Rainfall thresholds for possible landslide occurrence in Ulu Kelang, Selangor, Malaysia using TRMM satellite precipitation estimates

Norsuzila Ya'acob [1,2] **,Noraisyah Tajudin** [1] **, Azita laily Yusof** [1,2] **, Darmawaty Mohd Ali**[1,2]**and Suzi Seroja Sarnin**[1]

[1]Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam Selangor, Malaysia
[2]Wireless Communication Technology (WiCoT), Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

norsuzila@salam.uitm.edu.my,tnoraisyah@gmail.com,azita968@salam.uitm.edu.my, darma504@salam.uitm.edu.my, suzis045@salam.uitm.edu.my

Abstract. This study presents rainfall threshold-triggering landslide based on satellite remote estimates for prediction of possible landslide occurrence in Ulu Kelang, Selangor. Landslide events from 1999 to 2012 were collected. The short and long period of antecedent rainfall days were prepared for landslide days. The rainfall data is obtained from Tropical Rainfall Measuring Mission (TRMM) satellite precipitation data and have been used to analyze rainfall pattern, accumulated rainfall and rainfall threshold. The accumulated rainfall – accumulated rainfall (E-E) diagram is developed to represent the rainfall threshold in Ulu Kelang, Selangor. The rainfall threshold is divided into three different indexes; no landslide occurrences, minor landslide occurrences and major landslide occurrences. The results show that parameter of rainfall threshold obtained from satellite data estimates are lower than those obtained from rain gauge measurement. Therefore, rainfall threshold based on satellite remote estimates is possible to use for landslide prediction.

1. Introduction

Landslides are natural disaster that affecting many tropical countries, especially during the monsoon season. This phenomenon has created a major hazard that claimed life, damage properties and disruption of economic; and producing different environmental problems. Most of landslides are induced by incidences of heavy rain or prolonged rainfall during the monsoon season [1]. Based on Selective Malaysia Case History reported in National Slope Master Plan (2009-2023), rainfall is the major triggering factor which is represented 62% besides those others factors as such loading change (31%) and Water level Change (7.7%) [2].

The rainfall thresholds-triggering landslides have been well discussed and determined in past decade. It can be classified into five categories including intensity-duration (ID diagram), accumulated rainfall-duration (E-D diagram), Accumulated rainfall, intensity-accumulated rainfall (I-E diagram) and accumulated rainfall – accumulated rainfall (E-E diagram) [3]. In this study, E-E diagram was developed based on local rainfall condition to provide a prediction of landslide occurrence in Ulu

Kelang area. This rainfall threshold model is proved by Lee et al (2013) as the highest reliability index compared the other model [2]. Most of previous research was derived the rainfall threshold analysis or model by using rain gauges data to predict the possible occurrence of landslide. Furthermore, satellite data should be particularly useful to replace the traditional ground based measurement in ungauged and remote areas, whereas can provide a significant spatial and temporal reference in gauged area [5][6]. Satellite estimation data can provide a solution to the spatial sampling for the area has limited of the gauge-based network [7]. It's also provided the provision of spatially and temporally varying trigger and identify period when landslide may occur [8].

In this study, we analyze the rainfall threshold by implemented the data of satellite remote estimates provide by NASA's TRMM for the prediction of possible landslide in Ulu Kelang area. In particular (i) we analyze the rainfall pattern to overview of the rainfall conditions that had triggered the landslides; (ii) we derive the rainfall threshold for initiations of landslide and (iii) we compare with rainfall threshold obtained by rain gauge data to validate the rainfall threshold derived from satellite remote estimates for landslide prediction in Ulu Kelang, Selangor.

2. Methodology

2.1. Study Area and Data
This study was conducted in Ulu Kelang Area, Selangor with an area of 600 hectares located at the latitude of 3°12'30''N and 101° 45' 28''E with approximate distance of 5 km from Kuala Lumpur city centre. Ulu Kelang is an urbanization area which having very high demands on its land property and housing development particularly at the hillside area [9]. Ulu Kelang areas climate is commonly hot and humid as it is located in the tropical monsoon region. There are two periods identified as the wet season, from February to May and from September to December each year. According to Malaysian Meteorological department (MMD), the accumulated monthly rainfall for Ulu Kelang is between 58 and 420 mm per month and normally has more than 200 rainy days per year. The highest daily rainfall had been recorded ranged from 87 to 100 mm [10].

