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Investigation of The Effect of Topography On Shallow Landslide Occurrence Utilizing Physically Based Model

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ABSTRACT

Todays, slope and event of shallow landslides are of the fundamental administration challenges in utilizing uplands. This research aims at studying shallow landslides in the slopes of Javanrood region applying physically- based model (Talebi 2008), especially slope plan and longitudinal profile. Considering slope plan (concave, convex, parallel), longitudinal profile of slope (concave, convex, direct), subsurface hydrology, and soil mechanical features, this model analyzed slope stability factor. As a result, 12 slopes, including 7 sliding and 5 non- sliding slopes, were selected as case study in Javanrood region. Then all variables of slope stability analysis were extracted by field and experimental studies and factor of stability was calculated for each slope. The results showed that the occurrence of shallow landslide in Javanrood Region is due to topographical, hydrological, and geo-mechanical features of soil, as convergent slopes with concave longitudinal profile and the soils with low internal friction angle and high saturation storage are more prone to landslide. In addition to this, this research showed that slope stability analysis model is efficient enough to determine instability in slopes sliding under natural conditions, because in stable and unstable slopes, stability is less than1 and more than 1.5, respectively.

Keywords: *Factor of safety; Landslide; Physical based Model; Topography; Talebi (2008)*

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INTRODUCTION

Landslides are of the most well-known normal wonders overall, creating significant property harms and losses consistently (lan, 2004).Indeed, with the exception of the variables like soil profundity (Iida, 1999) and storm properties (D'Odorico et al., 2005) assuming a fundamental part in the instrument of landslide activating, the quality of the soil and the geometry of slope likewise handle activating of surface landslides. Besides, Hennrich and Crozier(2004) trusted that topographical properties, exceptionally incline point and convergence, control the stability of surface landslides. The discoveries from field studies and numerical simulation have indicated that bedrock profile curvature and slope plan shape impact subsurface stream and saturation of the slope a lot (Troch et al., 2003). Montgomery and Dietrich (1994) and Borga et al. (2002) contended that surface landslides increment soil saturation altogether, as well as decline shear strength of soil by surface topography through subsurface stream merging. In addition, slope angle, slope shape (e.g. concavity or convexity) and the soil (regolith) depth were viewed as the best controlling variables of surface landslides by Iida (1999).Utilizing field studies and numerical simulation, Crozier (2004) researched the impact of morphology and slope on stability in which the impressive impact of bed rock curvature and slope shape on subsurface stream and saturation were indicated. Talebi et.al (2008) gave a physical model which could explore the dynamic control of surface landslides in complex slopes. Those landslides which are generally made in the slopes with variable bed and various shapes are considered by the previously mentioned model. In addition, hydrology additionally influences landslide start a lot. Utilizing mathematical methods of slope stability analysis and modeling, some researchers (Crosta et al. 2003, Simoni et al., 2004, Rosso et al., 2006; Claessens et al. 2007,; Godt et al., 2008a, b; van Asch,2009, Baum et al., 2011,.Vita et al,2013,) have investigated the effect of hydrological processes on slope stability. They have defined a soil saturation index helping predict the groundwater level. The Physically based models have been applied by different investigators throughout the world to evaluate slope instability. Reviews outlining the methods are given by , Gorsevski et al. 2003 ; Salciarini et al. 2006 ; Fell et al. 2008 ; Sorbino et al., 2010; Rossi et al., 2013; Lu etal.2015; Bordoni 2015). Physically based models are used for the evaluation of landslide controlling slope instability. One of the most popular approaches is infinite slope stability analysis(e.g. Montgomery and Dietrich, 1994; Wu and Sidle, 1995; Van Beek, 2002; Borga et al., 2002; D'Odorico and Fagherazzi, 2003; Hennrich and Crozier, 2004; Claessens, 2005;, James etal,2010 ; Capparelli etal 2010; Nguyen Thanh,2013; Formetta,2014 ; Chae et al,2015 ; Davis,2015). In the aforementioned approach, the parameters, for example, cohesion, angle of internal friction, pore-water pressure, typical and tangent stresses, and soil weight are utilized to assess the stability of a slope. The proportion of nearby balancing out and main impetuses was extracted by the discoveries from safety factor in which the values more noteworthy than 1 indicate the stability of the slope. Conversely, the values under 1 indicate precarious conditions. Regardless of all fundamental process models presented to assess slope stability recently, none of them considered the impact of three dimensional hillslope shape (profile curvature and plan) on capacity and slope stability. Accordingly, fuse of the topographic structure of hydrologic processes in slope stability models perceiving the role of (three-dimensional) hydrological processes on slope stability better appears to be essential. This physically- based model is Talebi (2008), a model which determines stability coefficient for each slope in the respective region by combining slope morphology model, hydrology model and slope stability analysis.

