PROBABILITY OF LANDSLIDE OCCURENCE MAPPING USING PROBABILITY DENSITY FUNCTION: A CASE STUDY OF THE MAE THA GROUP IN NAM LI WATERSHED, THAILAND

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Abstract: Due to the spatial complication of mixing kinds of rocks in a geological mapping unit and its structure, any quantitative engineering property related to the landslide is not a single value. It exists in a range. This leads to existence in range of the landslide susceptibility indexes (LSIs) calculated from varying properties of a rock unit. The objective of the study is to analyze the probability of landslide occurrence of the Mae Tha Group in Nam Li watershed, Thailand using Probability Density Function (PDF). Referring to Tanang et al. (2010), by using GIS analysis, the range of LSIs in this rock unit (0.63-1.603) associated with landslide scars could be extracted. In this study, these LSIs were sliced into 11 ranges captured by 12 values (0.63, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, and 1.603) which were candidates to be a critical LSI. Performing on each TIN polygon of each candidate, slope of the polygon, the mean and standard deviation of LSIs calculated from the possible composite properties of the rock unit were input to PDF and resulted in the Probability of Failure Indexes (PFIs). For each candidate, a raster map layer of PFIs was generated and modified to be PFI-1 layer. Any cell with PFI equal to 1 was kept as 1 or as 0 otherwise. Then, overlay analysis of a PFI-1 raster layer of each candidate and landslide scar layer was operated to obtain the fitting ratio. Any PFI-1layer depicting the most fitting ratio was identified as the layer of critical LSI, which herein was 1.2. The PFIs raster layer of the critical LSI was then classified into 5 classes - very low, low, moderate, high, and very high, corresponding to the probability of landslide occurrence in the rock unit.

INTRODUCTION

The big landslide event occurring in the Nam Li watershed was on 20-22 May 2006. Landslide susceptibility mapping related to this event was studied and reported by Tanang, et al. (2010). To calculate LSIs of each TIN (Triangulated Irregular Network) polygons in the study area, engineering properties input in the equation were mainly based on mapping rock units. The mean, a single value, was used to represent each property. In fact, by geological mapping, the rock unit was classified and mapped according to rock types and time period when the unit was formed. This resulted that the rock unit mapped could consist of kinds of rocks. Moreover, by nature, each engineering property of a certain kind of rock will vary in a range, not a single value. Therefore, the LSIs of TIN polygons in the study area derived from single values of rock properties should not as much practically reflect the probability of landslide occurrences as it should be.

To cover engineering properties of rocks existing in the geological mapping unit as much as possible, the input of them for LSI calculation should be varied to be many values in a range. Then all possible combinations of these properties and slope can be used as representative inputs into the Probability Density Function (PDF) (Wyllie, 1999) and resulted in Probability of Failure Indexes (PFIs) which are further used to indicate probability of landslide occurrence. Therefore, the purpose of this study is to analyze the probability of landslide occurrence of the Mae Tha Group in term of PFI using PDF. The Mae Tha Group, mapped by Lamchuan and Sinpunanan (1987), was chosen as an example of the study because in the SPOT imagery dated 13 Jan 2007 landslide scars appear the most in this rock unit. The scars were visually extracted and converted to be a raster layer of 5 m x 5 m cell size for overlay analysis in the study.

STUDY AREA

Nam Li watershed (Figure 1) is located in Uttaradit Province, northern part of Thailand. It is a highland which consists of complex ranges and narrow basins. The drainage patterns are parallel and dendritic. The altitude of the area is 200-1200 m above the mean sea level. Slope of the area is generally high and becomes flat only in the narrow and low elevation area where flood occurred. Its geology is characterized by 4 geologic units consisting of Mae Tha Group (C), Kiu Lom Formation (P1), Triassic intrusive igneous rock (gr) and Phra That Formation (Tr1). Rocks of all geologic units are weathered to badly weathered.

