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Determination of Rainfall Characteristics and Soil Water Index for Debris and Mud Flow in Cameron Highlands, Malaysia

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Abstract – *In recent years, Debris and Mud flow occurs more frequently in landslide prone areas in Malaysia such as Hulu Kelang, Penang and especially Cameron Highlands. It is the most catastrophic type of landslides as it causes extensive property damage and casualties. The disaster effect can be minimized if we could predict spatially and temporally the impending event. As the susceptibility map of Cameron Highlands was established by the Department of Mineral and Geosciences, Malaysia in 2016, the temporal prediction serves to fill the lack of the warning system. The main triggering parameter of Debris and mud flow is rainfall and the data are more promptly acquired; therefore, this information is very crucial to investigate the correlation of the corresponding rainfall and the soil water index of the Debris and Mudflow in Cameron Highlands. The study adopts the tank model to calculate the soil water index. This method has been implemented by the Japan Meteorological Agency in their alert issuing system. 20 numbers of debris and mud flow were recorded in Cameron Highland from 1994 to 2020 and were investigated. The results show that the debris and mud flow are affected by the monsoon and during the prolonged rainfall whereby the continuous rainfall is more than 80mm. The SWI for debris and Mud flow in Cameron Highland is 61 on average. The findings in this study can be an input of the disaster management plan and responsible agencies in delivering the warning to the local community.*

***Key Words*: Temporal forecasting, Debris, Mudflow, Soil Water Index, Disaster Management, SWI, Cameron Highlands**

1.INTRODUCTION

Debris and mud flow as described by Dikau et. al. [1] is a landslide in which the individual particles travel separately within a moving mass while Varnes [2] defined it as descending and outward movement of slope forming run out affected by the gravity. It is one of the sediment related disasters that disastrous and causes fatalities. Apart from the geological and morphology setting of the affected area as well as the human activity, it is agreed that the rainfall is the main triggering factor for debris and mud flow to occur [3-5]. Due to the magnitude and frequency of such incidents, several studies have been made to estimate critical rainfall conditions that induce landslides. As suggested by Chen and Fujita [6], rainfall-based warning system is the most used sediment disaster warning systems while Keefer et al. [7] described that the system for issuing warnings of landslides in Francisco Bay Region, California is based on empirical and theoretical relations between rainfall and landslide initiation, geologic determination of areas susceptible to landslides, real-time monitoring of rain gauges and precipitation forecasts. Malaysia, on the other hand had developed the correlation based on the rainfall threshold mostly for shallow landslide and major landslide but not yet implemented the threshold as an operational warning model. The compilation of the studies is summarized in Table 1. The compilation shows that the threshold is based on the empirical model that represents the relationship of surface rainfall and event and less focusing on debris and mud flow. While there is a lack of follow –up on the conceptual model that is more representative of the hydro-metrological process, therefore, this study adopts the Soil Water Index (SWI) as a proxy to calculate the soil water content that initiated the debris and mud flow. The method considered the surface runoff, infiltration of rainfall to the underground and the discharge of the subsurface. As the works of Kuraoka & Mori [12], Mukhilisin et al. [13], and Matlan,et al. [15] did not determined the SWI value of their area of interest, Hulu Kelang and Ranau, Sabah respectively, therefore this study aim to determine the SWI value for debris and mud flow in Cameron Highlands, Malaysia.

Table -1: Summary of rainfall threshold study in Malaysia

References	Area	Landslide Type	Parameter	No of Events
Dom et al. [8]	Cameron Highlands	DMF	Rainfall index	2
Jamaludin & Ali [9]	Ampang/ Hulu Kelang	Shallow Landslide	I-D	16
	Penang	Shallow Landslide	I-D	15
Lee et al. [10]	Hulu Kelang	Major landslide	E_3-API_{30}	6
		Medium landslide	E_3-API_{30}	15
Jamaludin et al. [11]	Peninsular Malaysia	Shallow landslide & DMF	I_p-D	4
Kuraoka & Mori [12]	Peninsular Malaysia	Shallow landslide & DMF	SWI 72 hrs vs 1.5 hrs rainfall	8
Mukhilisin et al. [13]	Hulu Kelang	Landslide	SWI	15
Abidin & Dom [14]	Cameron Highlands	-	Rainfall index	4
Matlan et al. [15]	Ranau	-	SWI	10
Kasim et al. [16]	Peninsular Malaysia	DMF	I-D	8
Maturidi et al. [17]	Cameron Highlands	Shallow landside	I-D	12

