Relationship between the probability of landslide and sediment yield in Thailand

P. Rangsiwanichpong[1], S. Kazama[2] and D. Komori[1]

[1] Graduate school of environmental studies, Tohoku University, Sendai, Japan

[2] Graduate School of engineering, Tohoku University, Sendai, Japan

Abstract.

Landslides which occur in mountainous areas is the major source of sediment delivered to downstream areas. The probability of landslide depends on the rainfall variation, geology, and topography analyzed by digital elevation data within 1 km resolution. The results indicated landslide events has significant effect on the sediment yield in Thailand. We found most of sediment yield in Thailand occurred in the northern and southern regions. As a consequence of area coverage by mountains and steep slope areas, and heavy rainfall in monsoon season.

Keywords: landslide, Sediment yield, Thailand

1. Introduction.

Thailand frequently suffers from loss of lives and properties due to landslide (Syvitski & Miliman, 2007; Rahul, 2012; Vente et al., 2013). Several studies found that rainfall is an important factor of landslide events (Tomoyuki Iida, 2004; Fan et al., 2016). Landslide often occurs in Thailand as a consequence of heavy rainfall especially in the northern and southern regions of Thailand. Landslide debris in mountain area is a major source of sediment yield in downstream areas. However, there are a few studies that analyze the relationship between landslide and sediment yield in Thailand. Therefore, analysis of the relationship between landslide and sediment yield is one of the important challenges for this country. In 2011, Lin & Chen analyzed the relationship between rainfall energy, landslide and sediment yield in Taiwan. They found that high rainfall kinetics energy is one of the causes of sediment yield to river. In Romania, Broeckx et al., 2016 studied about the relationship between landslide susceptibility and sediment yield at a regional scale. They found that landslide is an important predictor of sediment yield in Romania. Furthermore, Chen et al., 2016 stated that landslide is related to sediment yield during typhoon events in Taiwan. They found landslide debris that was flown by heavy rainfall in the typhoon events have a strong effect on the sediment yield in downstream areas of Taiwan. In Thailand, many research studies about landslide hazard map such as Yumuang (2001), which studied about landslide and debris flow in Phetchabun Province by geographic information system (GIS) and remote sensing techniques. In 2007, Soralump S. analyzed landslide hazard map using the engineering soil properties.

Furthermore, Ono et al. (2014) assessed rainfall induced shallow landslide in Phetchabun and Krabi province in Thailand by shallow landslide instability prediction model (SLIP). Moreover, Rangsiwanichpong et al., (2015) analyzed the probability of landslide using probability model and compared the results with the real historical events in Thailand. The objective of this research is to analyze the relationship between sediment yields with the probability of landslide hazard in Thailand. We used the log-Pearson type III for analyzing the extreme period of rainfall and sediment data during 1998 to 2014 (16 years). In addition, we used the probability of landslide model for assessing the landslide hazard in Thailand.

2. Study Area.

Topography

Thailand is located at the center of Southeast Asia peninsula. The topography can be divided into 5 major physical regions consists of central valley, highlands of the north, northwestern, northeastern, and southeastern coast, and the peninsula. Roughly 20 percentages of Thailand is covered by mountains and hills, especially in northern and southern regions. Therefore, landslides occur frequently in Thailand due to the influence of monsoon rain. In most cases, landslide would occur in the northern and southern parts of the country which are mountainous. (Figure 1.)

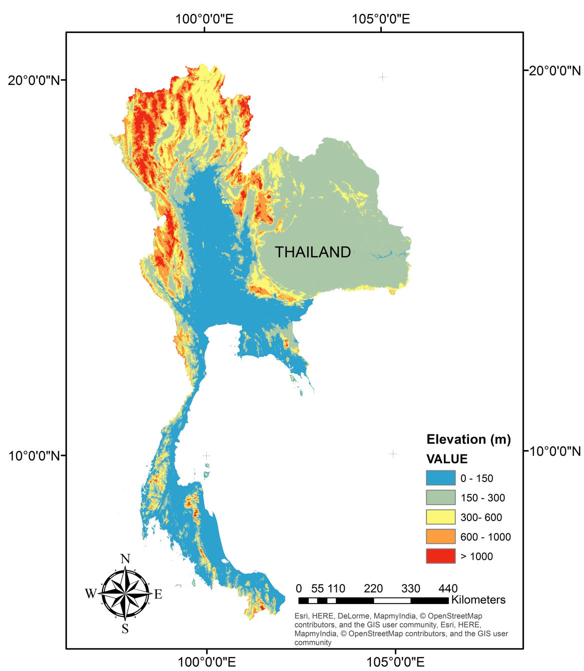

Figure 1. Elevation map of Thailand

Climate and weather in Thailand

Thailand's monsoonal climate has three main seasons. Firstly, dry cool climate affects the northeast monsoon during November to February. Secondly, warm climate from

