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Application of a Physically based Model for Terrain Stability Mapping in North of Iran

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APPLICATION OF A PHYSICALLYBASEDMODEL FOR TERRAIN STABILITY MAPPING IN NORTH OF IRAN

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I. Introduction

Landslides are one of the main geological problems in study area. Multiple causal environmental factors influence on the occurrences of landslides in along the road. Forested slope of northern a lborz mountainous in north of iran is one of the most hazardous sliding area. In the last few years, the landslide events have been increased due to large-scale and major land-use changes by agricultural and housing development, road and building constrictions in areas susceptible to landslides. The area's most seriously affected by landslide occurrence and caused destruction road accessing and rural settlements.

There are many approaches [fig.1] to assessing slope stability and landslide hazards (Sidle et al., 1985; Montgomery and Dietrich, 1988; Dietrich et al., 1992; Sidle, 1992; Dietrich et al., 1993; Montgomery and Dietrich, 1994; Wu and Sidle, 1995; Pack, 1995). The most widely used include (Montgomery and Dietrich, 1994): (A) field inspection using a checklist to identify sites susceptible to landslides ; (B) projection of future patterns of instability from analysis of landslide inventories; (C) multivariate analysis of characterizing observed sites of slope instability; (D) stability ranking based on criteria as slope, litho logy, land form, or geologic structure; and (E) failure probability analysis on slope stability models with stochastic hydrologic simulations. Each of approaches is valuable certain applications (Pack et al., 2001).

The geotechnical model, which is deterministic or probabilistic, has been widely employed in civil engineering and engineering geology for slope stability analysis. A deterministic approach was traditionally considered sufficient for both homogenous and non-homogenous slopes. The index of stability is a well-known safety factor, based on an appropriate geotechnical model and on the physical mechanical parameters. Calculating the safety factor requires geometrical data, data for the shear strength parameters and information on pore water pressure.

Montgomery and Dietrich (1994) developed a physically-based model based upon a combination of the infinite slope equation, and a hydrological component based on steady-state shallow subsurface flow. This model, called SHALSTAB, has been used extensively by researchers within the forestry field in the western US (Montgomery et al., 1998) and in Italy (Borga et al, 1998). Other slope stability models developed by the US Forest Service are the Level I Stability Analysis (LISA) and Stability Index Mapping (SINMAP) which are both based on the infinite slope equation. All the deterministic models were executed using special extension in the spatial analysis in recent types of the Arc GIS software (Safaei et al., 2010). The model has evaluated by comparison between landslide predictions by the model with occurrence landslide in the area.

Furthermore, this model has been applied successfully by several researchers in different parts around the world (Rafaelli et al, 2001; Csadei et al, 2003; Claessenss et al, 2005; Santini et al, 2009; Cervi et al, 2010). The methodology is a couple with a hydrological model and an infinite slope stability model using ARC GIS software. The model was applied to the road region named Kiasar in north of Iran. A digital elevation map (DEM) was prepared maps of slope and contributing area was also determined. The soil property parameters

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were obtained from laboratory testing extracted from 15 site investigations.

