LANDSLIDE ASSESSMENT USING GIS-BASED FREQUENCY RATIO METHOD: A CASE STUDY OF MAE-PHUN SUB-DISTRICT, LAPLAE DISTRICT, UTTARADIT PROVINCE, THAILAND

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ABSTRACT

Advancement in Remote Sensing technology and improvement in spectral and spatial resolution is increasing day by day. Moreover, coverage and availability of the products are becoming easier, so it is possible to monitor landslide susceptibility, damages and landslide inventory mapping using different satellite data. The principle factors that trigger mass movement (Landslide, Debris flow, Mudflow) are 1) Intense prolonged rainfall and Earthquake 2) Anthropogenic factor (construction on steep slopes, deforestation, urbanization, overloading, and mining activities). The landslide inventory maps' made by SPOT 5 satellite image. This study utilized the causative factors i.e. Slope, Elevation, Aspect, Plan and Profile Curvature, Land use/Land cover, proximity to streams and proximity to the road, using geospatial software to make a landslide susceptibility map. The correlation between the landslide and thematic layers has been analyzed in GIS environment, so it calculates the frequency ratio score for each class of thematic layers. The summation of frequency ratio was calculated for each parameter and consequently get the landslide susceptibility indices. Eventually, the study area was divided into five classes landslide susceptibility classes ranges very low (8.93%), low (24.21%), moderate (28.91%), high (23.92), and very high (17.02%). The results were also validated using success rate curve method, so the prediction accuracy found to be 60% which are acceptable results.

Introduction:

Landslide is a major hazard in the rugged region that causes widespread damage to human lives and infrastructure. Landslide is the major environmental hazard, which threatens and badly affect the socio-economic development in rough terrain (Petley, 2012). The major factors that trigger mass movement (Mudflow, Landslide, Debris flow) are 1) Prolonged and intense rainfall, Earthquake, 2) Anthropogenic factors (Construction on mountains, mining activities, and Deforestation). The best example of earthquake triggered landslides are: Chi Chi 1999 earthquake in Taiwan (Weissel & Stark, 2001), Kashmir earthquake (2005) Pakistan (Owen et al., 2008), Wenchuan earthquake 2008 in China (Gorum et al., 2011).

Landslide contributes about 9% of the global natural disasters (Gokceoglu et al., 2005). According to global damage statistics, due to landslides, 1000 people die every year and approximate damage to property is the US $4 billion per year (Lee & Pradhan, 2007). Landslide is considered as a third most devastating natural hazard in terms of degree of threating and widespread effects around the globe (Feizizadeh & Blaschke, 2011).

Rainfall considered as a major cause of landslides in Thailand because it is a tropical country, and exposed to monsoon and typhoons associated rainfall, which has a major influencing hand for a mass movement in the country. All the time landslide events (1988, 2001, 2006, and 2011) occurred in Thailand with intense rainfall (Mairaing, 2008; Potigavin, 1988). May 2006 heavy rainfall triggered flash flood and landslide in northern Thailand, hundreds of people killed and thousands of people stuck due to flood water and muddy material (Intarawichian & Dasananda, 2011). Mostly landslide susceptibility maps uttered through its cartographic means. Landslide susceptibility maps are beneficial for evolving mitigation plans and most appropriate places for construction.

Uttaradit is one of the provinces in the northern part of Thailand which accumulate an area of 7,838.6 sq.km. The province is located near the Nan river. Province is divided into 9 districts, 67 sub-districts (Tambon) and 562 villages (Center, 2006).

Mae-Phun is the study area *(Figure 1: Location Map)* which is sub-district of Laplae district in Uttaradit province. It lies between 17°39'10" to 17°48'40" N and 99°57'10" to 100°02'10" E, it has an area of 106 sq.km. Slope angle ranges from 40° to 75. Nevertheless, the topography of the study area varies from a flat surface in the southeast to steeply mountains in north and west. The Northern part of study area having upstream of Nan river. Major lithological units found in Mae-Phun are shale and siltstone; though, sometimes alluvial deposits also found in north part. The geologically study area covers mudstone, shale, and chest. Soli texture founded in three different type which includes clay, clay loam, and sandy clay loam (Boonyanuphap, 2013; Nachaiboon et al.). Climatically study area is considered as a tropical monsoonal. Climatic station of Uttaradit province showed average rainfall of about 1,506 mm from last 30 years (1981-2010) of meteorological data (Boonyanuphap, 2013).

