Rainfall-Induced Landslides in Cameron Highland Area, Malaysia

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\textbf{Abstract.} Cameron Highland is classified as one of the landslide-prone areas in Malaysia due to its hilly landform. It has been discovered that the landslides in Cameron Highland were mainly triggered by the intense rainfall since the area encountered high amount of rainfall throughout the year. This study is carried out to evaluate the correlation between the rainfall intensity-duration (I-D) and the landslide occurrences in the Cameron Highland area. Twelve cases of landslides in the study area had been selected for conducting the analysis of rainfall intensity-duration (I-D) that triggers the landslides. The important variables from the analysis such as the maximum rainfall intensity (I) and the duration of rainfall series (D) have been applied to establish the empirical rainfall intensity-duration (I-D) threshold for Cameron Highland landslide areas. Based on the study, by utilising the logarithmic scale graph and applying a power-law model from the general equation of $I = \alpha D^\beta$, the empirical I-D threshold for Cameron Highland landslide was determined as $I = 29.088D^{-0.075}$ ($I$ = rainfall intensity in mm/hr and $D$ = duration in hour). The empirical (I-D) threshold can be a functional mechanism for the Early Warning System (EWS) once it is further developed, that enable the relevant authority to prepare mitigation measures such as evacuation, spreading information to the civilian in order to prevent major losses and casualties due to the landslide events.

1. Introduction

Landslide is one of the major contributors to natural disaster worldwide. According to Cruden [1], landslides is a movement of the rock or debris flow or earth slope falls. It can be triggered by prolonged precipitations, earthquakes, and human activities. Thousands of fatalities have been recorded due to the landslide incidents. Furthermore, landslide also causes loss in economy and damages to the infrastructure and facilities. In Malaysia, high intensity rainfall and prolonged rainfall are the contributing factors to landslide occurrences. This is because Malaysia possesses a high amount of rainfall around 3000 mm annually due to the monsoonal system [2], which indicates that this country is susceptible to landslide especially in hilly and sloping areas.

Cameron Highland had been identified as one of the landslide-prone areas in Malaysia due to its mountainous landform. Geographically, Cameron Highland is situated in Peninsular Malaysia at the northwest of Pahang, with the altitude of 1829 meters above mean sea level having an area of 712.8-square kilometre [3]. The landslide has caused a lot of losses to the local people in Cameron Highland especially for those who lose their farm and plantation land that eventually losing their earning. Likewise, the tourists either from local or foreign countries will lost their interest to visit Cameron Highland due to occurrence of this kind of disaster. The sudden closure of roads during the landslide
may lead to wastage in money and time, as the people get stranded on the road due to the landslide obstruction.

There were many landslide events recorded in Cameron Highland in few years back. For records, the first landslide in Cameron Highland was reported on 11 May 1961, at Ringlet which had caused 16 fatalities [4]. Recently, there was a landslide that occurred at Kampung Tiga, Kuala Terla, Cameron Highland on 14 October 2018. According to Issahak [5], the tragedy had caused death of 3 foreign workers. Search and Rescue (SAR) operations were conducted by the Pahang Fire and Rescue Department, Royal Malaysian Police Department and Public Works Department to find the buried victims. The victim’s house was constructed on a steep slope which was a restricted area for residential dwellings. The authorities concluded that intense rainfall caused the slope to fail and eliminated the house at once [5].

The previous study has proven that, the dominant factor that cause the landslide in Cameron Highland is the intense rainfall. The landslide keeps happening every year and the people had to face with these circumstances reluctantly. Therefore, it is necessary to develop a mitigation plan, and one of the methods is by developing empirical threshold method to correlate the rainfall intensity (I) and duration (D) with the landslide occurrence in Cameron Highland. Subsequently, this study is focus on the development of rainfall intensity and duration threshold which would apply and incorporated in landslide early warning system in order to obtain the predicted landslide occurrence and allow the authorities to take necessary pre-emptive measures such as evacuation, alerting the rescue services, road closure and spreading of information to minimize the risk and effect of landslide.

2. Methodology And Materials

2.1. Methodology

Recognising that rainfall is the main triggering factor of landslide occurrence, researches have been carried out to investigate the relative role of the high intensity rainfall, antecedent rainfall, and how they can affect the pattern of the rainfall threshold. Dahal and Hasegawa proposed that the cumulative rainfall, antecedent rainfall, rainfall intensity, and rainfall duration are the most typical investigated rainfall parameter that are susceptible to landslide [6]. Anyhow, according to Nikolopoulos et al.,[7], the relationship between the rainfall intensity (I) and duration (D) are the most intended rainfall thresholds in the literature for possible landslide occurrence. Therefore, this study focus on the developing landslide threshold using rainfall intensity (I) and duration (D) for Cameron Highland area.