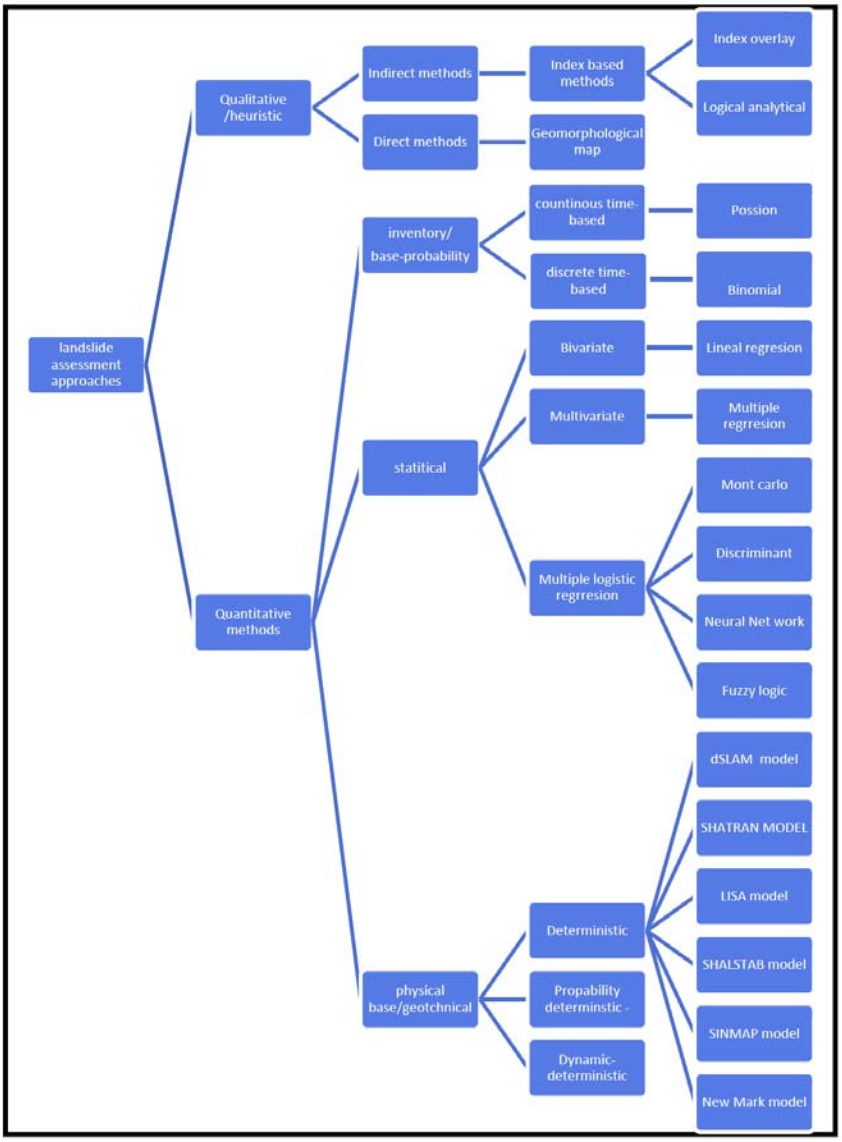

Figure 1 : Classification of landslide susceptibility assessment approaches (Safaei et al., 2010)

II. Study Area

The study area is located in the Northern Alborz Mountainous in Mazandaran state in north of Iran; the study area is approximately 200 km² as the portion of Tajan watershed in south of Sari's city and a long of Kiasar Road (Fig. 1).

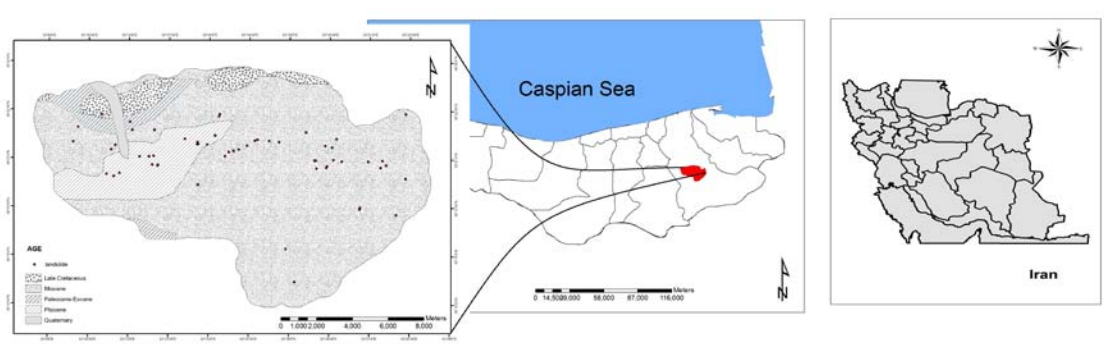

Figure 1 : Location map for the study area

The Digital elevation model (DEM) of the study area shows that the topographic elevation is from 210 to 1976 meters. Furthermore, the weather statistics show that the greatest amount of rainfall was occurred during December with a mean value of 110 mm.

