Landslide Warning by Rainfall Monitoring in Mountainous Area of Thailand

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Abstract
Landslide is a disaster caused by heavy rainfall in mountainous areas and it occurs in many countries including Thailand, especially in northern and southern regions. This problem is still arising and likely to escalate in the future. Generally, long-time of heavy rainfall is the cause of landslide. Landslide warning is done by monitoring rainfall amounts compared to critical rainfall amounts triggering landslides in the past. The objectives of the research are determination of critical rainfall for landslide warning in Thailand. In this research, critical rainfall in terms of duration and intensity appropriate for Thailand were determined by a study on landslide records in the past and rainfall records and the critical rainfall were then determined. Analytical results found that critical rainfall amounts in each area were different and duration of rainfall used in probability assessment of landslides was 4 days. Rainfall was divided into two sections: rainfall amounts in the past 3 days and daily rainfall on the day of consideration. The results could be applied to landslide warning in Thailand.

Keywords: Landslide, Critical Rainfall, Antecedent Rainfall, Risk Area, Unsaturated Soil

Introduction

Landslide is one of natural disaster damage greatly in different parts of the world both directly include; loss of life and properties and indirectly include; loss of the economy such as agriculture damage, people without a job, etc. Landslide is the movement of a mass of rock, debris, or earth down a slope (Cruden, 1991). They result from the failure of slope and are driven by the force of gravity. Generally, landslides are triggered by rainfall, but earthquakes and human activity which disturb slope stability may also trigger landslides.

Thailand is one country that has been affected by landslides as long. Most occur in the foothills in the north and south. From the record by Department of Mineral Resources found that a large landslide in Thailand caused a lot of losses one of the worst occurred at Phipun, Nakhonsrithammarat province in 1988. 230 people was injured and killed, more then 1,500 residents were destructed and 9.84 square kilometers of agricultural areas were damaged. From the record also found that landslide caused serious damage still occurred in the other part of this country such as Namkor, Petchaboon province in 2001and Lap Lae, Uttaradit province in 2006 in the north include Kaopanom, Krabi province and Noppitam, Nakhonsrithammart province in 2011 in the south.

Landslides always occur during rainy season with heavy rain. It often occurs together with flash floods which causes severe damage and extended more widely. Factors that influence the occurrence of landslides are characteristic of the areas. The areas has steep slope with low soil shear strength, landslide hazard is higher than the areas has lower slope or high shear strength of soil. Human is another factor effect to more landslide risk. Increase in population and demand to develop the economy as the driving force for intrusion into an area of high potential landslides. The development of slope areas such as buildings, roads, deforestation and agriculture are contributing to the stability of the slope is reduced. It is a result of landslide potential increase. To reduce losses due to landslides, we require the process of protection system appropriate for individual area characteristic. Landslide warning is one process to reduce the loss especially damaging to life.

Since landslide occurrence is triggered by rainfall, so the warning can be performed by rainfall intensity monitoring. The rainfall cause landslide is called critical rainfall that can be determined from correlation between the occurrence of landslides in the past and rainfall occurred in that period. It can be divided into 2 parts first is antecedent rainfall which influence to initial water content in soil mass and another occurred during landslide.

However, the effective landslide warning must have reliable landslide occurrence prediction and have long time enough to prevent or reduce losses. Lumb (1975) has defined the critical rainfall for landslide warning in Hong Kong, using the relationship between 15 days antecedent rainfall and rainfall in another day to predict the landslide. Zêzere et al (2005) studied the relationship between rainfall and landslide events in the past. They found that in case of shallow landslides, high intensity rainfall in short period induced landslides. However, in case of deep landslides, high intensity is not necessary but continuous occurring in long time is required. Cheborad et al (2006) proposed the critical rainfall in area of Seattle, Washington by the

landslide event during the years 1933-1997, which is the relationship between 15 days antecedent rainfall and cumulative rainfall in the last three days.

