APPLICATION OF THE SNAKE-LINE METHOD AS AN EARLY WARNING INDICATOR FOR LANDSLIDES IN SABAH

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ABSTRACT

A landslide is a highly catastrophic geological disaster that occurs on a frequent basis around the world, posing a significant risk to people's safety and property. In Sabah, Malaysia, landslides are one of the most common geohazards that happens during the rainy season. Therefore, a dependable and effective landslide early warning indicator is an essential part of disaster mitigation to minimise the risk of landslide. Hence, the objectives of this project are, firstly to study landslide cases and rainfall data in Sabah. Second objective is to analyse the working rainfall patterns associated with the landslide event. Third objective is to propose a critical line for the application of the Snake-Line Method in Sabah's landslide disaster mitigation. This research is conducted to study the application of the snake-line method as an early warning indicator for landslides in Sabah. The study area of this study will focus on the landslide cases in Ranau, Sandakan and Tambunan. The effect of rainfall to landslide events will be analyse based on working rainfall method. In this study, long working rainfall and short working rainfall are used to determine if a sequence of rainfalls is foreseeable to cause a landslide. A series of rainfall distributions will be observed by drawing a snake-line that represents the progression of a long and short working rainfall values. A critical line is derived from previous study dividing the occurring and non-occurring rainfall based on data from landslide cases. When the snake-line crosses or comes close to the critical line, an early warning can be sent out.

ABSTRAK

(Penggunaan Kaedah Garis Ular Sebagai Petunjuk Amaran Awal Tanah Runtuh di Sabah)

Tanah runtuh ialah bencana geologi yang sangat dahsyat yang berlaku secara kerap di seluruh dunia, menimbulkan risiko besar kepada keselamatan dan harta benda orang ramai. Di Sabah, Malaysia, tanah runtuh adalah salah satu geobencana yang paling biasa berlaku semasa musim hujan. Oleh itu, penunjuk amaran awal tanah runtuh yang boleh dipercayai dan berkesan adalah bahagian penting dalam mitigasi bencana untuk meminimumkan risiko tanah runtuh. Justeru, objektif projek ini adalah, pertama sekali untuk mengkaji kes-kes tanah runtuh dan data hujan di Sabah. Objektif kedua adalah untuk menganalisis corak hujan kerja yang berkaitan dengan kejadian tanah runtuh. Objektif ketiga adalah untuk mencadangkan garis kritikal bagi penggunaan Kaedah Garis Ular dalam mitigasi bencana tanah runtuh Sabah. Penyelidikan ini dijalankan untuk mengkaji penggunaan kaedah garisan ular sebagai petunjuk amaran awal kejadian tanah runtuh di Sabah. Kawasan kajian kajian ini akan memfokuskan kepada kes-kes tanah runtuh di Ranau, Sandakan dan Tambunan. Kesan hujan terhadap kejadian tanah runtuh akan dianalisis berdasarkan kaedah hujan kerja. Dalam kajian ini, hujan kerja lama dan hujan kerja pendek digunakan untuk menentukan sama ada urutan hujan boleh dijangka menyebabkan tanah runtuh. Satu siri taburan hujan akan diperhatikan dengan melukis garisan ular yang mewakili perkembangan nilai hujan kerja panjang dan pendek. Garis kritikal diperoleh daripada kajian lepas yang membahagikan hujan yang berlaku dan tidak berlaku berdasarkan data daripada kes tanah runtuh. Apabila garisan ular melintasi atau mendekati garisan kritikal, amaran awal boleh dihantar keluar.

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LIST OF SYMBOLS

α_t	Decay coefficient at t hours
R_t	Rainfall intensity at t hours
WR	Working Rainfall
WR_0	Previous hour working rainfall
$R(t)$	Rainfall intensity at t hours
I	Intensity
D	Duration of rainfall
T	Half-life
R_w	Working Rainfall
Σ	Sum

LIST OF ABBREVIATIONS

CAR	Calibrated Antecedent Rainfall
CL	Critical Line
DID	Drainage and Irrigation Department
DMG	Department of Mineral and Geosciences
ICSM	Inter-governmental Committee on Slope Management
MACRES	Malaysian Centre of Remote Sensing
MMD	Malaysian Meteorological Department
NSMP	National Slope Master Plan
PWD	Public Works Department
RAC	Absolute Cumulative Rainfall
RWA	Antecedent Working Rainfall
SL	Snake Line
SWCC	Soil Water Characteristic Curve
USD	United States Dollar
WR	Working Rainfall

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CHAPTER 1

INTRODUCTION

1.1 Overview

When many types of natural and manmade disasters happen, large numbers of people are killed, property is destroyed, livelihoods are ruined, habitat is destroyed, and many other catastrophic occurrences occur. A landslide is a highly catastrophic geological disaster that occurs on a frequent basis around the world, posing a major threat to people's lives and property (Kjekstad & Highland, 2009). Landslides are frequently caused by slope instability, distressed slopes, and cut slopes. In Hong Kong, it is estimated that hundreds of landslides occur each year as a result of old slope failures. It is termed as cut and fill slopes. Cut slopes are generally 40–70 degrees, whereas fill slopes are 30–35 degrees. They are particularly prone to failures during the rainy season, when intense rainstorms are linked with tropical typhoons or low-pressure troughs, due to a lack of geotechnical management and the fact that most of the slopes are exposed to significant deterioration (Kazmi et al., 2016).