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March through May and lastly, rainy season in the period of May to October with southwest monsoon. The annual rainfall in this country is 1,100 to 1,300 mm approximately. Furthermore, the southeast coast will has an extended rainy season throughout December, with the values of rainfall more than 2000 mm due to the effect of monsoon rainfall. Most of the annual rainfall occurs during the 4-5 months rainy season.

Historical of large landslide in Thailand

In 1998, landslide occurred in Kathun district, Nakhon Sithammarat Province, southern region of Thailand. The damage costed around 1 billion Thai baht was recorded as well as 230 deaths. In 2001, landslide occurred in Wang Chin district of Phare province due to the continuous heavy rainfall in that regions. The total damage of landslide in this event is 43 deaths. Another landslide in 2001, the event affected the villages in Phetchabun province, which killed 136 and injured more than 100. Several provinces in the northern of Thailand were also affected from landslide including Uttaradit, Sukhothai, Phrae, Lampang and Nan. The landslide events in these province during 2006 were subjected to serious flash flooding resulting in 87 deaths.

A large landslide event occurred at the Khao Panom Mountain in the end of March 2011, due to the area had steep slopes which is covered by dense tropical forest. Also this events resulted in a high degree of damage because the area is neighboring to the villages. The average annual rainfall in the Khao Panom area is normally more than 1,500 mm. The climate of this area is tropical, and most of the rainfall normally occurs between April and November. For this event, a heavy storm hits the area and three sub-watersheds were suffered from the intense rainfall. Subsequently, followed by landslides and debris flows. The return period of this storm event was estimated to be more than 50 years of daily rainfall. The damage from this event affected more than 800,000 people and 13 was killed

3. Data and methods.

3.1 Rainfall data

The rainfall data is a one of necessary factor for analyzing landslide hazard map. We used the daily rainfall data from 150 stations over Thailand by Thai Meteorological Department (TMD). We assessed extreme daily rainfall for 5, 10, 30, 50, and 100 year return period by frequency analysis of TMD data. In this research we used Double Mass Curve Method for check respectability of rainfall data. The double mass curve method is widely and easy to use for hydrology field and for more detail see in Merriam (1937) and Searcy et al. (1960). This method is based on the fact that a plot of the two cumulative quantities during the same period exhibit a straight continuous line, which means the data is unchanged.

3.2 Hydraulics gradient and relief data

Hydraulic gradient and relief data were important inputs for calculate the landslide probability. We calculated hydraulic gradient by Richards equation (1931). Moreover, calculate the future hydraulic gradient we used soil type, slope data and extreme daily rainfall. The soil type data collected from Land Development Department of Thailand and it was classified as clay silt and silt respectively. The relief data is a difference between maximum and minimum elevation inside the digital elevation map (DEM) by the United States Geological Survey (USGS)

3.3 Sediment data

In this research, we used 45 hydrological stations for observing sediment discharge from the Royal Irrigation Department (RID) (Figure 2.). These stations were selected overall area of Thailand, especially in landslide area. We used monthly sediment data during 1998 to 2014 (16 years) for the analysis.

