# FUZZY SET AND ANALYTICAL HIERARCHY PROCESS IN GIS APPLICATION.

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**Abstract** This article aims at applying spatial multi-criteria decision analysis for landslide risk area delineation. It is obvious that the methods used previously are lack of theoretical foundation which leads to imprecise results. Therefore, the new technique is introduced in spatial decision making analysis which consists of analytical hierarchical process and fuzzy set membership function.
The methodology is applied to delineate landslide prone area in Petcaboon province. It is found that the fuzzy set membership values of each attribute range from 0 to 1 according to its property. The criterion weight of slope, soil texture, landcover type, distance from stream, rock type and rainfall are 0.4105997, 0.297540, 0.130632, 0.093428, 0.03992883 and 0.02787083 respectively.
Having aggregated the standardized criterion map ,it is found that the landslide prone area exists in 6 amphoes, namely Lom Kao, Lom Sak, Khao Ko, Nam Nao, Muang and Wang Pong.

## 1.INTRODUCTION

The applications of GIS for any purposes i.e. determining the suitable location for the specific activity or identifying the hazard prone area are regarded as a spatial planning or a spatial multi-criteria decision analysis. (Malczewski,1991) That is a process that combines and transforms geographical data (input) into a resultant decision (output) as illustrated in Figure 1

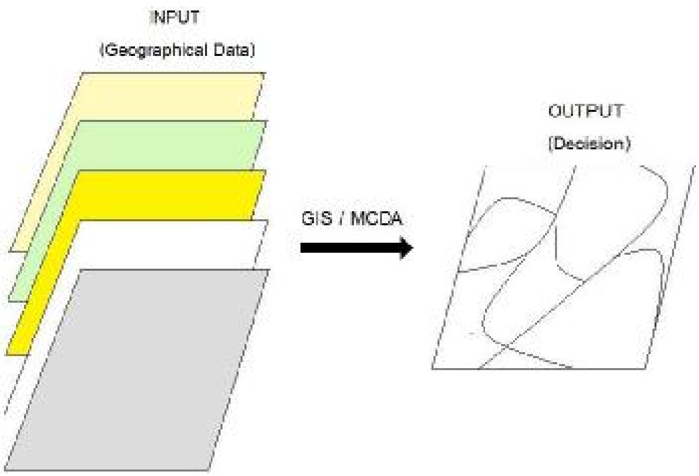


Figure 1 Scheme of spatial multi-criteria decision analysis

The procedures of multi-criteria decision analysis involve a set of alternative that are evaluated on the basis of conflicting and incommensurable criteria. (Malczewski,1991) As seen in Fig.1, the spatial data layers used as input data are so called criterion map. The criterion map used for the decision analysis not only have different unit of measurement but also different significance. It is, therefore the standardized criterion map using fuzzy set membership function and weighting for each criteria using pair-wise comparison, respectively are essential.
As already known that flash flood and landslide are natural phenomena which may turn to natural hazard or disaster as they affect to human life and theirs property. Therefore, the integrated risk management should be done to prevent the repetitive incidence. The mentioned management consists of 1.) identification of risk area 2.) mitigation measures 3.) preparedness measures 4.) response measures 5.) recovery measures. (Simpson, et al, 2008) This article, however presents only the identification of landslide risk area in Petchaboon province.

**2. THE STUDY AREA**

Petchaboon province is in the lower northern region of Thailand, locating between latitude 15°20’ to 17°10’ North and longitude 100°40’ to 101°45’ East. The total area is approximately 12,400 square kilometers. The boundary of the study area is shown in Figure 2.

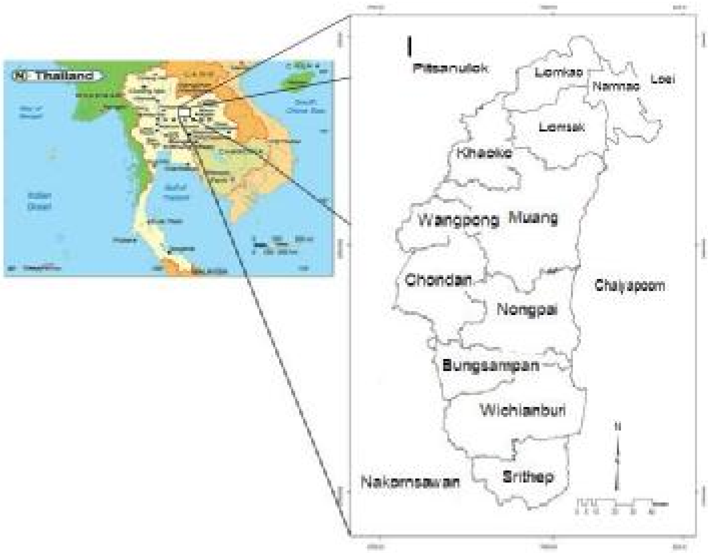


Figure 2.The location of the study area.

The topography of the area is characterized by gently sloping from the north to the south. The upper part is the mountainous area while the middle and lower part is the plain flanked with the mountain range.

The pedological setting is quite complex due to the variety of parent materials, for instance, Korat group consisting of limestone, shale, sandstone and intrusive igneous rock are found in the eastern part from north to south of the area. The coarse-textured soils, then are derived when these parent materials are decomposed.

**3. DATA COLLECTION AND PRE-PROCESSING PROCEDURES**

**3.1 Data used.**

1. Digital maps of the study area i.e. soil, geology, topography and stream data layer.
2. Satellite imageries of the study area acquired before and after 2001 landslide incidence.
3. The 1:25,000 scale aerial photographs covering Nam Ko and Nam Chun sub watershed.
4. Meteorological data.

**3.2 Data manipulation for generating criterion maps** as shown in Table 1

Table 1

| Criteria | Data type | Source | Pre-processing | Criteria map |
|---|---|---|---|---|
| Slope | Digital map | DEQP[1] | Surface Analysis | slope |
| Soil Texture | Digital map | DEQP[1] | Reclassify | Soil texture |
| Stream | Digital map | DEQP[1] | Buffer | Streambuff |
| Rock type | Digital map | DEQP[1] | Reclassify | Rock type |
| Landcover type | Satellite imageries[4] | GISDA[2] | Digital image processing | Landcover Type |
| Rainfall | Digital map | TMD[3] | Thiessen | Rainfall |

[1]Department of Environmental Quality Promotion, [2]Geo-Informatic and Space Technology Development Agency
[3]Thai Meteorological Department [4] Landsat 5 TM Path# 129 Row# 49 , acquired Feb.14,2001, acquired Mar.5,2008. Landsat 7 ETM+ Path# 129 Row# 48, acquired May 11,2002.

**4. METHODOLOGY AND ANALYSIS.**

**4.1 The framework.**

The conceptual framework of landslide risk evaluation can be summarized as follows :

1. Identify factors which influence landslide in the study area and considering as criterion for landslide risk area delineation. The mentioned procedure is referred as constitutive element or constitutive criterion.

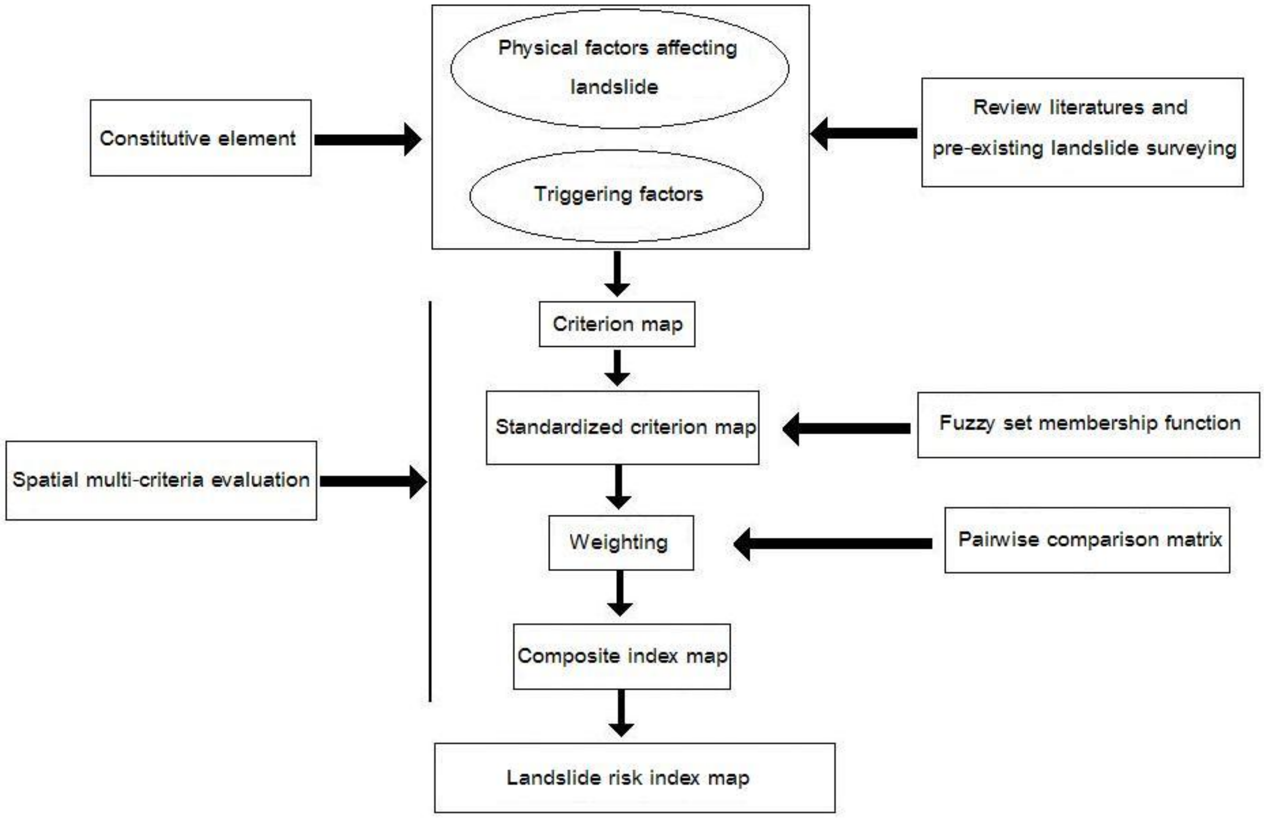


Figure3. Conceptual framework of landslide risk evaluation

2. Spatial multi-criteria evaluation. This stage of analysis consists of procedures as follows :

a. Construct criterion map and classify the alternative of risk area into five levels, i.e. very high, high, moderately, low and least risk.

b. Construct standardized criterion map. Due to the fact that the measurement of risk area is linguistic terms which is uncertainty. Fuzzy set membership application is, therefore, introduced in order to adjust the risk scores to be standard scores ranging from 0 to 1.

c. Weighting. The establishment of weight for a set of criterion according to theirs important is needed. In this article the pair-wise comparison method is used.

d. Composite the standardized criterion map to be a landslide risk index map using simple additive weighting technique.

**4.2 Hierarchical structure.**

Petchaboon province has experienced with landslide disaster many time with the severity one happened in August 11,2001. To prevent the landslide hazard, the integrated risk management should be studied. One of the integrated risk management is the delineation of landslide risk area

