# Rainfall – landslide potential mapping using remote sensing and GIS at Ulu Kelang, Selangor, Malaysia

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**Abstract**. This study presents the analysis of relationship between rainfall parameter and landslide occurrences in Ulu Kelang, Selangor by using geographic information system (GIS) and remote sensing data. Located in the country which near the equator line with tropical climates, Ulu Kelang receives averaging 2,400mm annually rainfall. Therefore rainfall is one of the main triggering factors that cause of landslide events. In this study, the rainfall threshold was conducted by using data obtained from Tropical Rainfall Measuring Mission (TRMM) satellite precipitation. The rainfall pattern, rainfall intensity and accumulated rainfall were analyzed to determine the best rainfall threshold that triggering the landslide events. While the SPOT-5 imagery is used to identify the land use mapping in Ulu Kelang area for years 2005 and 2009 using ERDAS Imagine 2014. The potential landslide areas have been mapped by using GIS-based statistic model; weighted linear combination (WLC) to identify the relationship between rainfall, landslide and others contributing factors including slope gradient, geology and land use. The results indicate the potential landslide with five different indexes: very low, low, medium, high and very high; were verified using historical landslide occurrences in year 2002 until 2009. The result showed that Rainfall-Landslide potential mapping would be useful as early warning of landslide occurrences and prediction of future potential landslides for development and land-use planning; and landslide risk management.

## 1. Introduction
Malaysia has experienced many landslides that have cause a numbers of death, destructiveness, and various losses to human living and a direct and indirect impact on environmental and economical. Landslides are one of the natural hazards in mountainous and tropical regions due to intensive rainfall and urban development over fractured hilly areas [1]. Ulu Kelang, Selangor is an urbanization area which having very high demands on its land property and housing development particularly at the

hillside area. Therefore the hazard and risk management should be in place during or before land use planning is implemented.

In the recent years, remote sensing and GIS techniques have been utilized to carry out analytical analysis for landslide hazard mapping. GIS can be transform the multilayered database (such as slope aspect and angle, geology aspect, precipitation and land use/land cover) into an aggregation of function value to obtain an index of propensity the land to failure [2].The advantages in GIS technology provides a significant contribution where the multi-criteria decision analysis concept was influence in analyzing and producing the final result [3][4]. There are studies have been carried out using GIS in Malaysia, particularly in Ulu Kelang shows that potential occurrence of landslides is quite high by analyzing landslide hazard map[5][6].

In this study we analyze the relationship between rainfall parameter and landslide occurrences in Ulu Kelang, Selangor by using GIS and remote sensing data to provide potential landslide mapping for predicting and monitoring the possible landslide occurrences. In particular (i) we derive the rainfall threshold for initiations of landslide; (ii) we analyze the contributing factors that cause landslides and (iii) we generate the potential landslide mapping using GIS for Ulu Kelang areas.

## 2. Methodology

### 2.1. Study Area and Data
This study is bounded by 101.75N to 101.78N and longitudes 3.17E to 3.21E. It is undulating areas and mountainous at the northern and eastern areas which form parts of Titiwangsa Mountain Range. The study area is falls in Ulu Kelang district, Selangor with monthly rainfall is between 58 and 420 mm per month and more than 200 rainy days per year. The highest daily rainfall had been recorded ranged from 87 to 100 mm [7]. The Daily Rainfall (TRMM_3B42_Daily v7) TRMM data product has been used for rainfall threshold analysis. While SPOT-5 images Panshrap All Bands with the path/row is 270/344 has been used in classification of land use mapping. For slope and rock geology were obtained by analyze the contour map and geology topography courtesy from Department of Survey and Mapping Malaysia (JUPEM) and Department of Mineral and Geoscience Malaysia (JMG).