Table 1 : Average Monthly rainfall data over a period of 10 years (2000 - 2010) covering three rainfall stations located within the study area

Rainfall (mm)	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Average	72.1	41.3	44.8	45.0	35.3	58.8	94.4	104.8	110.6	71	79.25	73.9
minimum	9	25	0.7	0.5	4.5	21	32.5	56	43.5	13	31	30.5
Maximum	136	64.5	106.5	89	103.5	83	160	167.5	144	243	150	157

Figure 2 : (a) A Landslide occurrence in the along the road (b) impact of landslide movement of the tree

Geological characteristics of the region are including the Paleozoic, Mesozoic and Cenozoic formations. The Miocene marls formation ($M^{m,s}_{2,3}$) consists of marl, calcareous sandstone, and siltstone, silty marl, sandy limestone and mudstone is the most extension and most of landslides located in this formation. Alborz Mountains range expands from the northern part of the orogenic part of the Alps to the western Himalayas in Asia. Within the area of study, a large section of the heights overlooking the city of Sari and some central parts of the area, the folding portions of Meo- Palaeocene, the southern parts of upper Cretaceous in the core of anticline and syncline or are in contact with protruding faults (Safaei et al.,2012). The faults are exposed in roughly East to West and these consist of two major thrust faults named Khazar and North Alborz fault and three minor faults with the North East - South West trend (fig.3).

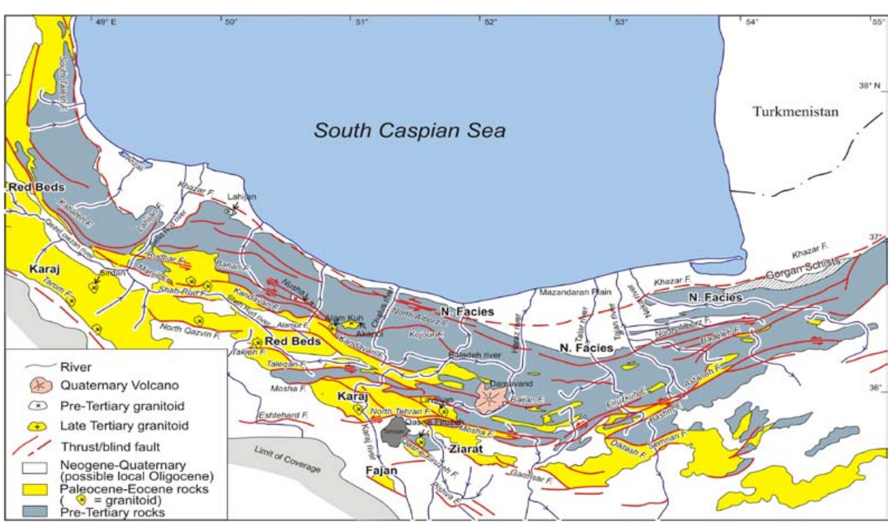

Figure 3 : Generalised geological-structural map of the Alborz (After Rezaeian, 2008)

III. Method

Field investigation and landslide inventory map

1. Geotechnical investigation of soil
2. Topographic attributes
3. Running landslide prediction model

In this study, methodology includes the following fourth main steps:

A landslide inventory has been mapped using the landslides that occurred within the area after construction road. The topographic attributes (slope and contributing area) were generated from the DEM with a 10 - 10 m grid size for the study while the Characteristics of Soil (thickness, hydraulic conductivity, density, cohesion and friction angle) obtained from field investigations and laboratory testing in 15 landslide points.

SHALSTAB(Shallow Landsliding Stability) is a deterministic model for predicting the rainfall shallow landslide, based on topographic control and has been developed since the early 1990s (Dietrich et al., 1992, 1993, 1995; Montgomery and Dietrich, 1994) .

