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# Monitoring of Unstable Slopes with Low Cost Sensor Network in Chibo, Kalimpong, Darjeeling Himalayas, India

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**Abstract.** Several studies have been conducted on developing an early warning system using rainfall and landslide histories. These studies only consider rainfall as a parameter and do not consider the effects of local geology, hydrology and topography which varies spatially and are critical for an early warning system. The paper presents a simple monitoring system using Micro electro mechanical systems (MEMS) tilt sensor and volumetric water content sensor instead of traditional instruments like extensometers and inclinometers. The MEMS-based sensor monitors the tilting angle of the sensor fixed at shallow depths and the variation in the tilting angle corresponds to the lateral displacement at the slope surface. Hence, the rate of tilting angle that surpasses a particular value implies an imminent slope failure. It is recommended that a precautionary measure for slope failure be issued at a tilting rate of 0.01°/h and warning of slope failure issued at a rate of 0.1°/h. The MEMS based tilting sensors are inexpensive and therefore it is imperative to install several low-cost sensors over an unstable slope to determine the failure section during the next rainfall event. This paper is an application of the technology in Chibo region of Kalimpong district in Darjeeling Himalayas which has been monitoring the region since June 2017. The system would help in developing an early warning system with an objective to save human lives.

**Keywords.** Shallow landslides, monitoring system, Chibo, Indian Himalayas.

## 1. Introduction

Landslides are a worldwide natural disaster with occurrences all across the globe causing massive destruction to human lives. About 16% of all the rainfall-triggered landslide events in the global dataset occurred in India during 2004-2016 [5]. The most landslide prone region in the country is the Indian Himalayan region with the North-East region being the most vulnerable. One of the most landslide prone areas is Chibo located in Kalimpong, Darjeeling Himalayas in the North-East region. The causes of the landslides in the region can be attributed to the complex geology, poor lithology, erratic monsoonal rainfall, improper drainage system and the increase in anthropogenic activities. The landslides lead to massive loss of agricultural land, life and property.

In order to study the relation between rainfall and landslide incidents thresholds have been usually defined using various techniques (Bayesian Inference, Frequentist etc.). Regional thresholds using Bayesian inference method (ID thresholds) and probabilistic

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method (Bayes' theorem) for the Kalimpong have been defined by [2] and [3,4] respectively. However, these methods may not always be useful in determining the exact time for landslide occurrences and are impossible to determine the landslide location. Therefore, a monitoring system was setup to overcome the challenges associated with rainfall thresholds. The monitoring system comprises of Microelectromechanical Systems (MEMS) technology consisting of tilt sensors and volumetric water content sensors. The use of such a system is unique compared to the traditional use of extensometers as they do not require skilled personnel for installation, detect small changes and are cheaper. The paper presents the results obtained from the sensors and its implication with the possible landslide occurrences in the future.

## 2. Study Area

Chibo is situated on the western slope (27°3′,88°27′30″) of the N-S Kalimpong hill in the eastern part of the Darjeeling Himalayas (Figure 1). The region experiences heavy annual rainfall (2000-4000 mm) with the majority of the precipitation during the monsoon seasons (June-October). The landslides in the region are also affected due to heavy antecedent rainfall [1]. The height of the region varies from 450 m to 1150 m. The area is also heavily drained due to the presence of several natural streams (jhoras). Geologically, the region comprises of Fold Thrust Belt rock from Precambrian to Quaternary ages. Chibo is in seismic zone IV which is a high-risk zone (BIS 2002). Landslides have also been aggravated due to the increase in economic development in the region especially the construction of roads. According to [5], of all the global Non-Seismic Non-Rainfall landslide events, 30% of those events are triggered due to road construction.

To determine the locations of the tilt sensors a comprehensive field visit along with interactions with local people were conducted during the monsoon of 2016 and slopes across two streams (Pyarieni and OC jhora) were selected. The areas around these jhoras have known to be draining the region and were a good fit for monitoring to understand the displacement in the region. Therefore, six tilt sensors and volumetric water content sensors along with a rain gauge and data logger was setup in the region (Figure 2).