This research is the study of the relationship between rainfall and landslides in the past to find the appropriate rainfall duration and critical rainfall for landslide hazard in the north and south of Thailand (Figure 1) where is landslide occur often. Landslide event data was gathered from the relevant authorities such as the Department of Mineral and Geotechnical Engineering Research and Development, Kasetsart University. The rainfall records were taken from the ground station of the Meteorological Department.

Figure 1 Mountainous area in the North and South of Thailand (Base on Google Maps, 2016)

Research Objectives

The important purpose of this research is critical rainfall determination for landslide prediction in warning system that appropriate for mountainous area in Thailand, especially in the north and south.

Research Methodology

This research methodology consists of two main steps: 1) determine the appropriate duration for critical rainfall assessment 2) determine the critical rainfall for landslide warning. The details are as follows.

1.) Appropriate rainfall duration determination
Two data types were collected in this step such as landslide events in the past and rainfall data from rainfall measurement station where locate near landslide occurred.

For landslides occurred in the past, using data from Department of Mineral Resource and Geotechnical Engineering Research and Development, Kasetsart University. For rainfall data was compiled by the Department of Meteorology in daily rainfall data format.

The study area is divided into sub-watershed by Thiessen Polygon Method to determine the rainfall measurement stations associated with the landslide that occurred in the past.

From daily rainfall data, cumulative rainfall was calculated in many periods from one day to seven days. The amount of rainfall that is equal to or greater triggering rainfall was counted and calculated probability of landslide in different durations. Rainfall duration that landslide can occur as most possibility is appropriate duration for landslide prediction in study area.

2.) Critical rainfall determination
The appropriate duration from step 1 is divided into two parts: first is antecedent rainfall, that effect to soil moisture increase before landslide occurred. And the second is daily rainfall, which is the last 24 hours rainfall during landslide.

Research Results

1.) Appropriate rainfall duration
From landslide data collection in the northern and southern of Thailand found that the landslides were occurred 169 events, as shown in Figure 2. The location of landslide events was superimposed on sub-watersheds, was created by Thiessen Polygon method, we can determinate rainfall measurement stations nearest to the area where the landslide occurred. Rainfall data from these stations were analyzed for appropriate rainfall duration further.

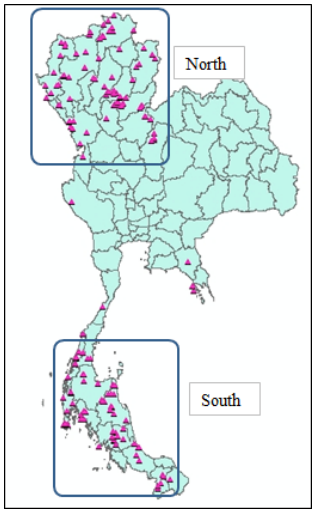
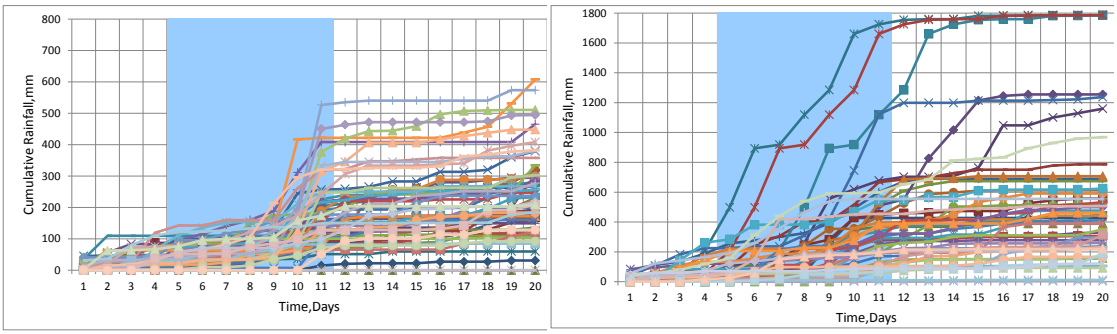