The rainfall data for Ulu Kelang area is obtained from TRMM satellite precipitation data in gridded point located at the latitude of 3.125° N and 101.125°E. In this study, TRMM Data product; Monthly Rainfall (TRMM_3B43v7) and Daily Rainfall (TRMM_3B42_Daily v7) have been used in rainfall analysis. Four locations have been selected to conduct rainfall pattern analysis; which are Taman Zoo View Landslide (29 Oct 2001), Taman Hillview Landslide (20 Nov 2002), Kampung Pasir landslide (31 May 2006) and Taman Bukit Mewah, Bukit Antarabangsa Landslide (6 Dec 2008). While the fourteen location of landslide event that occurred in Ulu Kelang areas between years 1999 to 2012 were selected for rainfall threshold analysis.

2.2. Method
The methodology structure for this study is shown in Figure 1. The research started by identifying the historical landslide information in various sources. Based on the historical landslide information, the rainfall data for selected cases were obtained from TRMM Satellite precipitation estimates at https: //giovanni.sci.gsfc.nasa.gov. The satellite data is extracted by using Python 2.7 script then export into Excel format for numerical analysis. The rainfall patterns were plotted by Excel and the rainfall threshold was constructed by using MATLAB. The validation of rainfall threshold is done by comparing with empirical rainfall threshold obtained by rain gauge data from previous researcher.

Rainfall pattern analysis was conducted to provide the overview of correlation between rainfall infiltration and landslide occurrence by investigating four landslide events in Ulu Kelang [5]. In this study, four patterns of rainfall were analyzed which are daily rainfall, the cumulative 3-day and the cumulative 30-day rainfall. The bar chart for rainfall pattern analysis has been plotted with previous three month rainfall distribution of landslide event.

The rainfall threshold were developed to determine the amount of rainfall that, when reached or exceeded, is likely to trigger landslides and also interpreted as an approximate lower-bound threshold.

Where is below the specified level of rainfall induced landslide activity does not occur, or occurs only rarely, and above which it may occur under certain condition [11]. In this study, the E3-E30 diagram is plotted to determine the rainfall threshold for Ulu Kelang area. The rainfall threshold was analyzed using historical landslide occurrence information since year 1999 – 2012.
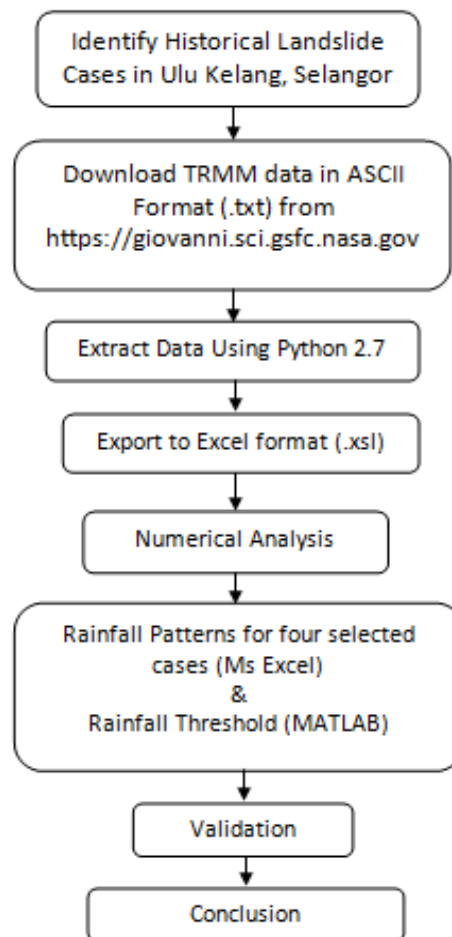
```
┌─────────────────────────────┐
│  Identify Historical Landslide  │
│  Cases in Ulu Kelang, Selangor  │
└─────────────────────────────┘
              │
┌─────────────────────────────┐
│   Download TRMM data in ASCII   │
│        Format (.txt) from       │
│  https://giovanni.sci.gsfc.nasa.gov │
└─────────────────────────────┘
              │
┌─────────────────────────────┐
│   Extract Data Using Python 2.7  │
└─────────────────────────────┘
              │
┌─────────────────────────────┐
│   Export to Excel format (.xsl)  │
└─────────────────────────────┘
              │
┌─────────────────────────────┐
│       Numerical Analysis         │
└─────────────────────────────┘
              │
┌─────────────────────────────┐
│  Rainfall Patterns for four selected │
│           cases (Ms Excel)       │
│                &                 │
│    Rainfall Threshold (MATLAB)   │
└─────────────────────────────┘
              │
┌─────────────────────────────┐
│            Validation            │
└─────────────────────────────┘
              │
┌─────────────────────────────┐
│            Conclusion            │
└─────────────────────────────┘
```

Figure 1.The methodology Structure

3. Result

3.1. Rainfall Pattern Analysis

Figure 2(a) to Figure 2(d) show the daily rainfall for four selected cases studies. From the observation in rainfall pattern chart, Taman Zooview landslide shows the amount of rainfall is reached more 40 mm during landslide event. Meanwhile Taman Bukit Mewah landslide is reached about 20mm; and Taman Hillview landslide and Kampung Pasir landslide were only less than 5 mm of rainfall amount in day of landslide event. In Figure 3(a) shows the total of previous 3-day daily rainfall measurement in Taman Zooview landslide is reached more than 110mm. These factors explain that the landslide in Taman Zooview on 29 October 2001 occurred because of heavy raining in short duration rainfall period.

On the contrary, happen at the Taman Hillview landslide, Kampung Pasir landslide and Bukit Mewah landslide occurred in very low amount of daily rainfall on the day of landslide occurrence. The rainfall pattern of three landslide events in Figure 2(b) to Figure 2(d) shows that heavy raining is not the factor of landslide occurrence. These four rainfall pattern were recorded most of the day is a rainy day in previous 3 month before landslide event.
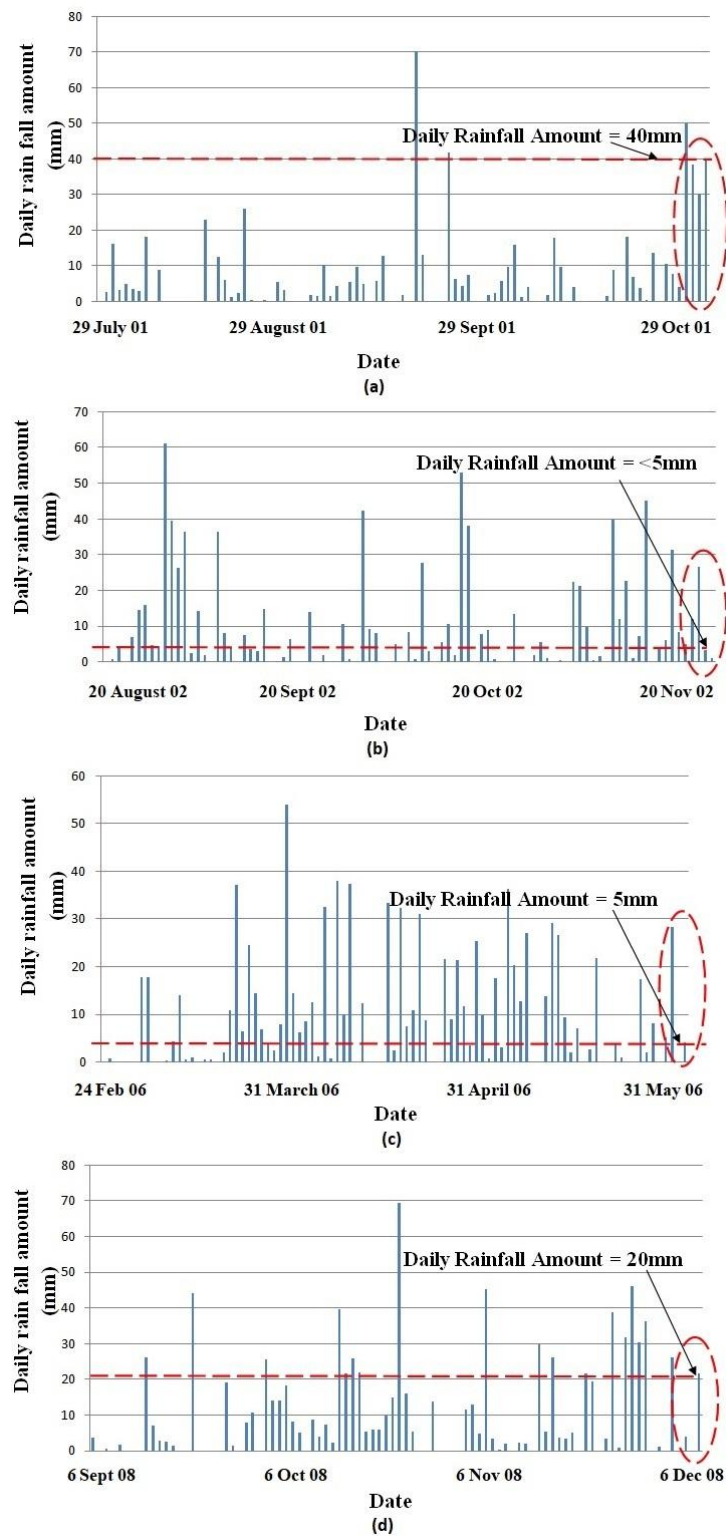
Figure 2. Daily Rainfalls for four selected case study: (a) Taman Zoo View Landslide on 29 Oct 2001,(b) Taman Hillview Landslide on 20 Nov 2002, (c) Kampung Pasir, Ulu Kelang Landslide on 31 May 2006 and (d) Taman Bukit Mewah, Bukit Antarabangsa Landslide on 6 Dec 2008
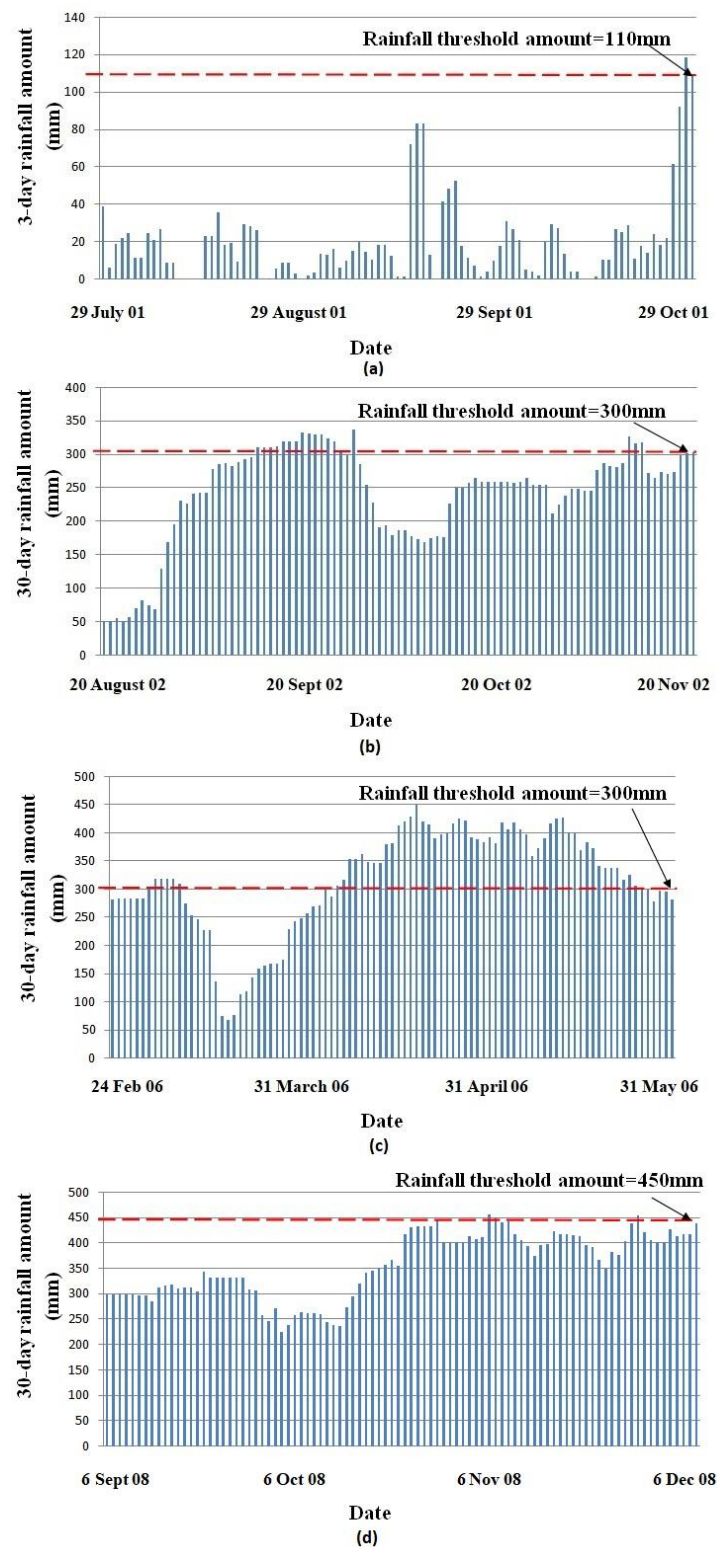
Figure 3. (a) 3 - day Cumulative Rainfalls for Taman Zooview Landslide on 29 Oct 2001, (b) 30-day Cumulative Rainfalls for Taman Hillview Landslide on 20 Nov 2002, (c) 30-day Cumulative Rainfalls for Kampung Pasir Landslide on 31 May 2006, (d) 30-day Cumulative Rainfalls for Taman Bukit Mewah, Bukit Antarabangsa Landslide on 6 Dec 2008

Figure 3(a) to Figure 3(d) show the critical rainfall duration for four selected cases studies. This analysis was resulted the best predicted of landslide occurrence for each case study. The best predicted of Taman Zooview landslide by the 3-day cumulative rainfalls with rainfall threshold amount about 110 mm. The 30-day cumulative antecedent rainfalls are the best predictions for the landslide at Taman Hillview, Kampung Pasir and Taman Bukit Mewah, Bukit Antarabangsa. The amount of rainfall threshold for both Taman Hillview landslide and Kampung Pasir Landslide were reaching about 300 mm. While Taman Bukit Mewah landslide was recorded as the highest rainfall threshold amount which reached about 450 mm.

There is big different value of rainfall threshold amount between Taman Zooview landslide and others three cases reinforce that the landslide occurs in Taman Hillview, Kampung Pasir and Bukit mewah were cause of long duration or prolonged continuous rainfall. From the rainfall pattern analysis, we can assume the rainfall conditions that had triggered the landslides in Ulu Kelang are because of either short and long duration or prolonged continuous period of rainfall.

3.2. Rainfall Threshold Analysis
The rainfall threshold that incorporates with 3-day versus 30-day cumulative for fourteen selected landslides event was developed for the best discrimination threshold of Ulu Kelang, Selangor. This method is appropriate with the rainfall condition that had triggered landslide in this area. The Rainfall threshold show in Figure 4(a) is based on two categories of landslide which are major landslide and minor landslide. This graph was formed from the mathematical equation with two limiting threshold line based on the occurrence of minor and major landslide events and also using the lower end of the plotted in the scattered graph [4]. By referring Figure 4(a), the rainfall threshold showed the limiting threshold line as following:

$$\text{For major landslide:} \quad E_3 = -0.607E_{30} + 161.71 \qquad (1)$$
$$\text{For minor landslide:} \quad E_3 = -0.607E_{30} + 110.02 \qquad (2)$$

The formed of two limiting threshold line was divided the graph area into 3 states known as major landslide likely, minor landslide likely and no landslide likely. This namely is based on plotted landslide category in that area of graph. Figure 4(b) presents the rainfall threshold chart formed by equation 1 and equation 2.
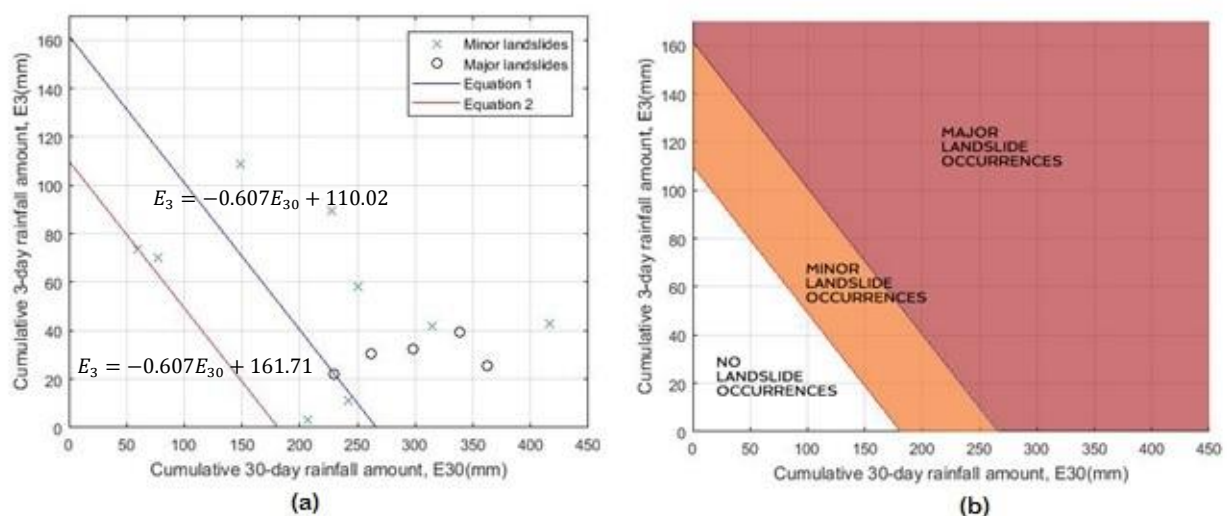

Figure 4. (a) Plotting of E3-E30 diagram for Historical Rainfall that have Resulted in Landslide. (b) Proposed E3-E30 Threshold Chart.

3.3. The Comparison of Rainfall Threshold with previous research

For the validation purpose, this rainfall threshold was comparing with the rainfall threshold in Figure 5, from previous research, Lee et al (2013) which obtained by using rain gauge data [2]. From the comparison, it shows the value of rainfall threshold equation is lower than value of rain gauge data's rainfall threshold equation. The rainfall threshold shows in Figure 4(a) stated that a cumulative precipitation exceeds the 3-day equalling and more than 5mm and threshold of 30-day cumulative equalling and more than 60mm can be consider trigger landslide. While the rainfall threshold in Figure 5 show exceeds 3-day cumulative equalling and more than 5mm and exceeds 30-day cumulative equalling and more than 160mm may trigger landslide in Ulu Kelang, Selangor.

Based on comparison of rainfall threshold obtained previous research which derived from rain gauge data, the rainfall threshold obtained from TRMM data precipitation are lower. Therefore, the proposed rainfall threshold obtains from TRMM data precipitation can be applied as rainfall threshold for the possible landslide occurrence.
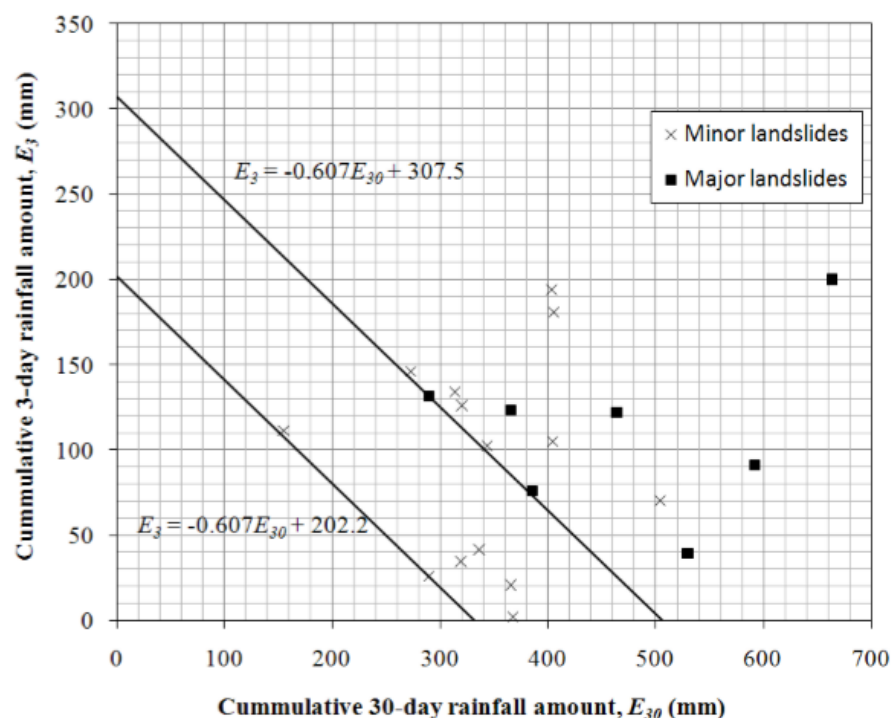

Figure 5. The E3-E30 diagram for Historical Rainfall that have Resulted in Landslide obtained from rain gauge data. Reprinted by permission from "Rainfall-induced landslides in Hulu Kelang area, Malaysia." by Min Lee Lee, Kim Yeong Ng, Yuk Feng Huang and Wei Chao Li, 2013, Natural Hazard 70(1) pp 353-375. Copyright 2013 Springer Nature.

4. Conclusion

The main objective of this study was to analyze the rainfall threshold obtained by TRMM data precipitation for used of prediction the possible landslide in Ulu Kelang. The E3-E30 threshold was developed to predict the landslide occurrence based on historical landslide event and rainfall condition where is identify through rainfall pattern. By referring the criteria of the E3-E30 diagram, the three states were determined: major landslide occurrence, minor landslide occurrence and no landslide occurrence. To validate this rainfall threshold is possible to predict the future landslide; the comparison between previous research rainfall thresholds which derived from rain gauge data was

done. And the result reveals that rainfall threshold obtained from TRMM data precipitation is lower than those obtained from rain gauge measurement. Finally, this proposed rainfall threshold can be applied for prediction of possible landslide occurrence in Ulu Kelang, Selangor.

5. Recommendation
For future research, rainfall threshold analysis can be combine with other landslide contributing factor such as land use, slop gradient, soil type etc to generate the Rainfall-landslide mapping using GIS software. This technique can be providing the more accurate prediction of future landslide.

6. Acknowledgments

7. References
[1]   Muhammad Mukhlisin, Mohd Raihan Taha & Jahara Matian. 2015. Analysis of Rainfall Effect to Slope Stability in Ulu Klang, Malaysia. *J Tekno*, Volume **72:3**,15-21.
[2]   Min Lee Lee,Kim Yeong Ng,Yuk Feng Huang and Wei Chao Li. 2013. Rainfall-induced landslides in Hulu Kelang area, Malaysia. *Nat Hazard* **70(1)** pp 353-375
[3]   C.F.Lee, C.M.Huang, T.C.Tsao, L.W.Wei, W.K. Huang, C.T. Cheng & C.C.Chi. 2016. Combining rainfall parameter and landslide susceptibility to forecast shallow landslide in Taiwan. *Geotechnical Engineering Journal of the SEAGS & AGSSEA* Vol. **47** No. 2.
[4]   Omar F. Althuwaynee, Biswajeet Pradhan and Nordin Ahmad. 2014. Estimation of rainfall threshold and its use in landslide hazard mapping of Kuala Lumpur metropolitan and surrounding areas. *Landslides* **12** pp 861–875
[5]   M.Rossi, S.Luciani, D.Kirschbaum, M.T. Brunetti, S. Peruccacci and F. Guzzetti. 2016. Statistical approaches for the definition of landslide rainfall thresholds and their uncertainty using rain gauge and satellite data. *Geomor* Vol. 285 pp 16-27.
[6]   Pari-Sima Katiraie-Boroujerdy, Ata Akbari Asanjan, Kuo-lin Hsu and Soroosh Sorooshian. 2017. Intercomparison of ERSIANN-CDR and TRMM-3B42V7 precipitation estimates at monthly and daily time scales. *Atmos* Vol. **193** pp 36-49
[7]   M.T. Brunetti, M.Melillo, S. Peruccacci, L.Ciabatta and L.Brocca. 2018. How far are we from the use of satellite rainfall products in landslide forecasting?. *Remote Sens Environ* **210** pp 65-75
[8]   J.C. Robbins. 2016. A probabilistic approach for assessing landslide-triggering event rainfall in Papua New Guinea, using TRMM satellite precipitation estimates. *J Hydrol* **541**, pp 296 – 309.
[9]   Zulkiflee Abd Latif, Siti Nur Afiqah Aman & Biswajeet Pradhan. 2012. Landslide Susceptibility Mapping Using Lidar Derived Factors and Frequency Ratio Model: Ulu Kelang Area, Malaysia. *IEEE 8th Int Colloquium on Signal Processing and its Applications (CSPA).*
[10]   Nader Saadatkhah, Azman Kassim & Lee Min Lee. 2014. Spatial Patterns of Precipitation, Altitude and Monsoon Directions in Hulu Kelang Area, Malaysia. *EJGE*. Vol. **19**.
[11]   Alan F. Chleborad, Rex L. Baum, and Jonathan W. Godt. 2006. Rainfall Thresholds for Forecasting Landslides in the Seattle, Washington, Area-Exceedance and Probability.*U.S. Geological Survey Open-File Report 2006–1064*