Note: DMF = debris and mudflows, I-D = rainfall intensity-duration threshold, E_3-API_{30} = cumulative 3-day rainfall–30-day antecedent precipitation index threshold, Ip-D = highest rainfall intensity-duration threshold, SWI = soil water index, I = rainfall intensity, D = rainfall duration, Ip = highest rainfall intensity, E_3 = cumulative 3-day rainfall amount, API_{30} = 30-day antecedent precipitation index.

1.1 Study Area

Cameron Highlands is one of the districts in Pahang, Malaysia. It is located between latitude 4.620034°N and 4.321226°N, and between 101.332293°E and 101.608324°E. The catchment area is 712km^2 compromises 3 major river catchment systems namely Telom Catchment in the North, Bertam catchment in the middle of the district and Lemoi Catchment. Both catchments are highly cultivated in the upstream region with several town centers while the Lemoi catchment is entirely in the jungle. The landscape of the Cameron Highlands is hilly with the elevation between 1,135m to 1,829m above sea level. More than 66% of slope gradient is 20° deriving dominantly from granitic development with many separation points and regions showing sedimentary arrangement at the western limits. Cameron Highlands received annual rainfall 3000mm on average while Taiwan 2500mm and Japan 1700mm. Since the 1900s, Cameron Highlands experienced rapid growth in terms of new land opening, deforestry for the pursuit of agricultural demand, infrastructure development and urbanization [19-20]. The geology, topography and the climates coupled with the human activity for the sake of development provide ideal settings or predispositions for the debris flow occurrences in Cameron Highlands.

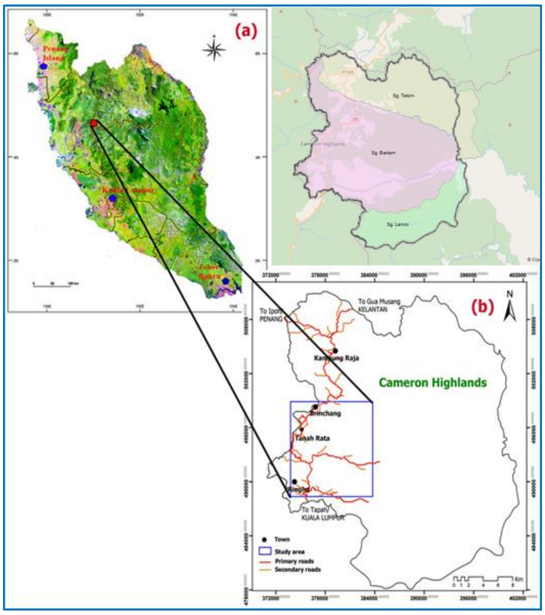


Fig -1: Cameron Highlands catchment

1.2 Debris and Mud Flow in Cameron Highlands

With increasing agricultural activities in the Study Area, there was a marked increase in debris and mud flow events which has been fatalistic when passed through certain populated areas. It has also caused extensive economic losses to the residents living in the river proximity. As confirmed by the Department of Minerals & Geoscience (JMG), 10.19% is Flow type [18]. The first historical Debris and Mud Flow in Cameron Highlands perhaps happened in 1994 that caused 7 casualties, 3 houses and 17 families relocated. The occurrence event of Debris and Mud Flow from 1994-2020 is compiled in the Table 2 below.

Table -2: Historical Debris and Mudflow Incident in Cameron Highlands.