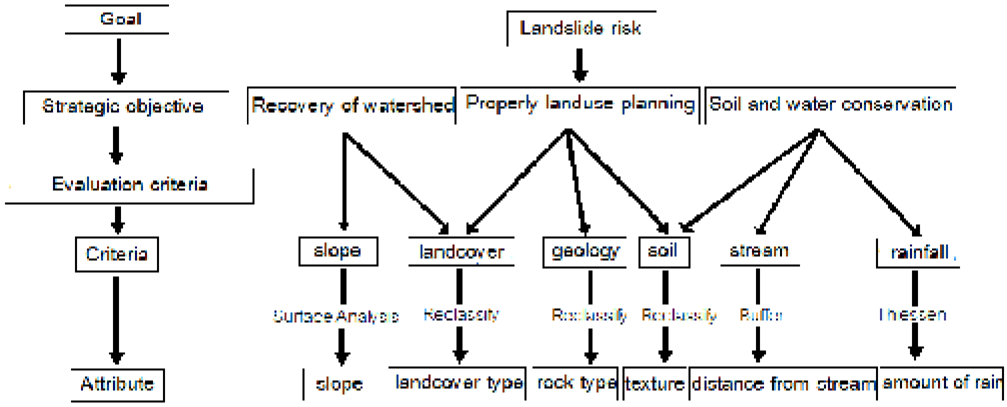


Figure 4 Hierarchical structure

### 4.3 Analysis procedure

**4.3.1 Criterion evaluation used in the analysis.** From the literature review, it is found that the factors influencing the landslide consist of 5 environmental factors i.e. slope, landslide, land cover type, distance from stream and rock type and 1 triggering factor i.e. amount of rainfall. (Klindao, 2008)
Godilano, 2004 stated that future landslide will occur under circumstances similar to the one of past landslide. The author, therefore studied the incident of landslide in Petchaboon province, occurring in August 11,2001. The location of landslide were determined by using Normalized Difference Vegetation Index,NDVI Technique and aerial photographs interpretation. After transferring the location of landslide to the scale of 1:50,000 topographic map. It was also found that the landslide occurred in Nam Ko and Nam Chun sub watershed . The physical properties of the area where the landslide taken place were then determined. These physical properties were evaluated with related to the landslide risk. The results of evaluation are shown in Table 2

Table 2 Properties of attribute related to the landslide risk.

| Slope (%) | Soil texture group | Distance from stream (meters) | Average Annual rainfall (mm.) | Landslide risk | Risk code |
|---|---|---|---|---|---|
| >35 | coarse | 50 | 1491.8-1825.5 | Very high | 5 |
| 25-34 | moderately coarse to medium texture | 100 | 1303.8-1491.7 | High | 4 |
| 15-24 | medium texture | 150 | 1145.7-1303.7 | Medium | 3 |
| | Fine | | 997.8-1145.6 | Low | 2 |
| 5-14 | Fine | >150 | 841.9-997.7 | Very low | 1 |
| <5 | Fine | | | No risk | 0 |

Table 2. (cont.)

| Land cover type | Rock type | Landslide risk | Risk code |
|---|---|---|---|
| Disturbed forest | Conglomerate, Sandstone, Shale , Sandstone and conglomerate interbedded with siltstone. | Very high | 5 |
| | Reddish brown sandstone, shale and siltstone. Brownish sandstone, Siltstone and shale | High | 4 |
| Crop land | Whitish sandstone interbedded with grey shale, shale,sandstone, siltstone, gravelly sandstone, granite and rhyolite, shale and thick bed of greyish limestone, chert interbedd with shale | Medium | 3 |
| Deciduous forest | | Low | 2 |
| Orchard | | Low | 2 |
| Village | | Very low | 1 |
| Miscellaneous | | Very low | 1 |
| Water bodies,paddy field | Alluvial deposits | No risk | 0 |

**4.3.2 Constructing the standardized criterion map.** The attribute of each criterion map must be analyzed how risk they are. For instance, having analyzed land cover type map, it is found that disturbed forest is high landslide risk while undisturbed deciduous forest is very low landslide risk as shown in Table 2. The risk measurement used is linguistic terms which is uncertain. Therefore, a fuzzy set is used for classification of phenomenon in criterion values where the classes do not have sharply defined boundaries. It deals with a class with a continuum of grade of membership (Baja,2001)

A fuzzy set A in X is characterized by a membership function *f* A(*x*) which associates with each point in X a real number in the interval [0,1]

$$\mu_A(x): X \longrightarrow [0,1]$$

with the values of *f* A(*x*) at *x* representing the "grade of membership" of *x* in A. Thus, the nearer the value of *f* A(*x*) to unity, the higher the grade of membership of *x* in A.

