DEVELOPMENT OF EMPIRICAL RAINFALL THRESHOLDS FOR LANDSLIDE FORECASTING IN PENINSULAR MALAYSIA

BY

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ABSTRACT

Peninsular Malaysia recorded a significant number of shallow landslides every year. The occurrences of slope failure cause massive losses in lives, socio-economy, and people's well-being. The disaster becomes more frequent in monsoon or rainy season (November until March) and (May to September) each year, whereby the extreme storm or prolonged rainfall triggers numerous slope failures. Recognizing the rainfall as one of the triggering factors of slope failure, hence, it is essential to develop the empirical rainfall thresholds for shallow landslides forecasting in Peninsular Malaysia. Thirty-seven cases of landslides were gathered from 1993 to 2018 to determine the correlation between the rainfall event and landslide occurrence. By performing the practical method, the important rainfall parameters consist of rainfall intensity, and rainfall duration was acquired from the rainfall series analysis that had triggered the landslide. The obtained rainfall intensity and rainfall duration from the selected cases were utilized to develop empirical Intensity-Duration (I-D) threshold, presented in scattered plots. The threshold line equation of $I = \alpha D^{-\beta}$ was derived by applying power model regression in double log coordinates. The best-fitted line generated in between the plot was parallelly drawn at the lowest data plot to indicate the minimum rainfall intensity that could trigger the landslide. Two types of thresholds were developed: (I_{max} -D) and (I_{mean} -D), in which both thresholds acquired identical rainfall duration, but with distinct rainfall intensities. The obtained maximum intensity in the series of rainfall was applied for (I_{max} -D) while the mean intensity (total cumulative in series of rainfall divide by rainfall duration) was specified for (I_{mean} -D). The proposed (I_{max} -D) and (I_{mean} -D) thresholds of Peninsular Malaysia are expressed as $I = 37.8D^{-0.114}$ and $I = 17.5D^{-0.722}$, respectively (I = rainfall intensity in mm/hr, and D = duration in an hour). Geology has shown that igneous rock types (granite) are more vulnerable to failure than other rock types, such as metamorphic and sedimentary. Furthermore, the developed I-D thresholds of Peninsular Malaysia dominate the mid-upper position compared to I-D thresholds from various studies worldwide. More rainfall is required to initiate the slope failure, which the thicker layer of Malaysian soils can hugely influence. The curve inclination for the mid-latitude region also resulted in higher value, including the I-D threshold of Peninsular Malaysia (-0.722 to -0.114) in comparison to cold climates region. Moreover, the validation of the developed I-D threshold with the latest landslides resulted in the actual festive event (I_{max} -D). However, (I_{mean} -D) recognized a single case with false-negative events to the threshold revision. The real-time rainfall monitoring was carried out and justified that the (I_{max} -D) threshold is more efficient than (I_{mean} -D) for landslide early warning system later in Peninsular Malaysia due to its high threshold value.