No	Year	Date	Time	Location
1	1994	6 Dec	8pm	Kg. Raja, Tringkap dan Tanah Rata
2	2000	6 Jan	3-4am	Bt 48-54, Kg Raja
3	2011	7 Aug	5.45pm	Kg Org Asli, Sg Ruil
4	2012	2 Feb	12am	Sg Perlong, Jln Perlong Kuala Terla
5	2013	23 Oct	1.05am	Pekan Ringlet & Lembah Bertam
6	2013	22 Oct	7.30-8.15pm	Kg Baru Ringlet
7	2014	5 Nov	7.50pm	Kg Raja, ringlet & Lembah Bertam
8	2014	30 Dec	5.30am	KM46, Jln brichang-Tringkap
9	2015	29 Apr	1.30am	SKJT Kuala Terla
10	2016	29 May	2.30am	Batu 49, Kuala Terla
11	2016	24 Dec	3.00pm	Kg. Bharat Tea, Kuarters Kerajaan Balai Polis, Tanah Rata
12	2017	3 Feb	3.45pm	Catus Valley, Pekan Lama Brinchang
13	2017	16 May	5.00pm	Kg Baru Ringlet
14	2018	14 Oct	4.30am	Batu 49, Kg.3 Terla
15	2018	24 Oct	4.00pm	Batu 51, Kg Raja- Kuala Terla
16	2018	31 Dec	9.00am	Jln Tapah - Cameron (Habu)
17	2019	25 May	6am	Jalan Ulu Merah, Ringlet
18	2020	15 May	8am	Jln Bt 49, Pos Terisu,Kuala Terla
19	2020	12 Aug	9pm	Mardi/Lembah Bertam Pos Lemoi
20	2020	12 Oct	6pm	Jln Ulu Merah

1.3 Rainfall Characteristics Related to Debris and Mudflow

The rainfall characteristic in a rainfall series as shown in chart 1 that induces the debris and mud flow is considered the corresponding responsible rainfall. According to Basile & Panebianco [20], the cumulative rainfall is the predisposition and rainfall intensity are the triggering parameters that could initiate the occurrence. The frequency of the debris and mud flow occurrences by the monsoon distribution also investigated as it affected by the monsoon [21,22]. The guideline by the Ministry of Land, Infrastructure and Transport (MLIT), Japan determined that a continuous rainfall more than 80mm or a rainfall intensity more than 20mm hourly could induce the debris and mud flow [23]. The rainfall duration has a closed correlation and therefore being a popular empirical model of Intensity-Duration (ID) threshold. [3-5, 24-27]. Nikolopoulos et al. [28] suggested that the short duration considered as less than 12-hr shall be excluded in the analysis to improve the bias and improve the performance of the ID relationship. As such, this study investigates the characteristics of the rainfall such as short intensity (high intensity, short duration) or prolonged rainfall (low intensity, long duration) that induce the Debris and mud flow in Cameron Highlands.

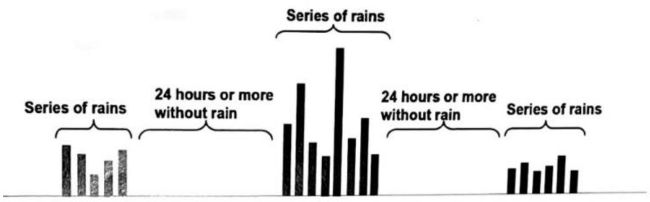
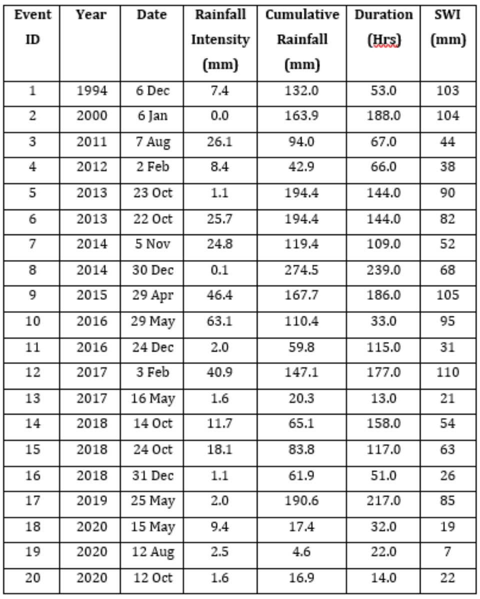