SHALSTAB combines a steady-state hydrological model with an infinite slope stability model. The model tested and applied first in United States and then in around the world and the results has been often satisfactory. It performs as an extension to the GIS program Arc View on DEM (digital elevation models). Equation (1) shows the main equation to the model to compute for each grid cell as unite mapping. Although it can be solved for the critical rainfall (Qc) required to trigger landslides in the study area, since we did not have much reliable data concerning the spatial variability of soil transmissivity (T), we used the ratio Qc/T, as mentioned by Dietrich and Montgomery (1998).

$$\log\frac{Q}{T} = \frac{sin\theta}{a/b}\cdot\left[\frac{c'}{\rho w\,.\,g.\,z.\cos^2\theta.\tan(\varphi,)} + \frac{\rho s}{\rho w}\cdot\ (1-\frac{\tan\theta}{\tan\varphi,})\right] \qquad (1)$$

Where:

Qc is the critical rainfall necessary to trigger landslides; T is the soil transmissivity (as a product of soil thickness and saturated hydraulic conductivity); a/b is the contributing area per contour width? θ Is the local slope, ρw is the density of water; g is the acceleration of gravity, z is soil thickness; ρs is soil bulk density, φ is the soil friction angle and c Is cohesion. The levels of instability base on Log $Q\cdot T^{-1}$classes have been shown in Table.2.

Table 2 : Class definition of SHALSTAB model

Classes SHALSTAB	Interpretation of Class
Chronic instability	Unconditionally unstable and unsaturated
Log $Q\cdot T^{-1} < -3.1$	Unconditionally unstable and saturated
$-3.1 <$ Log $Q\cdot T^{-1} < -2.8$	Unstable and saturated
$-2.8 <$ Log $Q\cdot T^{-1} < -2.5$	Unstable and unsaturated
$-2.5 <$ Log $Q\cdot T^{-1} < -2.2$	Stable and unsaturated
Log $Q\cdot T^{-1} > -2.2$	Unconditionally stable and unsaturated
Stable	Unconditionally stable and saturated

IV. Results

The Figure (4) shows a Geology and landslide distribution of the study area and that the places of highest instability is located in the around the main road of the region.

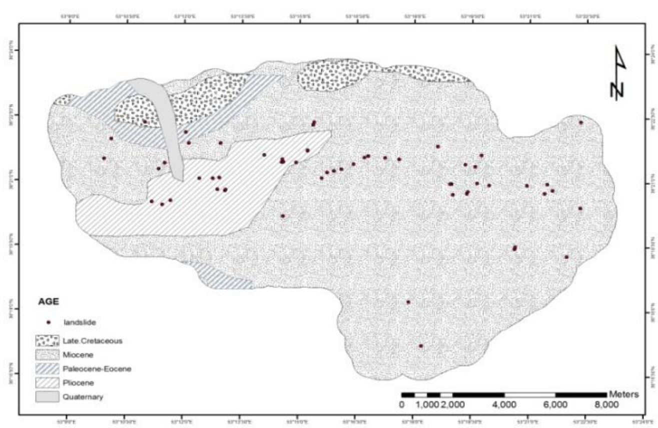

Figure 4 : Geology and landslide distribution map of the study area

Table 3 : Soil parameters obtained from boreholes

Sample	soil thickness	φ'(degrees)	c'(kpa)	ρs(kg/m^3)
1	2	0	50	2000
2	2.5	40	30	2100
3	4	5	35	1950
4	3.5	36	5	2100
5	5	14	40	2100
6	4	1	20	1800
7	4	29	0	2000
8	4	0	20	1800
9	3.5	30	0	1850
10	3.7	32	0	1980
12	2.85	3	49	1950
13	2	38	67	2100
14	3.7	13	26	1980
15	3	19	55	2060
Average	3.4	18.5	28.35	1983.5

Soil parameters obtained from boreholes shown that the mean values for running model are include 3.4(m), 18.5(degrees), 28.35(kpa) and 1983.5(kg/m^3) for H, φ', c', ρs respectively.

Contribution area and slope map extracted from DEM map using the model that shown in figures (5) and (6). The landslide susceptibility of study area based on different stability classes has shown in figure (7).

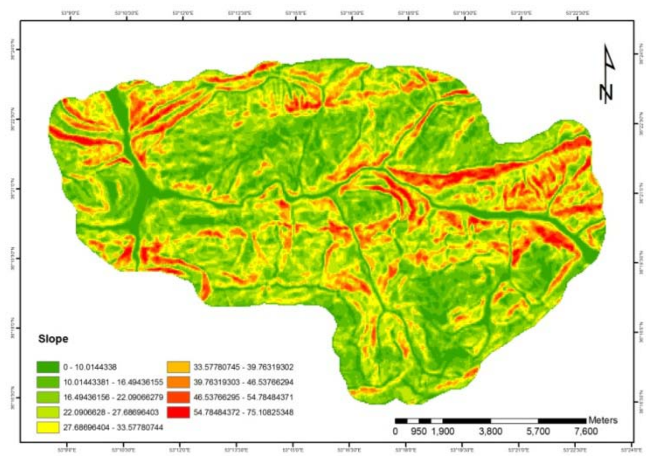

Figure 5 : Slope map of study area

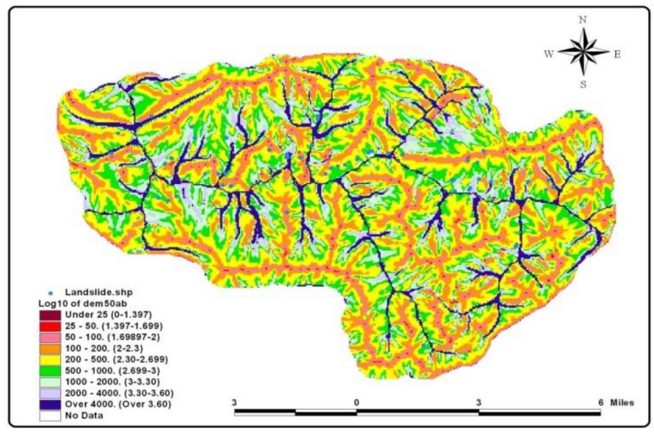

Figure 6 : Map of contribution area

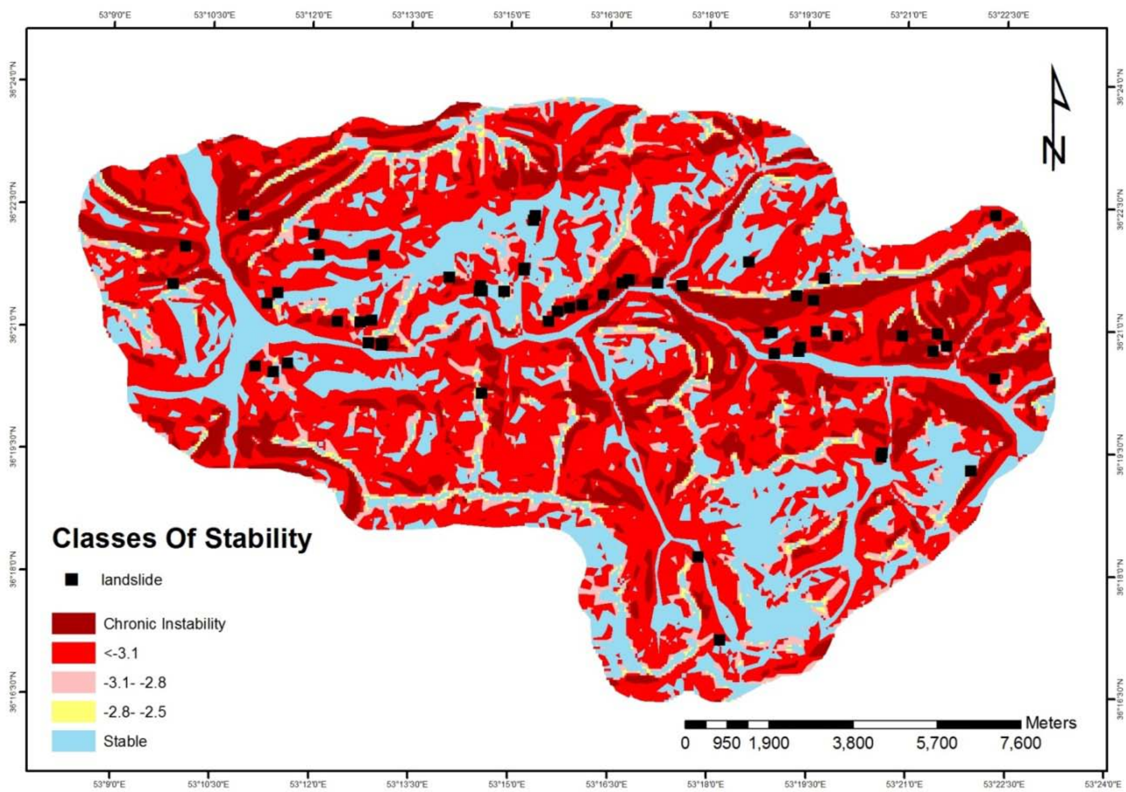

Figure 7 : Map of landslide susceptibility to translational landslide in the study area