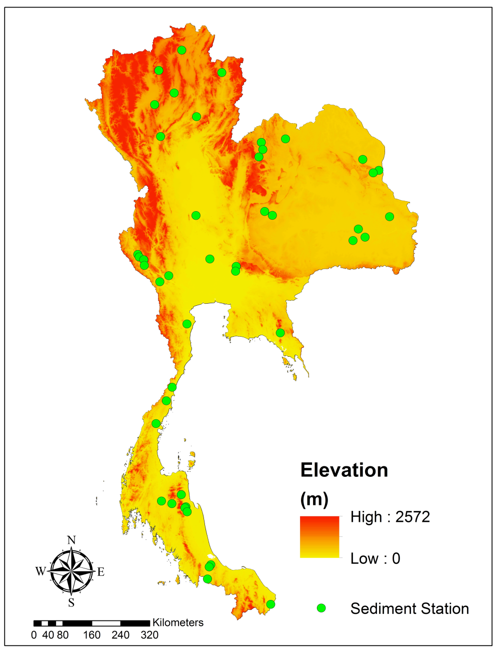

Figure 2. Location of sediment station

3.4 Log-Pearson Type III distribution

Log-Pearson Type III distribution was used for analyzing the extreme event of sediment data. The log-Pearson type III distribution is the most commonly used for evaluate the frequency distribution. It is similar to the normal distribution, except that the log-Pearson distribution accounts for the skew, instead of the two parameters, standard deviation and mean. When the skewness is small, the log-Pearson distribution can approximates a normal distribution. The log-Pearson type III distribution has been recommended by the U.S. Water Resources Council (Arora and Singh, 1989). The log-Pearson type III can be explained in equation 1.

$$X_{LP,T} = \bar{X} + K_{LP,T}S \quad (1)$$

Where, $X_{LP,T}$ is the logarithm of predicted discharge, at return period T, $\bar{X}$ is an average of annual peak discharge logarithms, $K_{LP,T}$ is a function of return period and skew coefficient as shown in Table 1 (Haan, 1977,). S is the standard deviation.

Table 1. Frequency Factors K for Gamma and log-Pearson Type III Distributions

WEIGHTED SKEW COEFFICIENT Cw	Recurrence Interval In Years							
	1.0101	2	5	10	25	50	100	200
	Percent Chance (>=) = 1-F							
	99	50	20	10	4	2	1	0.5
3	-0.667	-0.396	0.42	1.18	2.278	3.152	4.051	4.97
2.9	-0.69	-0.39	0.44	1.195	2.277	3.134	4.013	4.904
2.8	-0.714	-0.384	0.46	1.21	2.275	3.114	3.973	4.847
2.7	-0.74	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.36	0.518	1.25	2.262	3.048	3.845	4.652
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.8	4.584
2.3	-0.867	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.33	0.574	1.284	2.24	2.97	3.705	4.444
2.1	-0.946	-0.319	0.592	1.294	2.23	2.942	3.656	4.372
2	-0.99	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.294	0.627	1.31	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.14	-0.268	0.66	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-0.254	0.675	1.329	2.163	2.78	3.388	3.99
1.5	-1.256	-0.24	0.69	1.333	2.146	2.743	3.33	3.91
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.21	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.34	2.087	2.626	3.149	3.661
1.1	-1.518	-0.18	0.745	1.341	2.066	2.585	3.087	3.575
1	-1.588	-0.164	0.758	1.34	2.043	2.542	3.022	3.489
0.9	-1.66	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-0.132	0.78	1.336	1.993	2.453	2.891	3.312
0.7	-1.806	-0.116	0.79	1.333	1.967	2.407	2.824	3.223
0.6	-1.88	-0.099	0.8	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-0.083	0.808	1.323	1.91	2.311	2.686	3.041
0.4	-2.029	-0.066	0.816	1.317	1.88	2.261	2.615	2.949
0.3	-2.104	-0.05	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-0.033	0.83	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.4	2.67
0	-2.326	0	0.842	1.282	1.751	2.054	2.326	2.576
-0.1	-2.4	0.017	0.846	1.27	1.716	2	2.252	2.482
-0.2	-2.472	0.033	0.85	1.258	1.68	1.945	2.178	2.388
-0.3	-2.544	0.05	0.853	1.245	1.643	1.89	2.104	2.294

Table 1. Frequency Factors K for Gamma and log-Pearson Type III Distributions (Con.)

WEIGHTED SKEW COEFFICIENT Cw	Recurrence Interval In Years							
	1.0101	2	5	10	25	50	100	200
	Percent Chance (>=) = 1-F							
	99	50	20	10	4	2	1	0.5
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	-2.755	0.099	0.857	1.2	1.528	1.72	1.88	2.016
-0.7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	-2.957	0.148	0.854	1.147	1.407	1.549	1.66	1.749
-1	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.18	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.21	0.838	1.064	1.24	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.27	1.318	1.351
-1.5	-3.33	0.24	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.88	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.97	1.075	1.116	1.14	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.92	0.996	1.023	1.037	1.044
-2	-3.605	0.307	0.777	0.895	0.959	0.98	0.99	0.995
-2.1	-3.656	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	0.33	0.752	0.844	0.888	0.9	0.905	0.907
-2.3	-3.753	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	-3.8	0.351	0.725	0.795	0.823	0.83	0.832	0.833
-2.5	-3.845	0.36	0.711	0.711	0.793	0.798	0.799	0.8
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	0.376	0.681	0.724	0.738	0.74	0.74	0.741
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	0.39	0.651	0.681	0.683	0.689	0.69	0.69
-3	-4.051	0.396	0.636	0.66	0.666	0.666	0.667	0.667