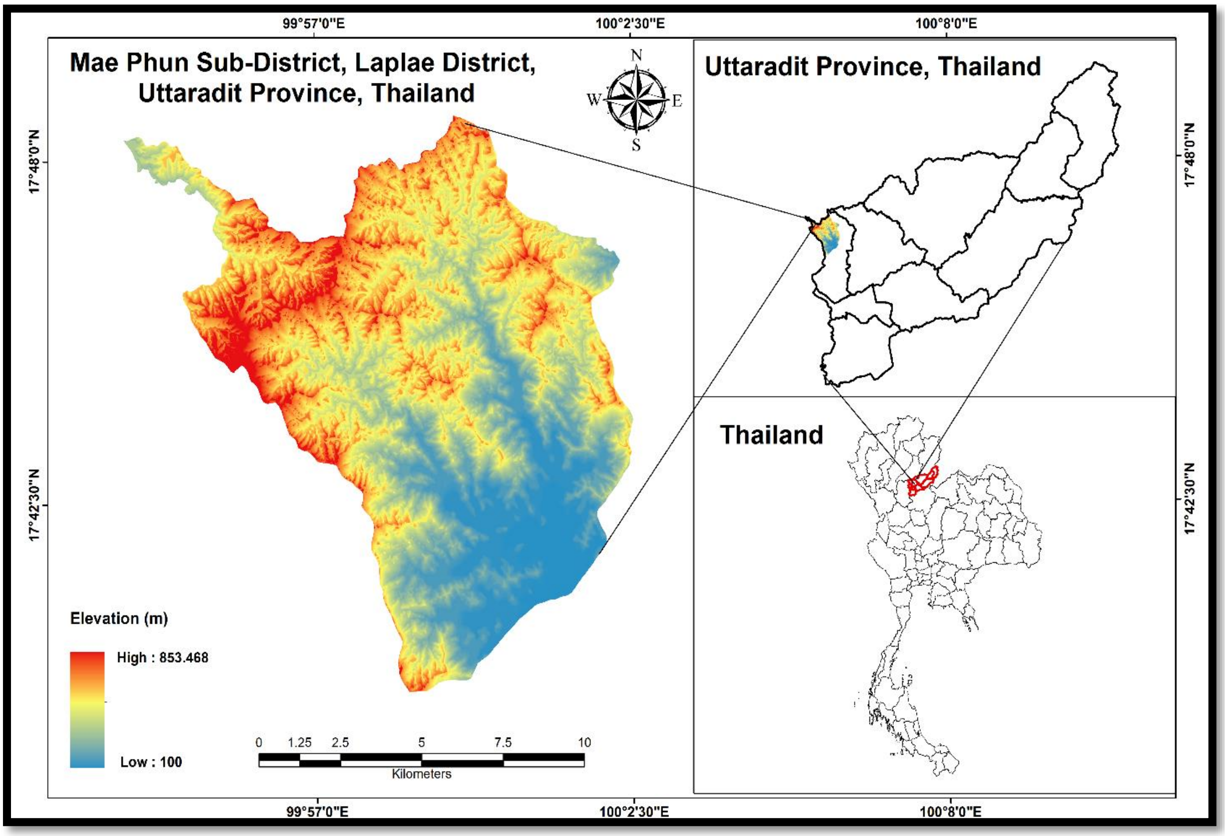

Figure 1: Location Map

Materials and Methods:

It is becoming more common to have landslide inventory towards susceptibility assessment (Ayalew et al., 2004). Before producing landslide inventory, an extensive and detailed field survey was conducted with the local and concerned people. For landslide inventory, SPOT 5 satellite image utilized which was acquired in December 2006 (Department of Natural Resource and Environment, Naresuan university) to pinpoint the landslide affected areas (Landslide inventory) using Arc Map 10.1 software. Afterwards, the area was calculated (Sq.m) using spatial function (Calculate geometry). After landslide inventory, it is necessary to investigate the area for information and collect the data because reliability and accuracy of the results depend on collected data (Aleotti & Chowdhury, 1999; Ercanoglu & Gokceoglu, 2004; Guzzetti et al., 2000). Therefore, few landslides controlling parameters (data) collected from different Thailand governmental organizations (Land development, Natural Resource and Environment, Thai Meteorological and Department of Natural Resource and Environment, Naresuan University).