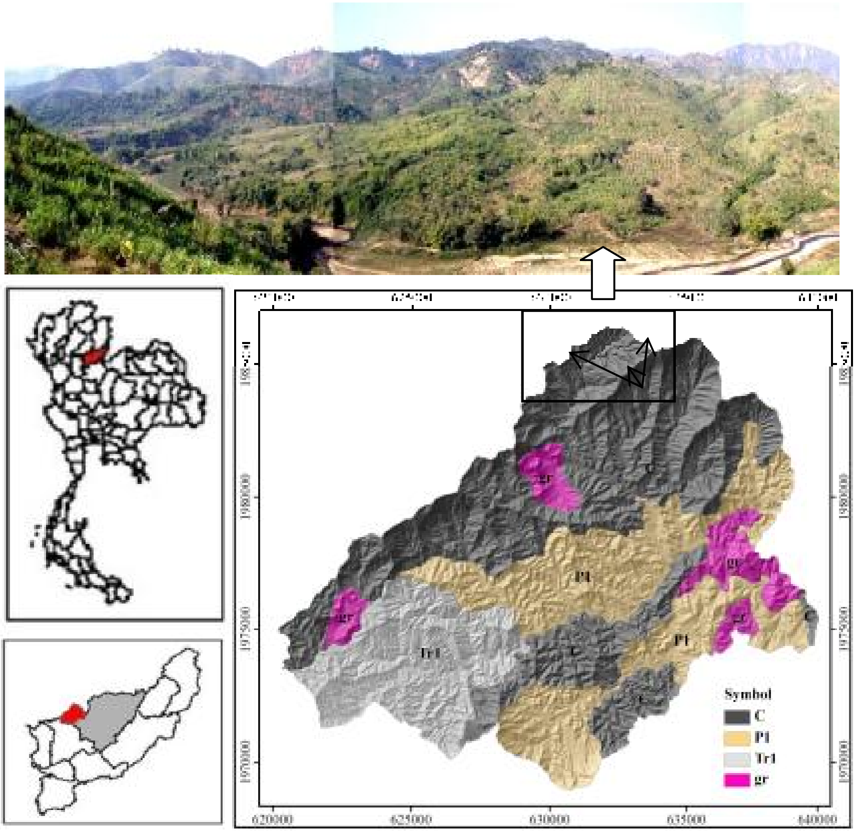


Figure 1: The study area at Nam Li watershed, Uttaradit province, Thailand

THE MAE THA GROUP

The rocks of the unit are Carboniferous phyllitic shale, slaty shale, phyllite, schist, and phyllite with augen chert (Lamchuan and Sinpunanan, 1987). From field investigation in the study area, the unit is composed of highly weathered rocks which are mainly phyllitic shale with chert interbedded, and minor meta-siltstone and silty shale. Its structures are folded and heavily fractured.

The slope failure occurred in the rock unit as shallow landslide with mainly circular sliding plane. The radius of the circular was so big that the failure is close to be plain type. The thickness of slope material above sliding planes (Z) observed in the field ranges between 1-3 m. The thickness of saturated slope material above sliding plane (Z_w) was assumed to be the same as Z when water fully filled into pores of materials and the failure occurred. The cohesion and internal friction angle (ϕ) were from the direct shear test in the engineering geological laboratory. The unit weight (γ) was adopted from the researches of Goodman (1989), Wyllie and Mah (2004), and Alden (2010) by matching rock types and characteristics.

The rock properties in ranges were broken down to be 6 classes by equal interval as shown in Table 1 for the LSIs calculation. Since Z_w and Z appear to be the same and the cohesion is considered stable, each TIN polygon falling into the rock unit contains 216 possible combinations of γ, ϕ, and Z.

Table 1: The classes of related rock and terrain properties used for LSI calculation.

Class	γ (kN/m^2)	ϕ (degree)	Z (m)
1	23540	13.0	1.0
2	23804	14.0	1.4
3	24068	15.0	1.8
4	24332	16.0	2.2
5	24596	17.0	2.6
6	24860	18.0	3.0

METHODS

The procedure framework of the study can be displayed as a flow chart in Figure 2. The validated probability of landslide occurrence map of the rock unit is expected to be the final output of the study.