Figure 2 Landslide event records in Thailand

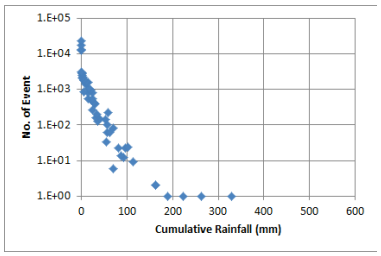
From daily rainfall data, the cumulative rainfall 20 days was calculated and landslides occurred at 11th day. Characteristic of 20 days cumulative rainfall for 169 events of landslide can be shown in figure 3. From this figure shows that cumulative rainfall in the early period rise slowly and tend to increased rapidly from 5th day until 11th day, after that the rate of increase slow down again. The period of cumulative rainfall increasing significantly takes about seven days.

Cumulative rainfall was calculated at different times varied from 1 day to 7 days from the date of the landslide back down. Relationship between the cumulative rainfall in several durations and probability of landslide (the number of rainfall which is equal or more than rainfall trigger landslide) were plotted in figure 4 and 5 for North and South of Thailand respectively. For small duration such as 1 day (figure. 1a and 1b), landslide events can occurred although rainfall intensity was low since unconsidered antecedence rainfall. Number of these events reduced when rainfall duration increase as shown in figure 1b to 1h for the north area and 2b to 2h for the south area. When we consider the lower part of each figure where is high landslide probability, when rainfall duration increase the number of high landslide probability decrease since uncertainty of rainfall intensity in each day. So, the optimized duration for landslide prediction can be determined from duration that can minimize antecedent rainfall effect and uncertainty of rain intensity.

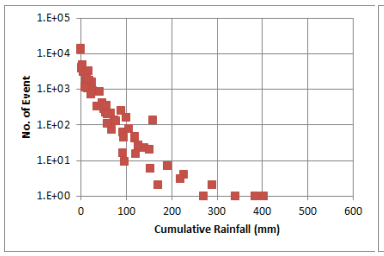


a. Northern Area b. Southern Area

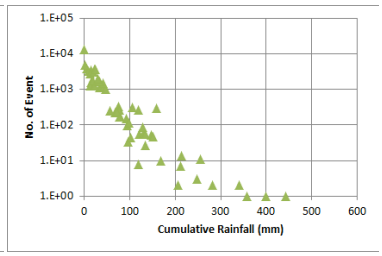
Figure 3 Cumulative rainfall 20 days cover day of landslide occurred.



