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RESEARCH ARTICLE

AN APPLICATION OF RAINFALL THRESHOLD FOR SEDIMENT RELATED DISASTER IN MALAYSIA, ISSUES AND CHALLENGES

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ABSTRACT

Sediment related disaster is the most significant natural disaster in Malaysia and many countries in this world from the perspective of magnitude, damage and loss to human life and infrastructure as well as disruption to socio-economic activities. Debris, mud flood, landslide and cliff failure are some of the major catastrophic problems and became a history for the country especially Cameron Highlands in a state of Pahang. As rainfall is the main culprit to sediment-related disaster occurrences, therefore the rainfall data is very crucial to be used in the correlation of the occurred events. Due to that fact, several studies worldwide have been made to estimate critical rainfall conditions and this being useful to draw the benchmark to predict the occurrences of the landslide specifically for DMF and shallow landslides. This paper discussed the development of the rainfall threshold in Malaysia by compiling the framework of the threshold to determine the lesson learned as well as the way forward. As Malaysia needs to move at a faster pace towards embracing the whole aspects in determining the threshold as well to implement it into the operational threshold, therefore the first step is very important to initiate the momentum while the collaboration or networking among government agencies in National Disaster Risk Reduction (DDR) should be enhanced and strengthened.

KEYWORDS

Sediment-related disaster, Landslides, Cameron Highlands, mud flood, rainfall, debris, mudflow, Threshold.

1. INTRODUCTION

There are 3 places of major occurrences of the landslide in Malaysia that are Hulu Kelang, Cameron Highlands and Genting Highland whereby most cases are occurred associated with rainfall. The Debris and Mudflow (DMF) is part of the sediment-related disaster and such a natural phenomenon whereby rainfall is the main trigger factor. It is also one of the landslide types in accordance with classification by a recent study (Varnes, 1978). Therefore, the worldwide had drawn their rainfall condition, due to the magnitude, frequency and consequences of the landslide in their countries. As defined by some research, rainfall threshold is where the condition of rainfall is breached and likely to pledge the landslide or event in the study area (Guzzetti et al., 2008). It is agreed that the rainfall threshold is the most significant tool to predict the impending landslide whereby it's been enhanced to have an adaptable and reliable prediction (Segoni et al., 2018).

The Landslide Early Warning System (LEW) is one of the passive countermeasures in the framework of landslide risk management (Fell et al., 2004). The prediction of the potential failure can be forecasted by gathering the important information related to the causal either by a spatial or climatic factor, types of behavior, and the risk to reduce the impact which also the key component in landslide hazard assessments (Chae et al., 2017). As referring to the rainfall threshold can be implemented as a warning model for both local landslides early warning system (Lo-LEWSs) and territorial landslide early warning system (Te-LEWSs) (Piciullo et al., 2018). The Lo-LEWSs is more specific to monitor a single landslide at the slope scale while (Te-LEWSs) is more to monitor multiple sites at the regional scale.

Meanwhile, a study evaluated the Japanese and Taiwanese early warning system of shallow landslide and DMF. The system in Japan was established in 1984 in which rainfall threshold was the main setting of the warning model (Chen et al., 2013). The model is based on antecedent rainfall or soil water index. Likewise, the system in Taiwan which is only for DMF was established in 2002 was known as the rainfall-triggering index (RTI).

Issues and the challenges of assessing the rain threshold for the alert, the forecast, and the warning rain when the rain threshold breached the value greatly concern the mud flood development model. The effectiveness of the warning model also depends on the false alert rate and time for evacuation. Therefore, this kind of effectiveness evaluation would only be possible once the warning model is well established with the specified or identified threshold. Based on this study, the rainfall index used by both countries were very noteworthy as non-structural countermeasures to the said disaster. However, this kind of threshold did not provide the spatial information and impact of the upcoming event. As highlighted, apart from strengthening the policy implementation, disaster risk management is one of the best prevention methods that includes the landslides data compilations and analysis, real-time monitoring, disaster preparedness and emergency response and susceptibility maps.

Consequently, this paper is collecting information on the rainfall threshold development framework and its employment in Malaysia by reviewing the

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published papers that focus on the events in Malaysia and finally to address the shortfall if any as well as the way forward.

2. Material and Methods

Malaysia investigates the initial rainfall condition that is likely to trigger the landslide, especially in the Debris and Mudflow. In 2004, exalted the benefits of flood hazard maps as a useful tool in predicting the onset of potential debris flow events. It introduces a chart of hourly and warranted rain that juxtaposes a snake line and a critical line, warning line, and evacuation line. The concept is introduced as a future enhancement to be taken up for further research and development in the field of debris-flow warning (Norlida et al., 2004).