3.5 Landslide mapping

We assessed landslide hazard map in Thailand by multiple logistic regression. The equation for assessing probability of landslide hazard was shown in equation 2. For more detail, refer to Kawague et al., (2010)

$$\mathrm{p} = \frac{1}{1+\exp[-(\psi_0+\psi_h\times hyd+\psi_r\times relief)]} \qquad (2)$$

Where P is the probability of landslide (%), ψ_0 is the interception, ψ_h is the coefficient of hydraulic gradient, ψ_r is the coefficient of relief energy, hyd is the hydraulic gradient (m/m), and $relief$ is the relief energy (m)

4. Results.

4.1 Analysis of landslide hazard map and probability trend

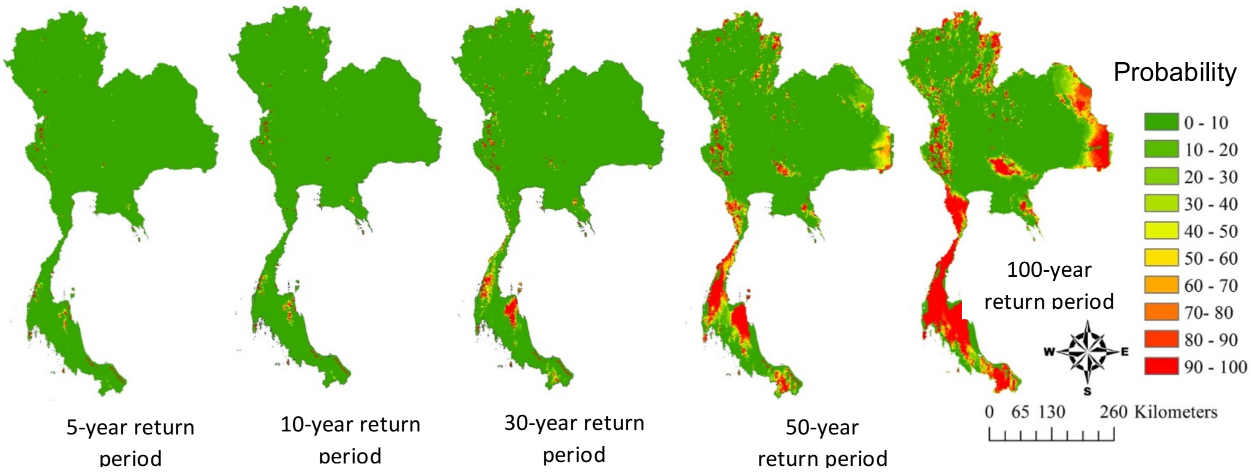

Figure 3. Landslide hazard map

We assessed landslide hazard map of Thailand at 5, 10, 30, 50, and 100 year return periods by probability of landslide model (Figure 3.). This study can explains a probability of landslide for each scenarios in term of return periods. The results found that the return period of rainfall mostly effective to landslide in Thailand. Consequently, the results shown that the northern and southern parts of Thailand have a risk of landslide hazard, which landslide in the southern part will occur from heavy rainfall with 10 year return period and the northern part will occur by rainfall with 30 year return period. However, most areas in the southern part are predicted to have higher risk due to higher probability of landslide events

4.2 Relationship between landslide and sediment yield

Thailand has a mean annual rainfall range of 1000-1300mm, especially in the southern part has a rainfall approximately 1450-2700 mm due to the effect of monsoon rainfall. From the results found that the sediment yield was occurred 0.19 million ton/km^2 approximately. The results showed that the sediment was occurred in the northern and southern regions because these areas was covered by the mountains and steep slopes. Furthermore, central region had the greater amount of sediment yield per square kilometer, due to the fact that this area is a downstream of many rivers in Thailand consisting of Ping, Wang, Yom, and Nan Rivers (Figure 4A). The major source of sediment in the central area is the landslide debris in the mountainous areas. Moreover, some river basin in the northern part of Thailand does not have a large dam and reservoir for interception the sediment to downstream area, especially the Yom River basin which the landslide events frequently occurred and caused high damage (Teerarungsigul et al., 2016; Department of Mineral Resources, 2012). Therefore, these are the important reasons to value of sediment in the central regions of Thailand.

