CRITICAL RAINFALL CONDITIONS FOR LANDSLIDES OCCURENCES TO DEVELOP WARNING SYSTEM IN CAMERON HIGHLANDS, PAHANG, MALAYSIA

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ABSTRACT

The present study aimed to develop a method for the prediction of the occurrence of sediment-related disasters resulting from landslides in the Cameron Highlands, Pahang. First, the author numerically discusses the correlation between rainfall conditions and the number of landslides using a drainage model, slope stability model, and rainfall runoff model. The rainfall conditions obtained numerically from the models are discussed, with respect to the plane of hourly rainfall and accumulated rainfall and snake lines of past rainfall events. Then, the snake lines that caused the sediment-related disasters have been compared with the simulated threshold curves to specify the critical line useful for the disaster occurrence. This study proposes the critical lines of rainfall conditions for five areas in the Cameron Highlands, Pahang.

Keywords: landslide prone area, critical rainfall condition, slope stability, snake lines, early warning.

1. INTRODUCTION

The Cameron Highlands is a district located in Pahang, the third largest state in Malaysia. The Telom River, Bertam River and Lemoi River are three main river basins with total catchment areas of 322 km^2, 263 km^2, and 112 km^2, respectively (Tenaga Nasional Berhad, Sedimentation Study Report, April 2). The Cameron Highlands is a landslide-prone area, as illustrated in ***Figure 1***, and on May 11, 1961, a landslide tragedy at Ringlet, Cameron Highlands was the first national disaster after Malaysia gained Independence on August 31, 1957. (National Slope Master Plan, 2009 –2023).

Several studies have been conducted on warning systems regarding sediment-related disasters. Abdul Muaz et al. proposed Empirical Intensity-Duration (ID) threshold for shallow landslides by considering 37 cases of shallow landslides in Peninsular Malaysia and 11 cases in the Cameron Highlands. This empirical threshold is based on historical landslides corresponding to the intensity of the rainfall when the event occurs.

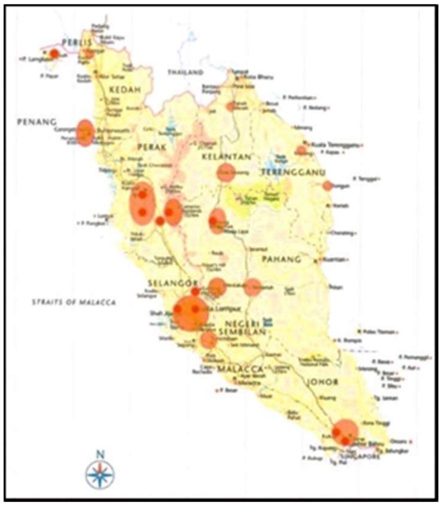

***Figure 1**: Landslide Prone Areas in Peninsular Malaysia*

Regional landslide early warning systems are unavailable, as they are under development; nevertheless, some initiatives have been taken at very specific sites. A landslide early warning system should be set up as part of preparedness and to increase resilience against landslides. Under these circumstances, this study was conducted with the following

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objectives.

a. To propose a method to determine the critical rainfall condition causes of shallow landslides.
b. To propose Landslide Early Warning System on a regional basis.

2. THEORY AND METHODOLOGY

2.1 Outline

The Rainfall-Sediment-Runoff Model (RSR) is a model for evaluating rainfall runoff, sediment runoff, and slope stability. The structure of the model is shown in ***Figure 2***. Topography is essential for the drainage model. Therefore, the usage of high-resolution topography is highly recommended for determining the unstable meshes representing shallow landslides.