In Malaysia, landslides are one of the most dangerous natural disaster that happens during the rainy season (Lateh & Ahmad, 2011). Landslides are common in Malaysia during the summer monsoon, especially during the Southwest Monsoon season the North-Eastern Monsoon (Majid, 2020). While Malaysia seems to be safe from major weather phenomena like earthquakes, hurricanes, and forest fires, it is nonetheless prone to floods, landslides, haze, and water pollution. Malaysia has been hit by 51 natural disasters in the last two decades up until August 2018, resulting in the deaths of 281 people, affecting over three million people, and the

loss of approximately 2 billion USD in property (*Extreme Weather: Malaysia's Flood Woes to Worsen*, 2021).

In Sabah, Malaysia, landslides are one of the most common geohazards (Rodeano Roslee, Sanudin Tahir, 2011). A report by Jabatan Kerja Raya detailed the losses incurred as a result of devastating landslides and according to the report, the maximum number of casualties caused by a single landslide occurred in Sabah on December 26, 1996. Aside from fatalities, the debris flow completely destroyed a few villages. Not only were there fatalities, but there were also road blockage and communication system problems that disrupted the entire planning and timetable during that time period (Kazmi et al., 2016).

It is conclusive from the observed landslide issues that they cause a great deal of damage and loss of life. Since landslides constitute a major threat to people's lives and property, forecasting their occurrence and defining effective early warning indicators for landslides are essential. Therefore, the in-depth study of snake line method as an early warning indicator for landslide has a major practical and economic importance to reduce the impact of landslide disasters based on the progression of long and short working rainfall values. In this study, long working rainfall and short working rainfall is used as a tool to determine if a sequence of rainfalls is foreseeable to cause landslides.

1.2 Definition

Landslide and early warning indicator have many definitions. Several of the most prevalent textbook definitions are quite similar, despite the fact that they differ in many ways. According to a study of the literature on "Landslide" and "Early Warning Indicator," both terms have various definitions. To prevent misinterpretation, previous research papers will be used to compile definitions of landslide and early warning indicators.

J. D. Dana introduced the term "landslide" in 1838, and it may be the earliest classification of landslides. The phrase "landslide" refers to a multitude of processes involving the downward and outward movement of slope-forming elements such as rock, soil, artificial fill, or a combination of these. The materials may collapse, topple, slide, spread, or flow as they move. Meanwhile, a landslide, according to Cruden (1991), is a rapid displacement of rock, residual soil, or sediments adjacent to a slope in which the moving mass's centre of gravity advances downhill and outward. A landslide, according to Hutchinson, is a reasonably rapid movement of soil and rock on a down slope that occurs on a discrete bounding slip of surface that is the moving mass (Hutchinson 1995). The five types of slope movement are fall, topple, slide, spread, and flow. The type of geologic materials (bed rock, residual soil, earth, and their mixtures) determines these modes (Cruden & Varnes 1996).

Meanwhile, the term "Early Warning Indicator" are risk mitigation methods that send out timely signals to people when the amount of danger to which they are exposed is deemed to be too high (Calvello et al., 2015). According to the United Nations, "early warning systems" are "the set of abilities needed to generate and disseminate timely and meaningful warning information that allows people and groups to prepare and act in the best way possible in order to minimise the risk of harm or loss." (*Early warning system*, 2020). Early warning indicator are monitoring devices that are designed to avert, or at the very least reduce, the impact of a danger on individuals, property, the environment, infrastructure, or more basic aspects such as livelihood (Medina-Cetina & Nadim, 2008).

To come to the point, a landslide is a natural disaster that involves the collapse, topple, slide, spread, or flow downward and outward of soil, rock, sediments, or a combination of these materials. Meanwhile, an early warning indicator is a risk mitigation mechanism that acts on the exposure of the elements at risk, particularly humans, by keeping them away from the dangerous region.

1.3 Research Background

Massive landslides have been triggered by the growing intensity and frequency of localised heavy rainfall as a result of global climate change (Park et al., 2019). As a result of the landslide catastrophe, the Malaysian government has been obligated to pay millions of ringgit in compensation to the victims and to rebuild destroyed infrastructure and utilities (Roslee et al., 2011). Landslide has a great impact on environment and socio-economic which include fatalities, property and facility damage, etc. (Majid, 2020). Therefore, a dependable and effective landslide early warning indicator is an essential component of disaster management, providing experts and decision-makers with timely and suitable information to reduce landslide risk.

Because present numerical weather predictions are precise enough to predict cyclonic air masses that produce storm rainfalls on a short time scale, these predictions open up new possibilities for usage in landslide early warning systems. As a result, various countries, including Italy, Norway, the United States, Brazil, and Japan, have developed landslide early warning systems, particularly for rainfall-induced landslides (Hidayat et al., 2019). The objective of a landslide early warning indicator is to minimize the risk of fatalities and other adverse consequences from landslide events (Ju et al., 2020).