Chart -1 : Concept of rainfall series

According to Rahman & Mapjabil [29], other factors, other than rainfall, could have triggered the occurrence of landslides, such as earthquakes, volcanic activity, and human engineering activity. However, according to Kasim et al. [21], rainfall is the primary cause of debris and mud flow in Peninsular Malaysia. Therefore, the rainfall characteristic for the study area such as rainfall intensity, cumulative rainfall, duration and SWI are calculated and summarized as table below;

Table -1: Summary of Rainfall Intensity, Cumulative Rainfall, Duration and SWI of Debris and Mud Flow in Cameron Highland**s.**



Event ID	Year	Date	Rainfall Intensity (mm)	Cumulative Rainfall (mm)	Duration (Hrs)	SWI (mm)
1	1994	6 Dec	7.4	132.0	53.0	103
2	2000	6 Jan	0.0	163.9	188.0	104
3	2011	7 Aug	26.1	94.0	67.0	44
4	2012	2 Feb	8.4	42.9	66.0	38
5	2013	23 Oct	1.1	194.4	144.0	90
6	2013	22 Oct	25.7	194.4	144.0	82
7	2014	5 Nov	24.8	119.4	109.0	52
8	2014	30 Dec	0.1	274.5	239.0	68
9	2015	29 Apr	46.4	167.7	186.0	105
10	2016	29 May	63.1	110.4	33.0	95
11	2016	24 Dec	2.0	59.8	115.0	31
12	2017	3 Feb	40.9	147.1	177.0	110
13	2017	16 May	1.6	20.3	13.0	21
14	2018	14 Oct	11.7	65.1	158.0	54
15	2018	24 Oct	18.1	83.8	117.0	63
16	2018	31 Dec	1.1	61.9	51.0	26
17	2019	25 May	2.0	190.6	217.0	85
18	2020	15 May	9.4	17.4	32.0	19
19	2020	12 Aug	2.5	4.6	22.0	7
20	2020	12 Oct	1.6	16.9	14.0	22

2. Methodology

The collection of the historical debris and mud flow is from the various sources and compiled accordingly to the information required to perform the calculation of rainfall intensity, rainfall duration and cumulative rainfall that induces the debris and mud flow in this study. One rainfall event or series in accordance with the guidelines for development of warning and evacuation systems against sediment-related disasters, MLIT, Japan is defined as the starting and ending of rain with no rainfall for 24 hours or over before the rain and after the rain. [23]. The rainfall intensity is the depth of rain during the event, while the rainfall duration is the total duration of the rainfall series of the event. Cumulative rainfall is the total of rain in the series.

Meanwhile, the rainfall data for this study is measured by a rain gauge and is presented in hourly format. This study uses all 6 numbers of existing rainfall stations networks, and the Thiessen Polygon method is used in this study as shown in Fig.3. The nearest rainfall station is used if the station is not available during the occurrence of the event.

The application of SWI in Cameron Highlands is estimated based on previous records of rainfall data and debris and mud flow events adopting the tank model illustrates in Figure below;

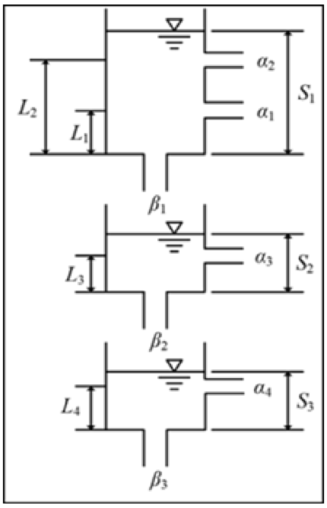


Fig -2: Three serial tank of Tank Model

The equation adopted for this study is as below;

$$\text{Soil Water Index (SWI)} = S_1 + S_2 + S_3$$
(Equation **Error! No text specified style in document.**.1)

$$S_1(t+\Delta t) = (1-\beta_1 \cdot \Delta t)\ S_1(t) - [\alpha_1\{S_1(t)-L_1\} + \alpha_2\{S_1(t)-L_2\}] \cdot \Delta t + R$$
(Equation **Error! No text specified style in document.**.2)

$$S_2(t+\Delta t) = (1-\beta_2 \cdot \Delta t)\ S_1(t) - \alpha_3\{S_2(t)-L_3\} \cdot \Delta t + \beta_1 \cdot S_1(t) \cdot \Delta t$$
(Equation **Error! No text specified style in document.**.3)

$$S_3(t+\Delta t) = (1-\beta_3 \cdot \Delta t)\ S_1(t) - \alpha_4\{S_3(t)-L_4\} \cdot \Delta t + \beta_2 \cdot S_2(t) \cdot \Delta t$$
(Equation **Error! No text specified style in document.**.4)

where,

S1, S2, S3 : Water storage in each tank (mm)