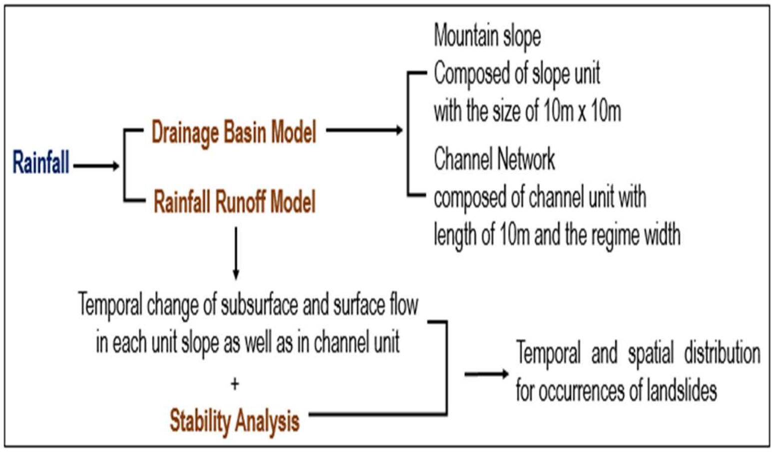
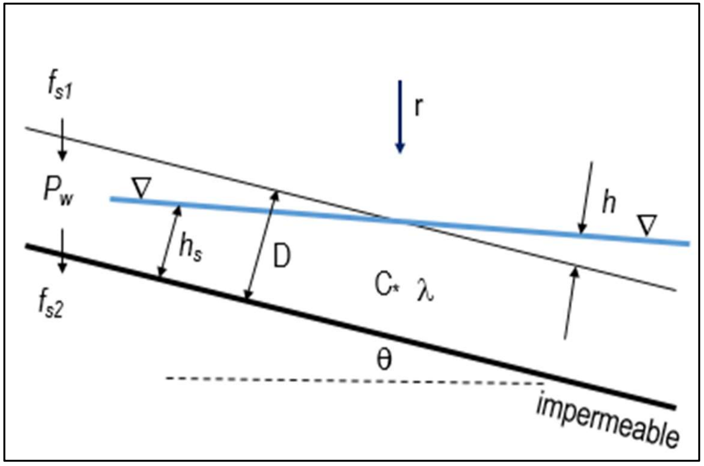


Figure 2*: Structure of Rainfall-Sediment Runoff Model to evaluate shallow landslides*

2.2 Rainfall Runoff Process Model in Slope Area

Figure 3 shows the rainfall-runoff process in a slope model in which subsurface flow occurs and increases. Surface flow occurs with an increase in the subsurface flow. The rainfall runoff process model computes such flows during rainfall events.



r	Rainfall Intensity
P_w	Water content of surface soil layer before the rainfall event
D	Thickness of the surface layer
h_s	Subsurface flow depth
h	Surface flow depth
λ	Porosity $\chi + c_* = 1$
θ	Slope gradient
f_{s1} f_{s2}	Infiltration capacity

Figure 3*: Diagram of rainfall runoff process model on the slope*

2.3 Slope Stability Model

The slope stability model is based on a balance equation. It is composed of resistance and driving forces. Coulomb friction and cohesion constitute the resistance force, while driving or gravitational forces are contributed by forces acting on the surface soil, subsurface flow, and surface flow. Landslides occur when the gravitational force is greater than the resisting force. A temporal change in moisture content, especially an increase in moisture content, can cause shallow landslides, especially when the surface soil D becomes fully saturated. The overall slope stability process is illustrated in ***Figure 4*** below.

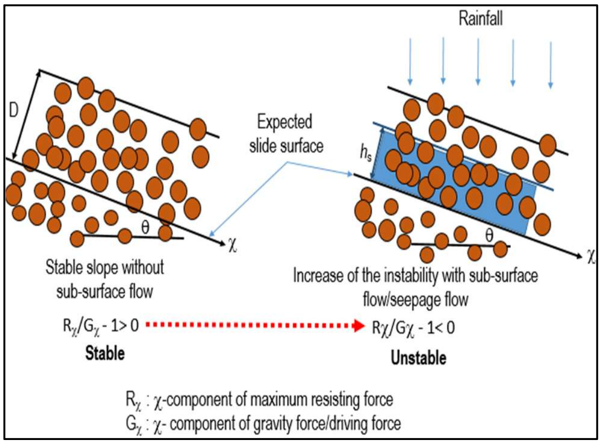


***Figure 4**: Impact of subsurface flow on slope stability*

P_w	Water content in the pores of the soil layer without seepage flow
c	Cohesion of the surface soil layer
σ	Mass density
ρ	Mass density of water
c_*	Sediment concentration $c_* = 1-\lambda$ (λ porosity)
ϕ	Internal friction angle of soil particles
D	Thickness of the surface soil layer
h_s	Depth of the subsurface flow
h	Surface flow depth

$h_s < D$ (without surface flow)

$$R_x = \{\sigma c_* D - \rho c_* h_s + \rho P_w (D - h_s)\ g\cos\theta\tan\phi + c$$
$$G_x = \{\sigma c^* D + \rho\ (1 - c^*)\ h_s + \rho P_w (1 - c_*)\ (D - h_s)\}g\sin\theta$$

$h_s > D$ (with surface flow)

$$R_x = (\sigma - \rho) c_* D g\cos\theta\tan\phi + c$$
$$G_x = \{\sigma c_* D + \rho(1 - c_*)D + \rho h\}g\sin\theta$$

The slope stability changes with condition of subsurface flow and surface flow due to rainfall. An unstable mesh, which corresponds to the potential occurrence of a landslide, occurs when the gravity force Gx is greater than the resisting force R_x.