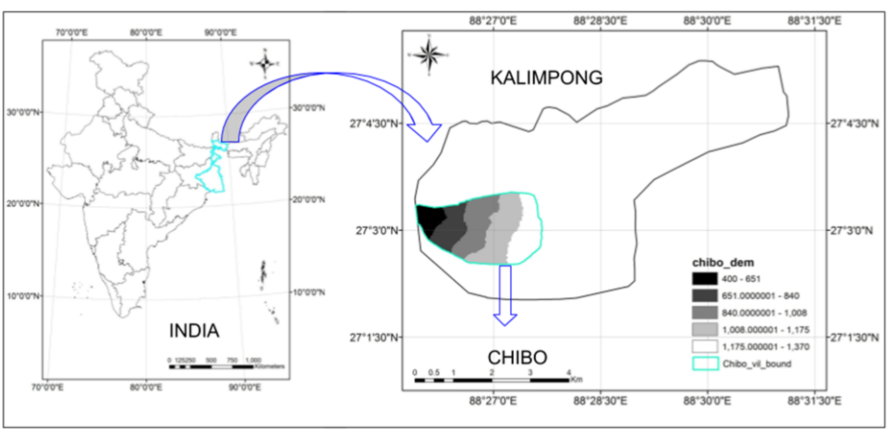


**Figure 1.** Study Area.

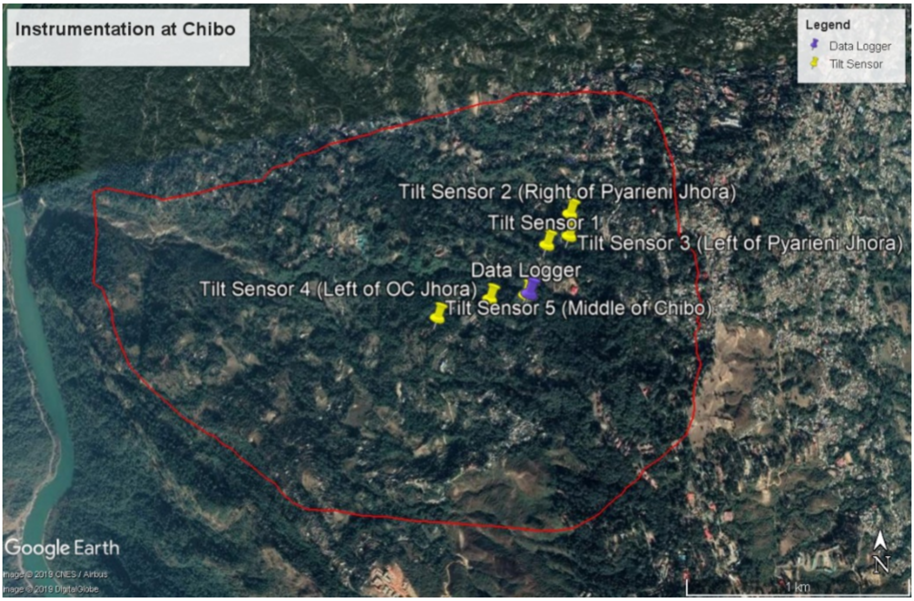


**Figure 2.** Location of the monitoring equipment (Source: Google Earth).

## 3. Monitoring System

The study uses a simple, reliable and robust monitoring setup with MEMS technology which measures the tilt angle of a rod installed at shallow depths. The system requires the installation of two iron rods in which a tilt sensor is strapped at shallow depths on one rod and a wireless transmission kit on the top of the other rod. The tilt of the rod is measured consecutively at every 10 minutes and the data is transferred through the transmission kit to a data logger via radio communication. The data from all the sensors are gathered to the data logger and are eventually communicated via the Internet. Such a monitoring setup is useful for shallow landslides only [1]. The total amount of rotation is calculated, and various warning systems are employed as per the tilting rates (0.01°/hr. for attention, 0.1°/hr. for alarm and 1°/hr. for failure) [6]. The cost of the one tilt sensor is around one thousand US$. The system has been tested for one year (June 2017-2018) and the results have been described in Section 4.

