Soil Moisture Sensor-Based Landslide Monitoring: A Laboratory-Based Approach for Guwahati City

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Abstract: - Various techniques for landslide mapping, monitoring and modelling are being employed in a variety of studies to keep people safe from landslides. Guwahati, a city in Assam (India) is surrounded by hills, with varied slope angles, become prone to landslide during monsoon season. Relative increase in the moisture content of soil is a major parameter for determining the occurrence of landslides that are induced by rainfall. An experimental model with varying slope angles is demonstrated to witness some proportionality behaviour of soil moisture value for the collected soil sample from landslide prone areas. The soil moisture sensor value increases with increase in slope angle. The toe position of moisture value also shows a significant display of data during landslide. This early warning module can be incorporated with the help of Blynk Application to send messages to the residents of landslide prone areas. This study would be a cost effective alternative for landslide early warning hazard monitoring and fast emergency response process and the model may be considered as a miniature version of real-life slope conditions for the hills of Guwahati city, Assam, India.

Key-Words: - Breakdown, Slope Angle, Toe of Slope Area, Top of Slope Area, Display, Early Warning

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1 Introduction

Natural catastrophes (landslide, flood, erosion etc.) cannot be prevented, but we can prepare ourselves by learning how to either mitigate them or set up an effective early warning system. Landslide is one such natural hazard that affects a small region ([1], [2], [3]). Landslide mitigation techniques involve mainly two methods- firstly, some advanced techniques like installing of abutment and anchor piles. However, the second option of installing a suitable alarm and warning system is a more economical option.

The unplanned construction due to rapid urbanization has pushed the city of Guwahati to the brink by destroying the natural balance of the city [4]. Along with gravity, heavy rainfall, earthquake and a slope that was cut, may also induce and trigger landslide like conditions. As per report, during June 14-June 21, 2022, around 72 landslides took place across the hills of Guwahati owing to the rain and as many as 266 families residing in locations vulnerable to mud slips have been asked by the District Administration to shift to the safer places. Hence an urgent need for landslide early warning process for the city of Guwahati is the objective of the study. The early warning system of landslide has 3 steps viz. landslide mapping, monitoring and modeling ([5], [6], [7]).

There are mainly two causes of rainfall induced landslides- reduction in soil's shearing resistance due to an increase in soil moisture content and increase in unit weight of the soil [8]. Landslides are further caused by changes in the slope angle, surface erosion, and an increase in pore water pressure in faults and joints [9].

Therefore, a rise in soil moisture content brought on by precipitation infiltration plays a crucial role in causing slope failure.

Additionally, slope collapses are usually caused by a specific area at the slope's toe where the soil moisture content nearly reached full saturation, even when other areas of the sliding mass were still partially saturated [10]. Here, a suitable experimental setup was developed to analyze the sensor readings. The results obtained during the experiment, can be extended well to the real-life landslide situations. Here, soil moisture sensors are installed at different slope areas (upper and lower set of sensors) and also at different distance from the top and toe of the slope. It is feasible to forecast when rainfall will cause a slope to fail by keeping an eye on the percentage of soil moisture content on the slope.

Numerous studies on landslide hazard zonation mapping were identified during the literature survey. There are several steep slopes in Hongkong which become prone to landslide during heavy seasonal rainstorms [11]. A relation between rainfall and landslide was deduced with a threshold of 70 mm/hour. In [12], susceptibility map for landslides has been created using neural network and analytical hierarchy process (AHP) and fuzzy methodology. A total of 5 risk categories were found out which are very low, low, moderate, high and very high. These categories were based on 5 parameters. These parameters directly influence the process of landslide. Several researches on landslide hazard zonation mapping were also found for the research area. In Italy ([13], [14]), a study was performed for landslide early warning with the help of drones which are equipped with optical cameras. Fuzzy interface System (FIS), Artificial Neural Network (ANN), Genetic Algorithm (GA), Unmanned Aerial Vehicle (UAV) photography may also be used for landslide simulation and prediction ([15], [16], [17]).

To study landslide/debris flow, it is always advised to prepare a landslide model in the laboratory ([18], [19], [20]). Hence, numerous laboratory based study in landslide/debris flow were also found in the literature. While developing a framework for community resilience from natural hazards in some landslide prone areas in Afganistan, it was found that some sort of early warning system may be incorporated with the aid of sms, mosque announcement etc. [21].

However, there is still a requirement for an experimental landslide early warning system to ensure effective execution of emergency responses to landslides for the city of Guwahati, Assam (India). Thus, this study aims to get a relationship among all the parameters that induces landslide. In Guwahati, out of 18 hills, 8 are found to be landslide prone. The soil collected is from such a landslide prone area of Guwahati City. Here, soil moisture sensors are placed at various places of the experimental set up and eventually tested with varied induced rainfall amount.

Key benefits and utility of the study named "Soil Moisture Sensor-Based Landslide Monitoring: A Laboratory-Based Approach for Guwahati City" are as follows:

a) Early detection of landslide
b) Loss in property and human casualty can also be minimized.
c) Cost effective alternative for landslide early warning system.

The research can also be combined with Artificial Intelligence. With the help of Python, which is the most simple, flexible and readable language, an AI themed early warning system with the sensor data obtained in the experimental study can be developed. A simple flow chart may be seen as below:

Previous data
⇩
Early warning threshold setting
⇩
Real time data
⇩
Threshold reached
⇩
Landslide early warning

2 Methodologies

2.1 Materials Used

This region's hill slopes are home to two distinct types of soil. Mature residual soils are defined as the highest layers, which are lateritic in origin and range in thickness from a few centimeters to a few (1-2) meters. They are distinguished by low permeability values, a high percentage of clay size particles, and a high plasticity index. Poorly graded silty sand can be used to describe the saprolitic soils that lie beneath the lateritic soils. ([22], [23]).

The experimental model (dimension 170 cm* 80cm*100cm), with the facility for changing the slope, was filled with the sample soil collected from Rani Region of Guwahati region. Method of compartmentalization or quartering is used for soil collection. Quartering process involves the division of a well mixed sample into four equal parts [24]. Two opposite quarters are discarded and the remaining two quarters are remixed until the required amount of soil is obtained. After compaction, the soil is ready for performing experiment with the experimental set up (Figure 1).

A solar powered water pump is used for inducing artificial rainfall which can sprinkle water uniformly to the slope section of the set up. Soil Moisture is one of the most important parameter when we talk about landslide. Arduino compatible Soil moisture sensor YL-38 (Figure 2) is utilized to measure the electrical resistance of soil between the two conductors of the probe. A variety of materials make up the soil, some of which include minerals and salts. These minerals and salts function as electrolytes—which can conduct electricity—when water is added and soil moisture sensor values are displayed.

2.2 Study Area

Rani (a Block under Kamrup (Rural) District, Assam, India) is chosen as the study area and the soil sample is collected from the hills of that area [25] (Figure 3). Rani area is located 93 kilometers from the district headquarters in Amingaon.

Figure 1: Experimental set-up with the sprinkler system

Figure 2: YL 38 soil moisture sensor

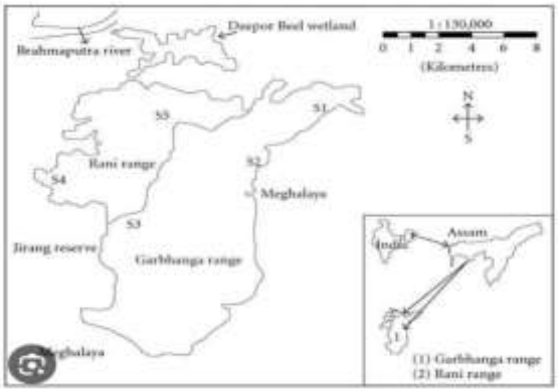

Figure 3: Study area map

2.3 Methods

The experiment was carried out with the induced rainfall which is powered by a solar powered water pump. The soil moisture sensors were placed at various places. The rainfall is measured with the help of a pre-calibrated water storage system. With the addition of water, the conductivity of the soil increases or resistivity of the soil decreases. A change in the moisture content would alter the voltage on the sensor's analog output. Moisture content scale would reflect these changes. The slope angles can be altered with the flexibility provision in the set up. Seepage system is also included in the set up to perform experiment with the seepage water value. Two sets of experiment were performed. First soil moisture sensor values were found for different slope angles. Second, by keeping the slope angle constant, moisture sensors were placed at different positions in the slope area.

3 Experimental Results and Discussion

3.1 Mathematical Formulation

Soil moisture index is a very important factor for rainfall induced landslide model development [26]. Landslide data obtained from the Executive Summary of Rapid Visual Screening for Potential Landslide Areas of Guwahati city prepared by District Disaster Management Authority are taken for finding the threshold of the rainfall intensity and duration. The intensity-duration (ID) threshold has the general form [27],

$$I = c + \alpha D^{\beta} \quad (1)$$

Where, I- Mean or average rainfall intensity
D- Rainfall Duration
c, α, β- Parameters that vary from places to places.

Before, rainfall is introduced to the experimental set up, soil moisture index M_0 (an important parameter in determining the landslide occurrence) is assumed to be negative. Let this value be F_C (mm) where F_C is the field capacity.
Therefore,

$$M_0 = - F_C \quad (2)$$

Now, soil Moisture index at time *t*,

$$M_t = M_{t-1} + R_t - D_t - E_t \quad (3)$$

Here, M_{t-1} is the soil moisture extent at time t-1,
R_t is the effective rainfall
D_t is the drainage
And E_t is the daily evaportranspiration
For calculation of drainage amount, drums of known capacity may be installed in the experimental set up.

3.2 Experimental Results

As stated earlier, the experimental set up has provision to change the slope angle of the set up, hence by changing the slope angle, with same amount of induced artificial rainfall, soil moisture sensor values are found out. The soil moisture sensor (YL-38) values are displayed in the 7 segment display and are plotted accordingly (Figure 4). As confirmed from the graph, soil moisture value (in percentage) for 40 degree slope angle (grey colored curve in the graph), is more than 30 degree slope angle (blue colored curve in the graph).

To verify the toe and top region dependency on landslide, the soil moisture sensors were placed at two different positions. Figure 5 and Figure 6 pictorially illustrate the readings obtained in Table 1 and Table 2. As evident from the graph, (x-axis mentions the rainfall amount (in L) and y-axis mentions the soil moisture sensor value (in Percentage)) the toe region plays an important role in the determination of landslide event occurrences. As the sensors are placed more towards the toe or top, the lower sensor's displayed data are comparatively more than the upper sensors displayed data.

The saturation point before breakdown (after about 50 L of induced rainwater), the soil moisture value does not change much for all the following cases. The result shows an increase in the soil moisture sensor value as the position of the sensor is coming near the toe region. The breakdown is achieved at about 70 L of induced rainfall. Initial condition was captured at time 12:14 pm and the final breakdown was captured at 01:01 pm (Figure 7). Whereas, the initial figure was clicked at time 11:12 am and the final breakdown was clicked at 11:50 pm (Figure 8).

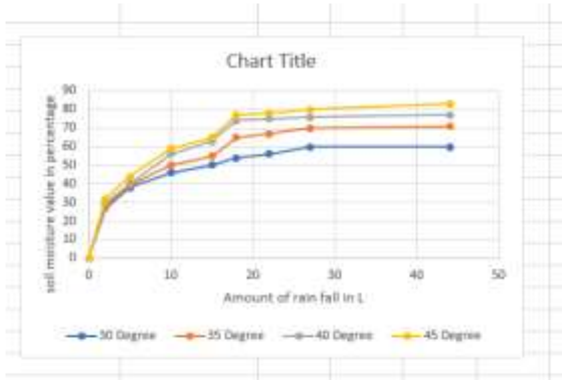

Figure 4: Soil moisture sensor value for different slope angles

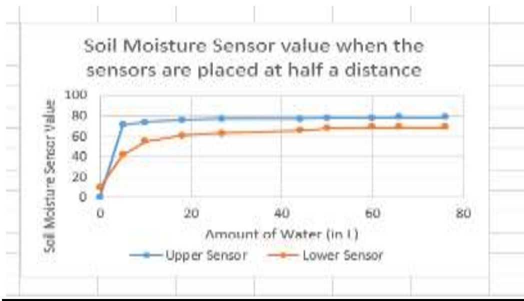

Figure 5: Upper sensor and lower sensor value for sensors placed at half distance from top and toe

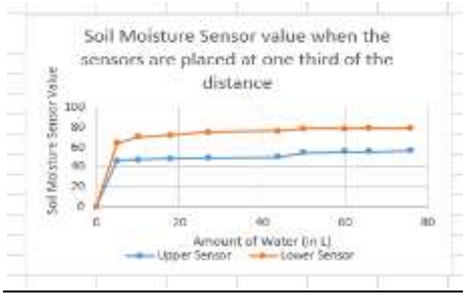

Figure 6: Upper sensor and lower sensor value for sensors placed at one third distance from top and toe.