3. DATA

3.1 Study Area

In this study, five areas were delineated for numerical analysis with a catchment area of 31.40 km^2, 17.03 km^2, 16.24 km^2, 10.06 km^2, and 13.14 km^2. The area was selected based on the town area, casualties, landslide events, and availability of data. The chosen study areas included Ringlet, Tanah Rata, Brinchang, Tringkap, Kuala Terla and Kampung Raja.

3.2 Data Availability

This study required topographical data, as shown in ***Figure 5***, for computation of the Rainfall Sediment Runoff (RSR) model. The DEM is available from the Mapping & Survey Department (JUPEM), which is responsible for Malaysia's survey and mapping activities. The DEM was updated in 2017 with a resolution of 10 m.

The historical landslide inventories, as illustrated in ***Figure 6***, were gathered and mapped by the Mineral and Geoscience Department (JMG). This landslide event was validated using historical rainfall events. Furthermore, the author also gathered information regarding historical landslide events that involved severe impact with casualties from a newspaper.

Approximately 17 rain gauge stations were identified in the Cameron Highlands. For the numerical analysis, hourly rainfall data were gathered from the Drainage and Irrigation Department (DID) and Slope Engineering Branch, Public Works Department (PWD).

The slope distribution is required to show the relationship between the slopes gradient and landslide event based on a balanced equation. The slope distribution was generated by the author, using ArcGIS, as shown in ***Figure 7***.