The statistical results of stability classification have shown in Table 4

Table 4 : The statistical summary of the results of the SHALSTAB analysis

	SHALSTAB Instability log(q/T) classes					
Area	10 (unconditionally Stable)	(-2.8- -2.5) (moderat)	(-3.1- -2.8) (moderate high instability)	<-3.1 (high instability)	-10 (unconditionally Unstable)	Total
Region (km^2)	50.7	3.81	13.46	96.5	31.5	195.97
% Area	25.9	1.9	6.9	49.2	16	100
Number of Landslide	7	0	4	37	15	63
%Landslide	11.2	0	6.3	58.7	23.8	100

V. Conclusion

In order to predict future landslides in the region, landslide susceptibility mapping has prepared in the area. Major part the slopes are covered by vegetation, which mainly consists of alder, hornbeam and maple then the model, is unable to calculate of Root Strength in slope stability. Therefore, this is an important limitation for application to the model in the area.

Figure (7) is shown different instability classes base on - log (q/T) parameter (Table 4). Approximately, 30% of the entire slope stability modeling area study area was classified as unconditionally stable. Furthermore, about 10 percent of observed landslides located in the stable zone that indicated error of the model. About 70% of the area classified as an unstable area that illustrated high-potential landslide hazard. About 16% of area classified as unconditionally unstable with 15 observed landslides and also on 50% is shown as a high instability zone with 37 landslide locations and about frequency of 60%. SHALSTAB instability classes on different lithology have been shown which Miocene information makes up nearly 90% of the underlying lithology that classified as instable or moderate instability. Therefore, the lithology is a most important intrinsic causal factor in study area.

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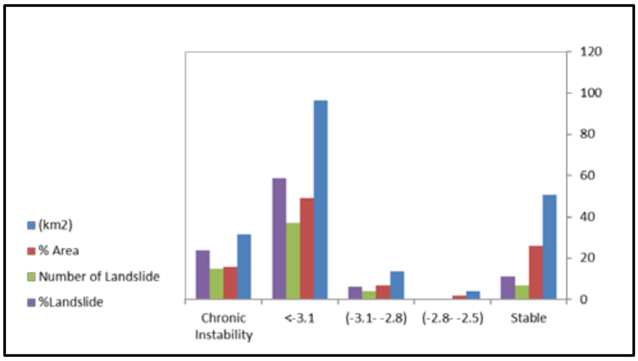

Figure 8 : Frequency and Distribution of landslides (number and area percentage) in different stability classes

Overall percentage of landslide points correctly classified up to 88%. Therefore, the results have shown that even using a small scale (1:50.000), the model is a considerable predictive tool to recognize landslide susceptible zones. Base on results, the model is more accurate in compare with other models for prediction rainfall induced landslide.

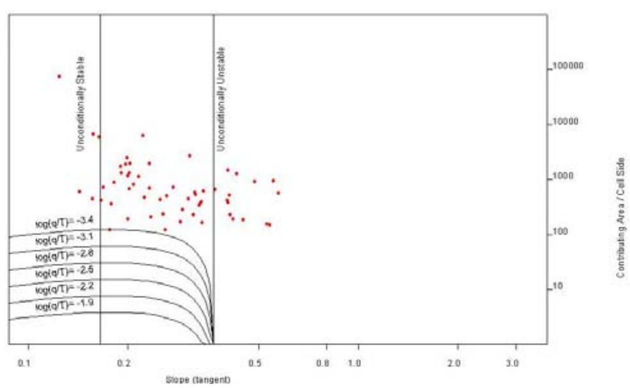

Figure 9 : Slope-contribution area plot of study area which landslide sites are indicated by the red points

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