# THE STUDY OF LANDSLIDE SUSCEPTIBILITY USING GIS BASED ON RAINFALL DERIVING FROM TRMM OVER NORTHERN THAILAND

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**ABSTRACT**: Landslide is the most harmful natural events in mountainous areas worldwide. It is also the most frequent hazard and devastating that affect life and property. Rainfall is one of the most important factors contributing to the event. Thailand has experienced a landslide for a long time. Particularly, Northern Thailand is mostly mountainous area and extreme rainfall in monsoon season. The objective of this research is to find a landslide susceptibility map using Geographic Information System (GIS) over northern Thailand. A large number of factors have been considered in this spatial analysis to find susceptible areas including elevation, slope angle, slope aspect, lithology, lineament, soil texture, land use/land cover, Normalized Difference Vegetation Index (NDVI) and rainfall. Based on reviews, rainfall observed at rain gauge stations was frequently used in previous studies. However, there is few rain gauge installed in mountainous region due to electricity. Therefore, rainfall estimated by satellite products can solve the problem. In this study, rainfall data was derived from Tropical Rainfall Measuring Mission (TRMM) was used as the most influencing factor triggering those susceptible areas. Frequency Ratio (FR) technique was used to investigate all of the factors to find the landslide susceptibility. From the results, we found that Phrae and Chiang Mai provinces have shown very high landslide susceptibility areas about 2,013.73 $km^2$ (approximately 2.15%). The accuracy of this map is 54.26% after validation by using the area under the curve. This study hopefully expects to provide useful information for the implementation of projects related to prevention, mitigation, preparation, response, and recovery from landslides, including planning for disasters in the future.

## 1. INTRODUCTION

Landslides are an important geological hazard around the world that it is essential to understand the potential exposure to landslide hazard in mountainous areas (Aditian et al, 2018). There are underlying factors related to the landslide events such are a topographic, lithology, soil texture, land use/land cover, and rainfall. In Thailand case, the previous studies found that there are fifty-one provinces facing a risk of landslide. From 1988 to 2006, there were more than ten areas faced with a massive landslide, and it had caused serious damage to human life and properties of people with the amount of economic loss more than 100,000 million baht (Dolah et al., 2015). Landslide events have been recorded more than 150 landslide occurrences between November 1970 and December 2011 in Thailand. Most events occurred in the northern region with high-frequency occurrence between May and August during rainy monsoon season (Soralump et al, 2012).

Northern Thailand is the most affected region on landslide which bad impact for society in many ways (Soralump, 2010). Many people have been died and properties are damaged for both natural and man-made resources. For instance, the landslide event on May 23, 2006, in Uttaradit, Sukhothai and Phrae provinces had been killed by 83 people and economic loss approximately over 300 million baht (Department of Mineral Resources, 2011). During 37 years from 1970 to 2006, Northern Thailand has lost the budget of 2,575.5 million baht, and the death toll had risen to 286 people (Soralump et al., 2012).

Currently, Remote Sensing (RS) techniques and Geographic Information System (GIS) have been widely applied to study landslide hazard. Due to its powerful tools, GIS can be used to manage, process and analyze in order to explore landslide causes based on statistical models. Statistical analysis methods are often used to determine the spatial relationship between past landslides and causal factors. There are many statistical methods such as the probabilistic frequency ratio (FR) model. Mapping for landslide susceptibility is more possibilities and popular (Intarawichian & Dasananda, 2011). Therefore, this study aims to develop a landslide susceptibility map using the frequency model considering with the related conditioning factor. Moreover, the area under the curve (AUC) is used to evaluate accuracy landslide susceptibility results based on the FR model against with the actual landslide inventory point data.

## 2. DATASETS AND STUDY AREA

### 2.1 Study Area

The study area is northern Thailand (Figure 1a) consisting of 9 provinces, namely Chiang Rai, Mae Hong Son, Chiang Mai, Lamphun, Lampang, Phayao, Nan, Phrae, and Uttaradit. The area is approximately 93,691 km$^2$. Most of the geography is complex mountains which are oriented in north-south direction with narrow river basins in between. The mountain range is about 1,600 m above mean sea level. The highest annual average temperature is 37 °C, which is different from the average minimum temperature of 21 °C in winter. The annual rainfall average is 1,230 mm. As shown in Figure 1b, *blue dot* and a *red dot* are validation and training data, respectively that shows most locations are located on the high mountains. The rainfall amount from TRMM with resolution at 25 km is superimposed with the distribution of rain gauge stations and landslide inventory points as shown in Figure 1c.