In this study, seven parameters were considered for landslide susceptibility assessment which was divided into three categories, human-induced, topographical/physical and climatological parameters. Many studies used topographical parameters which include slope, aspect, hill shade, drainage network (Dai & Lee, 2002; Ercanoglu & Gokceoglu, 2004) and very few literature found on plan and profile curvature (Ayalew et al., 2004). So, in this study the topographical constraints include (Elevation, Slope, Aspect, Plan and profile Curvature) was analyzed using digital elevation model (DEM), human-induced parameters include land use/land cover, Roads, Stream (Department of Natural resource and environment), SPOT 5 satellite image (Department of Natural Resource and Environment, Naresuan University) and climatological parameter include rainfall data of past 30 years (1988-2017) which was obtained from Thai meteorological department. Flowchart of the used methodology is given below in *(Figure 2: Methodology adopted in this research).*

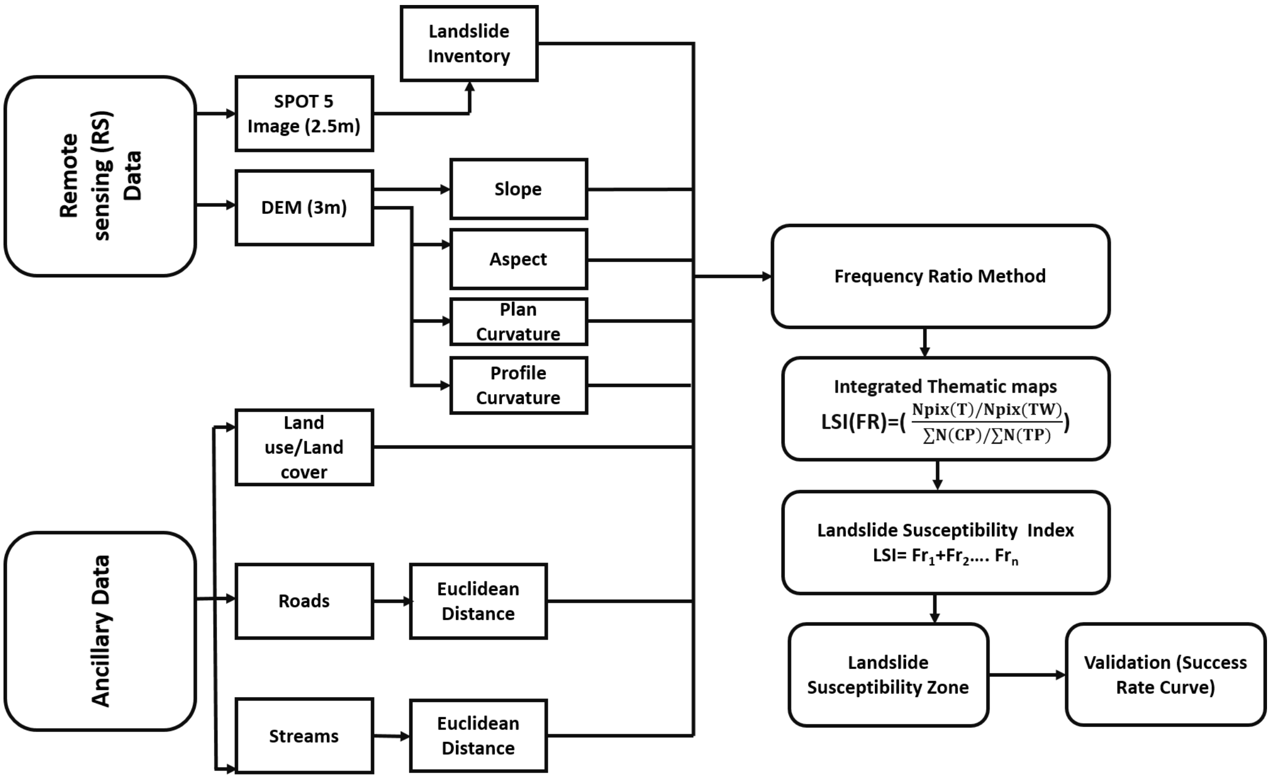

Figure 2: Methodology adopted in this research

Frequency ratio method:

Frequency ratio is a bivariate statistical approach and here it is used for the probability of landslide susceptibility with relation of other influencing factors i.e. slope, aspect, plan and profile curvature, land use/land cover, proximity to roads and stream. This method is used to prepare landslide susceptibility map using GIS. Frequency ratio method is based on the distribution of landslide and its influencing factors to make a correlation between them. Using FR method, the linkages were derived from the landslide and its conditioning parameters. Frequency is calculated using *(Equation.1)*. Consequently, the frequency ratio of each factor's type and range were calculated from their relationships with landslide events. The frequency which is calculated for sub-classes of each parameter were summed up to make a landslide susceptibility index map (Balamurugan et al., 2016; A. Yalcin et al., 2011). Below FR is defined:

$$Landslide\ evaluation\ (FR)=\left(\frac{Npix(T)/Npix(TW)}{\sum N(CP)/\sum N(TP)}\right) \ldots\ldots\ldots \text{Eq.1}$$