خلاصة البحث

سجلت شبه الجزيرة الماليزية عددا كبيرا من الانهيارات الارضية الضحلة سنويا. تسببت حالات انهيار المنحدر في خسائر جسيمة في الأرواح والاقتصاد الاجتماعي وفي رفاهية الناس. تتكرر الكوارث بشكل أكثر تواترا في موسم الرياح الموسمية أو الأمطار (من نوفمبر إلى مارس) و (من مايو إلى سبتمبر) من كل عام، حيث تؤدي العاصفة الشديدة أو هطول الأمطار لفترات طويلة إلى حدوث العديد من حالات انهيار المنحدرات. عرف بأن هطول الأمطار هو أحد العوامل المسببة لانهيار المنحدرات. ومن الضروري تطوير عتبات الامطار التجريبية للتنبؤ بالانهيارات الارضية الضحلة في شبه جزيرة ماليزيا. وقد تم جمع ٣٧ حالة من الانهيارات الأرضية من عام ١٩٩٣ إلى عام ٢٠١٨ لتحديد العلاقة بين سقوط الأمطار وبين وقوع الانهيارات الأرضية. ومن خلال تنفيذ الطريقة العملية، تتكون بارامترات هطول الأمطار الهامة من كثافة سقوط الأمطار، وتم الحصول على مدة هطول الأمطار من تحليل سلسلة هطول الأمطار التي تسببت في الانهيار الأرضي. تم استخدام كثافة هطول الأمطار التي تم الحصول عليها ومدة هطول الأمطار من الحالات المختارة لتطوير عتبة الكثافة التجريبية (I-D)، حيث عرضت في قطع الأراضي المتفرقة. تم اشتقاق معادلة خط العتبة $I = \alpha D^{-\beta}$ من خلال تطبيق انحدار نموذج القدرة في إحداثيات السجل المزدوج. تم رسم أفضل خط تم إنشاؤه بين قطعة الأرض بشكل متوازي عند أدنى مخطط للبيانات للإشارة إلى الحد الأدنى من كثافة هطول الأمطار التي يمكن أن تؤدي إلى الانزلاق الأرضي. تم تطوير نوعين من العتبات: (Iحد أقصى-D) و(Iمتوسط -D) ، حيث اكتسبت كلا العتبتان مدة مماثلة من هطول الأمطار ولكن مع كثافة عالية في هطول الأمطار. تم تطبيق أقصى كثافة تم الحصول عليها في سلسلة هطول الأمطار لـ (Iحد أقصى-D) بينما تم تحديد متوسط الكثافة (التراكم الإجمالي من سلسلة تقسيم هطول الأمطار حسب مدة هطول الأمطار) لـ (Iمتوسط -D). يتم التعبير عن العتبات المقترحة (Iحد أقصى-D) و (Iمتوسط -D) لشبه جزيرة ماليزيا على النحو التالي $I = ٨,٣٧ D^{-٠.١١٤}$ و $I = ١٧,٥ D^{-٠.٧٢٢}$ (I = كثافة هطول الأمطار في مم/ ساعة، و D = المدة في الساعة الواحدة) على التوالي. اكتشفت الجيولوجيا أن أنواع الصخور النارية (الجرانيت) أكثر عرضة للانهيار من أنواع الصخور الأخرى، مثل الصخور المتحولة والرسوبية. علاوة على ذلك، تهيمن عتبات I-D المتطورة في شبه جزيرة ماليزيا على المركز المتوسط العلوي مقارنة مع عتبات I-D من مختلف الدراسات في جميع أنحاء العالم. والأمر يتطلب المزيد من هطول الأمطار لكي تبدأ في انهيار المنحدر، والذي قد يؤثر بشكل كبير على الطبقة الأكثر سمكا من التربة الماليزية. كما أدى ميل المنحنى لمنطقة منتصف خط العرض إلى ارتفاع القيمة، بما في ذلك الحد من I-D في شبه الجزيرة الماليزية (من -٠.٧٢٢ إلى -٠.١١٤) مقارنة بمنطقة المناخ البارد. علاوة على ذلك، أدى التحقق من عتبة I-D المتقدمة مع أحدث الانهيارات الأرضية إلى الحدث الاحتفالي الفعلي (Iحد أقصى-D). ومع ذلك، تعرف (Iمتوسط -D) على حالة واحدة بها أحداث سلبية كاذبة لمراجعة العتبة. وقد تم رصد هطول الأمطار في الوقت الحقيقي وبرر أن عتبة (Iحد أقصى-D) أكثر كفاءة (Iمتوسط -D) لغرض نظام الإنذار المبكر بالانهيارات الأرضية في وقت لاحق في شبه جزيرة ماليزيا نظرا لارتفاع قيمة العتبة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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I	Rainfall Intensity (mm/hr)
I_{max}	Maximum rainfall Intensity (mm/hr)
I_{mean}	Mean rainfall Intensity (mm/hr)
D	Event Duration, (hour)
α	Threshold coefficient (constant of D)
β	Threshold coefficient (curve inclination / power of D)
FoS	Factor of Safety
τ	Shear Strength of the soil (MPa)