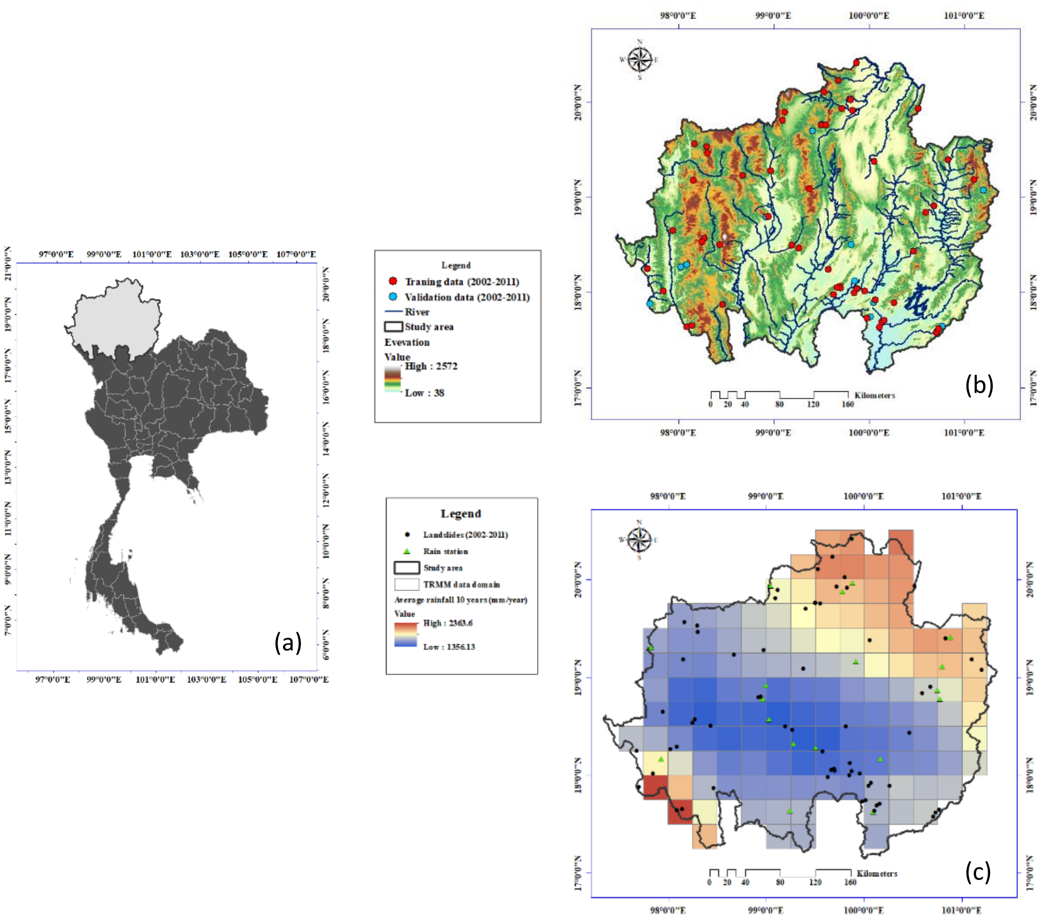


Figure 1 The study area: (a) study area in Northern Thailand, (b) topography, training and validation location and (c) annual average rainfall for 10 years obtained from TRMM 3B42 V.7.

### 2.2 Landslide conditioning factors

Ten factors used in the study area are shown in Figure 2. These maps are prepared in GIS software by classifying, random points, and reclassify to create landslide susceptibility map.