(A. Yalcin et al., 2011)

FR = Frequency ratio value
Npix(T) = Number of pixels that contain landslide for each class of a parameter
Npix(TW) = Total number of landslide pixels in study area
$\sum$N(CP) = Number of pixels in each parameter class
$\sum$N(TP) = Total number of pixels in study area
Fr_1 Fr_2,Fr_n = Fr is rating of each parameter class

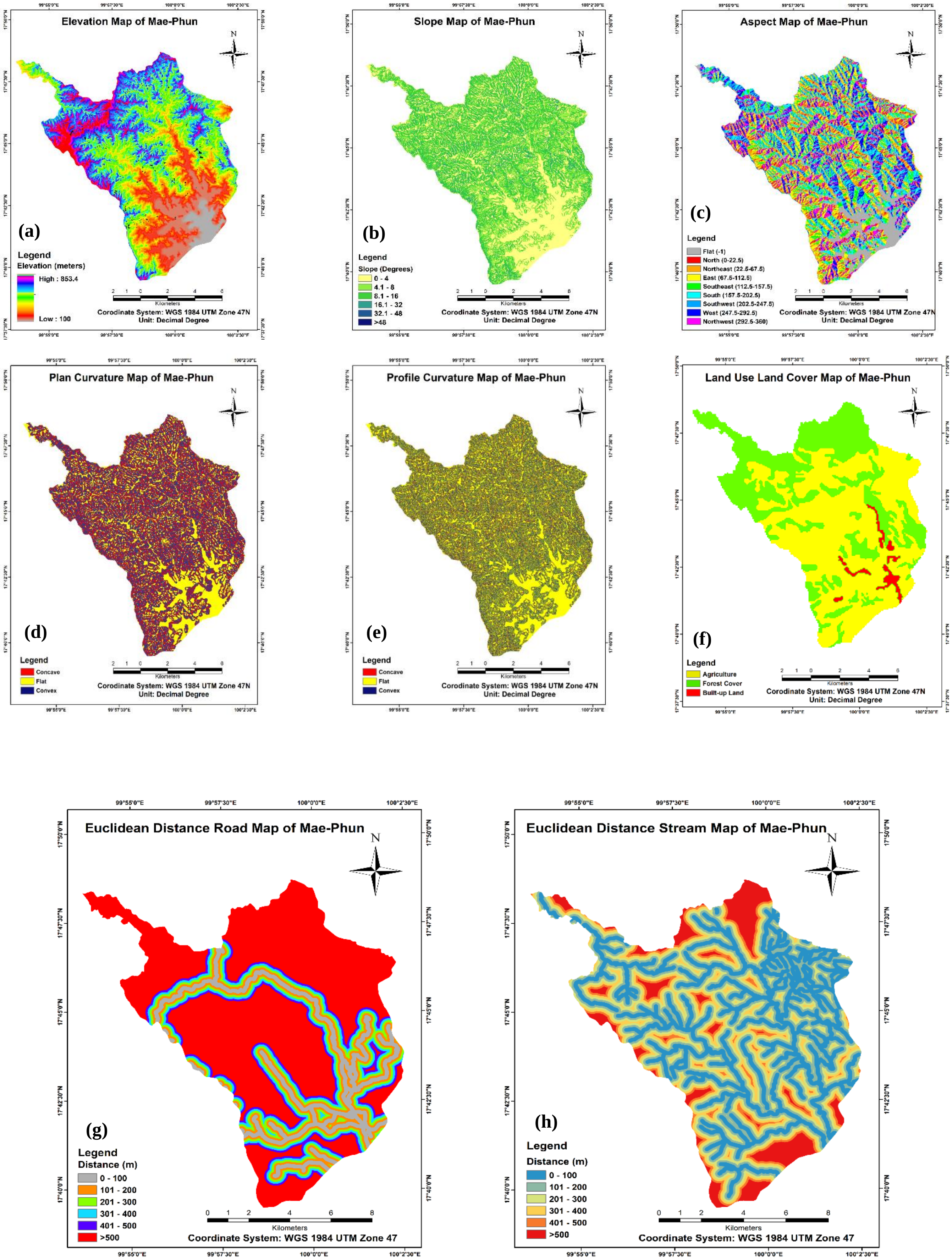

*Figure 3: **a)** Elevation, **b)** Slope, **c)** Aspect , **d)** Plan curvature, **e)** Profile curvature , **f)** Land use land cover, **g)** Proximity to road, **h)** Proximity to stream*