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The results of the return period of sediment by log-pearson type III are presented in figure 4B, 4C. As shown, the majority of sediment in Thailand has a significant increasing trend, especially in the area with high probability of landslide hazard (Northern and Southern regions). Therefore, landslide event is the one of major sources of sediment yields in Thailand.

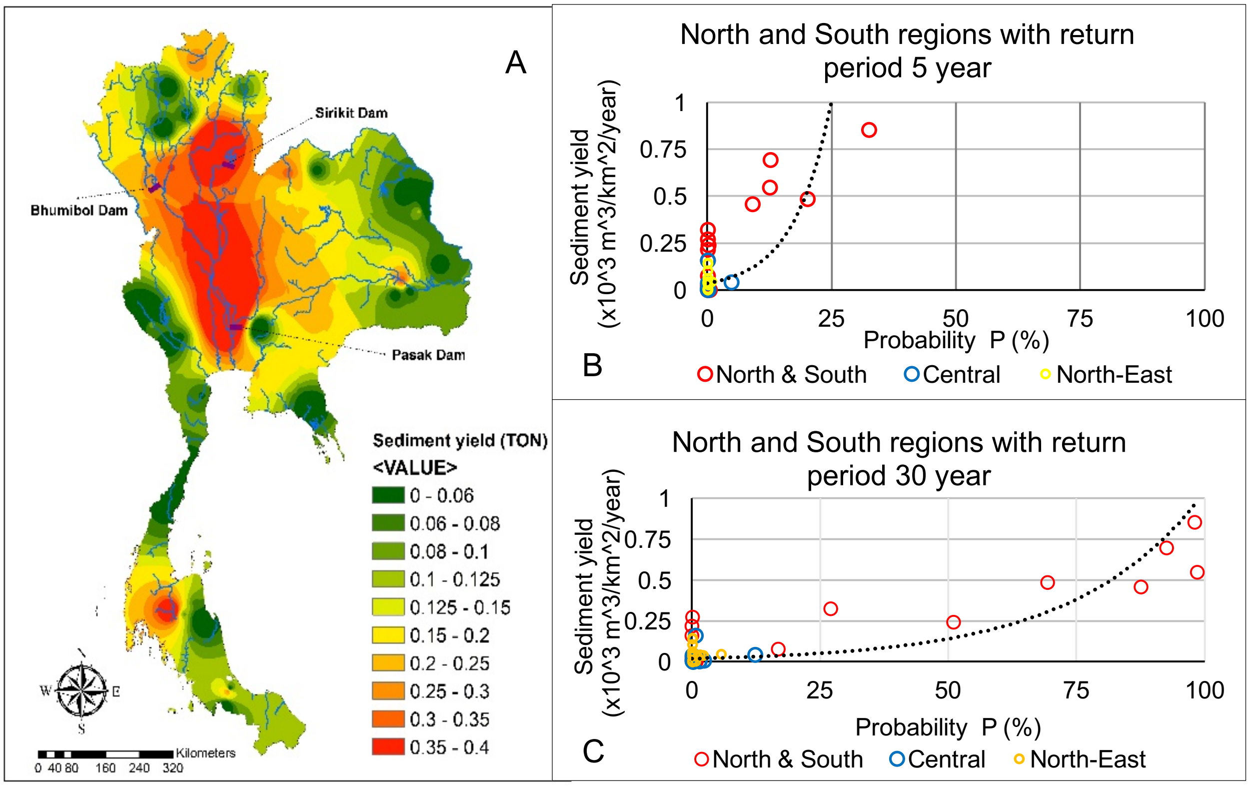

Figure 4. Relationship between probability of landslide and sediment yield

Conclusions.

This study demonstrates that probability of landslide hazard is an important predictor of sediment yield in Thailand and for this reason indicates the large importance that landslide may for sediment yield. The results show that the major sources of sediment yield in the central region was from the landslide in the upstream area in the landslide areas of the northern regions. We found significant relationship between probability of landslide hazard and sediment yield in Thailand. The trend of sediment yield is relate with the probability of landslide hazard, which it will increasing when the probability of landslide hazard increase.

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