The first attempt on the mud flow model, guided by Typhoon Committee Hydrology Component Workshop in 2004 (Norlida et al., 2006). The threshold was drawn based on two major Debris and Mudflow events in Cameron Highland and this method was developed in 2005 using the rainfall data from 1994 to 2002. The selection of the rainfall station is using the nearest station and does not explain further on this matter. However, there has been no significant incidence of mudflow that can be directly predicted by the threshold model ever since.

In 2011, of the particular interest of the work, some studies concluded that any landslide early warning systems to be developed in Malaysia should be implemented based on empirical correlation of precipitation and landslide events. The paper emphasized the advantage of an empirical approach over a physically based approach, especially at a regional level. The empirical model was looking into two parameters that are (i) Intensity vs Duration (ID) and (ii) Intensity vs Working Rainfall as a rainfall threshold. This paper reported on the few endeavors of Malaysia to develop the rainfall threshold to draw the empirical model as a model set in the early warning system. It is as well to note the pilot project selected by Public Works Department (PWD) for the National Slope Master Plan Study (NSMP) PWD, (2009). Thus the locations were Ampang /Hulu Kelang (100KM^2), Penang (293KM^2) and Cameron Highlands (712 KM^2). For the first two thresholds of Ampang/Hulu Kelang and Penang, it was a more landslide-prone area while for the Cameron Highlands case study more focusing on the debris and mudflow and was reported to use the works (Norlida et al., 2006). As for Ampang/Hulu Kelang, the threshold was developed based on 16 cases of landslides adopting the methodology with some enhancement and finally accomplishment the rainfall threshold for this area as expressed as:

$$I = 11D - 0.5317 \quad (1)$$

Where I = Rainfall intensity (mm/hr) and D= Duration (Hrs)

While the rainfall threshold for Penang area, the threshold was expressed as:

$$I = 15.64D - 0.81 \quad (2)$$

Where I = Rainfall intensity (mm/hr) and D= Duration (Hrs)

The dataset for Penang was based on 15 landslides and both data set for Ampang and Penang are using the landslide that was recorded from 1984 to 2010. In this paper, both correlations were claimed to be a very rough estimation. The criterion for the rainfall to be used in the analysis is using the single source of the nearest rain gauge to the event. Such it is claimed that the limitation of the rainfall data to the specific locations. Furthermore, this analysis does not elaborate further on the threshold parameter which seems to be important as part of the model fitting. On the other hand, the landslide record did not mention the sources and this concluded to the unspecified information other than limitation cases of landslide data.

Again in 2014, the correlation of DMF and rainfall intensity and duration for peninsular Malaysia. The study used only four events whereby 3 events located at the east highway of Peninsular Malaysia and another 1 event located at Gunung Pulai, Johor which is the Southern part of Peninsular Malaysia. In their analysis, they correlated the maximum hourly rainfall and its duration (Jamaludin et al., 2014). The 4 events of Debris Mud Flow then were compared to the worldwide threshold data as compiled. It is concluded that the said events were closed to the Intensity-Duration equation whereby the equation is expressed as;

$$Ip = 121.4 \text{ x } D^{-0.602} \quad (3)$$

Where *Ip*: Highest rainfall intensity during the rainfall event, *D*: Duration of the rain in Hours.

In their analysis, there are supposed 8 cases of recorded Debris and Mud Flow. Unfortunately, only 4 events finally selected for the analysis as the hourly rainfall data of the events were readily achievable. Furthermore, the treatment of the rainfall data which was the main setting of the model was not elaborated thoroughly in the paper. Nonetheless, based on the 4 events, it is concluded that the Malaysian threshold is higher than the threshold values of Europe.

Next, had to instrument the assessment of the debris flow hazard through the Public Works Department (PWD) due to the frequent basis of the occurred event and its hazardous impact. The study was conducted by estimating impending damage of debris flows and landslides (Kuraoka and Mori, 2014). Even though it is just the preliminary procedures of the rainfall threshold that may trigger the event, however, the study has managed to confirm the equation 1.3 above is the most representative of Malaysia cases. This study also the other type of rainfall threshold other than its intensity and duration that is snake curve and soil water index (SWI). The parameter that governed the curves is called rainfall depth that is working rainfall, the half-life of the long term (72 hours) as well as short-term working rainfall (1.5 hours). The events were confirmed to correspond well to the major rainfall events. However, this study did not mention the threshold value of the rainfall depth. Other than that, this study also attempts to apply the SWI method to correlate the rainfall and the landslide event. The method was well established and adopted by Japan Meteorological Agency (JMA) for their shallow landslide and Debris and Mud Flow warning and evacuation. However, in this paper, it is claimed that the SWI method is not readily applicable due to the shortage of the availability of 10 years of hourly rainfall data for the area of interest. As such, the study did not obtain the threshold as intended. Again, there is another incompleteness of the sources for both methods that were elaborated in this paper that is (i) the selection of the rain gauges that to be considered as the input data and (ii) the validation of the model.

After that study, the effect of rainfall on slope stability. The study was conducted at the Ulu Klang, Malaysia. This study is using effective working rainfall and SWI as rainfall threshold (Mukhlisin et al., 2015). The dataset of the landslide is 15 cases recorded from 1993 to 2012 and using the nearest rainfall station to the event. This study had successfully drawn the correlative relationship between the landslide and rainfall. However, there is no information on the threshold value and the validation of the model. Nonetheless, it is well concluded that this method can be applied to identify the threshold as well as be the tools for an alert system.

In the same year, further evaluated the works of the methodology for the development of the debris and mudflow warning system (DMFWS) for Cameron Highlands under the urgent need of Department Irrigation and Drainage Malaysia (DID). The setup of the model is based on rainfall intensity and working rainfall, further enhancement from the previous model in 2005 (Roseli et al., 2015; Norlida et al., 2006). It is improved with more rainfall data and more events including the two major debris and mudflow events that are the event occurred in October 2012 and the event occurred in November 2013. Both disasters smashed the Bertam River in the agricultural town of Bertam Valley. These disasters were eye-opening to the relevant authorities as to the costs to lost millions of Malaysian Ringgit, psychology effect to the community and several casualties. Therefore, in another word, the occurred DMF events somehow provide the opportunity for DID to further upgrade the established model into the new mathematical computer-based model as well as to have the framework of the early warning system. However, it was successfully mean to prove the computer model concept as the model development of the system was approved to develop without the database.

Next, had explored further the soil water index (SWI) as extended work of (Matlan et al., 2018; Mukhlisin et al., 2015). The site for the study area is in the mountainous area, Ranau, Sabah, Malaysia. It was based on the 10 recorded events of landslides. In their study, they had confirmed that the effect of working rainfall (14 days) and major rainfall (1.5hrs) are substantial to initiate the landslide. It is also concluded that the SWI method can be used as one of the parameters governing the rainfall threshold other than the rainfall index. This supports that the initial soil moisture is also significant in triggering the landslides. However, there is some missing information in this study such as the time of the event, the criterion to select the rainfall data that fits the specified area, and finally the threshold of the SWI. Nonetheless, the study should be able to see the response of SWI towards the landslides event whereby the rain infiltration will increase the water content and pore water pressure.

On the other hand, another researcher, had studied the effect of slope displacement on the stability of transmission tower structures which are located at the hilly topography and prone to landslide area (Khalid, 2020). The study area is at the border of Cameron Highlands and Kelantan, the

East Coast part of Malaysia. The study looked for the threshold value of the rainfall that could initiate the slope displacement at the study area. This study confirmed that the antecedent rainfall which in her study is 5 days, prolong rainfall (cumulative rainfall) and triggering value is the parameters that be able to predict the occurrence of landslide. Based on her finding, 91% of the predictive rainfall is a good response to the displacement data through statistical analysis. The finding also supported by other researchers, whereby the antecedent 5 days rainfall is an essential parameter to the landslide occurrence while had concluded that the soil properties are in response to the infiltration of rainwater consequently to play important role in slope stability. This study is not meant to implement the threshold at the local scale but rather to understand the response of the rainfall against the slope displacement consequently to the stability of the transmission tower (Naidu et al., 2017; Rahardjo et al., 2001; Rahimi et al., 2010).

3. Discussion

According to a previous study, 2 types of rainfall threshold are the physical based model and empirically based model. The physical-based model requires a higher budget as it required more detailed information on spatial and in situ specific instrumentations (Guzzetti et al., 2007). Meanwhile, the empirically based model is based on the correlations between rainfall events that caused the landslides. Most relationships are plotted in Cartesian, semi-logarithmic, or logarithmic coordinates. The rainfall threshold that was developed in Malaysia is an empirically based model. As cognized from the development of the threshold rainfall worldwide generally there are few steps involved in the procedure (Guzzetti et al., 2007; Segoni et al., 2018). These steps are the collection of dataset features, the identification of the threshold, and finally the validation of the threshold.

The features of the dataset are the landslide information (location, date and time of the occurrences and types of landslides) and the information on the rainfall associated with the event. The source of the landslide event can be obtained from reports, newspapers, the internet and official database. Based on the rainfall threshold that has been developed in Malaysia, some of these data are incomplete. In other words, there is no proper landslide catalog in Malaysia as there are pieces here and there. This catalog shall be improved in the nearest future to have as complete and reliable data as possible. Some papers also did not clearly state the sources of their recorded event. Most of the recorded events that are listed in the previous literature are without the information of the time of their occurrence. These data are very crucial as it is being used to relate with the causing rainfall.

Another issue that could be understood from the collected papers are the reported events are not inclusive. In other words, the recorded events were the only event with damaged properties or casualties involved. However, those events that happen in the forest or less risk were not recorded and such the analysis of the threshold does not include the natural slope. A comparison could be made in near future between the threshold at the disturbed slope (manmade) and the natural slope.

Other than that, the source of the rainfall is another crucial information in the rainfall threshold determination. The threshold that is available in Malaysia is based on hourly rainfall data which is measured by the rain gauges. This method is in line with most thresholds that were analyzed by other researchers in the world whereby more than half are using the hourly rainfall data to define the threshold. However, most of the thresholds that have been developed in Malaysia did not mention specifically the selection criteria of the rainfall gauge/sources that were being used in their analysis. It is as well, did not explain the details on the treatment to the input of rainfall data that was being used in the analysis. This includes rainfall data quality checking that involves filtering and data missing infilling. Due to the limitation of the rain gauges installed in the study area, it is in such circumstances that the researchers had the forced selection to rely on the existing rainfall network.

Nonetheless, this information should be mentioned in the criteria rainfall gauge selection either the analysis using the manual judgment, nearest rainfall station, sole reference, or automatic selection. As founded in previous study, the nearest rainfall gauge shall be considered within the 20KM range from the event else the analysis should be used the radar data (Winter et al., 2010).

On the other hand, suggested that only analyze the event that is within the 6KM range of the nearest rainfall gauge and exclude those that are not in this range (Althuwaynee et al., 2015). As defined before, another criterion to select the station should be based on the geographical and technical setting of the site (Martelloni et al., 2012). This led to the analysis is to use the Thiessen Polygon method for all the available rain gauges at the study area (Rosi et al., 2012; Berti et al., 2012).

The last step in the process of rainfall threshold development is the validation of the threshold. This is the major issue of the rainfall threshold that has been developed in Malaysia whereby there is no validation analysis to the threshold. As such, the development can be considered as a preliminary assessment of the application of the threshold. It is as expected as the established threshold were not implemented into operational early warning system except for the threshold developed by DID which can be considered as implemented into prototypal early warning system. As classified, the validation can be made using the same dataset or independent dataset while the common method of validation is not in place yet all over the world. As for Malaysia, the assessment of the threshold is more likely to confirm that a threshold is a significant tool as a prediction of the occurred event.

4. Conclusion

The issues and challenges on deriving the rain threshold discuss in the above paragraphs for the sediment related disaster in Malaysia. The rainfall threshold is critical in predicting the occurrences of landslides, particularly the DMF and shallow landslides in Malaysia. The procedures along the development process are equally critical. The landslide information shall have the databases on the record of the occurrence at the non-risk area and not limited to completed information such as date, time, location, and type of landslide. The record should be centralised and archive among government agencies involved in assessing the landslide in Malaysia.

The Public Works Department (PWD) is generally responsible for sediment-related disasters to mainly involve the large scale, linear type for road maintenance. The Malaysian Space Agency (MYSA) and the Department of Mineral and Geosciences (DMG) involving in medium-scale for land use planning (zoning). There are two agencies involved in rainfall data: the DID on the national rain networks while the Malaysian Meteorological Department (MMD) on the radar forecasting /Numerical Weather Prediction. The DID is responsible for providing flood forecasting and warning to the public, including sediment water-related disaster such as the mud flood. There is an urgent need for further collaboration, technical and technology sharing among these agencies. Among other agencies are the National Disaster Risk Reduction (DDR), headed by the National Disaster Management Agency (NADMA). The best platform for a centralized catalog should be through DDR and managed by NADMA.

The rainfall quantity and quality assessment shall derive the best rainfall threshold value. In addition, the assessment provides information such as the source of the recorded event and rain gauge selection. Lack of information leads to inadequate assessment as the threshold does not solely depend on the applied method.

Above all, the validation process is the key to the application of the rainfall threshold in Malaysia. While drawing the critical line and separation line between the occurrence & non-occurrence is very subjective, it requires engineering or modeller judgment; thus, this process is crucial to enhance the warning. It comprehends the model judgement when rain varies with time and space to suit the area conditions or situation. Such more data should be measured other than the rain threshold. These include the soil water content, hydrometric threshold and local observations of rivers and slope. Next is to check on the accuracy of the prediction once the threshold had established. Well, Malaysia is in need to define more on the validation process. Therefore the preliminary assessment of the rainfall threshold is very worthy to begin with for sediment-related disaster management.

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