Rainfall-triggered landslides mostly occurred in the mountainous region due to intense and prolonged rainfall (Mairaing, 2008). Rainfalls appear to be the major cause of landslides in Thailand (Potigavin, 1988). In May 2006, heavy rainfall recorded in Uttaradit province and due to that, it triggers flash flood and landslides. The average annual rainfall of Uttaradit province is shown below in *(Figure 4: Average Annual Rainfall in Uttaradit Province (1988-2017).*

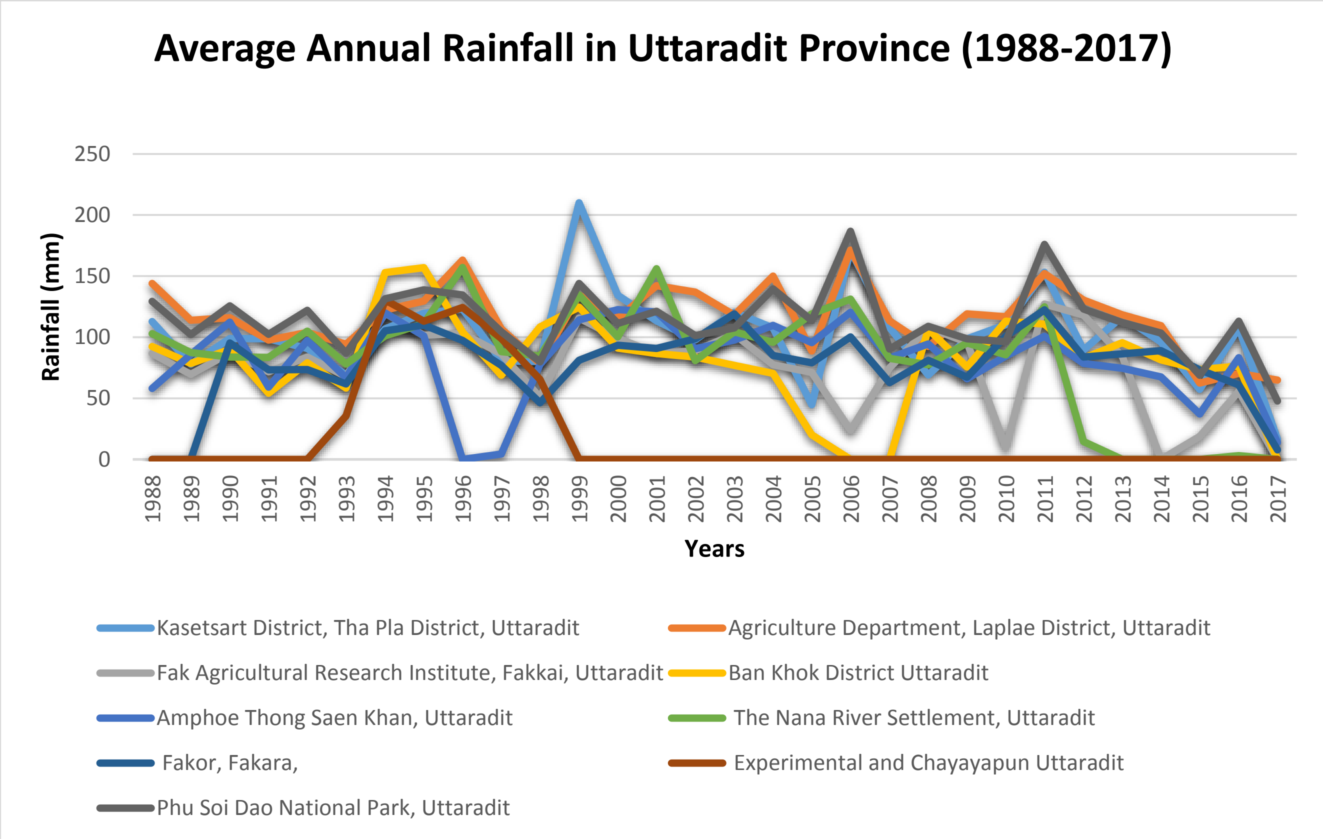

Figure 4: Average Annual Rainfall in Uttaradit Province (1988-2017)

Results and Discussion:

As far as frequency ratio method is concerned, the ratio explains about the area which is occupied by a landslide, to the complete study area. According to FR method, the value of 1 is an average point if the value is greater than 1 which means landslide has a higher correlation with the conditioning parameter; however, if the value is less than 1 means the lower correlation between them.