The fuzzy membership function used in the project is sigmoidal membership function which consists of two parameters i.e a and b as seen in the formula below

$$\text{Sigmoidal (X; a,b)} = \frac{1}{1+e^{-a(x-b)}}$$

where a = gradient control parameter
b= mid value which membership value equal 0.5

Figure 5 illustrates graphs a. where parameter a=2 and b=0 so called monotonically increasing sigmoidal function and b. where parameter a=-2 and b=0 so called monotonically decreasing sigmoidal function

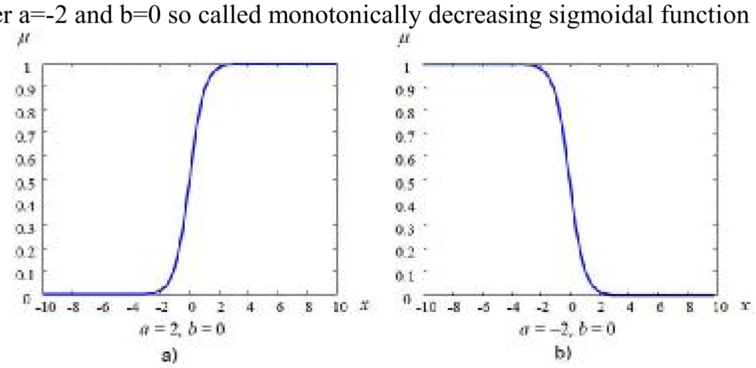


Figure 5 Sigmoidal membership function

The monotonically increasing sigmoidal function is applied to the criterion map of the study area and the results are shown in Figure 6

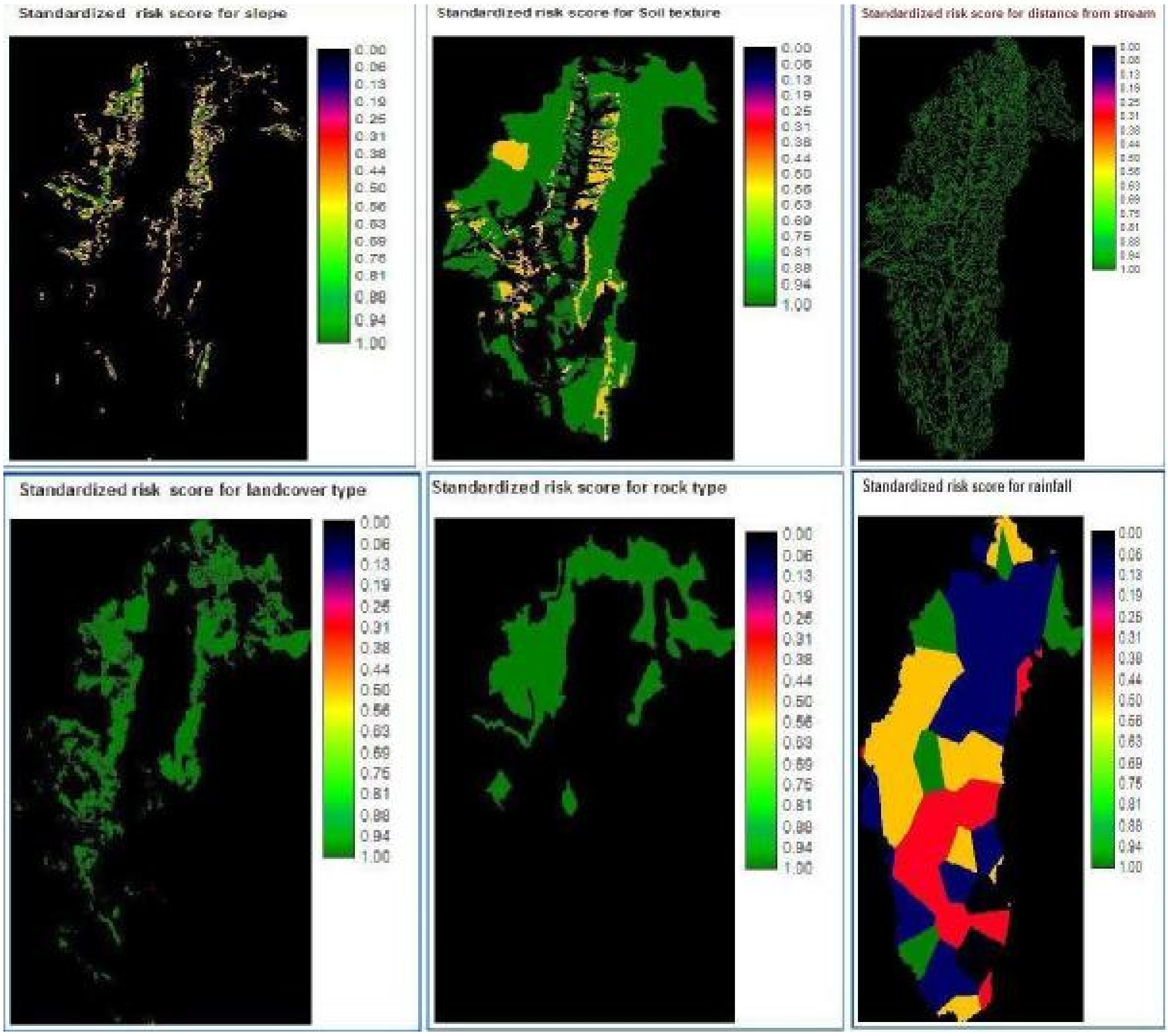


Figure 6 Standardized criterion map of the study area

**4.3.3 Weighting procedures**

1. Pair-wise comparison development using scale in Table 3 and the result is shown in Table 4

Table 3 Scale for pair-wise comparison

| Intensity of importance | Definition |
|---|---|
| 1 | Equal importance. |
| 2 | Equal to moderate importance. |
| 3 | Moderate importance. |
| 4 | Moderate to strong importance. |
| 5 | Strong importance. |
| 6 | Strong to very strong importance. |
| 7 | Very strong importance. |
| 8 | Very to extremely strong importance. |
| 9 | Extreme importance. |

Source : Saaty 1980

Table 4 Pair-wise comparison matrix

| Criterion | slope | soiltext | landcover | streamdist | rocktype | rainfall |
|---|---|---|---|---|---|---|
| slope | 1 | 3 | 4 | 5 | 8 | 9 |
| soiltext | 1/3 | 1 | 5 | 6 | 7 | 8 |
| landcover | 1/4 | 1/5 | 1 | 3 | 4 | 5 |
| streamdist | 1/5 | 1/6 | 1/3 | 1 | 4 | 5 |
| rocktype | 1/8 | 1/7 | 1/4 | 1/4 | 1 | 2 |
| rainfall | 1/9 | 1/8 | 1/5 | 1/5 | 1/2 | 1 |
| sum | 2.0194 | 4.634524 | 10.783333 | 15.45 | 24.5 | 30 |

2. Computation of the criterion weights. This step involves the following operations :

a. Sum the values in each column of the pair-wise comparison matrix.

b. Divide each element in the matrix by its column total. The resulting matrix is referred to as the normalized pair-wise comparison matrix.

c. Compute the average of the elements in each row of the normalized matrix, that is ,divide the sum of normalized scores for each row by 6 (the number of criteria) These averages provide an estimation 0f the relative weights of the criteria being compared as seen in Table 5

Table 5 Determining the relative criterion weights.

| Criterion | slope | soiltext | landcover | streamdist | rocktype | rainfall | weights |
|---|---|---|---|---|---|---|---|
| slope | 0.495186 | 0.647316 | 0.370942 | 0.323624 | 0.326530 | 0.3 | 0.4105997 |
| soiltext | 0.165062 | 0.215772 | 0.463678 | 0.388349 | 0.285714 | 0,266667 | 0.297540 |
| landcover | 0.123796 | 0.043154 | 0.092735 | 0.194175 | 0.163265 | 0.166667 | 0.130632 |
| streamdist | 0.099037 | 0.035962 | 0.030912 | 0.064725 | 0.163265 | 0.166667 | 0.093428 |
| rocktype | 0.061898 | 0.030824 | 0.023184 | 0.016181 | 0.040816 | 0.066667 | 0.03992883 |
| rainfall | 0,055021 | 0.026971 | 0.018547 | 0.012945 | 0.020408 | 0.033333 | 0.02787083 |
| | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | |

3. Estimation of the consistency ratio. In this step, we determine if our comparisons are consistent. It involves the following operations.

a. Determine the weighted sum vector by multiplying the weight for the first criteria (slope) times the first column of the original pair-wise comparison matrix, then multiplying the second weight (soil texture) times the second column of the original pair-wise comparison matrix and so on, as seen in Table 6

Table 6 Determining the weighted sum vector

| Criterion | Step 1 |
|---|---|
| slope | (0.4105997)(1)+(0.29754)(3)+(0.130632)(4)+0.093428)(5)+(0.03992883)(8)+(0.2787083)(9) |
| soiltext | (0.4105997)(0.33)+(0.29754)(1)+(0.130632)(5)+0.093428)(6)+(0.03992883)(7)+(0.2787083)(8) |
| landcover | (0.4105997)(0.25)+(0.29754)(0.2)+(0.130632)(1)+0.093428)(3)+(0.03992883)(4)+(0.2787083)(5) |
| streamdist | (0.4105997)(0.2)+(0.29754)(0.166)+(0.130632)(0.33)+0.093428)(1)+(0.03992883)(4)+(0.2787083)(5) |
| rocktype | (0.4105997)(0.125)+(0.29754)(0.1428)+(0.130632)(0.25)+0.093428)(0.25)+(0.03992883)(1)+(0.2787083)(2) |
| rainfall | (0.4105997)(0.11)+(0.29754)(0.125)+(0.130632)(0.2)+0.093428)(0.2)+(0.03992883)(0.5)+(0.2787083)(1) |

b. Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously as seen in Table 7

Table 7 Determining the consistency ratio

| Criterion | Step 2 |
|---|---|
| slope | 2.863155861/0.4105997=6.973107533 |
| soiltext | 2.150602495/0.297540=7.227944125 |
| landcover | 0.872143422/0.130632=6.676338279 |
| streamdist | 0.567751437/0.093428=6.076887411 |
| rocktype | 0.2455161/0.039928833=6.148842367 |
| rainfall | 0.175462/0.027870833=6.29554201 |

Next, the average value of the consistency vector so called lamda (λ) and consistency index (CI) are needed to be computed.

$\lambda$ =(6.973107533+7.227944125+6.676338279+6.076887411+6.148842367+6.29554201)/ 6
= 6.566443621

CI = (λ- n) / (n – 1)
= (6.566443621-6.0) / 5
= 0.113288724

c. Determine the consistency ratio (CR) which is defined as follows :

CR = CI / RI
= 0.113288724 / 1.24
= 0.091361874

The consistency ratio is less than 0.10 indicating a reasonable level of consistency in the pair-wise comparison

4.3.4 The aggregation of standardized criterion map. The techniques used in this step is a simple additive weighting (SAW) method. Each pixel of output map is the summation of the standardized score multiplied by theirs weight of each criterion map as can be written down into a matrix.

$$C = \begin{bmatrix} C_{11} \ldots\ldots\ldots C_{ji} \\ . \\ . \\ C_{1i} \ldots\ldots\ldots Cji \end{bmatrix} \times \begin{bmatrix} w_1 \\ . \\ . \\ w_j \end{bmatrix}$$

where $C_{ji}$ = criteria score of each alternative
$w_j$ = weighted value of each criteria
i = alternatives
J = criteria

## 5. RESULTS

The analysis undertaken in the preceding sections have resulted in a map of spatial distribution of landslide risk area as shown in Figure 7

## 6. CONCLUSION REMARKS.

The procedures of analysis used in the project based on the theoretical foundation which is likely accurate. However, other methodology should be applied in order to compare the results.

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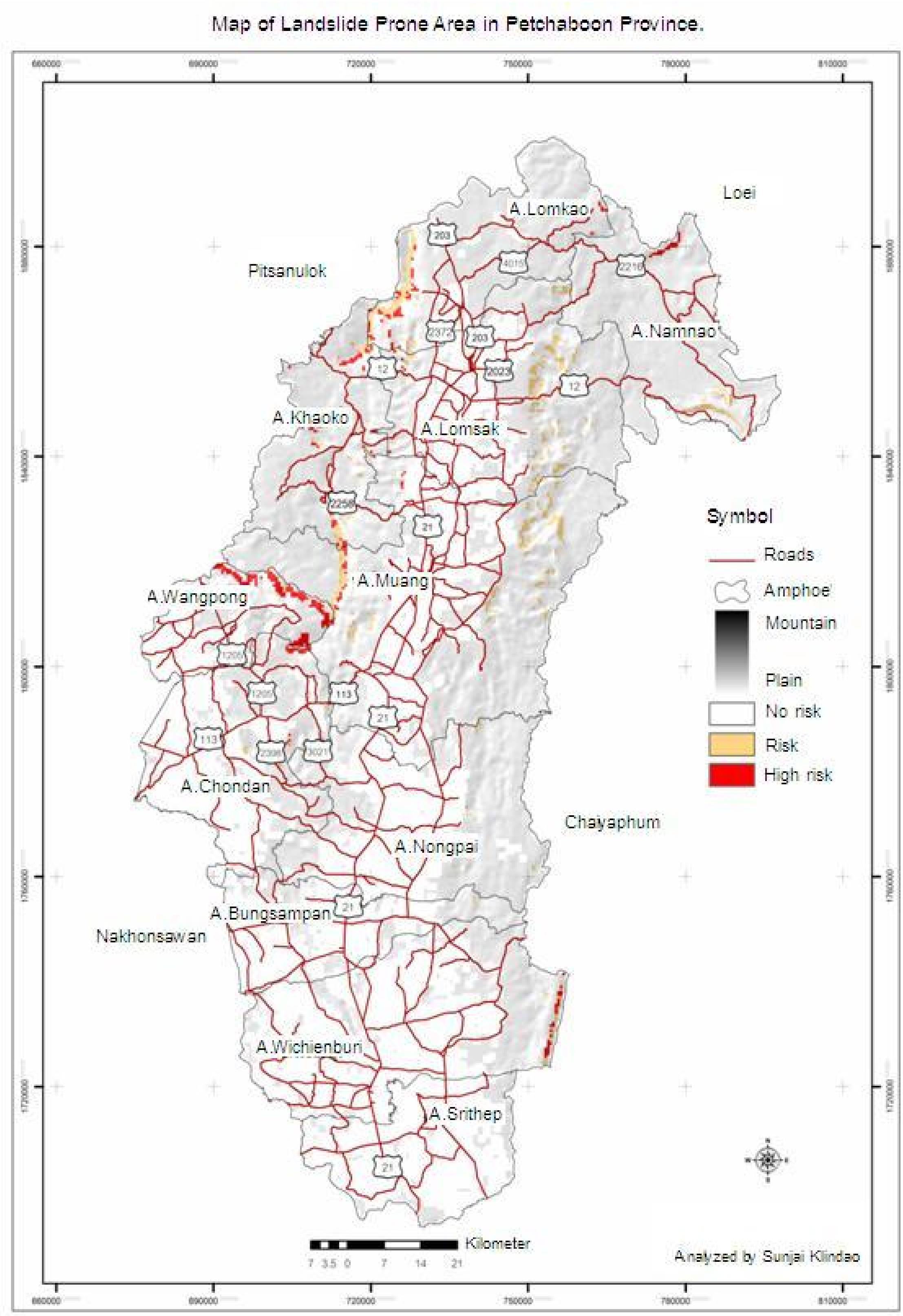


Figure 7 The spatial distribution of landslide risk area in Petchaboon province.