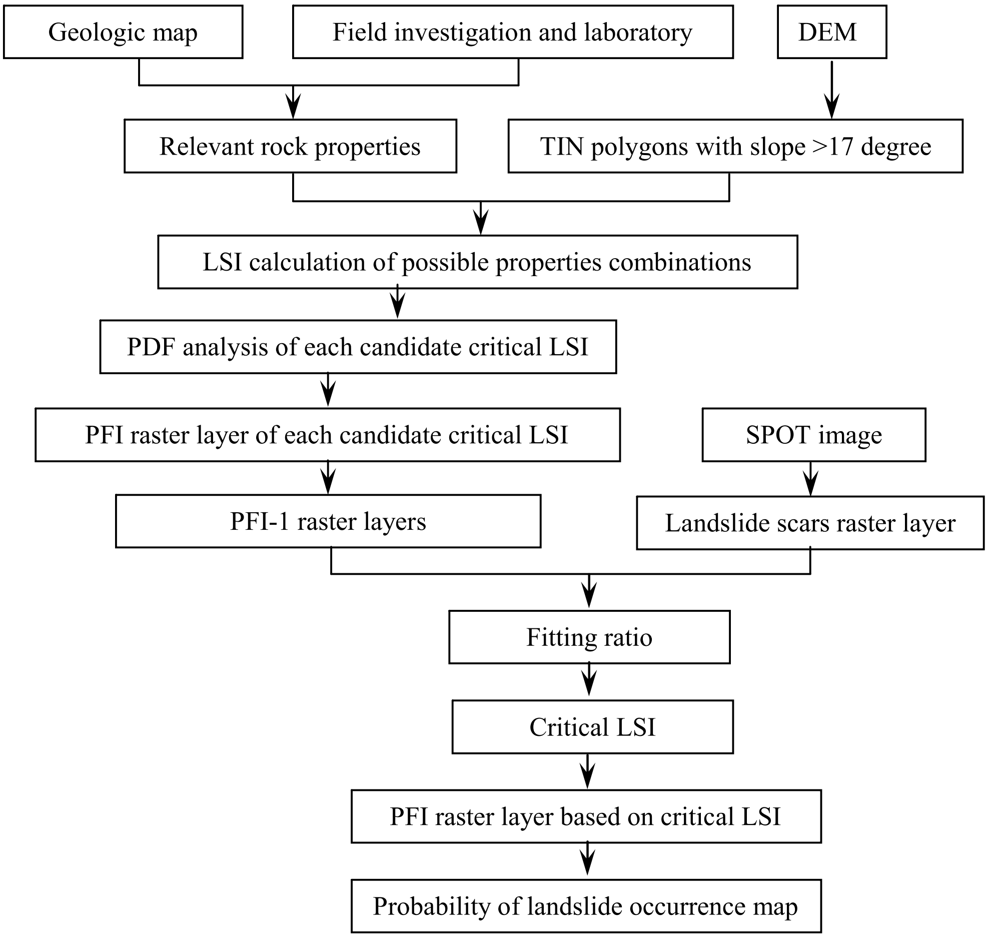


Figure 2: The procedure framework of the study.

The study procedure can be discussed as steps below.

1) From the high resolution DEM data in form of contour with 5 m interval of the Land Development Department (LDD) of Thailand, the grid DEM (5 m × 5 m) data and TIN were generated. The TIN polygons were considered to be able to better represent slope surfaces of the area than the grid cells. The slope angel as an attribute of each TIN polygon was later estimated. The intersection of TIN and the Mae Tha Group polygons could result in TIN polygons of the rock unit with identical slope. Only polygons with slope angle bigger than 17 degree (approximately 30%) were extracted for further LSI analysis and the rest was identified as insensitive area. This is because, in general, the critical angle of repose of material was approximately set up at 30% (Coe et al., 2000; Mahidol University, 2003). It means that the material with surface slope bigger than this angle could not be stable and more likely to slide down if triggered by very heavy rainfall.

2) As mentioned in Tanang et al. (2010), LSI was created on the basis of the factor of safety (FS) but the result is not as accurate as the one from site investigation to which FS is practically applied. The indexes obtained by this method are considered more objective and relying on geotechnical concept and theory, which are more related to the landslide occurrence than the conventional index model. The equation to calculate the LSI involving Mohr-Coulomb failure criterion (Das, 2007; Mergili and Fellin, 2009) as shown in equation (1).

$$FS=\frac{c+\left(\gamma\cdot Z-\gamma_w\cdot Z_w\right)\cdot\cos^2\beta\cdot\tan\phi}{\gamma\cdot Z\cdot\sin\beta\cdot\cos\beta} \quad (1)$$

where FS is the factor of safety which was represented to be the LSI, c is the cohesion of material (kN/m^2), γ is the unit weight of material (kN/m^3), γ_w is the unit weight of water (9.81 kN/m^3), Z is the thickness of slope material above sliding plane (m), Z_w is the thickness of saturated slope material above sliding plane (m), β is slope angle, and ϕ is the internal friction angle of material (degree).

From 6 classes of rock properties listed in Table 1, 216 possible combinations of rock properties of each TIN polygon were set up as input into equation (1). Considering the sensitive area of the rock unit, excluding the insensitive area, only slope angle could be varied among polygons. Each polygon was then ended up with 216 LSIs. All polygons of the sensitive area were transformed to be cell-based. With raster-based overlay analysis, the range of LSIs from cells associated with scars was able to be extracted. A number of sub-ranges was obtained sliding the range of LSIs and all sub-ranges were captured by a number of LSIs. Each of which became a candidate of the critical LSI that could provide the most accurate predicted probability of landslide occurrences.