Table 1: Upper and lower soil moisture sensor value for half distance position

Soil Moisture Sensor Value (in percentage) for Slope Angle 40 Degree (sensor position at half distance from tip and toe of the slope)			
Sl No	**Amount of Rainfall (in L)**	**Upper Sensor**	**Lower Sensor**
1	0	0	0
2	5	71	42
3	10	74	55
4	15	75	60
5	18	76	61
6	22	76	62
7	27	77	63
8	33	77	64
9	44	77	66
10	50	78	68
11	60	78	69
12	66	79	69
13	76	79	69
14	87	79	69
15	100	79	69

Table 2: Upper and lower soil moisture sensor value for one third distance position

Soil Moisture Sensor Value (in percentage) for Slope Angle 40 Degree (sensor position at one third of a distance from tip and toe of the slope)			
Sl No	**Amount of Rainfall (in L)**	**Upper Sensor**	**Lower Sensor**
1	0	0	0
2	5	46	64
3	10	47	70
4	15	47	71
5	18	48	72
6	22	49	73
7	27	49	75
8	33	50	75
9	44	50	76
10	50	54	78
11	60	55	78
12	66	55	79
13	76	56	79
14	87	56	79
15	100	56	79

Figure 7: Initial and breakdown conditions when sensors are placed at half distance

Figure 8: Initial and breakdown conditions when sensors are placed at one third distance

4 Sensitivity Analysis

The phenomenon of landslide depends on various parameters such as rainfall, humidity, temperature and most importantly soil moisture value. The above study was performed by considering increase in soil moisture sensor as the main parameter for occurrence of landslide. The occurrence of the landslide event may be identified with the help of an accelerometer sensor MPU 6050 that will provide the x-axis and y-axis displacement of the soil. Regression analysis was performed by taking rain fall, humidity and soil moisture data as input and displacement reading from accelerometer as the output. The Regression Statistics shows that R^2 value is the highest for soil moisture sensor data (Figure 9) proving the fact that soil moisture data is the most crucial factor in determining the landslide event occurrence i.e. rainfall induced landslides are most sensitive towards the change in soil moisture value.

Regression Statistics for Rainfall Data	
Multiple R	0.823017
R Square	0.677357
Adjusted R Square	0.631265
Standard Error	0.253621
Observations	10

Regression Statistics for Humidity Sensor Data	
Multiple R	0.925273
R Square	0.856129
Adjusted R Square	0.835576
Standard Error	0.16936
Observations	10

Regression Statistics for Soil Moisture Sensor	
Multiple R	0.967163113
R Square	0.935404488
Adjusted R Square	0.927330049
Standard Error	0.185028704
Observations	10

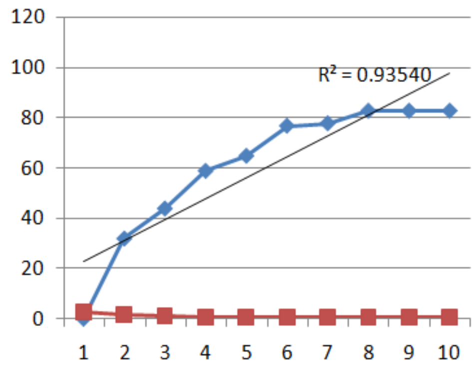

Figure 9: R^2 value displayed on graph

5 Conclusions

The landslides in this region of North East is rainfall induced, therefore the sprinkler system that was used in the experimental set up is more advisable than the seepage technique used in. Another observation from the tables and their corresponding graphs is that at first the change in sensor value is substantial compared to the marginal change after a particular value for equal amount of rainfall. This result can be integrated with wireless sensor network or artificial intelligence. Arduino based YL-38 soil sensor system provides a cost-effective solution for this natural/ human made hazard. The project can be extended to offer additional improvements for various industrial applications, including but not limited to construction sites, infrastructure projects, and precision agriculture practices [28] and oil and natural gas pipelines.

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Conflict of Interest

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