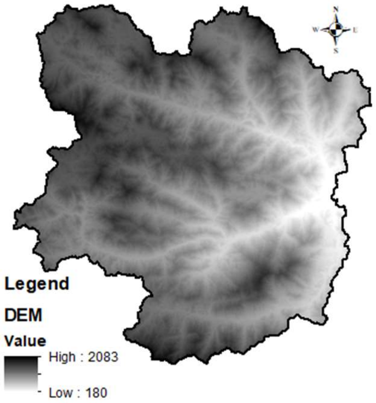


Figure 5: DEM

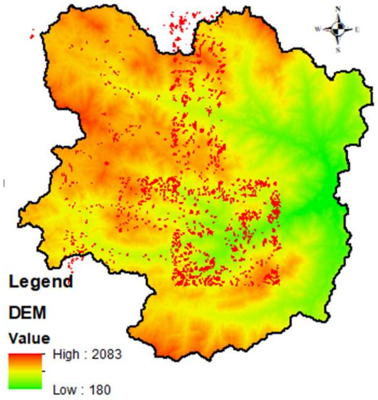


Figure 6: *Landslides distribution*

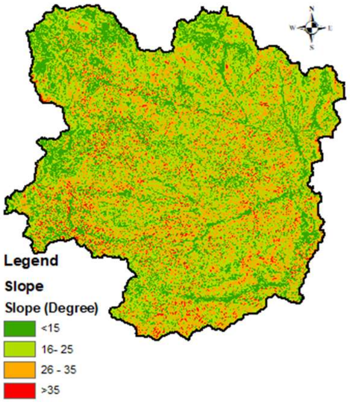


Figure 7: *Slope distribution*

4. RESULTS AND DISCUSSION

4.1 Relationship between Landslides resulting from rainfall

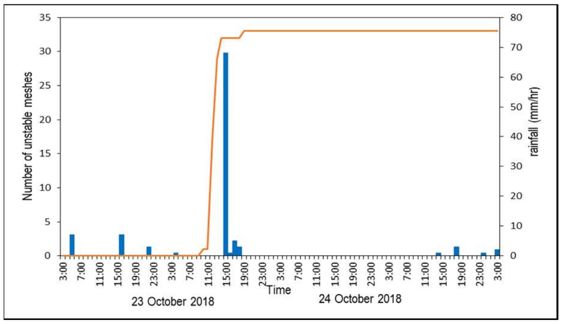


Figure 8: *Cumulative number of meshes for landslide and hyetograph*

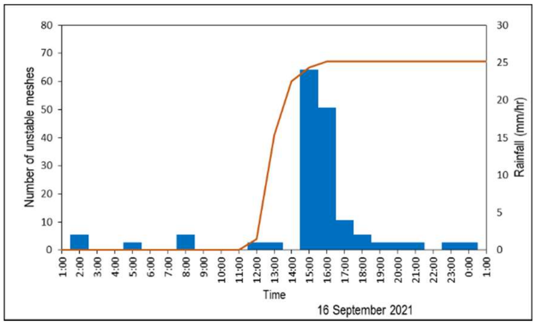


Figure 9: *Cumulative number of meshes for landslide and hyetograph*

The results shown in ***Figures 8*** and ***Figure 9*** are unstable meshes representing the number of landslides that consist of 100 m^2 for one unstable mesh. For Area 1, heavy rainfall occurred on October 24, 2014 at 3.00 pm and stopped after 7.00 pm; the intensity of rainfall was 68 mm. As shown, the accumulated number of unstable meshes increased during intense rainfall, which stopped at approximately 7.00 pm.

In the same area, on 16 September 2021, unstable meshes gradually increased between 12.00 pm to 4.00 pm. In addition, heavy rainfall occurred at 3.00 pm and stopped at approximately 4.00 pm. This scenario is illustrated in ***Figure 9***.

4.2 Correlation between occurrence of rainfall conditions and landslides

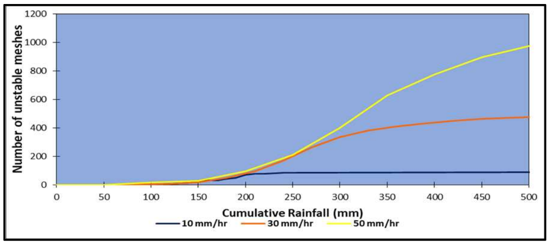


Figure 10: *Number of unstable meshes with constant rainfall*

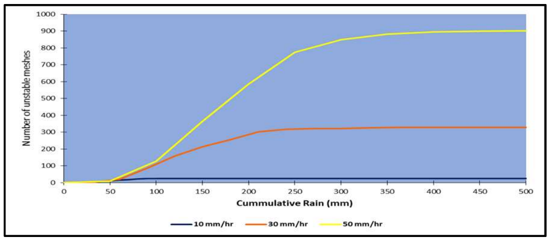


Figure 11: *Number of unstable meshes with constant rainfall*

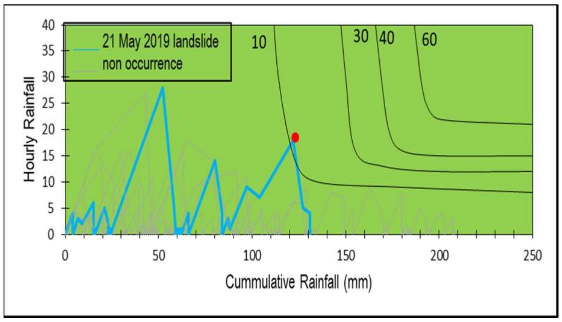


Figure 12: Rainfall condition curve and snake lines

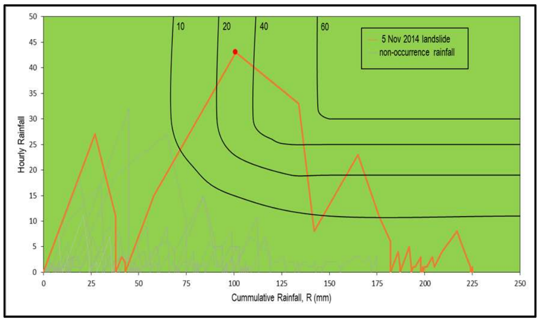


Figure 13: Rainfall condition curve and snake lines

Figure 10 and ***Figure 11*** show the unstable meshes with a constant rainfall of 10 mm/h, 30 mm/h, and 50 mm/h for a continuous period of 24 hours. These unstable meshes were converted to rainfall condition curves together with snake lines of the landslide events (***Figure 12*** and ***Figure 13***). The snake lines were analyzed to determine the critical condition curve that caused the sediment disaster. The rainfall curve for 10 was shown to be the critical rainfall condition in Area 1 and rainfall curve for 20 was shown to be the critical rainfall curve for Area 2. Both areas were computed using the same value parameters: a soil depth of 1.0 m, a hydraulic conductivity of 0.05 mm/s and an internal friction angle of 35 °. Furthermore, the cohesion of both areas was selected with a value of 4 kN/m^2 for Area 1 and 3 kN/m^2 for Area 2, after calibration and validation were performed. Different cohesion values indicate that the strength of the soil plays a significant role in slope stability. Area 1 is high endurance and resistance to landslides than Area 2. Therefore, Area 1 have high tendency for particles to adhere, and Area 2 have high possibility of having more landslides. However, other factors also contribute to landslides, such as the slope gradients in both areas.