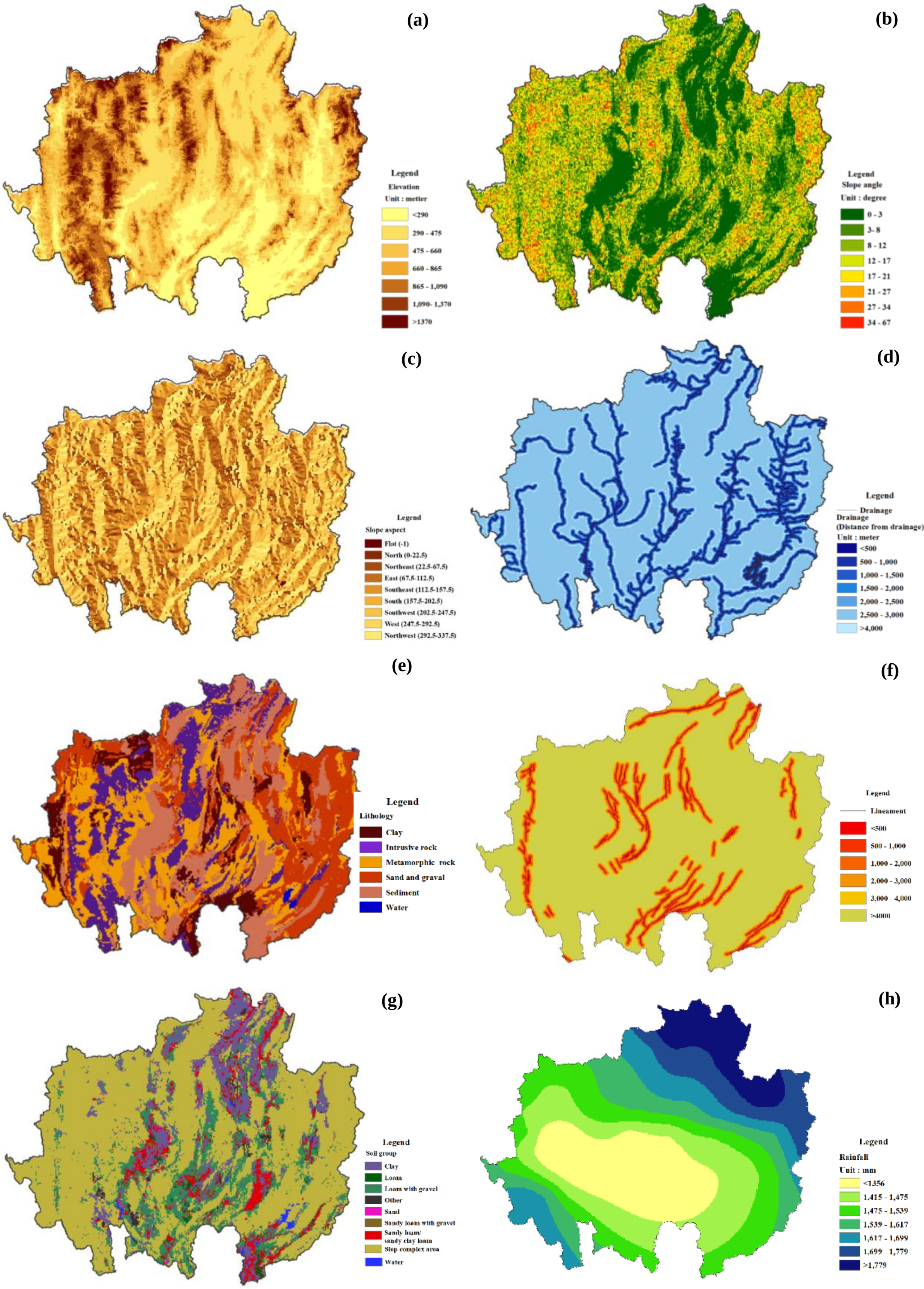


Figure 2 Landslide factors; (a) Elevation, (b) Slope angle, (c) Slope aspect, (d) Drainage, (e) Lithology, (f) Lineament, (g) Soil texture, (h) Rainfall, (i) Land use, and (j) NDVI.

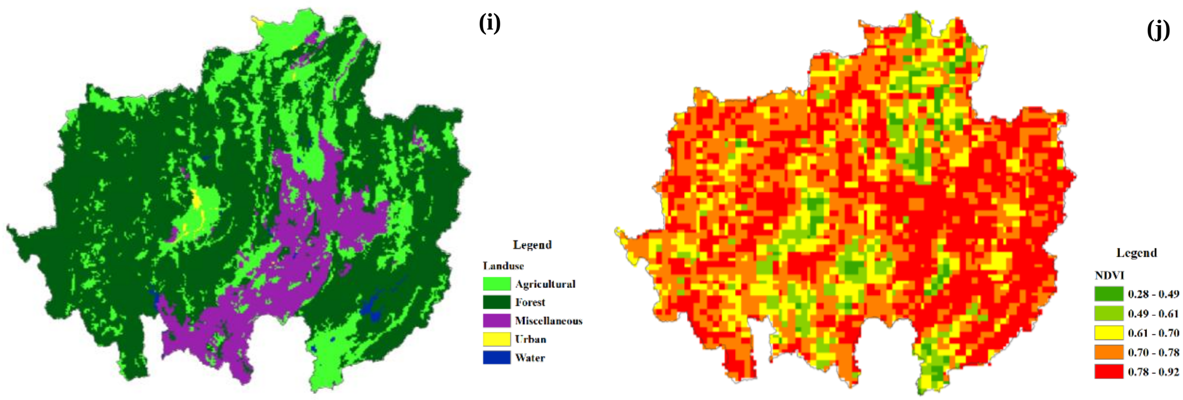


Figure 2 (Continue)