LIST OF ABBREVIATION

DID	Drainage and Irrigation Department of Malaysia
I-D	Intensity-Duration Threshold
LEWS	Landslide Early Warning System
PWD	Public Works Department of Malaysia
SEB	Slope Engineering Branch
USGS	United States Geological Survey
WGS	Washington Geological Survey

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The landslide occurrence has become one of the most dreadful disaster to the entire globe. Even at this modern age, the natural disaster caused consequential losses in terms of public safety and the socio-economy (Public Works Department of Malaysia, 2009; Vaz et al., 2018; Dikshit et al., 2019). Likewise, these dreadful circumstances have been encountered by a Southeast Asian country like Malaysia. Malaysia officially reported first fatal landslide on 11 May 1961, four years after the national independence. Sixteen total deaths were recorded in that historic landslide. The disaster continuously hit this country with a great number of events every year. In general, Malaysia consists of two mainland which are West Malaysia and East Malaysia, where both are separated by the South China Sea. Focusing on West Malaysia or better known as Peninsular Malaysia, this region lies in between the latitude of 1^o to 7^o heading to the north and widens with the longitude of 100^o to 105^o towards east, with the coverage area of 132,091 km^2 (Figure 1.1) (Department of Statistics Malaysia, 2018). The most terrible landslide in Peninsular Malaysia occurred on 11 December 1993, resulted in 48 deaths, and collapsed a 12 storey-block of apartment of Highland Tower in Hillview Residential, Ulu Kelang Selangor. The main cause of that fatal landslide is the prolonged rainfall, with additional issues of the poor design of the drainage system and retaining wall, that causing lateral movement of soil, resulted in major landslide (Kazmi et al., 2017). Landslide is defined as the movement of the rock or mass, or earth slope slips under the action of gravity (Cruden, 2003). It could be triggered either by intense, prolonged precipitations, earthquakes, volcanic eruptions or man-made (Cruden & Varnes, 1996). In the context of landslides in Peninsular Malaysia, this region has recorded numerous landslides every year, whereby it might be triggered by various factors including geology, morphology, hydrology or anthropic influence (Cerri et al., 2017). Nevertheless, extreme precipitation has been recognized as one of the factors of shallow landslide in Peninsular Malaysia from the context of hydrology. The climatic variation is in conjunction with the rainy or monsoon season that occur twice a year (November until March) and (May to September) (Suhaila et al., 2010). Due to the fact that Peninsular Malaysia is situated the mid latitude climate, this region received abundance of tropical rainfall during the monsoon period that have resulted in numerous slope failures. Several studies carried out the relation between the high intensity rainfall and the occurrence of landslide. This has led to the establishment of an empirical rainfall threshold that can be a useful practice in predicting the occurrence of landslides. The rainfall intensity-duration (I-D) threshold is one of the applicable rainfall thresholds nowadays. It was first proposed by Caine (1980) that developed the global I-D threshold. Therefore, this research proposes the empirical rainfall thresholds which so called of maximum intensity-duration, (I_{max}-D) threshold and mean intensity-duration, (I_{mean}-D) threshold for the purpose of landslide forecasting in Peninsular Malaysia. The important rainfall parameters are derived from the analysis series of rainfall to come up with the empirical rainfall thresholds. In general, the developed rainfall thresholds can determine the minimum rainfall intensity that could initiate the landslide in at particular duration. Basically, the empirical rainfall thresholds later could be useful for the implementation of landslide early warning system, whereby the authority could be aware with the possibility of upcoming catastrophe, and they would take pre-emptive measures such as evacuation, rescue, road closure and spread of information to the civilians in order to minimize the risk and dreadful consequence from the disasters.