The general form of equation that correlates between the rainfall intensity (I) and duration (D) threshold is defined as:

\[ I = \alpha D^{\beta} \]  

(1)

where I is the mean rainfall intensity (mm/h), D is the duration of the rainfall (hour), whilst \( \alpha \) and \( \beta \) are constants that are significant to the empirical data in adapting the power-law model. The constants later will provide some coefficients depending on the variables.

Nikolopoulos, et al.,[7] explained that there are several statistical methods that can be proposed to produce the rainfall intensity (I) – Duration (D) relationship, which include the Bayesian inference method by Guzzetti et. al [8] and the frequentist method proposed by Brunetti et. al [9]. Fig. 1 indicates the example of the graph of the precipitation in the estimation of the rainfall intensity (I) and duration (D) threshold. The ideal condition simply isolates between rainfall that have triggered the landslides which are the black dots, and the rainfall that have not triggered the landslides which are the white dots. Rainfall intensity (I) and duration (D) threshold is classified as the ideal case, where the
term of the ‘true’ threshold is shown on the boundary-lines. In easy words, from the graph, landslide is surely occurred once the rainfall intensities are above or exceeding the boundary lines.

![Figure 1: Rainfall intensity (I) and duration (D) threshold Condition [7]](image)

2.2. Study Area
Cameron Highland is situated in Peninsular Malaysia at the northwest of Pahang (Figure 2), with the altitude of 1829 meter above mean sea level and an area of 712.8-square kilometer. Cameron Highland is surrounded with the hilly landform and the factor of geological, morphology and climate contribute to the landslide occurrence [3].

The landslides occurrences were chosen based on the accessibility and availability of landslide data such as the landslides locations, time of their occurrences and the availability of the significant parameters such as the rainfall intensity and its duration. Twelve landslides occurrences in Cameron Highland were selected to be used for this research and they are described in Table 1. The data collection and the detailed information of the landslide cases in Cameron Highland have been assessed from slope branch, Public works Department of Malaysia (PWD). Moreover, the data can also be acquired from other sources such as the report of newspaper, journal and publication which provide the particular details for the date and time of the landslide events.
Figure 2: Location of Cameron Highland [10]
2.3. Rainfall Data

Hourly rainfall data were obtained from the Drainage and Irrigation Department of Malaysia (DID) for each of the landslide occurrences. Rainfall data was taken at close proximity to the landslide location in order to develop accurate landslide threshold. However, due to the limitation of coverage for the rain gauge station in Cameron Highland area, the rainfall records of the closest rain gauge stations range between 5km to 20km from the landslide locations were considered in the analysis [11]. Table 2 shows the list of rain gauge stations with the distant locations of landslide.

| No | Landslide Location                           | Selected Rain Gauge Station (Name) | Station Number | Distance Between Rain Gauge and Landslide Location (km) |
|----|---------------------------------------------|-----------------------------------|----------------|--------------------------------------------------------|
| 1  | Batu 51, Jln Kuala Terla, Kg Raja           | Ldg. Teh Sg. Palas               | 4514032        | 3.4                                                    |
| 2  | KM 78.8, Batu 49, Kampung Tiga, Kuala Terla, Cameron Highlands | Ldg. Teh Sg. Palas               | 4514032        | 3.5                                                    |
| 3  | Flower Farm, Batu 49, Kuala Terla, Kampung Raja | Ladang Boh (Bhg. Selatan)       | 4414038        | 11.2                                                   |
| 4  | Rumah Peranginan TNB Sharples, Tanah Rata  | Gunong Brinchang                 | 4514033        | 2.4                                                    |
| 5  | Pos Terisu                                  | Ladang Boh (Kawasan Kilang)      | 4414036        | 11.5                                                   |
| 6  | Pekan Ringlet, Lembah Bertam               | Ladang Boh (Bhg. Boh)            | 4414037        | 5.7                                                    |
| 7  | KM 46, Jalan Brinchang-Tringkap            | Ladang Teh Sg. Palas             | 4514032        | 1.8                                                    |
| 8  | Jalan Sultan Abu Bakar Brinchang           | Stesen Mardi Cameron Highland    | 4414040        | 6.3                                                    |
| 9  | Perkampungan Orang Asli Sungai Ruil, Brinchang | Stesen Mardi Cameron Highland    | 4414040        | 6.5                                                    |
| 10 | Kuala Terla, Cameron Highlands             | Gunong Brinchang                 | 4514033        | 5.0                                                    |
| 11 | Cameron Highland (exact location not mentioned) | Gunong Brinchang                 | 4514033        | 10.0                                                   |
| 12 | Kea Farm, Tringkap                         | Gunong Brinchang                 | 4514033        | 2.9                                                    |