So according to the FR ratio of all the thematic parameters explains that slope is the most crucial factor that destabilizes it, a high correlation was found at the slope angle ranges from 8^0-48^0 (1.10%-1.30%), at the aspect classes of Northern, Northeast and Eastern parts.

The representation of profile curvature can be found by the rate of change of slope for each cell in the direction of dipping; however, the surface bending perpendicular to the slope direction represent plan curvature. Both can control the movement of water from in and out of the slope; therefore, both factors are important for landslide studies (Ayalew et al., 2004). According to the analysis, high landslide correlation was found in concave and flat surfaces of profile and plan curvature (1.10-1.15%) and (1.15%-1.30%) respectively. Roads are the factor when it gets constructed the load on the topography and the heel of slope get decrease, which causes the tension and as a result cracks created due to stress increased on the backside of the slope and transformation of topography (Ali Yalcin, 2008). So, the FR ratio is high (1.26-1.32%) between the classes of 200-400 meter from the road.

After FR ratio, the LSI is calculated by summation of all the thematic layers using frequency ratio value *(Equation.2)*

$$LSI = Fr1 + Fr2 + Fr3 \ldots\ldots..Frn \ldots\ldots \text{Eq.2}$$

The LSI Values ranges from 3.39 to 8.31, higher the value of LSI, greater would be the occurrence of landslide and vice versa. Based on LSI values, the study area was divided into five equal zones from very low, low, medium, high, and very high zone. It is clear from the analysis that 17.02%, 23.92% 28.91% 24.21%, and 8.93% falls in very high, high, moderate, low and very low landslide susceptible zones respectively *(Figure 5: Landslide susceptibility zonation)*. The susceptibility map is indicating that around 40% of Mae-Phun area falls under highly susceptible zone. Massive damages can occur in future if the strategical planning against it were not taken in time.

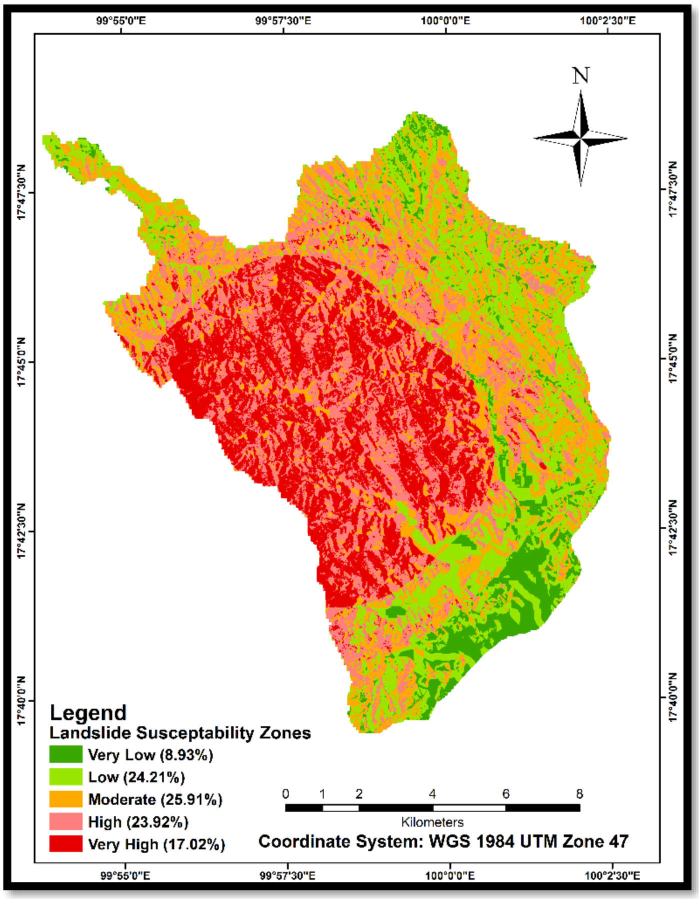

Figure 5: Landslide susceptibility zonation

Validation of Landslide Susceptibility Zonation:

Landslide susceptibility map which built through prediction modelling, for that it is necessary to validate it with landslide inventory(Deng et al., 2017). Success rate curve method uses the landslide susceptibility map and landsides to compare with each other. Mae-phun was assessed using FR Method for landslide susceptibility zonation and for validation purpose the success rate curve method has been used to calculate the accuracy of FR Method for selected thematic layers towards the occurrence of the landslide.