2. The study Area

An area was chosen in the range between 34^0 39′ to 34^0 56′ northern latitude, and 46^0 10′ to 46^0 36′ east of northwest part of Folded Zagros based on the slippery spots distribution in Javanrood basin including Zalan, Leyle, Bazan, and Safei Abad, (Figures 1 & 2). This region is totally hilly with the heights in the scope of 1000-2708m. It is perceived by the presence of compacted mounts with profound valleys. The yearly temperature and precipitation means are 15.6°C, and 600mm, individually. Javanrood local structure is stratified, albeit, because of various geographical structures, the shape and stature of strata are altogether different. In this regard, provincial mountains can be separated into two units including furrowed mounts and hill lands. Furrowed mounts have been made of alternate dark limestone with dim marl (Sarvak arrangement) or dark to dim argillous (clayey) limestone with dark shale (Garu arrangement), while hill lands cover focal and the eastern territory of this basin.In the focal part, the land surface is the same as Gourpi, comprising of dim marl and shale, and in the eastern part, it is comprised of Kermanshah radiolarite. Radiolarite lithology incorporates red, yellow to olive green, red and green shale, silica limes and supra-basic volcanic masses like serpentine. The surface of these slopes is covered by oak trees or under non-irrigated farms. Adjusting provincial landslides distribution with geographical guide uncovered that Gourpi and Kermanshah Radiolarite formations make ready for landslide event in the locale.