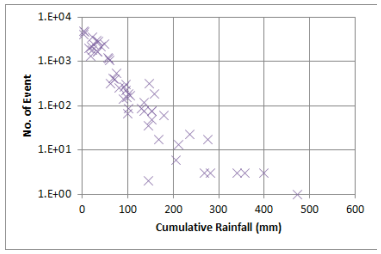
a. Duration 1 day



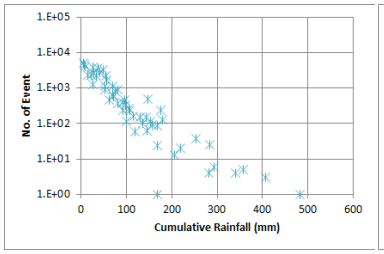
b. Duration 2 days



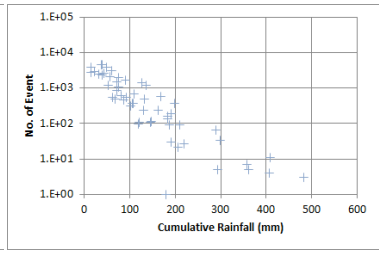
c. Duration 3 days



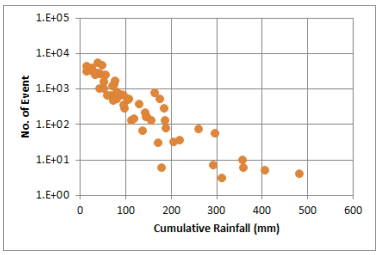
e. Duration 4 days



f. Duration 5 days

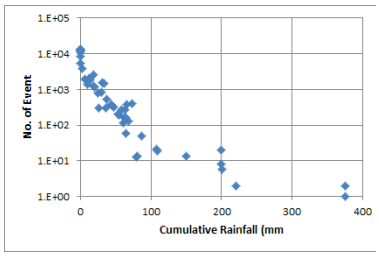


g. Duration 6 days

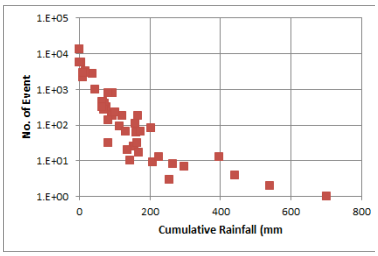


h. Duration 7 days

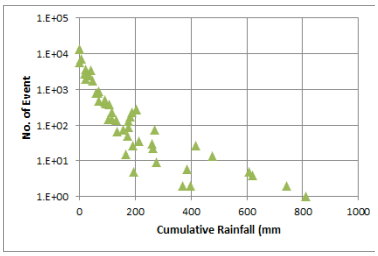
Figure 4 Probability of landslide due to rainfall in various durations for North of Thailand



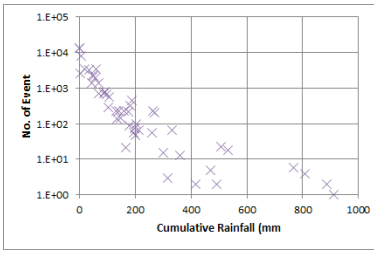
a. Duration 1 day



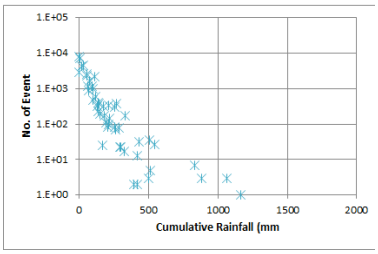
b. Duration 2 days



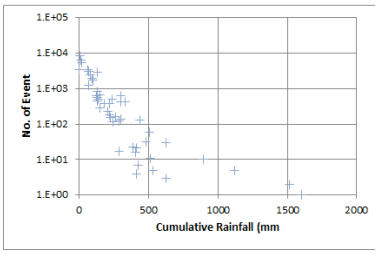
c. Duration 3 days



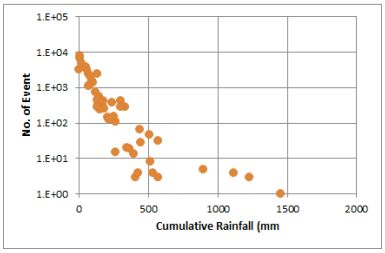
e. Duration 4 days



f. Duration 5 days



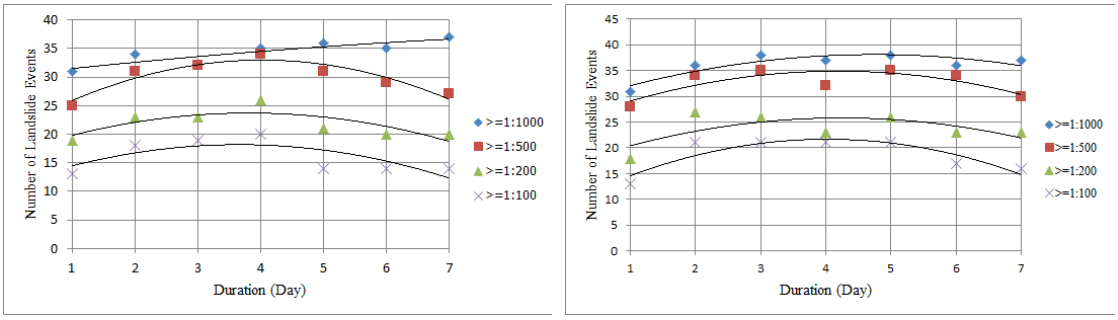
g. Duration 6 days



h. Duration 7 days

Figure 5 Probability of landslide due to rainfall in various durations for South of Thailand