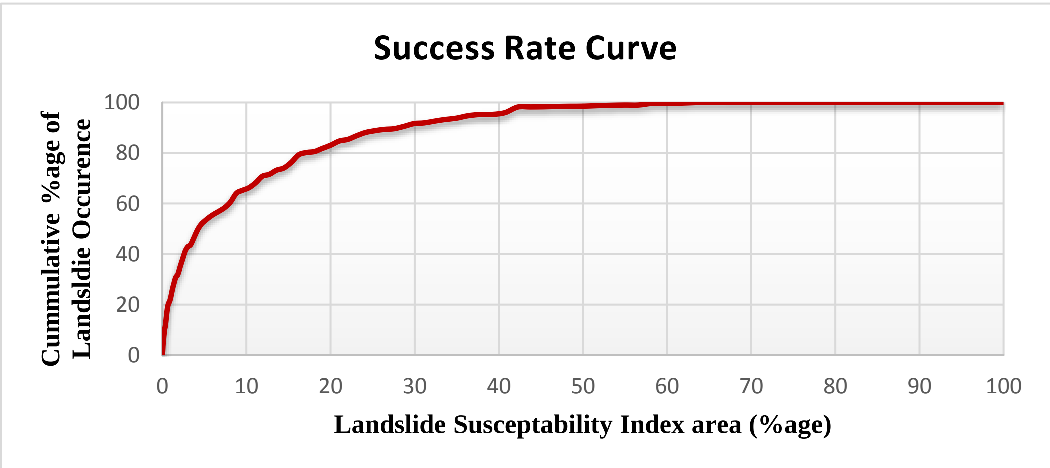

Figure 6: Mae-Phun, Landslide susceptibility success rate curve

To calculate the success rate curve the LSI values were divided into 100 equal classes and sorted in descending order which varies from very highly susceptible to very low susceptible classes. The landslide affected area which falls in each susceptible class was calculated through zonal statistic. The cumulative percentage was calculated for both susceptible class and landslide affected areas, to build success rate curve by plotting the data of cumulative percentage of landslide occurrences on the y-axis, and Landslide susceptibility index on the x-axis *(Figure 6: Mae-Phun, Landslide susceptibility success rate curve).* The success rate curve has a moderate curve which indicates acceptable results produce by using FR method for landslide susceptibility zonation. The final landslide susceptibility zonation map was validated using success rate curve and the prediction accuracy of the method found around 60%, which is acceptable results from FR Method.

Conclusion:

In this study, quantitative method (Frequency Ration) is used for landslide susceptibility assessment of Mae-Phun area. The resultant landslide susceptible zones were validated using success rate curve method for the effectiveness of model. For the FR Model different human induced, topographical and climatic parameters have been used in this study i.e. Slope, aspect, plan and profile curvature, proximity to streams and roads, land use/land cover, and rainfall to assess the landslide susceptibility.

It was analysed by using FR model that ratio was high at the slope angles range from 8^0-48^0 (1.10%-1.30%), in the slope facing to North, Northeast and Eastern part of the study area have high correlation with landslide susceptibility.

In land use type the forest land is more susceptible towards the landslide as it has a high correlation with landslide, though agriculture and built-up land are below the average value of 1. Moreover, the concave and flat surface of plan and profile curvature are more active toward the occurrence of landslide due to their high correlation with landslide (1.10%-1.30%). To develop the landslide susceptibility zonation map using frequency ratio model, all the ratio values of sub-classes of each selected factor were integrated using weighted sum techniques in ArcGIS environment to get the landslide susceptibility indices. Eventually the LSI was classified into five equal classes ranges from very low to very high susceptible class. The prediction accuracy of landslide susceptibility was found at the acceptable zone with 60%.

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REFERENCES

1 Aleotti, P., & Chowdhury, R. (1999). Landslide hazard assessment: summary review and new perspectives. *Bulletin of Engineering Geology and the environment, 58*(1), 21-44. doi:10.1007/s100640050066

2 Ayalew, L., Yamagishi, H., & Ugawa, N. (2004). Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan. *Landslides, 1*(1), 73-81. doi:10.1007/s10346-003-0006-9

3 Balamurugan, G., Ramesh, V., & Touthang, M. (2016). Landslide susceptibility zonation mapping using frequency ratio and fuzzy gamma operator models in part of NH-39, Manipur, India. *Natural Hazards, 84*(1), 465-488. doi:10.1007/s11069-016-2434-6

4 Boonyanuphap, J. (2013). Cost-benefit analysis of vetiver system-based rehabilitation measures for landslide-damaged mountainous agricultural lands in the lower Northern Thailand. *Natural Hazards, 69*(1), 599-629. doi:10.1007/s11069-013-0730-y

5 Center, A. D. P. (2006). Rapid assessment: Flashflood and landslide disaster in the provinces of Uttaradit and Sukhothai, Northern Thailand, May 2006.

