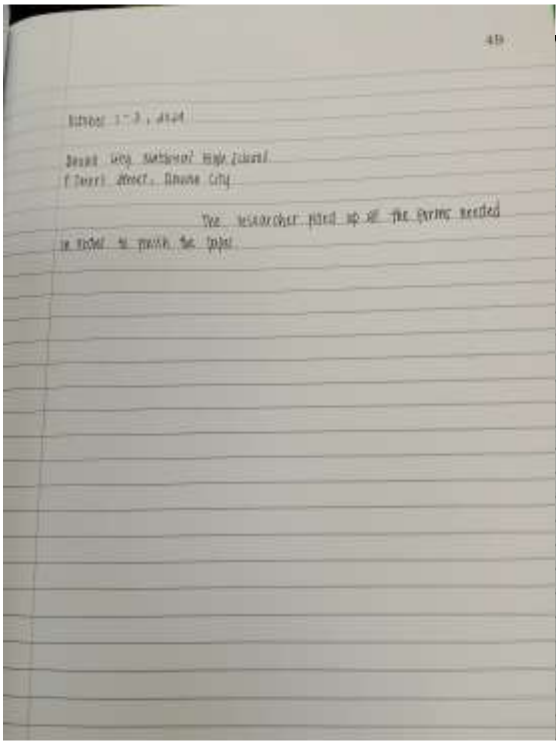

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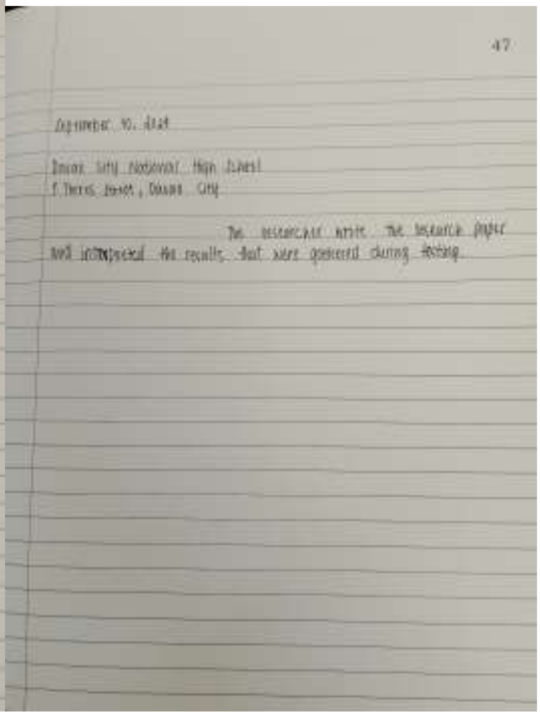

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September [illegible], 2024

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The researcher wrote the research paper and interpreted the results that were gathered during testing.