To determine appropriate rainfall duration, relationship between the number of landslide events and considered rainfall duration were plotted as shown in figure 6. The number of landslides were grouped by probability of rainfall caused landslide at 1: 1000, 1: 500, 1:200 and 1: 100 and plotted 2nd order polynomial trend line for each probability.



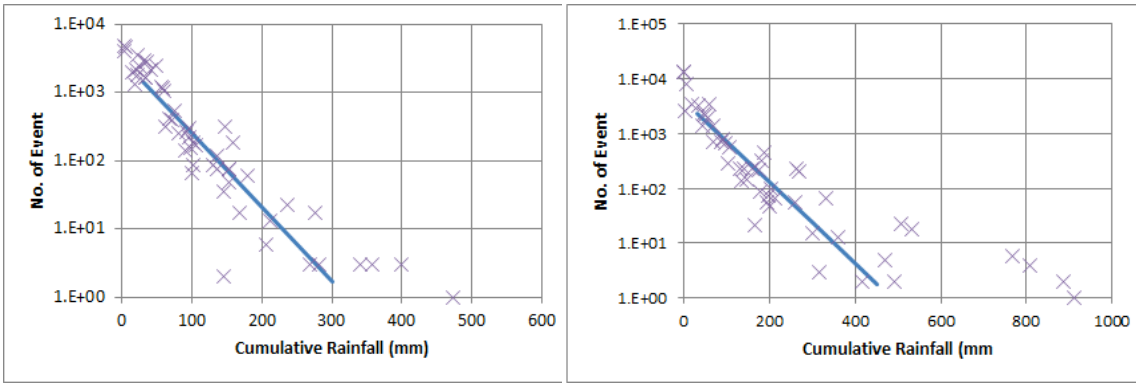
a. Northern Area b. Southern Area

Figure 6 Number of landslides at various durations.

From trend line found that the rainfall duration which had maximum number of landslide was four days in all probability. So this duration is appropriate rainfall duration for landslide prediction. In figure 6b (southern area) number of landslide events at 4 days duration is highest for probability equal or more then 1:100 but disagree for lower probability. Since, uncertainty of rainfall for the probability lower than 1:100 affect to landslide events for large duration from 3 days and longer.

2.) Critical rainfall

From figure 7 the critical rainfall trigger landslide can be defined as 2 values related to probability of landslide. For the north area (figure 7a), critical rainfall is 200 millimeters for probability about 1:20 and 100 millimeters for probability about 1:200. For south area (figure 7b), critical rainfall is 300 millimeters for probability about 1:20 and 170 millimeters. for probability about 1:200.