6 Dai, F. C., & Lee, C. F. (2002). Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong. *Geomorphology, 42*(3–4), 213-228. doi:http://dx.doi.org/10.1016/S0169-555X(01)00087-3

7 Deng, X., Li, L., & Tan, Y. (2017). Validation of Spatial Prediction Models for Landslide Susceptibility Mapping by Considering Structural Similarity. *ISPRS International Journal of Geo-Information, 6*(4), 103.

8 Ercanoglu, M., & Gokceoglu, C. (2004). Use of fuzzy relations to produce landslide susceptibility map of a landslide prone area (West Black Sea Region, Turkey). *Engineering Geology, 75*(3), 229-250. doi:http://dx.doi.org/10.1016/j.enggeo.2004.06.001

9 Feizizadeh, B., & Blaschke, T. (2011). Landslide risk assessment based on GIS multi-criteria evaluation: a case study in Bostan-Abad County, Iran. *Journal of earth science and engineering, 1*(1).

10 Gokceoglu, C., Sonmez, H., Nefeslioglu, H. A., Duman, T. Y., & Can, T. (2005). The 17 March 2005 Kuzulu landslide (Sivas, Turkey) and landslide-susceptibility map of its near vicinity. *Engineering Geology, 81*(1), 65-83.

11 Gorum, T., Fan, X., van Westen, C. J., Huang, R. Q., Xu, Q., Tang, C., & Wang, G. (2011). Distribution pattern of earthquake-induced landslides triggered by the 12 May 2008 Wenchuan earthquake. *Geomorphology, 133*(3–4), 152-167. doi:http://dx.doi.org/10.1016/j.geomorph.2010.12.030

12 Guzzetti, F., Cardinali, M., Reichenbach, P., & Carrara, A. (2000). Comparing Landslide Maps: A Case Study in the Upper Tiber River Basin, Central Italy. *Environmental Management, 25*(3), 247-263. doi:10.1007/s002679910020

13 Intarawichian, N., & Dasananda, S. (2011). Frequency ratio model based landslide susceptibility mapping in lower Mae Chaem watershed, Northern Thailand. *Environmental Earth Sciences, 64*(8), 2271-2285. doi:10.1007/s12665-011-1055-3

14 Lee, S., & Pradhan, B. (2007). Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. *Landslides, 4*(1), 33-41. doi:10.1007/s10346-006-0047-y

15 Mairaing, W. (2008). *Landslide problems and warning by geotechnical methods.* Paper presented at the 26th Conference of the ASEAN Federation of Engineering Organization.

16 Nachaiboon, U., Phewnil, O., Duangmal, K., Chanwong, N., Rollap, P., Wichittrakarn, P., & Nimpee, C. Effect of Landform Pattern on Soil Particles in Landslide Crisis Area of Mae Phun and Mae Phrong Watershed, Uttaradit Province, Northern of Thailand.

17 Owen, L. A., Kamp, U., Khattak, G. A., Harp, E. L., Keefer, D. K., & Bauer, M. A. (2008). Landslides triggered by the 8 October 2005 Kashmir earthquake. *Geomorphology, 94*(1–2), 1-9. doi:http://dx.doi.org/10.1016/j.geomorph.2007.04.007

18 Petley, D. (2012). Global patterns of loss of life from landslides. *Geology, 40*(10), 927-930.

19 Potigavin, N. (1988). The 1988 Lnadlisde in Southern of Thailand *Department of Land development, Ministry of Agriculture, Thailand*.

20 Weissel, J. K., & Stark, C. P. (2001, 2001). *Landslides triggered by the 1999 Mw7.6 Chi Chi earthquake in Taiwan and their relationship to topography.* Paper presented at the Geoscience and Remote Sensing Symposium, 2001. IGARSS '01. IEEE 2001 International.

21 Yalcin, A. (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): Comparisons of results and confirmations. *CATENA, 72*(1), 1-12. doi:http://dx.doi.org/10.1016/j.catena.2007.01.003

22 Yalcin, A., Reis, S., Aydinoglu, A. C., & Yomralioglu, T. (2011). A GIS-based comparative study of frequency ratio, analytical hierarchy process, bivariate statistics and logistics regression methods for landslide susceptibility mapping in Trabzon, NE Turkey. *CATENA, 85*(3), 274-287. doi:http://dx.doi.org/10.1016/j.catena.2011.01.014

Annexure: