Application of Analytical Hierarchy Process (AHP) and Factor Analysis Model (FAM) for Landslide Susceptibility Analysis (LSA) at Kota Kinabalu area, Sabah, Malaysia

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The aim of this study was to produce Landslide Susceptibility Level (LSL) map for Kota Kinabalu area in Sabah, Malaysia by using bothAnalytical Hierarchy Process (AHP) and Factor Analysis Model (FAM). Firstly, landslide locations were identified by aerial photographs and satellite images interpretations, field observation and secondary data resources. A total of 367 landslides were mapped from various sources. Secondly, the landslide inventory maps were randomly split into a dataset of 256 landslides (70 %) for running the both models and the remaining 110 landslides (30%) was used for validation purpose. Fifteen data layers, as the landslide causing factors has been used to detect the most susceptible areas. These factors are lithology, soil textures, lineament, weathering, magnitude, spreading distance, slope angle, height slope, rainfall, groundwater level, landuse, friction angle, cohesion, shear strength and rock quality designation (RQD). Lastly, LSL maps were produced using AHP and FAM. For verification purpose, Area Under the Curve (AUC) method were used in the format of GIS (Geographic Information Systems). The verification result showed that AHP (91%) performed better than FAM (85%) for the study area. The resulting LSL map can be used by local administrator or developers to locate areas prone to landslides, determine the land use suitability area as well as to organize more detailed analysis of the identified "hot spot" areas.

Keywords: Landslide Susceptibility Analysis (LSA), Analytical Hierarchy Process (AHP), Factor Analysis Model (FAM), Sabah.

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I. INTRODUCTION

The Kota Kinabalu district in Sabah, Malaysia (Figure 1), which has growing population, was proposed to be used for a pilot research and development of Landslide Susceptibility Analysis (LSA) study by using Analytical Hierarchy Process (AHP) and Factor Analysis Model (FAM). The effect of the pressure of development activities that lead to rapid cut works or reclamation of slopes for road construction, infrastructure development and construction of dwellings or buildings is more widespread and has spread to hilly areas with a large population. Impact from these activities, several cases of catastrophic landslides have occurred. For example, on 26th December 2001 and 30th June 2006 landslides occurred in the same place at the Lok Bunuq village area which resulted in 10 fatalities and losses amounting to hundred thousands of Malaysian ringgit. A landslide event involving an embankment slope (causeway) also occurred on 10th October 2006 in the Menggatal-Sepanggar highway area (Karambunai) with tragic impacts on the locals with 2 lives lost, and some cases of landslide also occurred simultaneously on the same day (June 6, 2010) involving the embankment slope along Shantung Road, Bantayan Road, Bukit Bendera Road, Bukit Padang Road and Minitod Road resulting in interference of the traffic communications system for months. The immediate response was a directive to stay away or vacate residences or buildings with no exemption in the areas hit in this study area. For example, the Shantung-Penampang road settlement area, the Yayasan Sabah College Community lectures building, the Taman Fantasy and Taman Winley areas, and the MARA University of Technology Malaysia (UiTM) Sabah branch campus (lectures building) all had to be abandoned because their state was found to be unstable and there was a worry that they would be affected in the event of another landslide occurring.

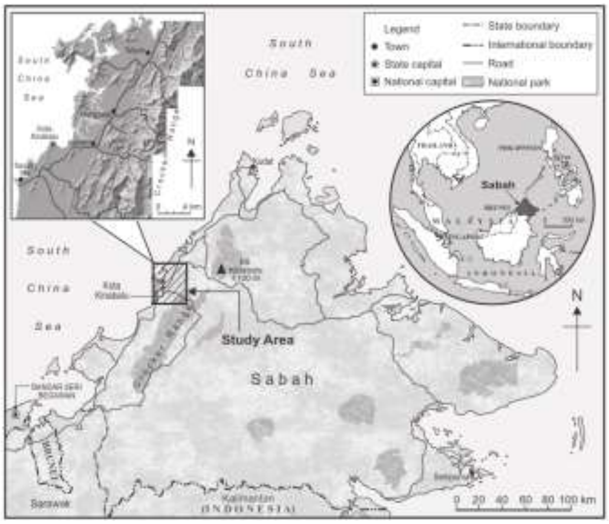

Figure1. Locality map of the studied area

II. RESULTS AND DISCUSSIONS

In the literature, there are four different approaches to the analysis of LSA, namely: landslide inventory-based probabilistic, heuristic (which can be direct geomorphological mapping, or indirect qualitative map combination), statistical (bivariate or multivariate statistics) and geotechnical approach (Aleotti et al.,1999; Guzzetti et al., 1999)(Table 1).

Table 1. Different approaches to the analysis of LSL

Approach	Models/Methods		Reference (e.g)
Probabilistic	Regional landslide inventories from aerial photograph and remotely sensed image		Akgun et al. (2008)
Heuristic	Geomorphological mapping & index overlay mapping		Van Western et al. (2003)
	Analytical Hierarchy Process (AHP)		Mezughi et al. (2012)
Statistical	Bivariate Method	General Stability Index	Carrara (1982)
		Frequency Index	Temesgen et al. (2001)
		Surface Percentage Index	Uromeihy & Mahdvifar (2000)
		Statistical Index Method	Oztekin & Topal (2005)
		Weighting Factor	Cevik & Topal (2003)
		Certainty Factor	Luzi & Pergalani (1999)
		Conditional Analysis	Duman et al. (2005)
		Weights of Evidence	Thiery et al. (2007)
		Landslide Susceptibility Analysis (LSA)	Süzen & Doyuran (2004)
		Information Value Method	Sreemal et al. (2003)
	Multivariate Method	Multiple Linear Regression Analysis	Wieczorek et al. (1996)
		Discriminant Analysis	Santacana et al. (2003)
		Logistic Regression Analysis	Ayalew & Yamagishi (2005)
		Principal Component Analysis (PCA)	Baeza & Corominas (2001)
		Fuzzy Systems	Champati Ray et al. (2007)
		Artificial Neural Networks (ANN)	Kanungo et al. (2006)
		Expert Systems	Pistocchi et al. (2002)
		Factor Analysis Model	Rodeano et al. (2012a)
Geotechnical	Infinite Slope Model (ISM)		Rodeano et al. (2012b)
	Stability INdex MAPping (SINMAP)		Zaitchik et al. (2003)
	Transient Rainfall Infiltration and Grid-based Regional Slope-stability Analysis (TRIGRS)		Salciarini et al. (2006)

III. SUMMARY

A. Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a multi-criteria decision making approach, where factors are arranged in a hierarchical structure (Saaty, 2008). In landslide research, this method requires expert knowledge to structure the importance of different landslide factors into a matrix. AHP compares the importance of different factors in a pairwise matrix with scales ranging from one to nine to show the degree of comparative importance. Based on the AHP (Eq. (1)), the equation to construct the LSL is

LSL = B1m1 + B2m2 + B3m3+...+BnMn (1)

Where B1 is the eigen value or the coefficient of factor '1' and m is the weighting given to factor '1'.

B. Factor Analysis Model (FAM)

The Statistical Package for Social Science(SPSS) was used for the factor analysis model (FAM)

(Johnson and Wichern, 2002; Coakes, 2008) of the data collected from the survey. The FAM as stated Eq. (2) below:

$$
\begin{aligned}
X_1 - \mu_1 &= \ell_{11}F_1 + \ell_{12}F_2 + \cdots + \ell_{1m}F_m + \varepsilon_1 \\
X_2 - \mu_2 &= \ell_{21}F_1 + \ell_{22}F_2 + \cdots + \ell_{2m}F_m + \varepsilon_2 \\
X_p - \mu_p &= \ell_{p1}F_1 + \ell_{p2}F_2 + \cdots + \ell_{pm}F_m + \varepsilon_p
\end{aligned} \quad (2)
$$

Johnson and Wichern (2002) express the orthogonal factor model with m common factors as Eq. (3) follows:

$$\underset{(pX1)}{X} = \underset{(pX1)}{\mu} + \underset{(pXm)}{L}\underset{(mXm)}{F} + \underset{(pX1)}{\varepsilon} \quad (3)$$

where,

μi = mean of variable I, εi = ith specific factor, Fj = jth common factor & ℓij = loading of the ith variable on the jth factor

IV. ACKNOWLEDGMENT

A. Landslide Hazard Identification (LHI)

Landslide Hazard Identification (LHI) involved three (3) main phases; namely desk studies, field studies and laboratory studies. The desk studies involved aerial photograph interpretation 1:10,000 scale (Years 2005 dan 2010) and satellite images analyses (Spot-5 dan QuickBird II) (using Erdas V.9.2 software), and extensive studies of literature review and secondary data collections. All of these sources were analysed and reclassified to get an idea or preliminary information about the landslide distribution and historical data (frequency) aspects in the study area. The product from the desk studies established a "Landslide Distribution Map" (LDM) (Figure 2).

The field studies in LHI involved sampling of rocks and soils, engineering geological mapping, questionnaire survey on AHP and FAM parameters to experts, observation of landslide hazard characterization information, such as lithology, soil types and land use; and extracting a digital elevation model. For the laboratory studies in LHI, all samples of rocks and soils obtained from the field were analyzed and evaluated for their engineering properties in accordance with the standards recommended by the ISRM (1979), ISRM (1985)and British Standard BS 1377 (1990) such as the direct shear test for rock mechanic testing and the triaxial test (Consolidated isotropically undrained, CIU) for soil mechanic testing.

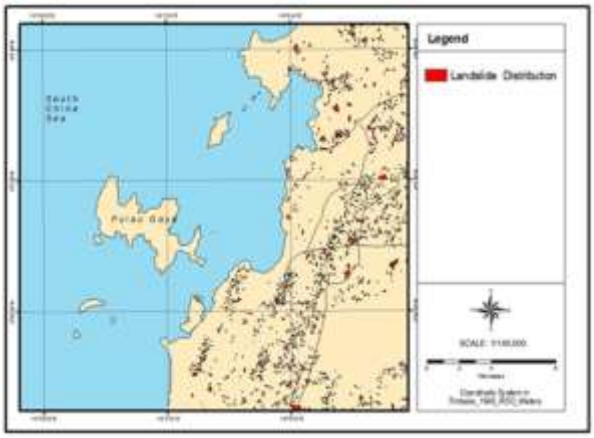

Figure 2. Landslide distribution map (LDM)

B. Production of the thematic data layers for Landslide Susceptibility Analysis (LSA)

After all the laboratory studies were completed, with the combination of fieldwork (engineering geological mapping, questionnaires and observation information), laboratory studies and GIS extraction results, fifteen data layers were produced to represent the lithology, soil textures, lineament, weathering, magnitude, spreading distance, slope angle, slope height, rainfall, groundwater level, landuse, friction angle, cohesion, compressive strength and rock quality designation (RQD) (Figure 3). Each information characterization in the LHI data layers were allocated a certain proportion/rating of the values obtained as a result of the AHP and FAM analysis.

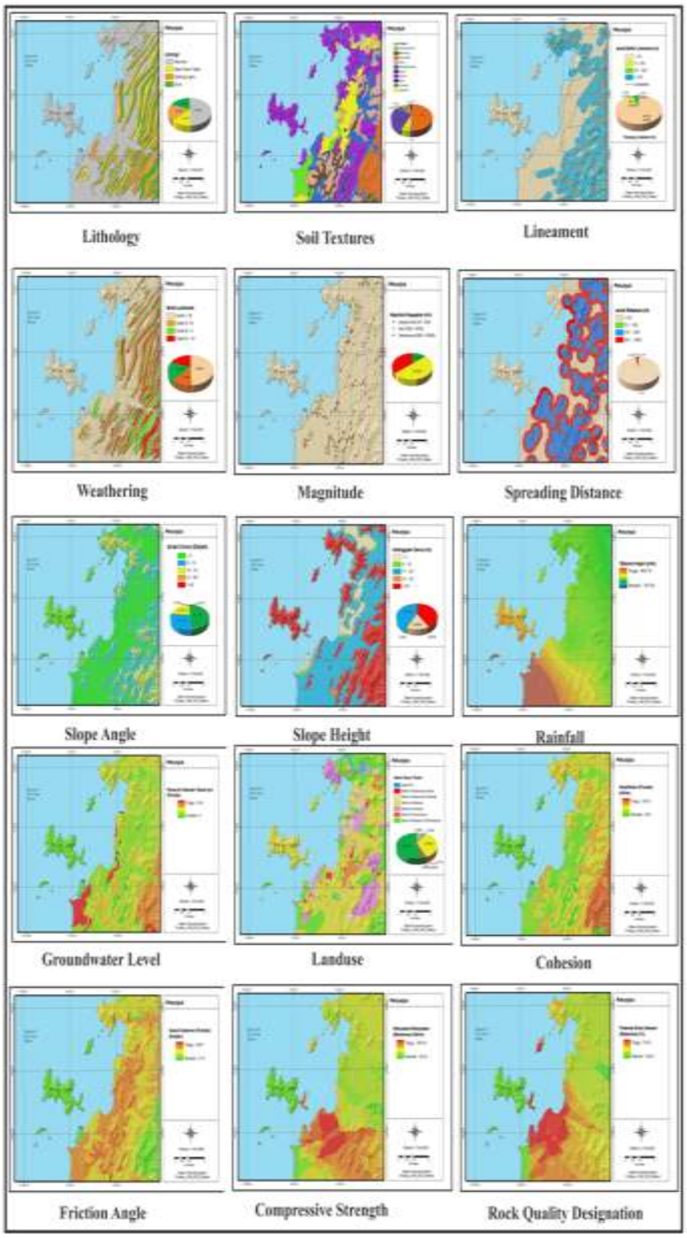

Figure3. Thematic data layers for Landslide Susceptibility Analysis (LSA)

C. Application of Analytical Hierarchy Process (AHP)

Values ranging from 9 (extremely) to 1 (equally) and 1/9 (opposite extremely) are assigned by expert judgment to each pair of parameters yielding a square reciprocal matrix by rating rows relative to columns The LSL map is established according to Eq. (4). The consistency of the weights and ratings are evaluated by taking the principal eigenvectors of each matrix and calculating the consistency index (CI) and consistency ratio (CR). The values are given in Table 2 is found that all CR values are less than 0.1 (0.0129) and consequently this proves the preferences utilized to produce the comparison matrixes are consistent.

$$\sum [(8*Lithology) + (8*Soil) + (7*Lineament) + (6*Weathering) + (7*Magnitude) + (7*Spreading) + (13*Slope) + (13*Height) + (7*Hydrology) + (7*Hydrogeology) + (3*Landuse) + (4*Cohesion) + (4*Friction) + (4*Compressive) + (4*RQD)] \quad (4)$$

Based on Analytical Hierarchy Process (AHP) result, the values obtained showed that the proportion of the geological characterization factor (29% of variance) and geomophometric factor (24% of variance) are the factors that cause a significant landslide. This is followed by the geodynamics features (14% of variance), hydrology / hydrogeology (14% of variance), soil mechanic characterization (8% of variance), rock mechanics characterization (8% of variance) and land use (3% of variance).

In terms of LSL, the results of the AHP for the Kota Kinabalu area suggest that 31.40% of the area can be categorised as having very low susceptibility (VLS), 36.07% as low susceptibility (LS), 9.29% as moderate susceptibility (MS), 16.51% as high susceptibility (HS) and 6.73% as very high susceptibility (VHS) (Figure 4).

Table 2. Evaluation of the consistency of the preferences used for rating the parameters and categories.

Total inverted row	0.0667

Normalized Principal Eigen Vector	
Lithology	0.08
Soil	0.08
Lineament	0.07
Weathering	0.06
Magnitude	0.07
Spreading	0.07
Slope	0.13
Height	0.11
Hydrology	0.07
Hydrogeology	0.07
Landuse	0.03

Cohesion	0.04
Friction	0.04
Compressive	0.04
RQD	0.04
Total	1.0000

	Principal Eigen value
Max lambda	15.2876
n	15
CI	0.0205
RI	1.59
CR	0.0129

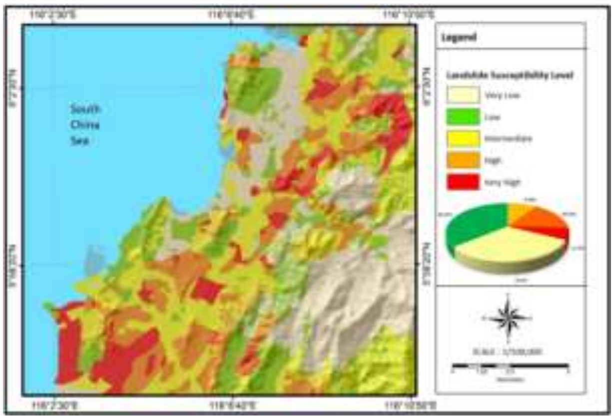

Figure4.Landslide Susceptibility Level (LSL) map using AHP

D. Application of Factor Analysis Model (FAM)

The Kaiser-Meyer-Olkin and Bartlett's test results in Table 3 show that the Bartlett test of sphericity is large and significant ($p<0.01$) and KMO is greater than 0.6, thus factorability is assumed.

Table 3. KMO and Bartlett's Test

KMO and Bartlett's Test		Landslide
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.648
Bartlett's Test of Sphericity	Approx. Chi-Square	299.871
	Significance	0.000

Inspection of the anti-image correlation matrix reveals that all our measures of sampling adequacy are well above the acceptable level of 0.5. Therefore none of the variables was excluded from the analysis. Table 4 below displays the total variance explained at two stages for factors causing landslide. At the initial stage, it shows the factors and their associated eigen values, the percentage of variance explained and the cumulative percentages. Two factors were extracted because their eigen values were greater than 1. When two factors were extracted, then 45.625% of the variance could be explained.

In terms of LSL, the results of the FAM for the Kota Kinabalu area suggest that 15.80% of the area can be categorised as having very low susceptibility (VLS), 21.07% as low susceptibility (LS), 2.78% as moderate susceptibility (MS), 42.14% as high susceptibility (HS), 17.43% as very high susceptibility (VHS) and 0.78% as extremely high susceptibility (EHS) (Figure 5).

Figure 5. Landslide Susceptibility Level (LSL) map using FAM

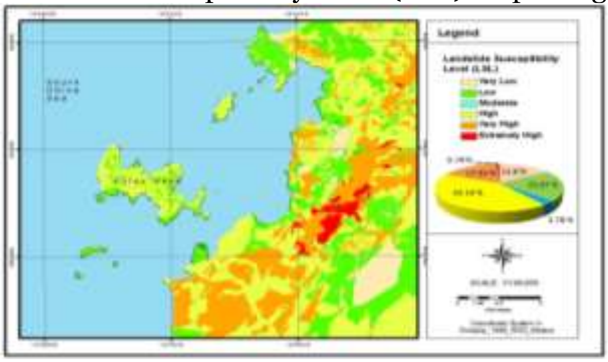

Table 4. Total variance explained for factors causing landslide (Measures of Sampling Adequacy, MSA) (Extraction Method: Principal Component Analysis)

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
Slope Angle	2.019	28.848	28.848	2.019	28.848	28.848	1.606	22.946	22.946
Lithology	1.174	16.777	45.625	1.174	16.777	45.625	1.588	22.680	45.625
Soil Types	.999	14.268	59.893						
Rainfall	.831	11.876	71.769						
Cohesion	.738	10.545	82.314						
Compressive	.684	9.770	92.084						
Land use	.554	7.916	100.000						

E. Landuse Suitability Evaluation

In general, the VLS to MS areas refer to stable conditions with flat to moderately steep slopes with pasture and these areas are highly recommended for any future planning developments. In contrast, HS to EHS areas represent areas with unstable conditions with steep slope segments. HS to VHS areas are basically not recommended to be developed due to geological, hydrological and geotechnical constraints. However, if there is no choice or the developer or the local authorities really want to develop these areas, some procedures to be observed. EHS areas are strictly not recommended to be developed and provisions for suitable non-structural works planning control.

V. ACKNOWLEDGMENT

For validation of landslide susceptibility calculation models, two basic assumptions are needed: (1) landslides are related to spatial information, such as topography and geology, and (2) future landslides will be precipitated by a specific impact factor such as rainfall or earthquake (Chung & Fabbri, 1999). In this study, the two assumptions are satisfied because the landslides were related to the spatial information, and the landslides were precipitated by one cause-heavy rainfall in the study area.

The LSL maps result was validated using known landslide locations. Verification was performed by comparing the known landslide location data (in Figure 2) with the LSL maps (Figure4and5). The validation results is shown in Figure 6 for the AHP and FAM. Figure 6 illustrates how well the estimators perform with respect to the landslides used in constructing those estimators. To obtain the relative ranks for each prediction pattern, the calculated index values of all cells in the study area were sorted in descending order. The success rate validation results were divided into 100 classes with accumulated 1% intervals, according to the landslide susceptibility index value.

As a result, considering all the factors used in the study area, the 90–100% (10%) class, with the highest possibility of landslide, contains 38% and 60% of the landslide grid cells in success rate and so on until the calculation of 0% -100% (100%) of 100% of the total area in the rates obtained in this model, respectively. In the case of the 80–100% (20%) class, this contains 61% and 70% of the area in success rate using the AHP and FAM.

To compare the result quantitative, the areas under the curve were re-calculated as if the total area is 1 which means perfect prediction accuracy (Lee & Dan, 2005). So, the area under a curve can be used to assess the prediction accuracy qualitatively. The area ratios were 0.91 and 0.85, and we could say the prediction accuracy is 91% and 85%, respectively. Overall the case of both factors AHP used showed a higher accuracy than cases of FAM.

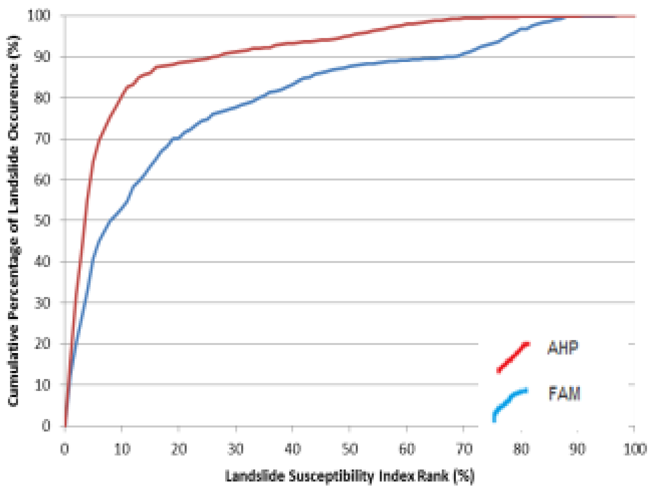

Figure6. Illustration of cumulative frequency diagram showing landslide susceptibility index rank (y-axis) occurring in cumulative percentage of landslide occurrence (x-axis)

VI. ACKNOWLEDGMENT

In light of available information, the following conclusions may be drawn from this study:

a. LSA study allows collecting, management, analysis and dissemination of a large amount of data, widespread in the region. All of these actions, based on continuous scientific and technologic research, with a strong multidisciplinary component and the involvement of local, regional, and interregional authorities, allow effective regional land-use planning.

b. This AHP and FAM had higher prediction accuracy. The prediction accuracy is 91% and 85%, respectively. Overall the case of both factors, AHP showed a higher accuracy than cases of FAM.

c. GIS geospatial technology capability of LSA provides a valuable tool for gaining susceptibility level estimates at the regional scale. This result highlights the importance of the potential effects of landslides in the study area. The resulting LSA can be used by local administration or developers to locate areas prone to landslide area, determine the land use suitability area, to organize more detailed analysis in the identified "hot spot" areas and can manage the impact of landslide disaster that may affect the regional economy (loss and damage to property) or welfare of the community (deaths and homeless) (risky areas).

VII. ACKNOWLEDGMENT

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[1] BaAkgün, A. & Bulut, F. (2008). GIS-based landslide susceptibility for Arsin-Yomra (Trabzon, North Turkey) region. Environmental Geology. 51, 1377–1387.

[2] Aleotti, P. & Chowdhury R. (1999). Landslide hazard assessment: summary review and new perspectives. Bull. Eng. Geol. & the Env. 58, 21–44.

[3] Ayalew, L. & Yamagishi, H. (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in Kakuda-Yahiko Mountains, Central Japan. Geomorphology. 65, 15-31.

[4] Baeza, C. & Corominas, J. (2001). Assessment of shallow landslide susceptibility by means of multivariate statistical techniques. Earth Surface Processes and Landforms. 26(12), 1251-1263.

[5] British Standard BS 1377. (1990). Methods of Test for Soils for Civil Engineering Purposes. London: British Standard

Institution.

[6] Carrara, A 1982, Cartografia tematica, stoccaggio ed elaborazione datiConvegno Conclusivo Progetto Finalizzato Conservazione del Suolo, Relazione Generale, Sottoprogetto Fenomeni Franosi, 9-10 June 1982, Rome. 265-281.

[7] Cevik, E. & Topal, T. (2003). GIS-based landslide susceptibility mapping for a problematic segment of the natural gas pipeline, Hendek (Turkey). Environmental Geology. 44, 949–962.

[8] Champati, Ray., Suvarna Dimri, P. K., Lakhera, R. C. & Sati, Santosh. (2007). Fuzzy-based method for landslide hazard assessment in active seismic zone of Himalaya. Landslides. 4, 101–111.

[9] Chung, C. J. & Fabbri, A. G. (1999). Probabilistic prediction models for landslide hazard mapping. Photogrammetric Engineering & Remote Sensing. 65(12), 1389-1399.

[10] Coakes, S. J., Steed, L. & Price, J. (2008). "SPSS 15.0, Analysis without Anguish," John Wiley & Sons, Hoboken.

[11] Duman, T., Can, T., Emre, O., Kecer, M., Dogan, A., Ates, S. & Durmaz, S. (2005). Landslide inventory of southwestern Anatolia, Turkey. Engineering Geology. 77, 99–114.

[12] Guzzetti, F., Carrarra, A., Cardinali, M. & Reichenbach, P. (1999). Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy, Geomorphology. 31, 181-216.

[13] ISRM (International Society for Rock Mechanics) 1979, Suggested methods for determining the uniaxial compressive strength and deformability of rock materials. ISRM Commission on Standardization of Laboratory and Field Tests. Int. J. Rock Mech. Min. Sci. 16, 135-140.

[14] ISRM (International Society for Rock Mechanics) 1985, Suggested methods for determining point load strength. ISRM Commission on Standardization of Laboratory and Field Tests. Int. J. Rock Mech. Min. Sci. 22(2), 51-60.

[15] Johnson, R. A., & Wichern, D. W. (2002). Applied Multivariate Statistical Analysis. Fifth Edition. Prentice-Hall, Inc, Upple Saddle River.

[16] Kanungo, D. P., Arora, M. K., Gupta, R. P. & Sarkar, S. (2008). Landslide risk assessment using concepts of danger pixels and fuzzy set theory in Darjeeling Himalayas Landslides. 5, 407–416.

[17] Lee, S. & Dan, N. T. (2005). Probabilistic landslide susceptibility mapping in the Lai Chau province of Vietnam: focus on the relationship between tectonic fractures and landslides. Environ. Geol. 48, 778–787.

[18] Luzi, L. & Pergalani, F. (1999). Slope instability in static and dynamic conditions for urban planning: the "Oltre Po Pavese'case history (Regione Lombardia – Italy). Natural hazards. 20, 57-82.

[19] Mezughi, T., Akhir, J. M., Rafek, A. G. & Abdullah, I. (2012). Analytical hierarchy process method for mapping landslide susceptibility to an area along E-W Highway (Gerik-Jeli) Malaysia. Asian Journal of Earth Sciences. 5(1), 13-24.

[20] Oztekin, B. & Topal, T. (2005). GIS-based detachment susceptibility analyses of a cut slope in limestone, Ankara–Turkey. Environmental geology. 49, 124–132.

[21] Pistocchi, A., Luzi, L. & Napolitano, P. (2002). The use of predictive modeling techniques for optimal exploitation of spatial databases: a case study in landslide hazard mapping with expert system-like methods. Environmental Geology. 41, 765–775.

[22] Roslee, Rodeano., Jamaluddin, Tajul Anuar. & Abd. Talip, Mustapa. (2012a). Intergration of GIS using GEOSTAtistical Interpolation Techniques (Kriging) (GEOSTAINT-K) in deterministic model for landslide susceptibility analysis (LSA) at Kota Kinabalu, Sabah, Malaysia. Journal of Geography and Geology. 4 (1), 18-32.

[23] Roslee, Rodeano., Jamaluddin, Tajul Anuar. & Abd. Talip, Mustapa. (2012b). Landslide susceptibility mapping (LSM) at Kota Kinabalu, Sabah using factor analysis model (FAM). ISSN 2231-8844. Journal Advanced Science and Engineering Research. 2, 80-103.

[24] Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process. Int. J. Services Sciences, 1(1), 83-98.

[25] Salciarini, D., Godt, J. W., Savage, W. Z., Conversini, P., Baum, R. L. & Michael, J. A. (2006). Modeling regional initiation of rainfall-induced shallow landslides in the eastern Umbria Region of central Italy. Landslides. 3(3), 181–194.

[26] Santacana, N., Baeza, B., Corominas, J., De Paz, A. & Marturiá, J. (2003). A GIS-Based multivariate statistical analysis for shallow landslide susceptibility mapping in La Pobla de Lillet area (Eastern Pyrenees, Spain). Natural Hazards. 30(3), 281-295.

[27] Sreemal, P. S., Champati Ray, P. K. & Srivastav, S. K. (2003). Remote sensing and GIS based method and software customization for landslide hazard assessment along Silchar–Shillong Highway, Northeast India. Trop Agric. Res.. 15, 316–326.

[28] Süzen, M. L. & Doyuran, V. (2004). A comparison of the GIS based landslide susceptibility assessment methods: multivariate versus bivariate. Environmental Geology. 45, 665–679.

[29] Temesgen, B., Mohammed, M. U. & Korme, T. (2001). Natural hazard assessment using GIS and remote sensing methods, with particular reference to the landslides in the Wondogenet area, Ethiopia. Physics and Chemistry of the Earth, Part C: Solar, Terrestrial and Planetary Science. 26(9), 665-667.

[30] Thiery, Y., Malet, J. P., Sterlacchini, S., Puissant, A. & Maquaire, O. (2007). Landslide susceptibility assessment by bivariate methods at large scales: Application to a complex mountainous environment. Geomorphology. 92(1-2), 38– 59.

[31] Uromeihy, A. & Mahdavifar, M. (2000). Landslide hazard zonation of the Khorshrostam area, Iran. Bulletin of Engineering Geology and the Environment. 58(3), 207-213.

[32] Van Westen, C. J., Rengers, N., Terlien, M. T. J. & Soeters, R. (1997). Prediction of the occurrence of slope instability phenomena through GIS-based hazard zonation. Geologische Rundschau. 86(2), 404-414.

[33] Van Westen, C. J. & Lulie Getahun, F. (2003). Analyzing the evolution of the Tessina landslide using aerial photographs and digital elevation models. Geomorphology. 54(1-2), 77– 89.

[34] Wieczorek, G. F., Gori, P. L, Jager, S., Kappel, W. M. & Negussey, D.

(1996). Assessment and management of landslide hazards near Tully Valley landslide, Syracuse, New York, USA. Proc VII Int. Symp. Landslides, Trondheim, June 1996. 411–416.

[35] Zaitchik, B. F., van Es, H. M. & Sullivan, P. J. (2003). Modeling slope stability in Honduras: parameter sensitivity and scale of aggregation. Soil Sci Soc Am J. 67(1), 268–278.