3) Together with each candidate LSI (x), the mean ($\bar{x}$) and standard deviation (SD) of LSIs of each TIN polygon were calculated and input into equation (2), the PDF for PFI calculation (Wyllie, 1999), as shown below.

$$f(x)=\frac{1}{SD\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{SD}\right)^2\right] \quad (2)$$

where x is LSI of a candidate, $\bar{x}$ and SD is the mean and the standard deviation of LSIs in each TIN polygon.

Then, for each TIN polygon, PFI of each candidate LSI was achieved. For all TIN polygons, the values of calculated PFIs were between 0 and 1.

4) To find out the actual critical LSI, the layers of TIN polygons of all candidates could be transformed to be raster layers and later were modified to be PFI-1layers. Any cells with PFI equal to 1 were kept as 1 or as 0 otherwise. The PFI-1 cell is the cell containing PFI equal to 1 and considered to be the cell can mostly be subject to landslide occurrence. A number of PFI-1 raster layers obtained was equal to a number of the candidates. Overlay analysis using equation (3) of each PFI-1layer of a candidate and the raster layer of landslide scars was performed for finding the layer capable to provide the most fitting ratio.

$$FR=\frac{A\cap B}{(A\cup B)-(A\cap B)} \quad (3)$$

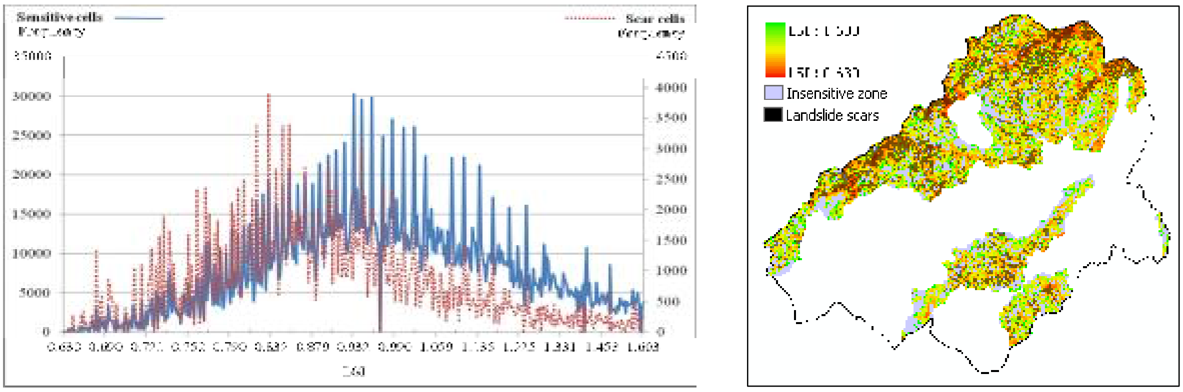
where FR is the fitting ratio of a number of cells obtained from the intersect of PFI-1 and scars cells ($A\cap B$) and the difference number of cells between the union of all PFI-1 and scar cells and the intersect of PFI-1 and scar cells (($A\cup B$)-($A\cap B$)). ($A\cap B$) is a number of PFI-1 cells falling in landslide scars which indicated the predicted accuracy while ($A\cup B$)-($A\cap B$) is the disagreement number of PFI-1 and landslide scar cells which indicated their discrepancy. The LSI of a candidate layer that could provide the best fitting or the highest ratio was identified to be the critical LSI.

5) The raster layer of the critical LSI with the originally calculated PFI of each cell was then classified to be 5 classes from very low to very high probability of landslide occurrence. The frequency of scar cells and their associating ratio in each class was then checked to see the prediction capability of the landslide occurrence map.

RESULTS AND DISCUSSION

According to the method described above, the results of the study are as follows:

1) As a raster layer with 5 m x 5 m cell size, the rock unit contains 3,311,172 cells of sensitive area and 324,245 cells of the landslide scars. The range of calculated LSIs associated with scars was between 0.630-1.603. In Figure 3, the plot shows the relationship of the frequencies of all scar cells and sensitive cells according to varying LSIs and their spatial distribution in the map of the rock unit. Both frequency curves show fair corresponding in shape of the normal distribution.