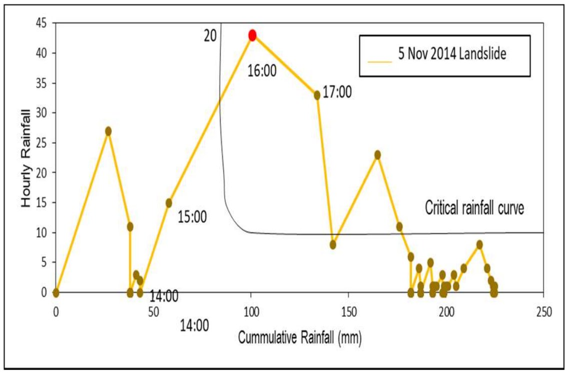


Figure 14: Critical rainfall curve for disaster and snake lines

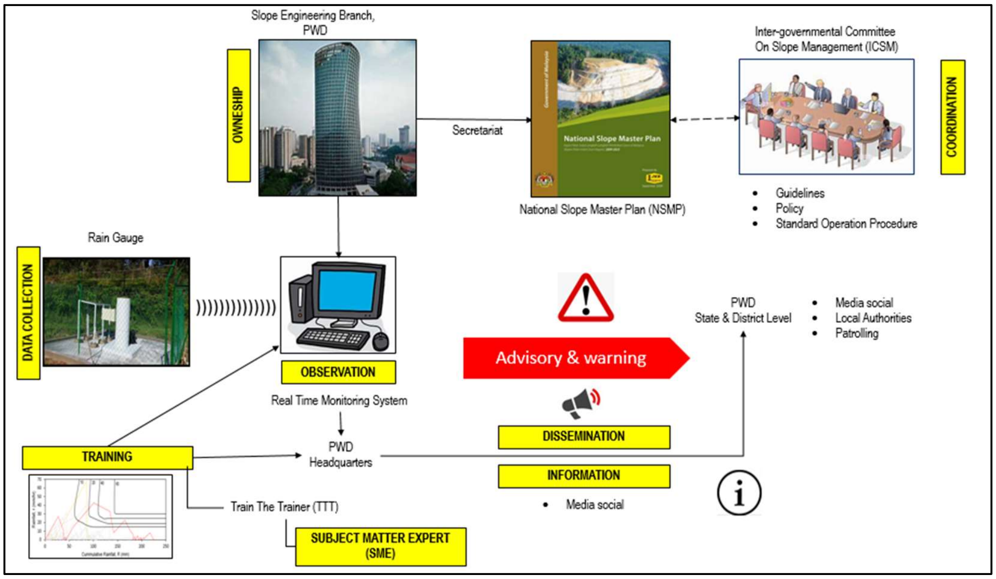


Figure 15: Schematic Diagram of Setting up an Early Warning System

Figure 14 shows that landslides could be predicted, and an early warning and advisory could be disseminated for safety purposes and to advise people to avoid that area. The advisory and warning information can be an early, such as an alert 3 hours before the sediment-related disaster occurs, and it would be more beneficial by combining it with rainfall forecast values because it can then be used for generating prediction at an earlier time point. The critical rainfall curve should be inputted into the Landslide Early Warning System as shown in ***Figure 15.*** This figure shows a comprehensive schematic of the Landslide Early Warning System for some targeted regions.

5. CONCLUSION AND RECOMMENDATION

The present study proposed a method to formulate critical rainfall conditions for disaster occurrence due to landslides, as well as identified critical curves of the disasters resulting from landslides, focusing on five sites in the Cameron Highlands.

The proposed method can be applied to different sites where there are a data on landslide disasters. Thus, this method is expected to play an important role in warning systems for disaster mitigation.

As the Slope Engineering Branch, Public Works Department (PWD) has a system that can retrieve and monitor rainfall intensity by real time monitoring, the process should be started from training program “TRAIN THE TRAINER” on how to determine the critical rainfall condition by sharing knowledge, through coaching and mentoring methods, and by communication between colleagues in the PWD.

The Inter-governmental Committee on Slope Management (ICSM) is held every year as part of the National Slope Master Plan strategic plan. This platform can be used to expand the method through presentation to various stakeholders.

Therefore, the author strongly suggests that Landslide Early Warning should be set up as soon as possible for better resilience against landslides in the future. Malaysia should have at least a regional warning for landslides, which can be improved over time.

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7. REFERENCES

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