3. Results And Discussion

Table 3 shows the variables adapted in developing the empirical rainfall intensity – duration (I-D) threshold graph. From the parameters, the scatter plot has been applied to the graph in order to discover the correlation between the rainfall intensity (I) and duration (D) and its relationship with the occurrence of the landslide as shown in Figure 3. The vertical axis represents the Intensity, I (mm/hr) while the horizontal axis represents the Duration, D in hour. The graph has been plotted in the logarithmic scale for both X and Y-axes. From the scatter plot, the best fit line or trend line has been established and the equation that correlates between the Intensity (I) and Duration (D) had been
generated from this empirical solution. The coefficient from the general equation of Intensity-Duration (I-D) relationship, which are $\alpha$ and $\beta$, have been determined in related to the previous landslide cases in Cameron Highland area. Moreover, the threshold has been established by drawing the line that had been emulated from the best fit line at the lowest data in the graph. The threshold will act as the boundary between occurrence and non-occurrence of landslide and can be used to predict the upcoming landslide event in Cameron Highland area.

From the empirical Intensity-Duration (ID) threshold graph (Figure 3), the Rainfall intensity (I) – Duration threshold equation has been obtained as follows:

$$ I = 29.088D^{0.075} \quad (2) $$

From the equation, $\alpha = 29.088$ and $\beta = 0.075$ have been obtained to predict the possibility of the upcoming landslide in the Cameron Highland area based on past landslide events. From the developed threshold, it was found that the range of the rainfall duration that triggers the landslide is between 7 hours to 236 hours (Figure 3). The results are reasonable since the water requires different time to adequately seep into the soil layer to trigger the slope failure subject to the different types of slope conditions. Moreover, from Table 3, it was recorded that the amount of rainfall intensity for the triggering landslide ranged between 12.4 mm/hr to 42.6 mm/hr. The 12.4 mm/hr is considered moderate rainfall (11-30 mm/hr) meanwhile 42.6 mm/hr is considered as heavy rainfall (30-60 mm/hr) recognized by Drainage and Irrigation Department of Malaysia (DID)\[12\].

Based on the threshold, the rainfall event for less than 10 hours requires 25 mm/hr intensity to trigger the landslide, while 22 mm/hr intensity is seemed to be adequate to initiate the landslides if the rainfall is non-stop beyond 24 hours. The gap between the rainfall intensity for the short and long rainfall durations is reasonably small because the threshold line appeared to be less steep. Hence, the developed empirical I-D threshold for the landslide occurrence in Cameron Highland area will allow the authority to incorporate the threshold in the landslide early warning system. Subsequently, the authority can take pre-emptive actions such as evacuation of the affected areas and applying Emergency Preparedness Response Plan to reduce the risk and consequences of the landslide occurrences.

| No | Landslide Date | Maximum Rainfall Intensity (mm/hr) | Duration(hour) |
|----|----------------|-----------------------------------|----------------|
| 1  | 24/10/2018     | 25.5                              | 57             |
| 2  | 14/10/2018     | 42.6                              | 12             |
| 3  | 25/1/2017      | 15.1                              | 91             |
| 4  | 25/12/2016     | 39.3                              | 211            |
| 5  | 14/1/2016      | 20.7                              | 9              |
| 6  | 30/12/2014     | 13.2                              | 236            |
| 7  | 5/11/2014      | 31.5                              | 7              |
| 8  | 10/11/2013     | 27.5                              | 106            |
| 9  | 7/8/2011       | 26.1                              | 22             |
| 10 | 10/10/1996     | 13.8                              | 229            |
| 11 | 1/12/1995      | 12.4                              | 8              |
| 12 | 24/10/1995     | 17.1                              | 150            |
Figure 3: Intensity-Duration Threshold Graph for the landslide occurrence in Cameron Highland area

4. Conclusion
Rainfall intensity (I) and rainfall duration (D) had been acquired for twelve selected landslide cases in Cameron Highland area for the threshold analysis. From the analysis, the important variables such as maximum rainfall intensity, (I) and duration, (D) had been applied to develop the empirical rainfall intensity –duration (I-D) threshold for predicting the landslide in Cameron Highland area. The empirical I-D threshold that has been achieved by applying best-fit line and adapting power law equation. The I-D threshold equation had been developed in term of general equation, \( I = 29.088D^{-0.075} \), where the value of coefficients are \( \alpha = 29.088 \) and \( \beta = 0.075 \). Based on the threshold, the rainfall event for less than 10 hours requires 25 mm/hr intensity to trigger the landslide, while 22 mm/hr intensity is seemed to be adequate to initiate the landslides if the rainfall is non-stop beyond 24 hours. The develop threshold can be used in landslide early warning system to notify and inform the authority for executing evacuation measure in order to reduce the consequences of landslides event.

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