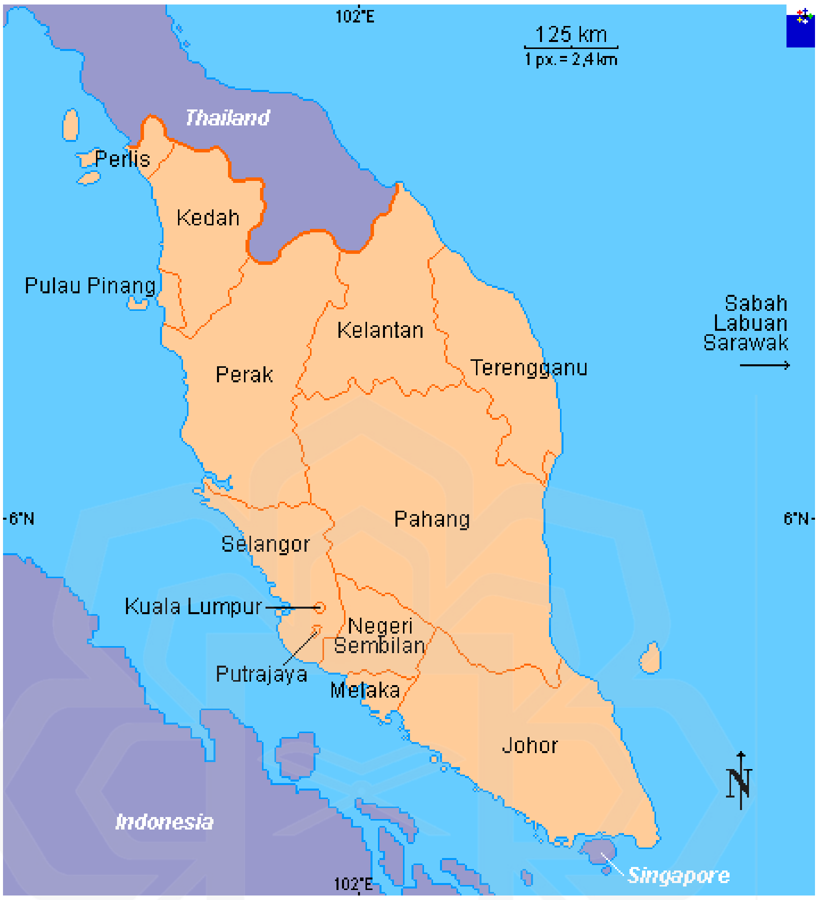

Figure 1.1 The Map of Peninsular Malaysia According to States. Retrieved From : (https://www.crwflags.com/fotw/flags/my(w.html)

1.2 STATEMENT OF THE PROBLEM

Peninsular Malaysia has recorded numerous landslips episodes every year that significantly affects the socio-economy and well-being of the people. The monetary losses caused by the landslide event from 1973 until 2007 reached out to RM 2961 million (PWD, 2009). Apart from that, almost 600 hundred death tolls were recorded in the past 34 years due to this catastrophe (PWD, 2009). This number will keep rising if there is no proper mitigation taken into consideration. It is agreed that the landslide could be triggered by various factors namely geology, lithology, morphology, etc., however, since this region reported a great number of landslides triggered by intense precipitation, hence, the meteorological factor could be emphasized in the first place. For this reason, it is essential to establish a rainfall threshold for the purpose of landslide forecasting in this region. The analyses series of rainfall that triggered the slope failures can obtain the necessary rainfall parameters to develop the empirical rainfall thresholds, by performing the practical method. The established rainfall thresholds later could be implemented in the application of Landslide Early Warning System (LEWS), that would enable the involved authorities to conduct further action in mitigating the losses from this threatening events. In addition, antecedent rainfall and short extreme rainfall can mutually influence the occurrence of shallow landslide in the context of Peninsular Malaysia. The developed rainfall thresholds are compared with various selected thresholds worldwide to distinguish the position of the rainfall thresholds among the comparison, which certainly depends on the proposed threshold values from respective region. Eventually, the developed rainfall thresholds require a necessary validation with the recent landslide occurrence to ensure the reliability of this rainfall threshold for application of LEWS later.

1.3 RESEARCH OBJECTIVES

The study aimed to achieve the following objectives:

1. To develop empirical rainfall thresholds by deriving the rainfall parameters based on the analysis series of rainfall using practical method.
2. To compare the developed rainfall thresholds for Peninsular Malaysia with various rainfall thresholds worldwide for recognizing the effect of rainfall-triggering landslide at respective region.