**Landslide inventory location:** This factor was derived from Geotechnical Engineering Research and Development Center (GERD). It is landslide occurrences in Thailand from 1970 to 2006. However, landslide occurrences between 2002 and 2011 (64 points) were used in this study. The analysis was divided into two sets; 1) 80% of landslide occurrences training dataset to generate a landslide susceptibility maps, and 2) the remaining 20% as testing dataset applied for validation. The function of a subset feature in Geostatistical analyst tool was used to random the area.
**Rainfall:** Rainfall is extensively considered as the main factor of landslide occurrence. It is an important factor to analyze for the landslide susceptibility (Wu et al., 2016). Daily rainfall in this study was extracted from TRMM 3B42 V.7 at resolution of 0.25° (https://pmm.nasa.gov/data-access/downloads/trmm) ranging from 2002 to 2011. The annual rainfall average over a ten-year period was done by using Kriging interpolation on GIS software.
**Elevation:** This factor was derived from Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) with spatial resolution at 30 m (https://earthexplorer.usgs.gov/).
**Slope angle (°) and Slop aspect:** The slope angle (°) was obtained from the SRTM DEM as well as elevation. Similarly, the slope aspect in this study area was generated from SRTM DEM.
**Drainage (Distance from drainage):** It is one of the factors that play a significant role in mass movements. Some hills have a slight inclination, density of drainage or streams that cause high landslides occurrence (Abedini et al., 2017).
**Lithology:** We obtained lithology data from the Department of Mineral Resources. Lithological characteristics have a huge impact on the physical properties, therefore affecting the possibility of land sliding (Khan et al., 2019). To explain the tendency of structures to landslides, it is essential to assess the density of existing landslides (Abedini et al., 2017).
**Lineament (Distance from lineament):** The spatial distribution and lineament characteristics generally determine the distribution and intensity of co-seismic landslides (Khan et al., 2019). We derived this factor from the Department of Mineral Resources and make a buffer at distance of 500 m for each interval.
**Soil texture:** We used a soil group from the Land Development Department (LDD). The soil quality in the group may vary by the geological conditions of the areas.
**Land use/land cover:** It has a great influence on landslide distribution. Forest areas have fewer landslides compared to arid areas. Vegetated land providing strong root systems will stabilize slopes in term of the mechanical and hydrological systems (Khan et al., 2019).
**NDVI:** This factor is downloaded from https://modis.gsfc.nasa.gov/data/dataprod/mod13.php. It is monthly vegetation indices L3 Global 0.05Deg CMG product (MYD13C2).

## 3. METHODOLOGY

The methodological framework to create landslide susceptibility map is shown in Figure 3. Ten factors (e.g. elevation, slope angle, slope aspect, drainage, lithology, lineament, soil texture, rainfall, land use and NDVI) were used in the analysis based on FR model.

