Application of engineering geology parameters to improve scrutinization of landslide zoning methods

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Abstract: Investigation of the main triggering factors of different types of landslides is one of the main tasks of engineering geologists. Much work has been conducted to interpret the effect of different factors on slope instability. However, the effect of engineering geology and geotechnical properties on active masses as the most important factors was rarely considered. There are several methods for regional assessment of landslides. The most popular one is preparing a zoning map of landslide hazard and risk. Using these methods, the effective factors on landslide instability are ranked and, based on these rankings and some simple rules, the necessary maps will be produced.

Review of previous work shows that normally the results of this method are not comparable with the real events. In some cases the correspondence of high hazard areas obtained from these methods and landslide events is less than 50%. It was found that most of this difference and error arises from inappropriate evaluation of geological and engineering geological factors. The susceptibility of different formations to generate sand, silt or clay-rich layers through mechanical and chemical weathering is the main factor that has to be taken into account. The Paleo-morphology method for the study of the source of deposited materials is a successful method to evaluate the general geotechnical characteristics of slopes. This method is capable of simulating the original morphology and showing the source of deposited materials. Then, by comparing the laboratory data for the different bulk composition of deposits, the materials can be ranked based on their geological and geotechnical characteristics. These rankings of masses can be used to improve scrutinization of landslide zoning models. This method and its application in the Alborz Mountains, in northern Iran, is introduced in this paper.

Résumé: L'investigation sur les facteurs déclencheurs principaux de différent type de glissement de terrain est une tache très importent pour les ingénieurs de géologie. Il existe plusieurs recherches sur l'interprétation de l'effet de différents facteurs sur l'instabilité des pentes. Cependant l'importance et l'influence des propriétés géologiques et géotechniques des massifs actifs été rarement considérées. Il y a plusieurs méthodes d'évaluation régionale de glissement de terrain. Les méthodes le plus connue comprends à préparer un carte de classification de risque de glissement de terrain. Dans ces méthodes, après avoir classifier les facteurs d'influence, différentes cartes nécessaires se produit en utilisant quelques règles simples.

La revue littérature montre que normalement les résultats de cette méthode ne sont pas comparables avec les événements observés. Dans quelques cas, pour les zones prévues comme très risqué, moins de 50% se coïncide avec la réalité. On a trouvé que pour le plus part des cas, cette différence est causée par l'erreur d'évaluation des caractéristiques géologique et géologie de l'ingénieur. A ce regard, le point très importent à tenir en compte est le suivant: la susceptibilité des formations à la production des couche riches en sable, silt et argile par le phénomène de désagrégation physique et mécanique. La méthode de paleo-morphologie pour l'étude de ressource des matériaux déposés est une méthode appropriée à fin d'évaluation générale des propriétés géotechniques des pentes. Cette méthode est capable à simuler la morphologie originale des pentes et bien détecter las source des matériaux déposés. Puis, par l'évaluation des caractéristiques géotechniques des matériaux désagrégés, le classement des matériaux est exploitées pour améliorer les modèles.

Keywords: engineering geology, mechanical properties, clay minerals.

INTRODUCTION

Regarding systematic regional development plans, and the necessity of development to higher elevation, engineering geology study is concerned at the preliminary study. Investigations and studies about the causes of landslides have formed one of the most active branches in geosciences during the last decades, which is greatly improved by the development of relevant new technologies. On the basis of planning requirements, landslide studies will be done on two scales; regional and site studies. Site study is usually planned and undertaken for specific purposes and used to support some particular project. The result of such study would be the estimation of a safety factor by using as much data as available. Regional study of slope instability is the basis of regional development plans. Such investigations usually are presented by hazard and/or risk zonation maps. There are many different methods for preparing landslide zonation maps. In most regional evaluating methods, by choosing some effective factors on slopes instabilities and defining some rules for each pixel of study area, a quantitative value is calculated, and then the values classified into 'completely unstable' to 'completely stable' classes to form the landslide zonation map.

The objective of a landslide hazard zonation map is subdivision of an area into zones with an equal susceptibility to, or possibility for, the occurrence of mass movement. Three main scales of analysis are used; Regional scale (<1:100,000), a medium scale (1:50,000-1:25,000) and a large scale (>1:10,000), (Westen 1993).

Since 1970, different methods for preparing landslide zonation maps have been introduced and applied. In all suggested methods, scoring and weighting of effective factors are varied due to the specification of the study area. In almost all models, essential factors such as topographical landform, slope angle, geology including lithology, and structure are considered. Variant factors such as precipitation, groundwater, and earthquakes are evaluated too. The number of necessary factors employed was suggested by the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE, 1993) as shown in Table 1.

Radbruch & Wentworth (1971) proposed a method with the scale of 1:170,000, which classified some factors such as slope angle, precipitation, and soil and rock characteristics, into classes between 1 to 6 that stood for minimum and maximum abundance of landslides. Then, based on the occurrence of landslides, soil and rocks were divided into 8 classes.

Brabb (1972) assigned values for effective factors as 1 to 3 for preparing hazard map based on geological setting and landslide inventory maps. He found a good relation between landslide occurrence and geological setting.

Stevenson (1977) proposed a formula involving clay (P), water (W), slope angle (S), slope complexity (C), and land-use (U) for clay slopes of the Tasmania region. The risk was then calculated as: Risk= (P+2W)*(S+2C) (U); the first two brackets presenting hazard and multiplying by U offering risk. If the value of risk was 60 or higher, failure happened. The risk value of 50 was critical, and when the value was less than 50, the slope was stable.

Table 1. Various grades of landslide hazard zonation map based on ISSMGE recommendation

Grade 1	**Grade 2**	**Grade 3**
1-Available data and historical earthquake data 2-Geological, geomorphology, and vegetation maps	1-Aerial photography and remote sensing 2-Field work 3-Precipitation and vegetation data	1- Geotechnical investigations data 2- Data analysis
1:5,0000 and 1:100,000	**1:10,000 to 1:100,000**	**1:5,000 to 1:25000**

Meneroud (1978) scored six factors of topography, discontinuity in rocks including orientation, dip angle, and spacing, vegetation, existence of retaining structures, obvious failure, and hydrology between 0.1 and 2. In this method for the evaluation of the level of risk, the scores are summed together to form the landslide hazard map.

Nelson (1979) proposed a method to prepare a landslide hazard map at a scale of 1:125000. In this method, a slope gradient map of less than 5%, between 5% to 15%, and more than 15%, a landslide deposit inventory map, and a landslide sensitivity map on the basis of occurrence were prepared and crossed. Then, the region is divided into 6 classes to predict the landslide probability of the area.

Later, the Japanese Kanagawa Prefecture Report (1987) suggested a more complete method with a scale of 1:50,000 weighting 7 factors as shown in Table 2.

Table 2. Factors of Kanagawa method

Maximum acceleration in GAL (W1)		Length of counter line in metres (W2)		Maximum elevation difference in metres (W3)		Rock hardness (W4)	
GAL	Value	length	Value	Difference	Value	type	Value
<200	0	<100	0	0-50	0	Soil	0
200-300	1.004	100-150	0.71	50-100	0.055	Soft rock	0.169
300-400	2.206	150-200	0.32	100-200	0.591	Hard rock	0.191
>400	2.754	>200	0.696	200-300	0.804		
				>300	1.431		

Table 2. (continued)

Fault length in metres (W4)		Cut slope Length or embankment in metres (W6)		Topographical landform (W7)	
Length	Value	Length	Value	Form	Value
0	0	0-100	0	Convex line	0
0-200	0.238	100-200	0.539	Straight line	0.151
>200	0.710	>200	0.845	Sinus line	0.184

Then, the weight of each pixel was calculated as: W=W1+W2+W3+W4+W5+W6+W7, where W is failure susceptibility. Stability classes were defined by following practical as Table 3:

Table 3. The result of stability evaluation by Kanagawa method

W	2.93 3.53 3.68			
Class of each unit of the net	A (stable)	B	C	D (unstable)
Number of slides in each unit of the net	0.00	1-3	4-8	9

One of the most careful and reliable methods was suggested by Anbalgan (1992). He proposed a method to prepare maps at 1:12,000 scale. Three main factors were used to evaluate the landslide susceptibility. Maximum values of each factor were as shown in Table 4.

Table 6. Maximum values of Anbalgan method

Effective factors on instability	Maximum value	Effective factors on instability	Maximum value
Lithology	2	Relative topography	1
Discontinuity	2	Land use and vegetation	2
Slope geometry	2	Groundwater condition	1
		Sum of values	10

In this method, lithology was classified into four types. Type 1: extremely hard rocks including quartzite, granite and gneiss with a value between 0.2 and 0.4. Type 2: sedimentation rocks (well or poorly cemented) including a range from sandstone with well-cemented layers and layers of marlstone to sandstone with poor cementation and thin layers of shale and marlstone. The value of this type ranged from 1 to 1.3. Type 3: soft rocks including slate and pelite, schist and shale with inter-beds of clay and non-clay, layers of shale and ultra-weathered schist. The value assigned for this type ranges from 1.2 to 2.0. Type 4: soils including compact fluvial and alluvial, eluvial, sandy soils with natural surface, collovial including rock boulders, clay soil, and sand. Old compact soil and young loose soils belong to this type. The values of this type ranges from 0.8 to 2.0.

Sub-factors of weathering: included ‘extremely weathered’ C1, ‘medium weathered’ C2, and ‘slightly weathered’ C3. This sub-factor was C3=2, C2=3, and C1=4 for type 1 of the lithology. For lithology type 2 the values were C3=1, C2=1.25, and C1=1.5.

Discontinuity: regarding the relationship between slope and the dominant discontinuity angle, which could be planar or wedge shape, the thickness of soil over the slope received the value of 0.2 to 0.85. Exceptionally, where the thickness of soil was more than 15m, the values increased to 1.3.

Slope morphology: This characteristic was classified into cliff/rock, relatively steep slope, gentle slope angle, or very gentle slope angle, the values allocated for each class would be 0.2, 1.7, 1.2, 0.8, and 0.5 respectively.

Relative topographical difference: it was divided into <100m with the value as 0.3, between 101 to 300m as 0.6, and where >300m the value was 1.0.

Land-use: including agriculture land-use with the value as 0.65, residential and dense with 0.8, medium coverage of vegetation as 1.2, scattered vegetation 1.5, and arid land as 2.0.

Condition of groundwater: including with water current as 1.0, saturated as 0.8, 0.5 for wet, 0.2 for moisture soil, and 0.0 for dry soil.

In the final stage, by summarizing the values and scores landslide probability hazard was considered in terms of 5 levels, as shown in Table 7.

Table 7. Landslide susceptibility hazard and scores in Anbalgan method

Class	Score	Susceptibility hazard	Class	Score	Susceptibility hazard
I	>3.5	VL	IV	6.1-7.5	H
II	3.5-5.0	L	V	>7.5	VH
III	5.1-6.0	M			

VL: very low, L: low, M: medium, H: high, VH: very high

MAIN PURPOSE OF THIS WORK AND METHOD OF INVESTIGATION

In almost all the models mentioned, essential factors such as topography and landform, slope angle, geology including lithology and structure, as well as variable factors such as precipitation, groundwater and earthquakes have been considered. The scoring of factors that are capable of quantitative evaluation such as slope angle topographical parameter, earthquake and precipitation in most models are similar. The weighting of these factors depends on their effectiveness in a certain area. The main problem that affects the reliability of hazard assessment methods is the evaluation of geological and geotechnical characteristics of land that play the main role in slope instability. As is clear from mentioned methods, the scoring and weighting of geological factors in each model varies, due to the specification of the study area and the different role of this factor on triggering landslides.

To improve scrutinization of landslide hazard zonation, in particular for large scale landslide hazard maps, the parameters of engineering geology and geotechnics should be carefully taken into account. In this paper the method of paleo-morphology was suggested as an effective tool for detailed field classification. This method was employed in a landslide prone area. Comparing with the landslide inventory map for this area, the result was very reasonable.

STUDY AREA

The selected area is located along the Haraz Highway (52°13'E to 52°20'E and 35°54'N to 35°59'N), one of the busiest highways from Tehran to the Caspian Seaside (Fig. 1). A large scale geology map of the region was prepared by detailed field survey. The geology of the area, part of the southern flank in Central Alborz, is very complex and mainly composed of:

- *Shemshak Formation* (lower Jurassic): this formation in study area composed of shale, dark sandstone, with organic component and coal layers.
- *Lar Formation* (upper Jurassic): this formation in study area comprises thick layer massive limestone with 150 to 200m thickness
- *Tiz-Kuh Formation* (lower Cretaceous): this formation in study area shows light fine-grain limestone. Morphology of Tiz-Kuh Formation forms steep slopes in study area similar to Lar Formation
- *Quaternary Formations*: Alluvial terraces with slight tilting to the valley are the most common Quaternary formation around study area. Scree and colluvium are also widely distributed in the area and form soft deposited material at the toe of steep mountains.

Structural elements such as faults, joints, and bedding layers, except folding forms weakness surfaces and discontinuities and have some effective role in slope instabilities. Anticline and synclines with a W-E trend are sequentially repeated in the study area (Fig. 1). Most of the old or young landslides are located close to major faults. It seems that activity of these faults has some effect on instabilities in the region.

Earthquakes around the study area are mostly large and shallow. According to the historical seismology study of the region, the depth of earthquakes ranges widely from 10 to 20Km. and most of the quakes in the study area are between 0 to 5.9 in magnitude (Ms)[6]. The maximum acceleration of the activities of 17 faults within 100Km of the study area for average earthquake magnitude of 6 ranges from 0.03g to 0.45g.

Based on the analysis of 11 years data of climatology station, the maximum precipitation was 720.9 mm in 1996, and the minimum precipitation was 347.1 mm in 1990. Maximum precipitation is 119.5 mm in March and the minimum is 2 mm in September. At the same period of time, the maximum precipitation belonged to winter with 85.5 mm and the minimum, 6.9mm belonged to summer. Regarding the average amount, the total precipitation in winter is more than spring. The average monthly precipitation in the area is 45.55 mm.

The study area is known as a landslide prone area. As shown in Figure 1, many landslides have occurred in this area. Some villages and residential sites are located in this area. This area has suffered mostly from damage due to landslide activity. Evidence for landslide activity is clear as tensional cracks on the ground surface and in rural houses, bending of power line and trees, and disturbance of morphology.

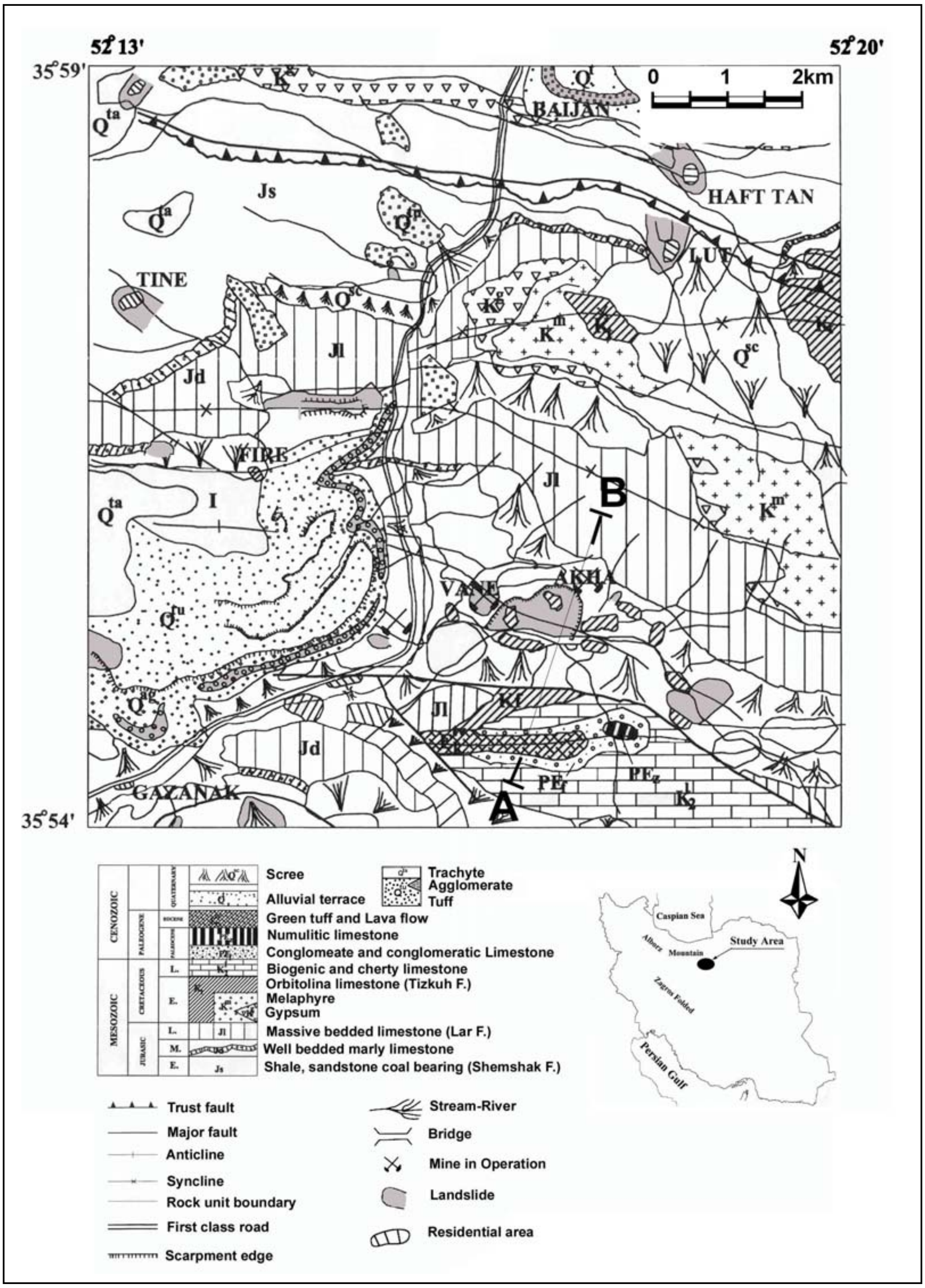


Figure 1. Location and detail geological map of the study area.

PALEO-MORPHOLOGY METHOD

As mentioned, scoring the geological and geotechnical behavior of hard and soft masses is one the most important part of landslide hazard mapping. Generally, different rock units of geology formations mechanically and chemically weather rapidly to produce different kind of soils. Parts of these detached materials eroded off the area by transporting stream and rivers to the lowlands depressions and most part of them remain at foot hill as colluvium or at outlet of mountain as alluvium. In most landslide hazard zonation methods the geological ranking of material is based on a simple definition of rock and soft soil. The review of the final results of some methods is not comparable with the landslide events that have happened in the field. In some cases the match between high hazard zones and actual landslides is less than 50%. These differences and errors arise, for the most part, from inappropriate evaluation of geological and geotechnical properties of masses.

The Paleo-morphology method (Shoaei 2001) was suggested for the study of source formations of deposited material and for a careful evaluation of geological and geotechnical characteristics of masses on slopes. The susceptibility of different formations to generate sand, silt or clay-rich layers through mechanical and chemical weathering is the main factor that has to be taken into account.

The method of Paleo-morphology is based on the fact that proper knowledge of structural geology and lithology of an area can be used to simulate the original morphology. Thus, the composition and the sequences of sedimentation of deposited material can be evaluated. An example of such a simulation is shown in Figure 2. If the original morphology had been composed of clayey layers, it would be expected to have clay-rich deposit at the foothills that are unstable in the presence of water with slow failure rate, or the presence of coarse sandstone layers in the original morphology should have resulted in a sandy deposit at the foothills that is susceptible to liquefaction and rapid failure due to additional loading.

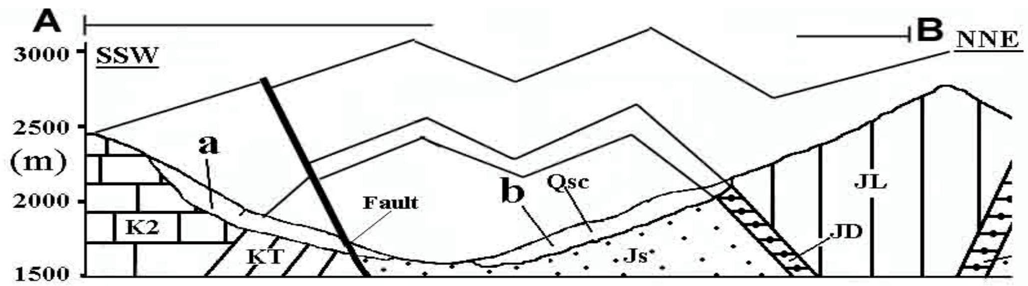


Figure 2. Example of paleo-morphology simulation, the direction of section is shown in Figure 1.

In this section the deposited material of area “a” is more stable than area “b” because the amount of clay content in JD and Js formation is much higher than K2 and KT as the source of “a” and “b”, respectively. This was confirmed in the field survey. Combination of field assessment data with quantitative analysis of different bulk composition of deposits through laboratory works will result in the engineering geological and geotechnical ranking and sub-ranking of soft material in mountainous terrain.

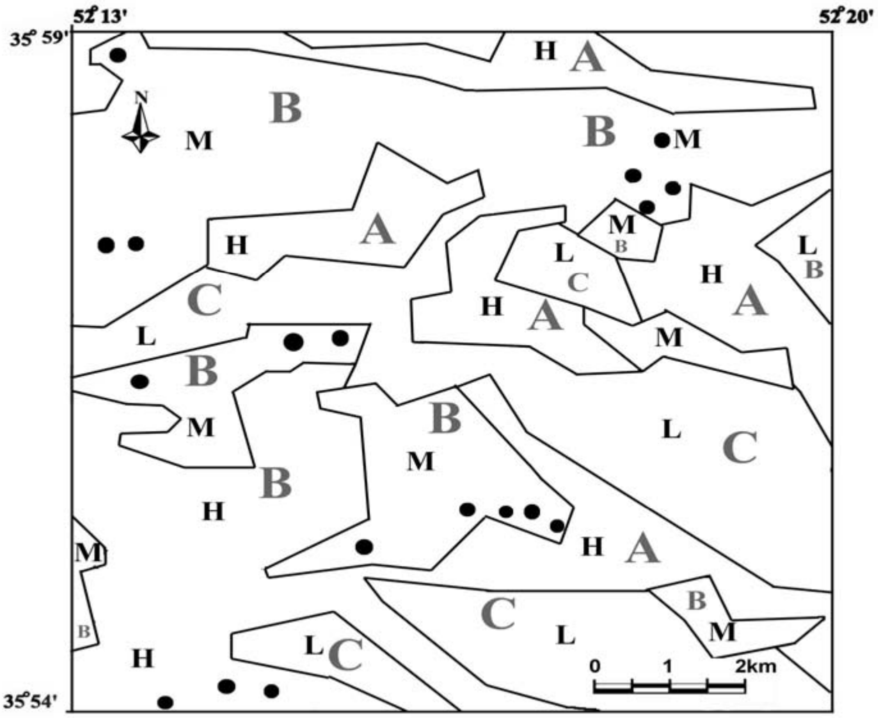
An area of 100km^2 (10*10km) was selected for landslide hazard mapping. The method of Anbalgan (1992) was selected for modification because of its suitability for large scale mapping and a good classification of lithology. The details of this method are mentioned in a previous chapter. Based on effective factors in the selected area, the landslide hazard map for this area was prepared. The result is shown in Figure 3.

At the next stage, first, the different class ranking was revised based on the capability of Paleo-morphology method. Four types of Anbalgan were modified as follows:

- Class 1: The value of hard rocks including quartzite, granite and gneiss, crystalline limestone ranges between 0.2 and 0.4.
- Class 2: sedimentation rocks with well cement including sandstone to hard marlstone (well cemented) ranges from 0.5 to 1.0.
- Class 3: The values of layers of marlstone to sandstone with poor cementation and thin layers of shale and marlstone range from 1.0 to 1.5.
- Class 4: The values soft rocks including slate, schist and shale. The value assigned for this type ranges from 1.2 to 2.0.

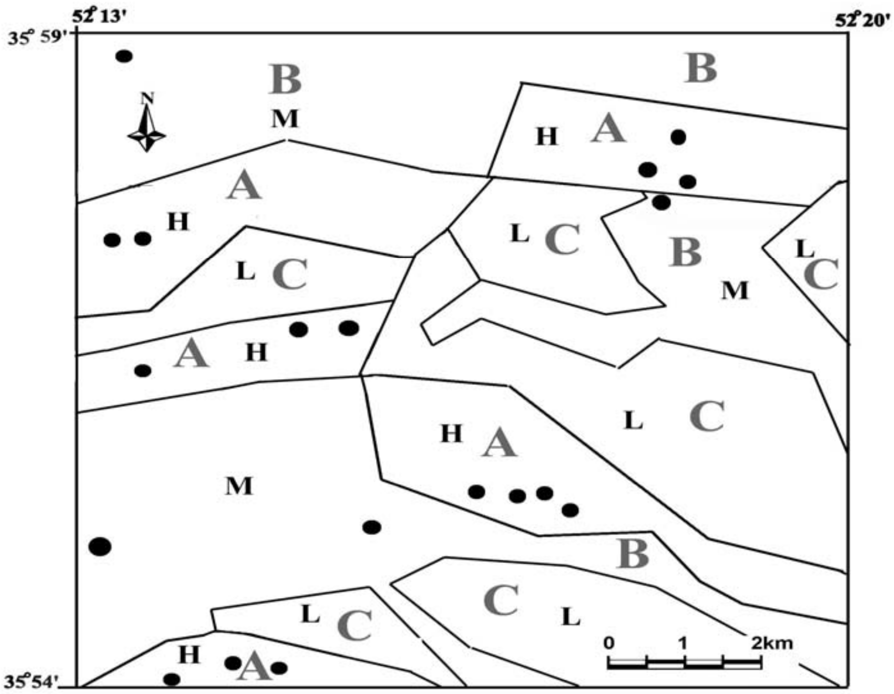
A “coefficient of clay effect” was considered for the values of this class:

- Coefficient “2.5” for the soft rocks with approximately >50% clay content or having >50% inter-bedded clayey layers.
- Coefficient “2” for the soft rocks with approximately 20-40% clay content or having 20-40% inter-bedded of clayey layers.
- Coefficient “1.5” for the soft rocks with approximately 5-20% clay content or having 5-20% inter-bedded of clayey layers.



●: Landslides, A(H): High hazard, B(M): Medium Hazard and C(L): Low hazard

Figure 3. Landslide zonation map using conventional method of geological and geotechnical scoring and ranking.



●: Landslides, A(H): High hazard, B(M): Medium Hazard and C(L): Low hazard

Figure 4. Landslide zonation map using paleo-morphology for field evaluation of geological and geotechnical properties of masses

- Coefficient "1" for the soft rocks with approximately <5% clay content or having <5% inter-bedded of clayey layers.

- Class 5: Soils including compact fluvial and alluvial, eluvial (clay soil), sandy soils with natural surface, colluvium including rock boulders, clay soil, and sand. Old compact soil and young loose soils belong to this type. The values of this type ranges from 1.5 to 2.0.

Sub-classification was performed for material in class 5:
A "coefficient of clay effect" was considered for the values of this class:

- Coefficient "2.5" for the soft rocks with approximately >50% clay content or having >50% inter-bedded of clayey layers
- Coefficient "2" for the soft rocks with approximately 20-40% clay content or having 20-40% inter-bedded of clayey layers
- Coefficient "1.5" for the soft rocks with approximately 5-20% clay content or having 5-20% inter-bedded of clayey layers
- Coefficient "1" for the soft rocks with approximately <5% clay content or having <5% inter-bedded of clayey layers.

The effect of weathering in Anbalgan method is combined with lithology classification. Then, the modified classification of lithology and Paleo-morphology method were employed for geological and geotechnical ranking of deposits. The new classes of rock and soil were used for preparing landslide hazard zonation map. The result is shown in Figure 4.

DISCUSSION AND CONCLUSION

Figure 3 shows the prepared landslide hazard zonation map using 4 classes of lithology suggested by Anbalgan (1992). The studied area is divided into "A", "B" and "C" zones standing for "High hazard", "Medium hazard" and "Low hazard" of landslide, respectively.

The total number of landslides in this area was 18 with 16.7% of them located in high hazard zones, 83.3% of them in medium hazard zones, and nothing in low hazard zones. This accuracy is nearly acceptable for preparing regional scale maps of landslide hazard. However, the location of 83.3% of landslides in medium zones is a sign of low adequacy of this model for larger scale maps.

The prepared map using modified classes of lithology and Paleo-morphology method for field evaluation is shown in Figure 4. As it is obvious from this map, among the total of 18 actual landslides in the area, 77.7% are located in high hazard zones, 22.22% in medium hazard zones, and nothing in low hazard zones. The good agreement between the result of the model and inventory map of occurred landslides confirms the high accuracy of the suggested method. This method can be employed for improving scrutinization of landslide zoning methods by detailed re-classification of geological and geotechnical properties of slope masses.

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