(a) **(b)**

Figure 3: Frequencies of sensitive and scar areas according to candidates of critical LSIs (a) and spatial distribution of scar and LSI areas (b).

2) The range of active LSIs (0.630-1.603) was sliced into 11 ranges captured by 12 values of 0.63, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, and 1.603. These 12 LSIs became candidates to be a critical LSI. It means that one of them could be the most sensitive LSI indicating the highest probability of landslide occurrences in the rock unit area. The PFIs of all TIN polygons were calculated under each candidate LSI and presented as PFI-1 raster layers shown in Figure 4. The cells with PFI equal to 1 are depicted in red while the ones with PFI less than 1 are in green. The scar cells are displayed in black.

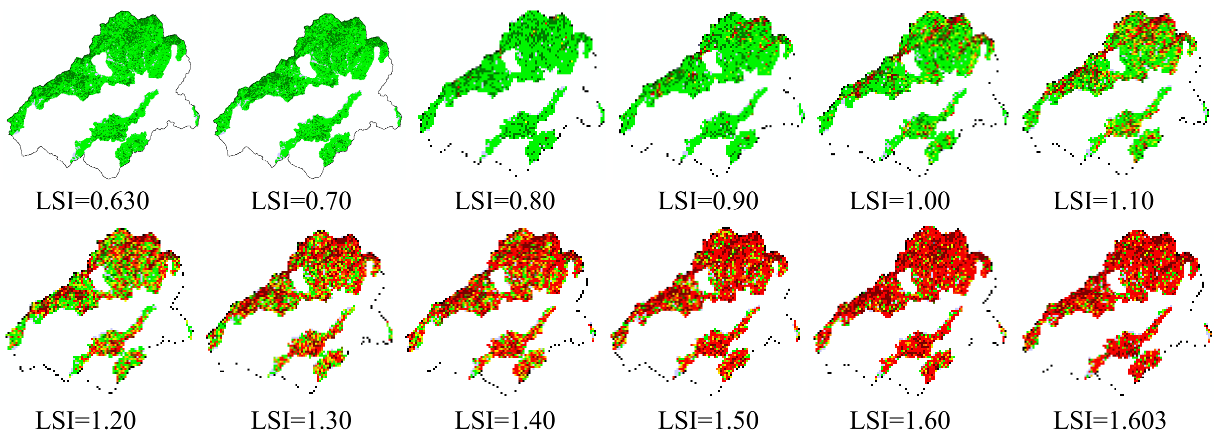


Figure 4: The PFI-1 raster layers of 12 candidates of a critical LSI.

Obviously, a number of red cells and their association with the scar cells are increased with increasing candidate LSI. In contrast, a number of green cells and their association with the scar cells are increased with decreasing LSI. Therefore, the fitting ratio (FR) of PFI-1 layer of each candidate was calculated and the results are shown in Table 2 and Figure 5. From the results, the candidate LSI 1.2 provided the best fitting ratio (0.143). Thus, the critical LSI is

1.2 from which calculated PFIs will best reflect the most accurate probability landslide occurrences of the rock unit when compared to the landslide scars occurred in the big event.

Table 2: The fitting ratios of all candidate critical LSIs.

Candidate LSI	Number of cells					FR
	(A)	(B)	(A∩B)	(A∪B)	(A∪B) - (A∩B)	
0.630	0	324245	0	324245	324245	-
0.700	0	324245	0	324245	324245	-
0.800	172	324245	0	324417	324417	-
0.900	22201	324245	6583	346446	339863	0.019
1.000	178940	324245	42689	503185	460496	0.093
1.100	543630	324245	104865	867875	763010	0.137
1.200	1097816	324245	177999	1422061	1244062	0.143
1.300	1662508	324245	231580	1986753	1755173	0.132
1.400	2137465	324245	265487	2461710	2196223	0.121
1.500	2476847	324245	285814	2801092	2515278	0.114
1.600	2734189	324245	298496	3058434	2759938	0.108
1.603	2734189	324245	298496	3058434	2759938	0.108

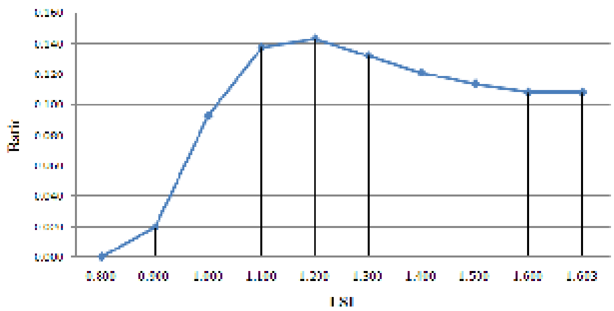


Figure 5: Variation of fitting ratios according to candidates of critical LSIs.