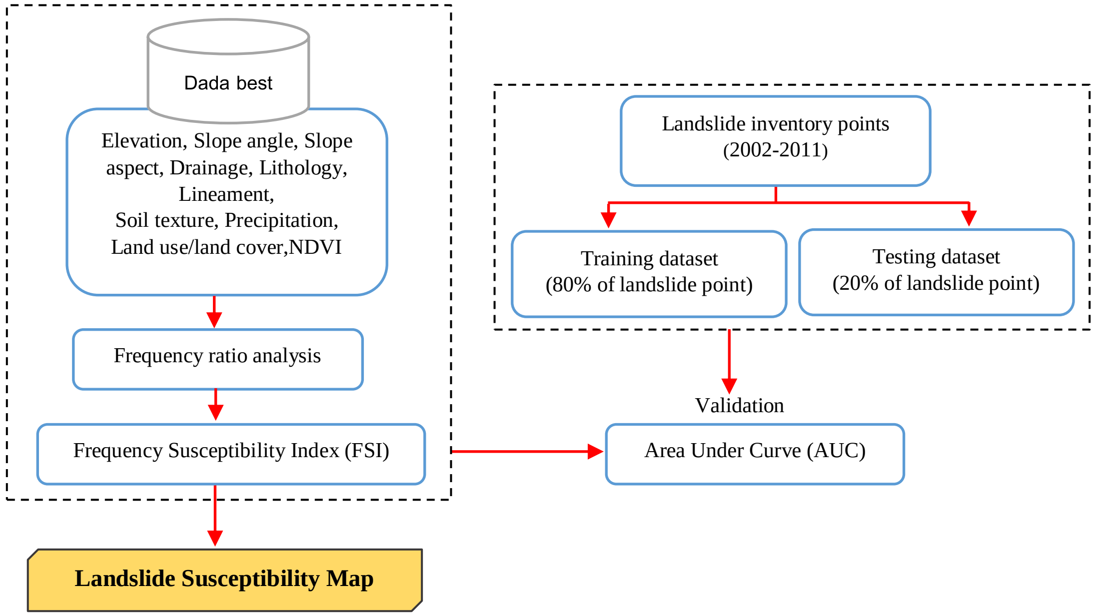


Figure 3 Landslide susceptibility map framework.

The frequency ratio (FR) model is the distribution/probability method based on the relationships between landslide occurrence and each conditional factor. For this analysis, FR value of 1 indicates the average value on the map. If the FR value is greater than 1, the correlation between landslide occurrence and conditioning factor is high. On the other hand, a value of lower than 1 that means a lower correlation (Khan, 2019; Wu, 2016). To produce a landslide susceptibility map, the landslide susceptibility index (LSI) was calculated by a summation of each factor weighting value using the following equation:

$$LSI = \sum FR \tag{1}$$

*Where* LSI is the landslide susceptibility index, and FR is the frequency of each conditioning factor type. Then, the landslide susceptibility map was developed by LSI with classification into five classes; namely very low, low, moderate, high, and very high.

## 4. RESULT AND DISCUSSION

### 4.1 Landslide susceptibility map

The results provide as the FR values for all factor classes for the full extent of the study area as shown in Table 1 listing the level of correlation between landslide occurrences and factors. For the elevation factor, altitude above 1,370 meter is the highest FR value, whereas the class of 660-865 is the lowest FR value. For the slope angle, the class of 21-27 degrees is the highest FR implying the most landslide event that may occur. However, slope angle less than 8 degrees is the least landslide occurrences (FR equal to 0.09). The southeast direction of slope aspect is the highest FR values, followed by flat (0.16), northeast (0.14), north (0.10), east and west (0.09), south (0.06), and northwest (0.04), respectively. For the drainage factor, a class of higher than 3,000 meter is highest FR value, while classes of 1,500-2,000 and 2,000-2,500 has FR value equal to 0 that is the least effect landslide occurrence. For the factor of lithology, sand and gravel is the highest FR value (0.31), followed by clay (0.30), Intrusive rock (0.19), sediment (0.10), and metamorphic rock (0.09), respectively. Water factor has FR value equal to 0 that is the least effect landslide occurrence. For the lineament (Distance from lineament), a class of 3,000-4,000 meter is the highest FR value, while the class of 2,000-3,000 meter has FR value equal to 0 that is the least susceptibility from landslide. For the soil texture, complex slope area is the highest FR value (0.25), followed by sand (0.22), sandy loam and sandy clay loam (0.21), loam (0.20), and clay (0.13), respectively. Whereas, loam with gravel, sandy loam with gravel, and other area have FR value equal to 0 that is the least effecting from landslide. For the rainfall factor, the rainfall class higher than 1,779 mm is the highest FR value. In term of NDVI factor, class of 0.78-0.92 has the highest FR value with positive value. Table 1 also represents the frequency ratio in each factor with landslide occurrence.