α1, α2, α3, α4 : Discharge coefficients of each lateral holes (1/hr)

β1, β2, β3 : Discharge coefficients of each vertical holes (1/hr)

L1, L2, L3 : Height of each lateral holes (mm)

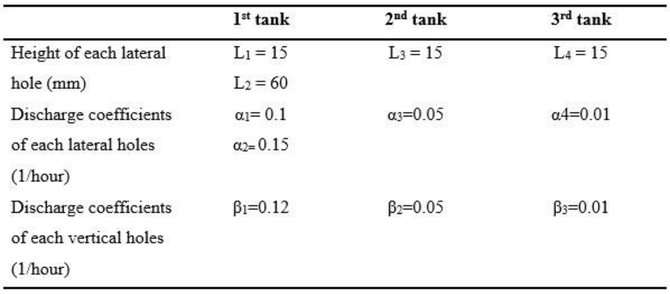
Δt1 : Step time (1hour)

R : Rainfall (Hourly rainfall)

The constant parameters of discharge coefficients and the height of each lateral holes uses the ones that were developed by Okada et al. [30]. Consequently, despite the diverse geological conditions, the JMA accepted it for their early warning system for all of Japan. This was used in Taiwan to calculate their SWI for mass movement prediction tools Chen et al. [31] and large-scale landslides Lin et al. [32]. Okada et al. [30]. investigated fixed parameters with the accustomed parameters for different localities and found comparable drifts. Furthermore, the SWI indicates the slope's conceptual water content.

Table 2 shows the constant parameters for each layer or tank in equations 2.1 to 2.4.

Table -2: Parameters of SWI



	1st tank	2nd tank	3rd tank
Height of each lateral hole (mm)	$L_1 = 15$ $L_2 = 60$	$L_3 = 15$	$L_4 = 15$
Discharge coefficients of each lateral holes (1/hour)	$\alpha_1 = 0.1$ $\alpha_2 = 0.15$	$\alpha_3 = 0.05$	α4=0.01
Discharge coefficients of each vertical holes (1/hour)	$\beta_1 = 0.12$	$\beta_2 = 0.05$	$\beta_3 = 0.01$

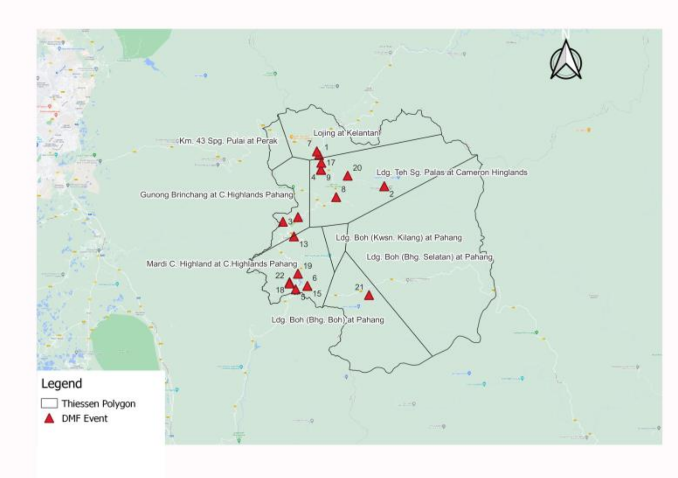


Fig -3: Event and the Thiessen Polygon of the Rainfall Station

3. Finding

The debris and mud flow in Cameron Highlands occur frequently during the Northwest Monsoon (8 out of 20 events) followed by Southwest Monsoon (6 out of 20 events). Apparently, it occurs the most in October, May and December. The occurrence frequency by the month and monsoon distribution is shown in the Chart-2 and Table-3 below;