3) The originally calculated PFIs raster layer of the critical LSI 1.2 were then classified to be 5 classes from very low to very high using equal ranging and the result is shown in Figure 6. The graph depicting the percentages of class and scar areas of every class including their associating ratio is displayed in Figure 7.

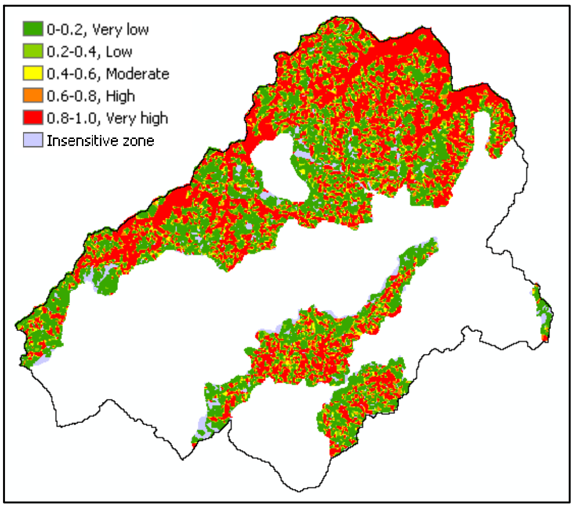


Figure 6: The distribution of PFI classes in the rock unit, based on the critical LSI 1.2.

The classes of very high and very low cover the main part of the rock unit with almost equal area (46.24% and 45.05%, respectively). Big numbers of scars fall into these two classes while the rests show little existence percentage of both scars and areas. This can mislead that landslide scars have more relation to the very low class than the other classes except the very high one. This result will be not supported by the theory. But when the associating ratios of scars and class areas shown in Figure 7 are considered, it reveals that the proportions of scars existing in class areas strongly agree with theory. The higher associating ratio is increased with the higher PFI class. The area of very high class has higher chance of landslide occurrence which is confirmed by the higher associating ratio.

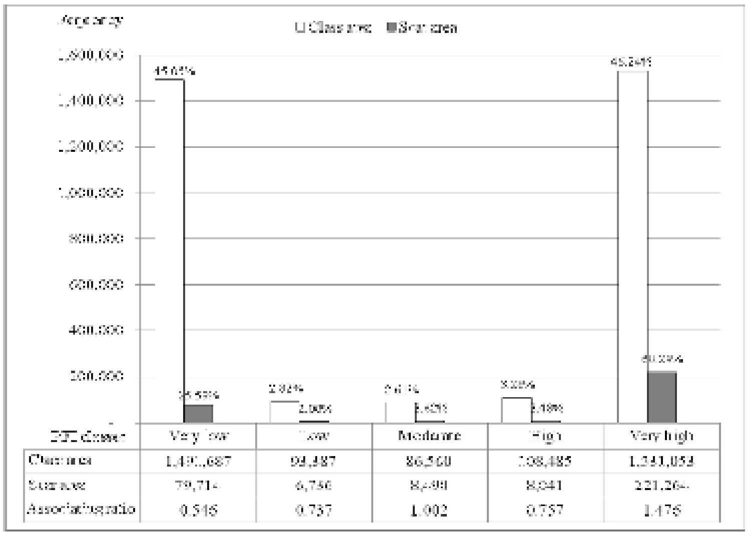


Figure 7: The cell-based and percentage of scar and class areas including their associating ratios.

A little conflict can be observed between the moderate and high classes. The scars existing in the moderate class or its associating ratio is a bit higher than of the high one. This could happen because the existing areas of these two classes in the rock unit are a bit too small, only 2.61-3.28 %, to express the good representation.

CONCLUSIONS

The study develops the systematic procedure to classify probability of landslide occurrence in the high risk area that had the case of big landslide event. The rock types and their engineering properties appearing in nature and geologic map unit, engineering laboratory and practice, and the inferred statistic method such as probability density function were agglomerated in the classification method. This provides more scientific sense when compared to other methods relied more on subjective or expert opinions. Full functions of GIS techniques were also applied and enable the study to successfully achieve the fruitful results with good spatial presentation in form of map.

The study took the insensitive area out at the beginning. Plus, associating ratio was applied to validating each class of classification result. This makes validation method and results more reasonable and scientific. The results show strong agreement with the theory.

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