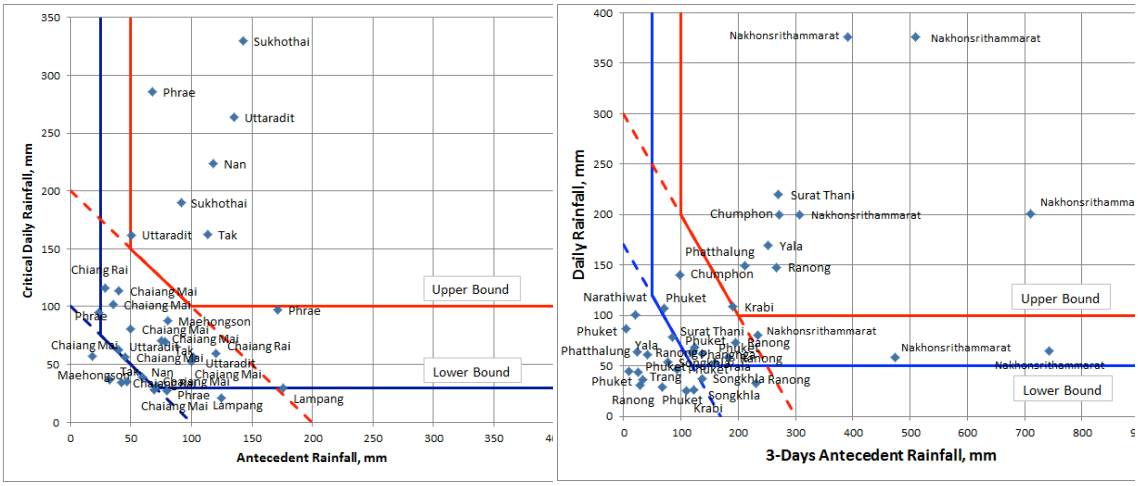
a. Northern Area b. Southern Area

Figure 7 Probability of landslide due to 3 days rainfall durations

After appropriate rainfall duration was determined already, the critical rainfall was defined by divide rainfall into 2 portions; first is 3 days cumulative rainfall (R_a) before landslide and second is rainfall in the 4th day (R_f) that landslide is predicted to occurred. Relationship between 3 days antecedent rainfall and daily rainfall in the 4th day were plotted as shown in figure 8.

From rainfall triggered landslide data (figure 8a), appropriate critical rainfall for the north of Thailand can be divided into 2 zones. First is the mountainous area in the upper northern area include Maehongson, Chiang Rai, Chiang Mai, Lampang and Tak Province. The critical rainfall for this area, where is lower boundary, is 100 millimeters for 4 days cumulative rainfall. In this part, minimum R_a is 25 millimeters and minimum R_f is 30 millimeters. Another is lower northern area include Phrae, Nan, Uttaradit and Sukhothai province. The critical rainfall for this area, where is upper boundary, is 200 millimeters for 4 days cumulative rainfall. In this part, minimum R_a is 100 millimeters and minimum R_f is 100 millimeters.

For the south of Thailand, appropriate critical rainfall can be divided into 2 zones (figure 8b). First is the mountainous area near Andaman coastal area such as Phuket, Phang-Nga, Krabi and Ranong province, etc. The critical rainfall for this area is lower boundary that is 170 millimeters for 4 days cumulative rainfall. The minimum R_a is 50 millimeters and minimum R_f is 50 millimeters. Another is mountainous area near Gulf of Thailand such as Nakhonsithammarat and Surat-Thani province. The critical rainfall for this area is upper boundary that is 300 millimeters for 4 days cumulative rainfall. The minimum R_a is 100 millimeters and minimum R_f is 100 millimeters.



a. Northern Area b. Southern Area

Figure 8 Critical Rainfall

Conclusion and Suggestion

The appropriate rainfall duration for landslide prediction in the north and south of Thailand is 4 days. Critical rainfall is divided into 3 days antecedence rainfall and daily rainfall in the 4^{th} day. For the North, critical rainfall appropriated for this area can be divided into 2 patterns for upper and lower parts. In the upper part, critical rainfall is lower than lower part. In the south, critical rainfall appropriated for this area can be divided into 2 patterns for West coat and East coast. In the West coast, the mountainous area near Andaman, critical rainfall is lower than East coast, where is the mountainous area near gulf of Thailand.

From the result of this study found that duration for critical rainfall calculation is important factor affect to reliability in landslide assessment. In addition, the selection of rainfall measurement stations associated with landslide event affect analysis as well. Sub watershed area that divided by Thiessen polygon method is not considered by topographic of area. So, the landslides occurred in areas far away from the station and the topographic quite different or the other side of the ridge may be not associated with rainfall data record.

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