**Table 1** Frequency ratio values in each conditioning factors.

| Factor | Class | Total number of pixel | | Landslide occurrence | | Frequency ratio |
|---|---|---|---|---|---|---|
| | | Number | % | Number | % | |
| **1.Elevation** | <290 | 1,521 | 17.31 | 6,509 | 13.37 | 0.18 |
| | 290 - 475 | 2,197 | 25.00 | 13,361 | 27.45 | 0.12 |
| | 475 - 660 | 2,197 | 25.00 | 9,776 | 20.09 | 0.17 |
| | 660 - 865 | 845 | 9.62 | 7,871 | 16.17 | 0.08 |
| | 865 - 1090 | 1,183 | 13.46 | 6,056 | 12.44 | 0.15 |
| | 1090 - 1370 | 507 | 5.77 | 3,775 | 7.76 | 0.10 |
| | >1370 | 338 | 3.85 | 1,319 | 2.71 | 0.19 |
| **2.Slope angle (°)** | 0 - 3 | 1,521 | 17.31 | 12,319 | 25.19 | 0.09 |
| | 3 - 8 | 1,014 | 11.54 | 7,967 | 16.29 | 0.09 |
| | 8 - 12 | 1,352 | 15.38 | 7,522 | 15.38 | 0.13 |
| | 12 - 17 | 1,183 | 13.46 | 7,058 | 14.43 | 0.12 |
| | 17 - 21 | 1,521 | 17.31 | 6,021 | 12.31 | 0.18 |
| | 21 - 27 | 1,690 | 19.23 | 4,565 | 9.34 | 0.26 |
| | 27 - 34 | 507 | 5.77 | 2,601 | 5.32 | 0.14 |
| | 34 - 67 | 0 | 0.00 | 847 | 1.73 | 0.00 |
| **3.Slope aspect** | Flat | 1,014 | 11.54 | 3,963 | 8.14 | 0.16 |
| | North | 845 | 9.62 | 4,953 | 10.18 | 0.10 |
| | Northeast | 1521 | 17.31 | 6,552 | 13.46 | 0.14 |
| | East | 845 | 9.62 | 5,847 | 12.01 | 0.09 |
| | Southeast | 1,690 | 19.23 | 5,044 | 10.36 | 0.21 |
| | South | 507 | 5.77 | 4,974 | 10.22 | 0.06 |
| | Southwest | 1,183 | 13.46 | 6,472 | 13.30 | 0.11 |
| | West | 845 | 9.62 | 6,067 | 12.47 | 0.09 |
| | Northwest | 338 | 3.85 | 4,795 | 9.85 | 0.04 |
| **4.Drainage (Distance from drainage)** | <500 meter | 1,014 | 11.76 | 3,759 | 8.03 | 0.18 |
| | 500-1,000 meter | 1,014 | 11.76 | 2,936 | 6.27 | 0.23 |
| | 1,000-1,500 meter | 507 | 5.88 | 2,595 | 5.54 | 0.13 |
| | 1,500-2,000 meter | 0 | 0.00 | 2,382 | 5.09 | 0.00 |
| | 2,000-2,500 meter | 0 | 0.00 | 2,302 | 4.91 | 0.00 |
| | 2,500-3,000 meter | 5,070 | 58.82 | 30,839 | 65.84 | 0.11 |
| | >3,000 meter | 2,366 | 27.45 | 2,028 | 4.33 | 0.34 |
| **5.Lithology** | Clay | 2,535 | 29.41 | 12,771 | 26.37 | 0.30 |
| | Intrusive rock | 1,183 | 13.73 | 12,484 | 25.77 | 0.19 |
| | Metamorphic rock | 1,352 | 15.69 | 4,264 | 8.80 | 0.09 |
| | Sand and gravel | 1,183 | 13.73 | 11,130 | 22.98 | 0.31 |
| | Sediment | 0 | 0.00 | 133 | 0.27 | 0.10 |
| | Water | 2,366 | 27.45 | 7,657 | 15.81 | 0.00 |
| **6.Lineament (Distance from lineament)** | <500 meter | 338 | 3.92 | 1,541 | 3.23 | 0.03 |
| | 500-1,000 meter | 845 | 9.80 | 1,371 | 2.87 | 0.09 |
| | 1,000-2,000 meter | 169 | 1.96 | 1,433 | 3.00 | 0.02 |
| | 1,500-2,000 meter | 169 | 1.96 | 1,278 | 2.68 | 0.02 |
| | 2,000-3,000 meter | 0 | 0.00 | 1,165 | 2.44 | 0.00 |
| | 3,000-4,000 meter | 7,098 | 82.35 | 1,187 | 2.49 | 0.85 |
| | >4,000 meter | 0 | 0.00 | 1,134 | 2.38 | 0.00 |
| **7. Soil texture** | Clay | 676 | 7.84 | 5,783 | 11.93 | 0.13 |
| | Loam | 507 | 5.88 | 2,766 | 5.71 | 0.20 |
| | Loam with gravel | 0 | 0.00 | 319 | 0.66 | 0.00 |
| | Other | 0 | 0.00 | 170 | 0.34 | 0.00 |
| | Sand | 1,352 | 15.69 | 6,809 | 14.05 | 0.22 |
| | Sandy loam with gravel | 0 | 0.00 | 167 | 0.34 | 0.00 |
| | Sandy loam and sandy clay loam | 5,915 | 68.63 | 31,690 | 65.40 | 0.21 |

**Table 1** (Continue)

| Factor | Class | Total number of pixel | | Landslide occurrence | | Frequency ratio |
|---|---|---|---|---|---|---|
| | | Number | % | Number | % | |
| 8. Rainfall | <1,356 | 2,366 | 23.73 | 6,926 | 15.58 | 0.18 |
| | 1,415-1,475 | 1,521 | 15.25 | 6,948 | 16.06 | 0.12 |
| | 1,475-1,539 | 1,183 | 11.86 | 7,162 | 15.69 | 0.09 |
| | 1,539-1,617 | 845 | 8.47 | 6,997 | 10.68 | 0.07 |
| | 1,617-1,699 | 845 | 8.47 | 4,763 | 9.13 | 0.10 |
| | 1,699-1,779 | 507 | 5.08 | 4,072 | 8.22 | 0.07 |
| | >1,779 | 1,352 | 13.56 | 4,056 | 9.10 | 0.20 |
| 9.Land use/land cover | Agricultural | 0 | 0.00 | 155 | 21.91 | 0.00 |
| | Forest | 2,028 | 23.53 | 10,607 | 0.32 | 0.33 |
| | Miscellaneous | 5,070 | 58.82 | 30,358 | 62.72 | 0.29 |
| | Urban | 0 | 0.00 | 237 | 0.49 | 0.00 |
| | Water | 1,521 | 17.65 | 7,044 | 14.55 | 0.38 |
| 10.NDVI | 0.28-0.49 | 169 | 1.96 | 2,356 | 4.83 | 0.09 |
| | 0.49-0.61 | 845 | 9.80 | 5,593 | 11.46 | 0.20 |
| | 0.61-0.70 | 1,352 | 15.69 | 10,458 | 21.44 | 0.17 |
| | 0.70-0.78 | 3,380 | 39.22 | 17,724 | 36.33 | 0.25 |
| | 0.78-0.92 | 2,873 | 33.33 | 12,655 | 25.94 | 0.29 |

It was found that the high and very high class are counted as of 10.59% and 2.15% to the total area, respectively. The moderate class is counted for 32.35% to the study area. An area under of low and very low susceptibility class is counted for 37.74% and 17.17% to the total area, respectively. Very high landslide susceptibility areas are found over Phrae and Chiang Mai provinces, whereas Nan, Phayao, Chiang Mai, Chiangrai, Uttaradit, and Mae Hong Son provinces are located in very low landslide susceptibility class (Figure 4).