## 4. Results and Discussions

The data obtained from the tilt sensors are the tilting rates in parallel (X-axis) and perpendicular (Y-axis) direction to slope along with the volumetric water content sensor data. The tilting rates from the sensors have been plotted in Figure 3 and 4 on the left side of the ordinate whereas the right side of the ordinate represents the local rainfall values collected from the rain gauge. Figure 5 depicts the change in water content values across one year and the precipitation values. On analyzing the data, it can be observed that the variation in tilting rate is in accordance with the rainfall occurrence. The tilting variation starts from atop the slope (Sensor 2) followed to the centre (Sensor 3) and little to no movement at the bottom. The values obtained from the water content sensors cannot be solely used to forecast landslide events as its change is more convenient instead of absolute values [7]. Also, it is difficult to accurately determine the exact location of possible slope failure using water content sensors only [1].

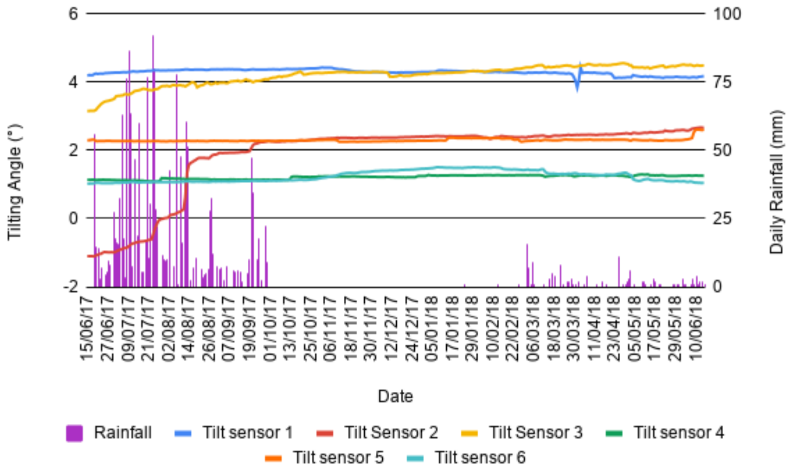


**Figure 3.** Time history of tilting rates in X-direction for all 6 sensors.

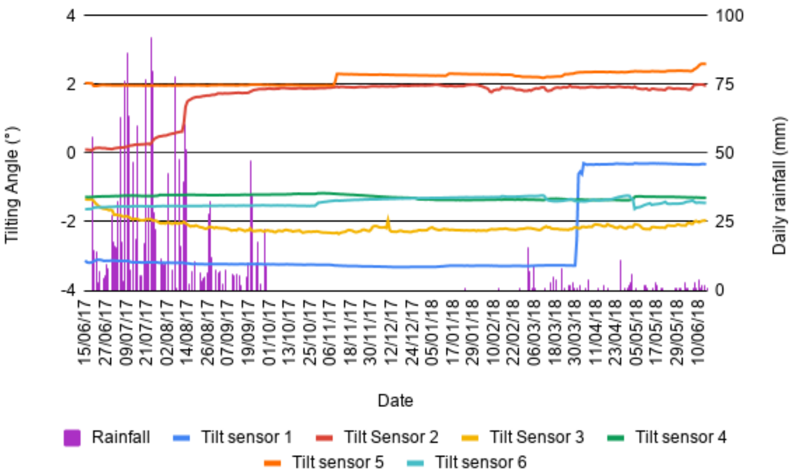


**Figure 4.** Time history of tilting rates in Y-direction for all 6 sensors.

The data obtained majorly shows changes in Sensor 2 and 3. The role of antecedent rainfall also plays a major role in landslide initiation in the area as depicted in the data. However, in sensor 1 there can be seen a sharp change in tilting rate in Y-direction during the month of March 2018 and can be neglected as such a drastic change can be attributed to external factors. The tilting rates in sensor 2 and 3 can see a slight increase during the monsoon of 2017 and the onset of monsoon 2018. However, the observed tilting rates never cross the threshold of 0.1°/hr. for alarm generation. In the case of the other four sensors, the tilting rates barely cross 0.01°/hr. for attention to be required. The field visit conducted after the monsoon of 2017 confirms the monitoring results and displacement in the area around sensor 2 and 3 was observed. The results obtained from all the sensors have been categorized into three landslide susceptible zones (very high, moderate and low) and depicted in Figure 6.