### 2.2. Method
Based on Figure 1, the methodology structure in this study is divided into three phases. The first phase is acquisition of required data including rainfall data, slope gradient, soil properties and satellite images for land use mapping. It is followed by second phase which data have been process and analyze using statistical method for rainfall analysis, ERDAS Imagine Software for image processing and ArcGIS for GIS analysis. Finally, the third phase is the data integrated and representation to establish the relationship between rainfall and landslide occurrence.
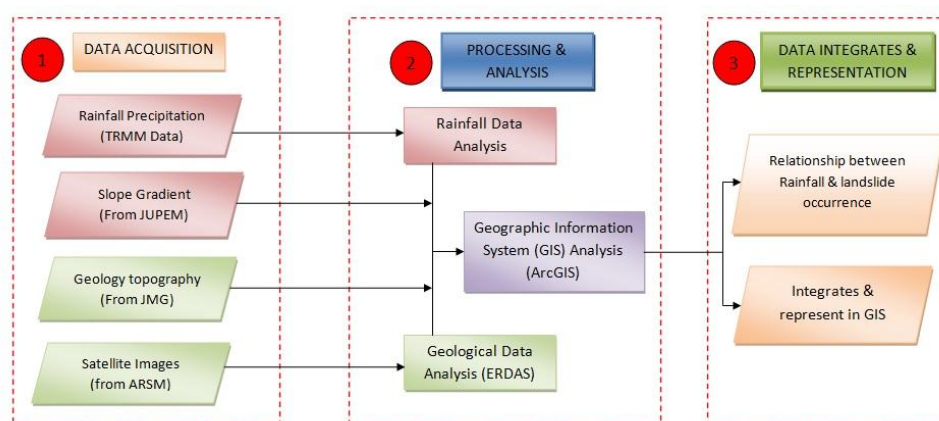


**Figure 1**. The methodology Structure of Rainfall landslide Potential Mapping

In this study, the Cumulative 3 – day Rainfall versus Cumulative 30-day Rainfall (E3-E30) is plotted to determine the rainfall threshold for Ulu Kelang areas. The rainfall threshold was analyzed using historical landslide occurrence information from year 1999 until 2012. ERDAS Imagine Software is selected to process and analyze the SPOT-5 image to obtain land use mapping. ArcGIS v10.2.2 Software is used to analyze the landslide potential areas in Ulu Kelang. The potential areas are determined by using WLC method. This method is applied to identify the relationship between landslide, rainfall and other contributing factors; slope gradient, geology and land use. The risk analysis is calculated within different score or rank of different grouping depending on their correlations with landslides. Each group is consists of inter-parameter variable. The inter-parameter score or rank values were assigned through the level of probability of landslide occurrences. Pair Wise Comparison tool was applied as a technique to derive the weightings for each landslide dependent parameter. The formula for the risk analysis score is the sum of the products of dependent parameter and inter-parameter. In general the risk analyses of landslide occurrence based on equation:

$$\text{SWM} = \sum W_i \times R_i \tag{1}$$

where $W_i$ = map weight  $R_i$ = Ranking for the each layer

The risk score formula based on four parameter and inter-parameter score as follow:

$$\text{Risk Score} = W_{rainfall} \times R_{rainfall} + W_{slope} \times R_{slope} + W_{geo} \times R_{geo} + W_{LU} \times R_{LU} \tag{2}$$

where:
$W_{rainfall}$ is the parameter weighting for rainfall threshold
$W_{slope}$ is the parameter weighting for slope gradient
$W_{geo}$ is the parameter weighting for geology
$W_{LU}$ is the parameter weighting for land use
$R_{rainfall}$ is the inter-parameter weighting for rainfall threshold
$R_{slope}$ is the inter-parameter weighting for slope gradient
$R_{geo}$ is the inter-parameter weighting for geology
$R_{LU}$ is the inter-parameter weighting for land use

There are five risk analysis of ratings; very low risk, low risk, medium risk, high risk and very high risk. The landslide potential map was validated using the location of historical landslide into two set of the landslide potential map for year 2005 and 2009.

## 3. Result

### 3.1. Rainfall Threshold

The rainfall threshold that incorporates with 3-day versus 30-day cumulative was developed by plotted 3-day and 30-day cumulative rainfall for fourteen selected landslide events based on two categories of landslide which are major landslide and minor landslide. This graph was formed two limiting threshold line based on the occurrence of minor and major landslide events. The formed of two limiting threshold line was divided the graph area into 3 states known as major landslide occurrences, minor landslide occurrences and no landslide occurrences as shown in Figure 2(b). By referring Figure 2(a), the rainfall threshold showed the limiting threshold line as following:

$$\text{For major landslide: } E_3 = 161.71 - 0.607E_{30} \tag{3}$$

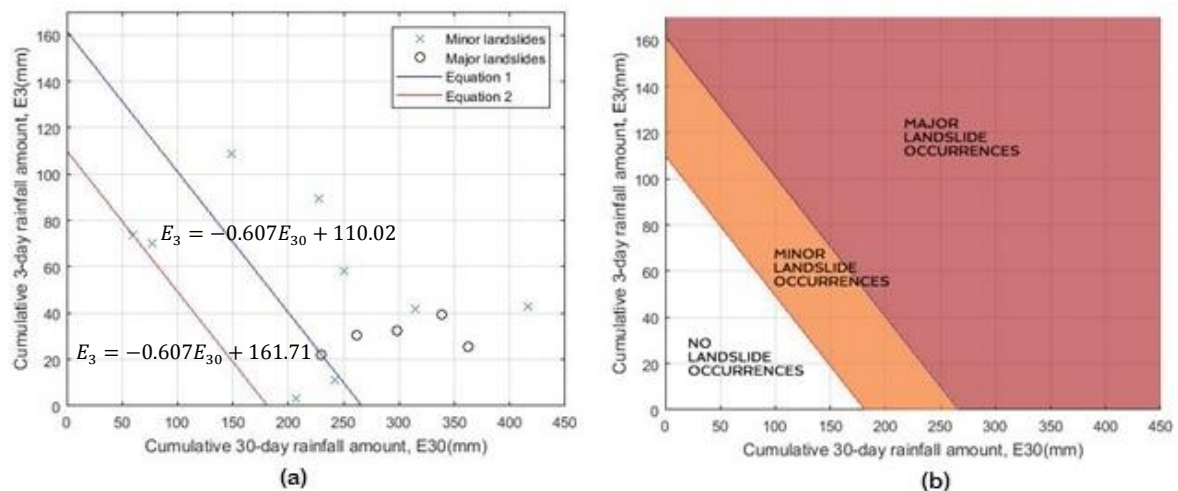$$\text{For minor landslide: } E_3 = 110.02 - 0.607E_{30} \tag{4}$$

**Figure 2.** (a) Plotting of Cumulative 3-day Rainfall – Cumulative 30-day Rainfall (E3-E30) for Historical Rainfall that have Resulted in Landslide, (b) Proposed Cumulative 3-day Rainfall – Cumulative 30-day Rainfall (E3-E30) Threshold Chart.

*3.2 Contributing Factor*

In this study, there are two set of land use map were used and contributed with five classes were included construction area (Yellow), green area (Green), road (Black), urban area (Red) and water body (Blue). Figure 3(a) and 3(b) shows the land use map of Ulu Kelang areas for the year 2005 and 2009. The rank values of land use classification have been determined based on judgment and previous study. The construction area was stated as highest rank because the land tends to be more risky than others. It is followed by urban area, water body, road and green area.
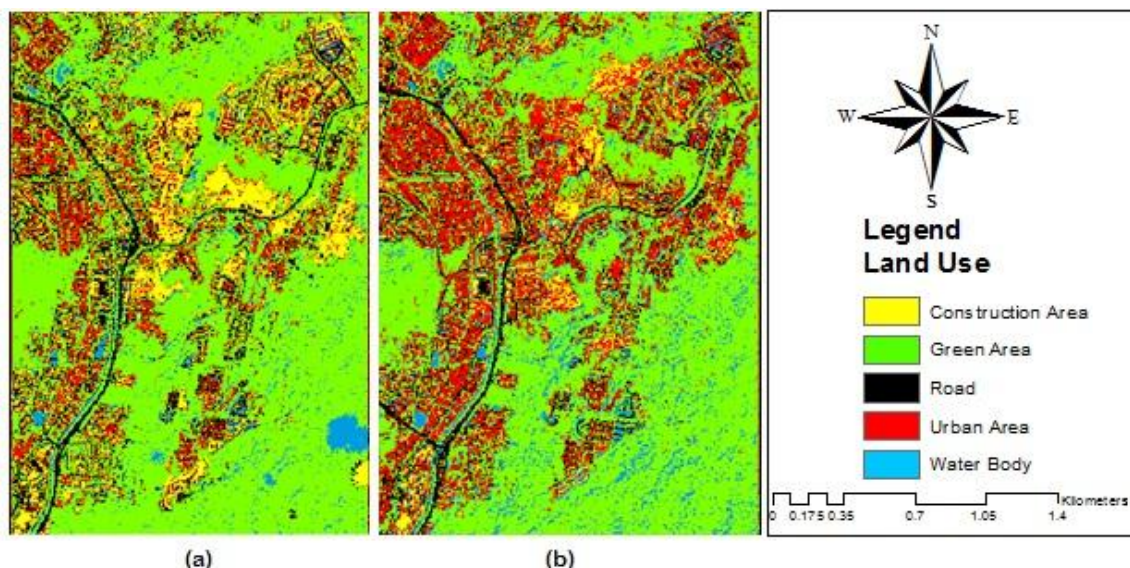


**Figure 3.** Land Use map of Ulu Kelang area: (a) year 2005 (b) year 2009

The slope gradient map with six classes was generated from contour map using TIN Raster tool which is shown in Figure 4(a). The rank value will be higher when the gradient of slope increased. The analysis showed that 15.5% of slope area is above 25 degree which is stated as a risky hilly area by Mineral and Geosciences department [8]. While in geological aspect was classified in two types of rock; known as rock of intrusive acid and non-intrusive acid. The highest rank value is allocated to

rock intrusive acid because the hilly area with intrusive acid rock gives a higher probability of landslide occurrences [9]. Figure 4(b) is shows the type of rock in Ulu Kelang. The details of weightage and ranking for all parameter in rainfall-landslide potential mapping analysis are illustrate in Table 1.
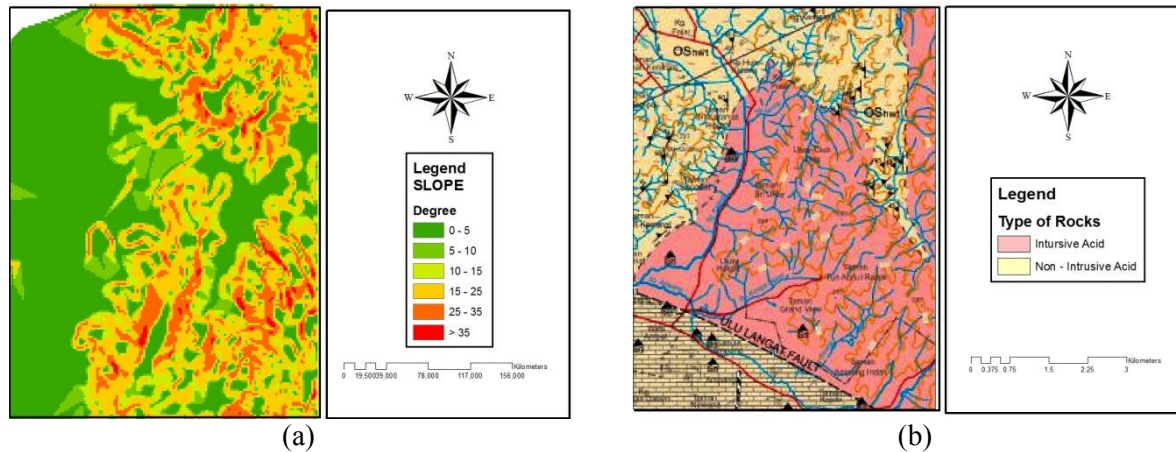




(a)                                                                              (b)

**Figure 4.** (a) Slope gradient and (b) Rock geology

**Table 1**. Parameter, weightage and ranking for rainfall-landslide potential mapping analysis.

| Parameter | Weightage | Inter- Parameter | Score/Ranking |
|---|---|---|---|
| **Rainfall Threshold** | 0.375 | Rainfall I : $E_3 < 110.02 - 0.607E_{30}$ | 1 |
| | | Rainfall II : $110.02 - 0.607E_{30} < E_3 < 161.71 - 0.607E_{30}$ | 2 |
| | | Rainfall III : $E_3 > 161.71 - 0.607E_{30}$ | 3 |
| **Land Use** | 0.25 | Green Area | 1 |
| | | Road | 2 |
| | | Water Body | 3 |
| | | Urban Area | 4 |
| | | Construction Area | 5 |
| **Slope Gradient (Degree)** | 0.25 | 0-5 | 1 |
| | | 5-10 | 1 |
| | | 10-15 | 2 |
| | | 15-25 | 3 |
| | | 25-35 | 4 |
| | | >35 | 5 |
| **Rock Geology** | 0.125 | Non-Intrusive | 1 |
| | | Intrusive acid | 2 |

*3.3 The Analysis relationship between rainfall and landslide occurrences.*

*3.3.1   Potential landslides analysis*

Landslide potential map was generated using raster calculator technique. The risky analysis was calculated by using equation (2). The result showed the possibilities of landslide occurrences in Ulu Kelang areas. The greatest of risky value or score resulted, the highest potential of landslide occurrences. The risky level is classified into five classes; very low (green), low (light green), medium (yellow), high (orange) and very high (red). Eight location of landslide events occurred in year 2002 to 2009 were used to validate the landslide potential analysis.

Figure 5(a), 5(b) and 5(c) shows the three landslide potential map formed from three rainfall threshold parameter in year 2005. The landslide potential map in Figure 5(a) shows that areas are covered with the very low risk to medium risk level of potential landslide occurrences. This map contributes 37110 pixels of very low risk, 1483 pixels of low risk and 494 pixels of medium risk area. There are only 4 pixels orange colour spot which is indicate the high risk level and 0 pixel red colour spot means no location is under very high risk of landslide occurrences. This result is prove that rainfall threshold with no landslide occurrences parameter is forming the lowest potential of landslide occurrences.

Figure 5(b) shows the landslide potential map formed from rainfall threshold with minor landslide occurrences parameter. There is increment of areas which is fall under medium, high and very high risk level where are spot as yellow, orange and red colour. The very high risk level is covered about 28 pixels of areas in the map. While landslide potential map in Figure 5(c) shows 1198 pixels and 1774 pixels of areas are covered with orange and red colour spot which is indicate the high and very high potential of landslide occurrences. This map is formed by using major landslide occurrences parameter. Table 2 shows the number of pixel for each risky level for three rainfall threshold parameter in year 2005. The risky level is classified into five classes; very low (green), low (light green), medium (yellow), high (orange) and very high (red). Eight location of landslide events occurred in year 2002 to 2009 were used to validate the landslide potential analysis.
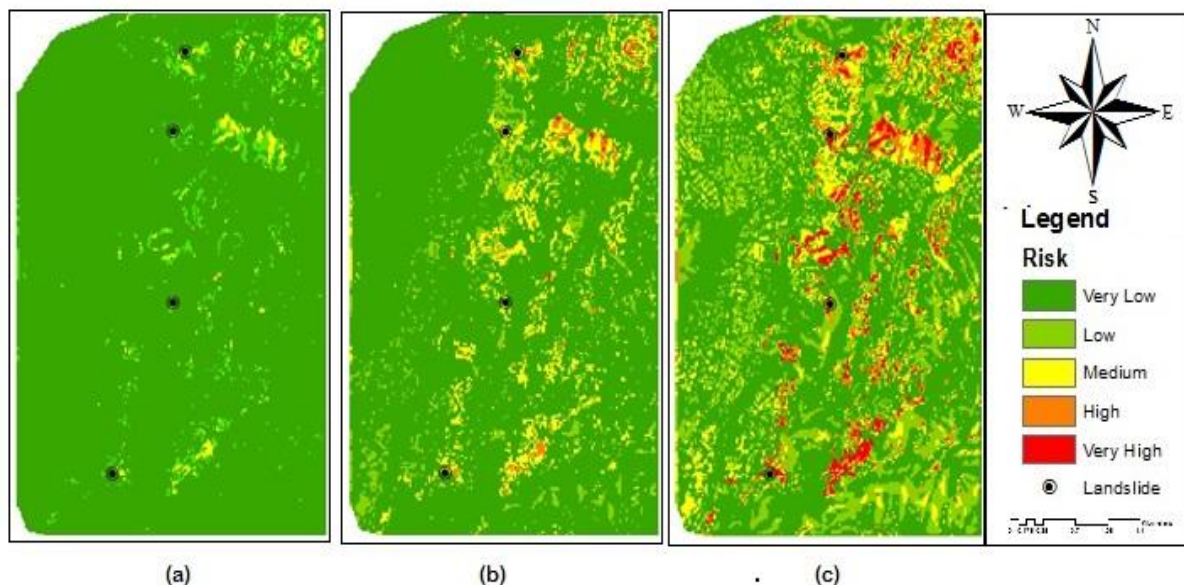


**Figure 5.** Landslide Potential Map in year 2005 (a) Rainfall threshold with no landslide occurrences, (b) Rainfall threshold with minor landslide occurrences and (c) Rainfall threshold with major landslide occurrences

From the analysis, rainfall was affected the landslide occurrences. When amount of rainfall is reaching the rainfall threshold, the landslide potential map was indicating the highest risky areas. If the rainfall amount below rainfall threshold, the landslide potential area is reduce. The landslide potential map was validating using location of historical landslide by comparing coordinate system between

historical landslides and potential landslides in the map. The validation results showed the historical landslide events were located at very high risk of landslide occurrences areas.

**Table 2**. The Comparison the number of pixels in three indexes
of rainfall threshold for landslide potential map 2005

| Risky level | Landslide Potential Map 2005 (Pixel Count) | | |
|---|---|---|---|
| | **Rainfall Threshold No landslide likely** | **Rainfall Threshold Minor landslide likely** | **Rainfall Threshold With Major landslide likely** |
| **Very Low** | 37110 | 32987 | 23157 |
| **Low** | 1483 | 3132 | 8739 |
| **Medium** | 494 | 2474 | 4223 |
| **High** | 4 | 470 | 1774 |
| **Very high** | 0 | 28 | 1198 |

*3.3.2    The comparison of landslide potential analysis*
The comparison analysis was conducted between landslide potential map in year 2005 and landslide potential map in year 2009. Both of landslide potential maps is shown in Figure 6(a) and 6(b) which is set to major landslide occurrences parameter. Both maps indentifying there are orange and red colour spot area which is be a sign of the high potential area of landslide occurrences. Thus, the potential landslide map can be used as an early warning for responsible agencies which are monitor the landslide occurrences.

There are slightly different areas (in pixel) for the high risk area is recorded in year 2005 and 2009 where are 1774 pixels for year 2005 and 1778 pixels in year 2009. The result shows decreasing from 1198 pixels to 525 pixels of very high risk area in year 2005 to 2009.  The decrement of very high risky area was affect because of 23 % decrement in construction area which identified as the high weighting in land use parameter. There is increasing of urban area but it not affected the potential landslide areas because its only involves lowland area. The numbers of potential landslides was decreased from year 2005 to year 2009, which is similar with result in GIS analysis.
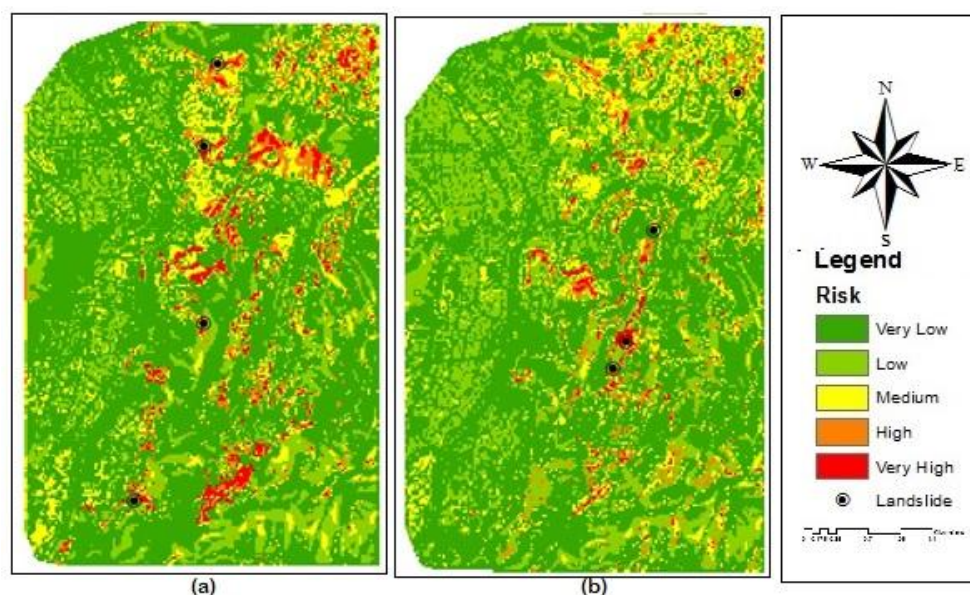


**Figure 6.**Landslide Potential Map (a) year 2005 and (b) year 2009

## 4. Conclusion

Rainfall analysis was conducted to define the correlation between rainfall and landslide occurrence. There are three conditions of landslide occurrences: major landslide occurrence, minor landslide occurrence and no landslide occurrence. By included the rainfall parameter as a trigger factor with three main factors: Slope gradient, geology and land use then the prediction of potential landslide occurrence was conducted to produce landslide potential map for Ulu Kelang areas. The results indicate the potential landslide with five different indexes: very low, low, medium, high and very high; were verified using historical landslide occurrences in year 2002 until 2009. The model of Rainfall-Landslide potential mapping would be useful as early warning of landslide occurrences and as well as prediction tool for future potential landslides in development and land-use planning; and landslide risk management.

## 5. Recommendation

For future research, the landslide-related factor as the aspect angle, soil moisture and texture, curvature and normalize difference vegetation index (NDVI) can be implemented to get more accurate analysis. The other GIS-based method such as frequency ratio (FR), certainty factor (CF) and analytic hierarchy process (AHP) can applied to derive the relationship between landslide-occurrence location and each of the factors contributing landslide occurrence for more comprehensive result.

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