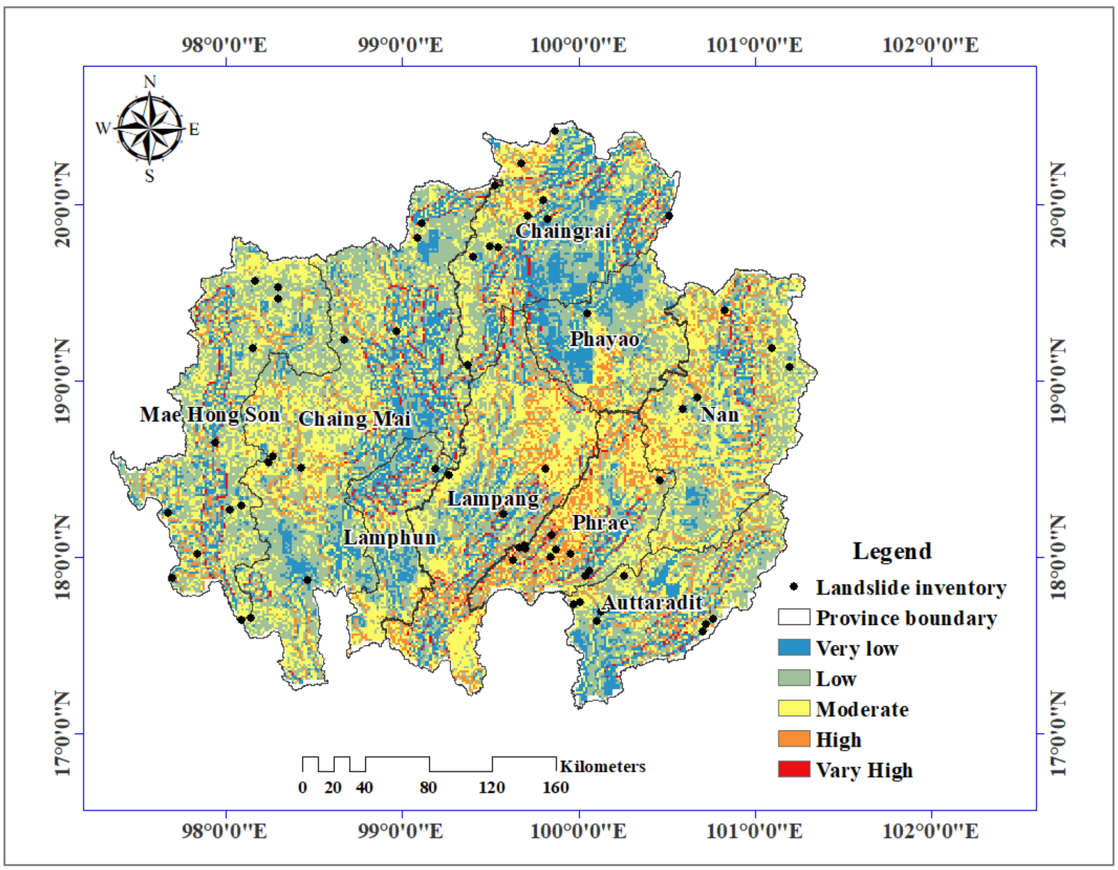


Figure 4 Landslide susceptibility map by Frequency ratio model.

**Table 2** Landslide susceptibility classes.

| Landslide susceptibility classes | Area ($km^2$) | % of area | Number of landslide points (out of 64) |
|---|---|---|---|
| Very low | 16,056.90 | 17.17 | 8 |
| Low | 35,288.76 | 37.74 | 14 |
| Moderate | 30,248.87 | 32.35 | 26 |
| High | 9,904.68 | 10.59 | 10 |
| Very high | 2,013.73 | 2.15 | 4 |

**4.2 Validation of landslide susceptibility map using AUC**

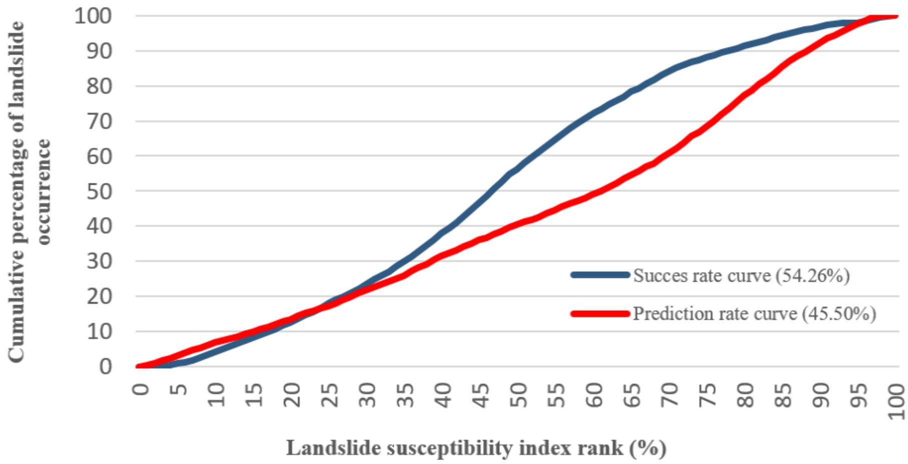


Figure 5 AUC of landslide susceptibility map by x-axis is landslide susceptibility index rank and y-axis is occurring in cumulative percent of landslide occurrence.

Landslide susceptibility map is validated by AUC curve. As shown in Figure 5, the ordered pixels is divided into 100 classes and LSI ranks (0–100) labeled on the x-axis start from high portion to low portion of LSI values. In this study, the first set (success rate) is based on data of 52 landslide events and the second set (prediction rate) is based on data of 12 landslide events. As the result of calculated AUC for both cases, the success and prediction rate curves are 54.26 and 45.50, respectively.

**5. CONCLUSION**

The main purpose of this study is to develop a landslide susceptibility map in northern Thailand. Ten factors related to landslide occurrence factors has been selected based on literature reviews. FR model was divided into two sets; 1) training area (80%) and 2) testing area (20%). The landslide susceptibility map was validated by landslide inventory points from 2002 to 2011 according to the AUC. Two provinces, which are Phrae and Chiang Mai, are found in the very high landslide susceptibility class. The results of landslide susceptibility areas based on the FR model have been compared with the AUC. Generally, the high-performance FR model is considered to have more than 70% accuracy value. However, the accuracy value of the current FR model was only 54which is considered relatively low accuracy. The accuracy of the model might have been affected by distribution of the random points (factors) used in this study. Therefore, we need to consider more factors and experiment with training and validating data in more details to gain insight into physical contributions of the factors to landslide occurrences.

## 6. ACKNOWLEDGEMENTS

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