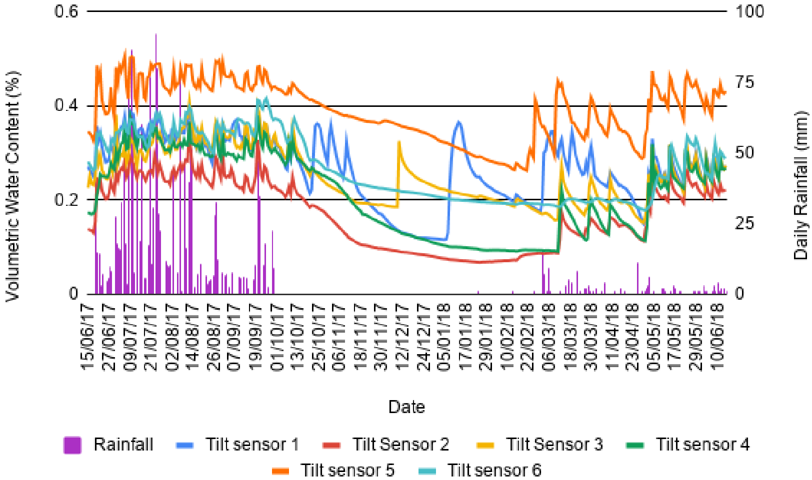


**Figure 5.** Time history of tilting rates in volumetric water content for all 6 sensors.

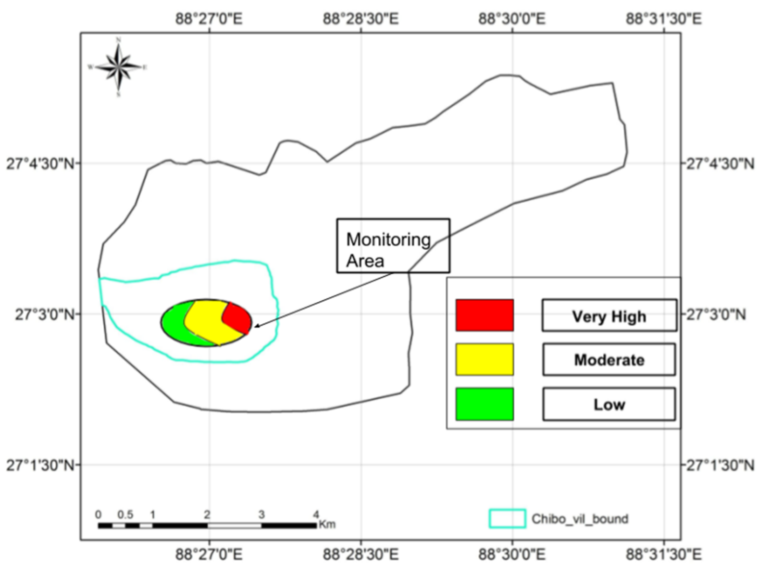


**Figure 6.** Landslide Hazard map for the monitoring area.

## 5. Conclusions

The present study depicts the installation and analysis of a monitoring system setup in Chibo, Darjeeling Himalayas. The conclusions from the analysis are:

1) The tilting rates in both the X and Y direction can be observed significantly during the monsoon season of 2017 and 2018. However, during the observation period there were no cases of slope failure and the sensor also did not provide a false alarm.
2) The variation in tilting rates was primarily seen in sensor 2 and 3 which were installed across Pyarieni and OC jhora and were confirmed with the field study. Therefore, the areas around these jhoras are most susceptible to landslides in the future.
3) An accurate reading of hourly precipitation or antecedent rainfall for landslide occurrence could not be observed as there was no incident of the landslide. Therefore, a long-term monitoring effort needs to be taken up to accurately predict the exact amount of rainfall required and would also ascertain the system's capability in forecasting landslides in the Indian Himalayan region.

This use of monitoring setup is the first of a kind setup for Indian Himalayan region and can be used for other regions also. The site-specific results obtained can further be utilized by calibrating the obtained regional rainfall thresholds thus eliminating the use of monitoring equipment in other regions.

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