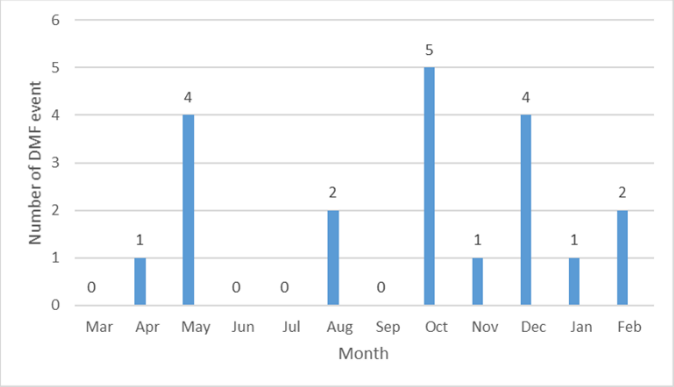


Chart -2: Frequency of Debris and Mud Flow Occurrence by Month

Table -3: Frequency of Debris and Mud Flow Occurrence by Monsoon

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
No. of DMF	0	1	4	0	0	2	0	5	1	4	1	2
Total	1		6				5		8			
Monsoon	Inter Monsoon		Southwest Monsoon				Inter Monsoon		Northeast Monsoon			

The finding in this study also suggested that debris and mud flow in the study area is potentially to happen more during the prolonged rainfall whereby 13 events (65%) fall in this condition. This result is contrary to the guideline by MLIT Japan that only 6 events (30%) of rainfall intensity more than 20mm. However, 60% of the event shows cumulative rainfall more than 80mm as per guideline. The finding is summarised in the chart-3 and Table-4;

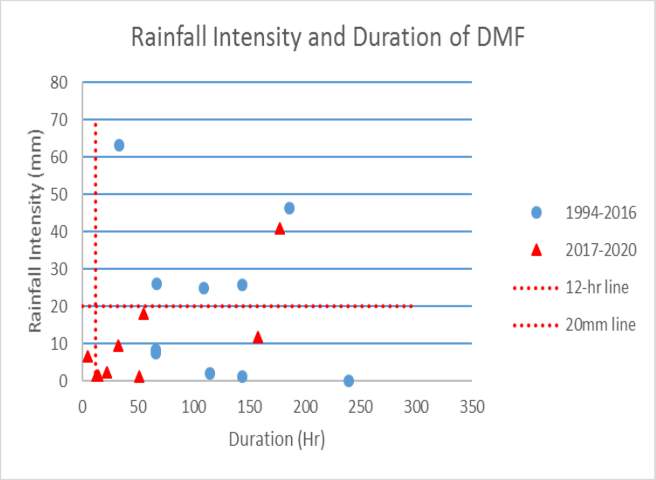


Chart -3: Rainfall Intensity and Duration of Debris and Mud Flow

Table -4: Summary of the rainfall condition of Debris and Mud Flow

Rainfall condition	Number of events
Low intensity (<20mm), long duration (>12hrs)	13
High intensity (>20mm), long duration(>12hrs)	6
Low intensity(<20mm), Short duration(<12hrs)	1
High intensity(>20mm), Short duration(<12hrs)	0

4. CONCLUSIONS

Based on the findings of this study, it can be concluded that when rainfall conditions are low intensity and long duration there is a higher percentage of debris and mud flow occurrence than when rainfall conditions are high intensity and short duration. However, with a longer duration, the parameter's contribution to the event is significant to the intensity of the rainfall parameters. The debris and mud flow are likely to happen more in the study area when the cumulative rainfall is more than 80mm for the duration of the series more than 24-hour.

While the SWI for Cameron Highlands is 61 on average. The first historical ranking of SWI was 105 in 2015 followed by SWI in 2000, 104 and 1994, 103. The historical value of the SWI can be the benchmark of the debris and mud flow occurrences in the study area. The finding for the SWI value shows that the value has decreased in recent years. This could be due to the rapid land opening for the agricultural activities or the failure occurs at the same slope.

This study also can be served as the basis of the threshold establishment in the future study of SWI in Cameron Highlands other than its goal to contribute to the disaster management plan, as well as responsible agencies in conveying the warning to the local community.

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