Hence, this research is conducted to study the application of the snake-line method as an early warning indicator for landslides in Sabah. The effect of rainfall to landslide events will be analyse based on working rainfall method. A series of rainfall distributions will be observed by drawing a snake curve line that represents the progression of long and short working rainfall values. A critical line will be produced dividing the of occurring and non-occurring rainfall in Sabah based on data from landslide cases. When the snake-line crosses or comes close to the critical line, an early warning can be sent out.

1.4 Problem Statement

There are a variety of landslide-related challenges that can be addressed with better risk management. Aside from that, effective mitigation methods and analysis of landslide events and rainfall data will help to reduce the danger and impact of landslides.

According to the local research review, there was some research conducted about the landslide cases in Malaysia such as Lateh & Ahmad (2011) about landslide issues in Penang, Akter et al. (2019) discussing about landslide disaster in Malaysia, and Kazmi et al. (2016) about contributing factors of major landslide in Malaysia. However, all of the studies focused more on the landslide cases in the West Malaysia and there is still lack of study about landslide cases in Sabah. Despite there are a few studies about landslide in Sabah such as hazard identification in Sabah, landslide hazard factors in Sabah, landslide susceptibility mapping at Sabah, landslide is still a repeated geohazard in Sabah. It was probably because the engineers did not take the recommended preventive actions and slope design standards seriously, or because the actual mechanism of the landslides has yet to be discovered.

Rainfall events are generally the main cause of landslides (Segoni et al., 2014). In tropical regions like Malaysia, where the soil deposits are mainly residual soils, rainfall-induced landslides are a common geohazard (Huat et al., 2012). This is generally described as rainfall related with a particularly intense thunderstorm or a long-duration, lower-intensity rainfall event, such as the cumulative effect of monsoon rains in Malaysia (Matlan et al., 2018). Therefore it is important to analyse the rainfall induced landslide as it have resulted in not only extensive damage to properties but also loss of lives (Gian et al., 2017). However, there is still a lack of extensive analysis on rainfall induces landslide in Sabah.

1.5 Objectives of Study

The purpose of this research is to study the application of the snake-line method as an early warning indicator for landslides in Sabah. The following are the main objectives of this research work:

a) To study the landslide cases in Sabah
b) To study the rainfall data in Sabah.
c) To analyse the working rainfall patterns associated with the landslide event.
d) To propose a critical line for the application of the Snake Line Method in Sabah's landslide disaster mitigation.

1.6 Scope of Study

The study deals with the application of snake-line method as an early warning indicator for landslides in Sabah, Malaysia. The study area of this study will focus on the landslide cases in Ranau, Tambunan and Sandakan. Ranau is an administrative district of Sabah and also a part of the west-coast division that include Kota Kinabalu. Ranau's geography is characterised by undulating lands with a valley plain in most regions (*Sejarah: Laman Web Rasmi Pejabat Daerah Ranau*, 2017). Tambunan, located in the southwest corner of Ranau, is dominated by lowland paddy fields and agricultural lands. Along the Ranau-Tambunan route, it is evident that landslides are extremely common in this region (Simon et al., 2017). Sandakan is a town on the eastern coast of Sabah, overlooking the Sulu Sea, and is known as one of Malaysia's port towns (*Sea Port*, 2021).

To study the landslide cases and rainfall data in Sabah, the landslides data are obtained from the data source of Jabatan Kerja Raya Sabah and through literature reviews. Meanwhile the daily rainfall records are collected through the Department of Irrigation and Drainage (DID), Sabah. The data obtained is from the year 2010 to 2020. Then, the working rainfall patterns associated with the landslide

event are analysed. For each landslide event, the working rainfalls are utilised to establish the critical duration of antecedent rainfall or the rainfall threshold.

In this study, data from a previous study are used to propose a critical line that can be used as a reference in the application of the snake line method as an early warning indicator for landslides in Sabah. This line can be used as a reference in the application of the snake line method as an early warning indicator for landslides in Sabah.

The non-occurring and occurring rainfall points are plotted based on previous study. The term "occurring rainfall" refers to a series of rainfalls that result in at least one disaster, whereas "non-occurring rainfall" refers to a series of rainfalls that do not result in a disaster. The line dividing the area of the occurring and non-occurring landslides is the critical line.

Then, the long working rainfall and short working rainfall is used as a tool to determine if a sequence of rainfalls is foreseeable to cause landslides. A series of rainfall distributions will be observed by drawing a snake curve line that represents the progression of long and short working rainfall values. When the snake-line crosses or comes close to the critical line, an early warning can be sent out.

1.7 Significance of Study

The main importance of this study is that it can help to minimise the impact of landslides on people, property, and lives. There are various additional important aspects of the study that are further discussed below.

The early warning indicator for landslide can gives information through specified institutions, allowing them to take action to minimise or limit the risk of landslide and plan for effective response (Calvello et al., 2015). This will help relevant government department and organisations in making decisions to take appropriate measures, such as opening temporary shelters, emergency procedures,