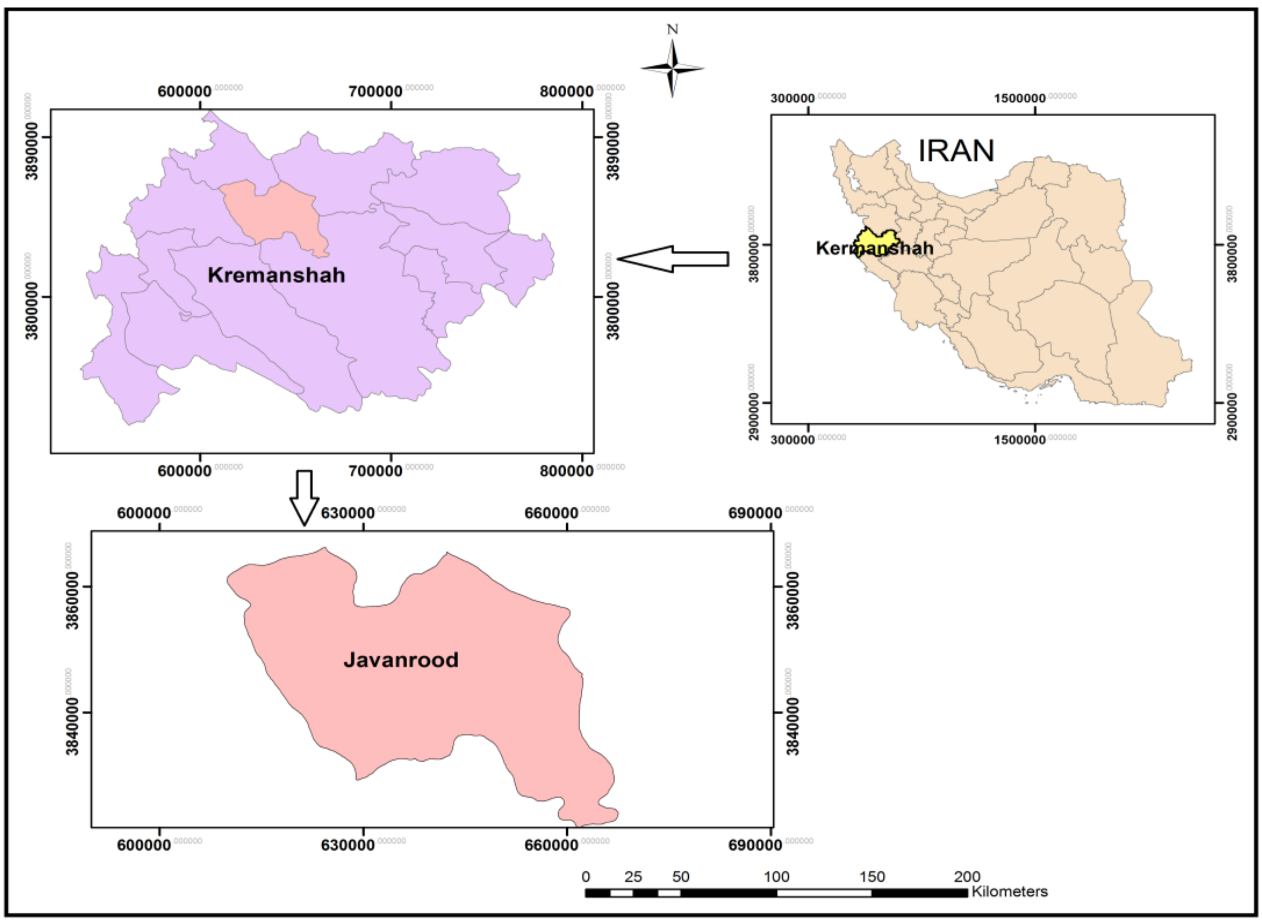

Figure 1: Geographic location of the studied area

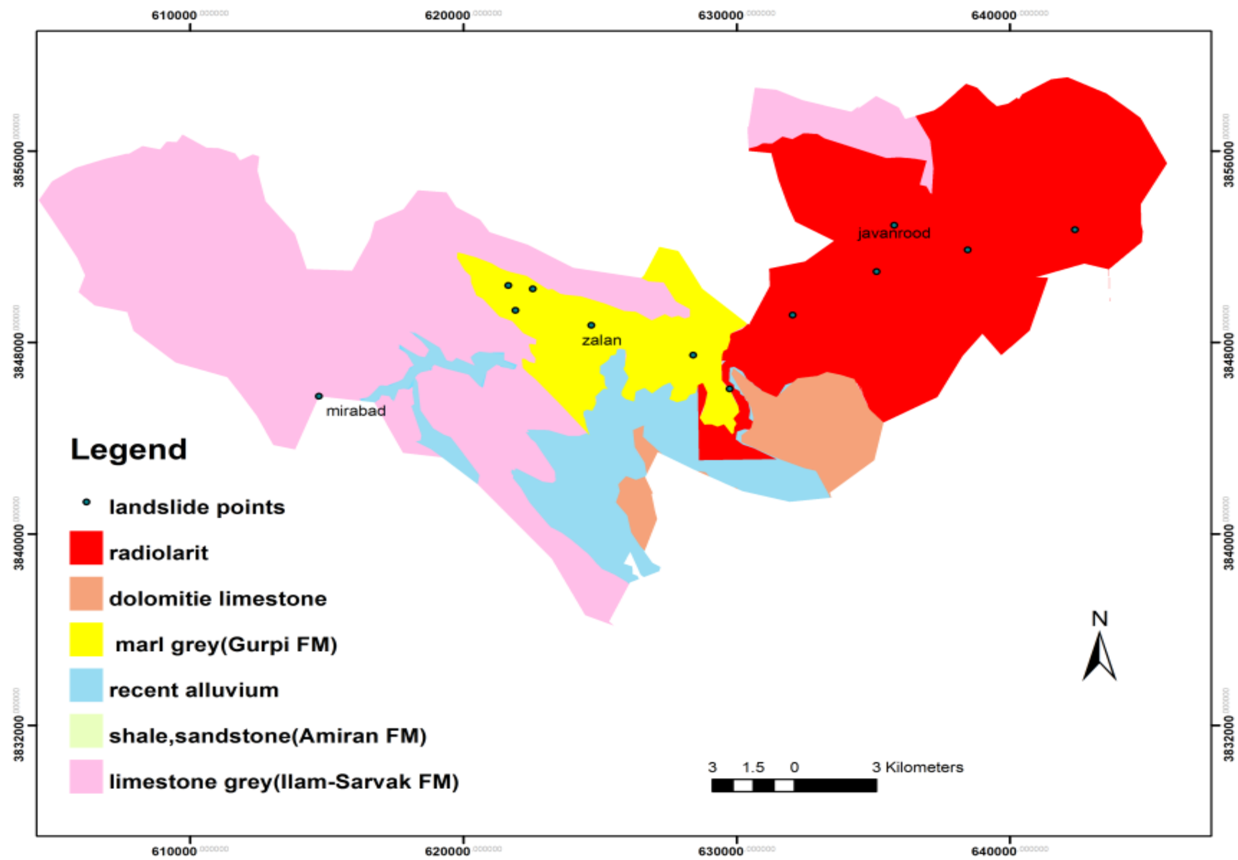

Figure 2: Geological map of the studied area

3. MATERIALS AND METHODOLOGIES

3.1. Applied Materials

Application of materials in this research was Javanrood s 1. 50000 topographic maps, 1; 100000 geological maps, 1; 55000 spatial images, Google earth satellite images, GPS, 20m altitude numerical models, Arcgis and Matlab softwares and laboratory parameters, including dry soil specific weight(γ_d), wet soil specific weight (γ_t), hydraulic conductivity, soil internal friction angle (φ), soil cohesion, and the porosity of the soil.

3.2. Research Method

This research was completed through the fields, and empirical methods. Search steps are summarized as following:

3.2.1. Data Bank Preparation

Geomorphologic, hydrological, and mechanical properties of soil slopes in the area under consideration were the necessary information in this study. This information to all only to get, it was important to hang sample to measure the variables mentioned above to identify. First, a landslide distribution map (Fig. 3) was prepared in the considered area, second, on this basin, sample slopes were chosen for measuring essential variables. Landslide distribution maps were prepared, using satellite imagery and field observations. Like, after locating sliding masses, the location was determined by the GPS and transferred to key regional aid map. Sample slopes recognized as 12 slopes; 5 stable (lack of Land sliding) and 7 unstable slopes (having Land sliding mass). They were 1- 12 numbers. 1-5 slopes are stable and, 6-12 unstable. After selecting the sample slopes, vital parameters were evaluated as follows:

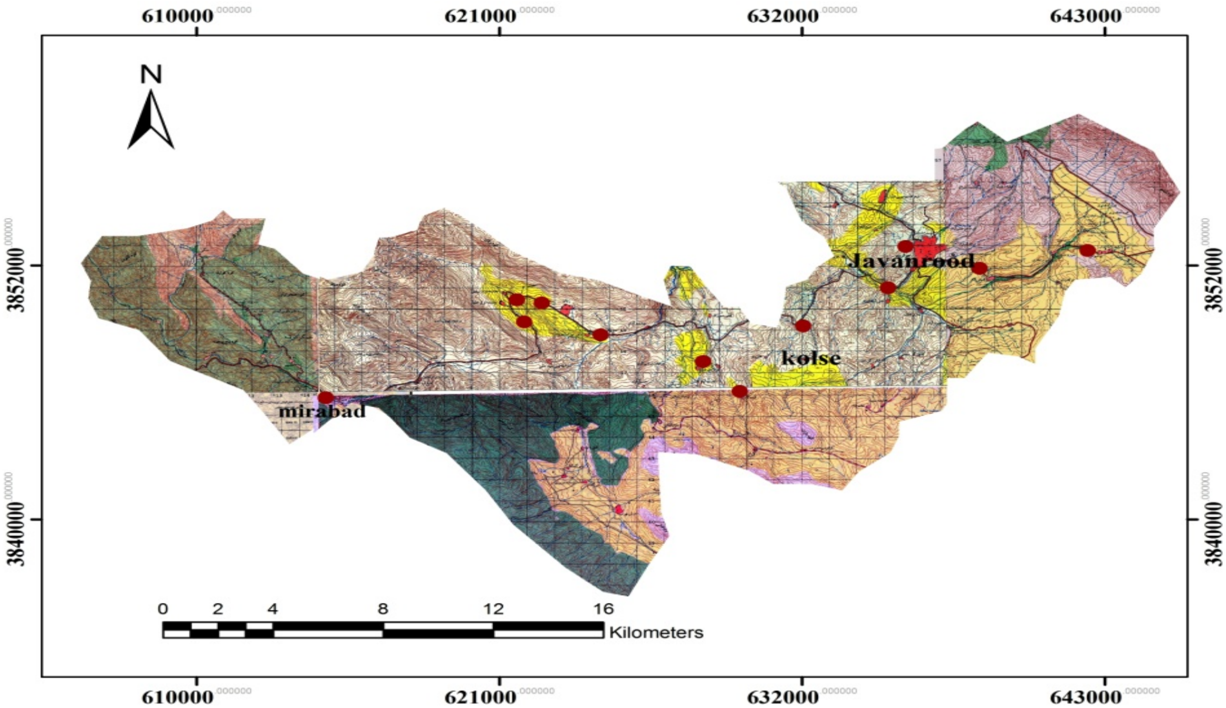

Figure 3: Slope distribution map of the studied area

3.2.1.1. Soil Mechanical features

Sampling of the soil from each slope was performed based on the mechanical components of soil. 50 kg of soil was expelled from each incline, from 75 cm to 1cm in depth. So as to inspecting delicate and coarse soils samples, a core cuter devise and scoop individually were utilized. Soil samples were taken to Kermanshah soil mechanical laboratory, Office of Kermanshah Province. The essential parameters were determined respectively by utilizing direct shear test, including dry soil specific weight (γ_d), wet soil specific weight (γt), hydraulic conductivity, soil internal friction angle (φ), soil cohesion, and soil porosity.

3.2.1.2. Determining the geometric parameters of slopes

Aside from utilizing the maps for topography, Dem (the altitude numerical model) with a pixel size of 20 by 20 m and satellite pictures were utilized for determining the morphology parameters as well as to distinguish the different slope sorts.for example, mean slope (beta), slope width (W), slope length (L) area, slope profile curvature (n), were extracted by utilizing GIS program, manual, and laser tape measure, clinometer, slope geometry attributes. Evan`s (1980) bivariate function was utilized for determining the profile curvature in the slopes. Hence, we have found that from all 12 slopes, 2 were convex, 7 flat, and 3 concave.

3.2.1.3. Determining root cohesion values

Keeping in mind the end goal to recognize the impact of root cohesion on the applied model, in the wake of determining the utilization of each slope (wood, pasture, cultivated, arid), Kayastha (2006) and Vinh`s (2007) classification (table1) were utilized.

Table 1: Root Cohesion Values for Different Land Uses (Kayastha, 2006.Vinh, 2007)

Land usage	Root cohesion ($\frac{KN}{m2}$)
farm lands	1
Wood lands	8
Rural and construction area	0
Shrubs and bare hills	1

3.2.1.4. Determining the amount of rainfall

One of the main factors leading to landslides is rainfall. In this regard, it was considered a maximum 24-hour rainfall during a period of 20 years of statistics on each slope. Utilized measurements are identified with 4 precipitation stations (Zalan, Dehrash, Javanrood, and Banchaleh). Utilized values were viewed as in light of vicinity of landslide to the previously mentioned stations.

3.2.2. Model implementation, evaluation and results analysis.

The model utilized as a part of this research was the model of Talebi (2008) which was indeed, an amplified model of a physically-based model, being a blend of geometry model, hydrology model (perpetual condition), and unending slope stability theory. This model is used to study shallow landslides in slopes with different topography in regards to arrange shape (concave, convex, parallel), and profile curvature (concave, convex and direct). It considers the impacts of slope morphology on saturation storage of plan shape and length profile. To perform this model, the accompanying steps have been utilized:

3.2.2.1. Slope geometry

To concentrate on the impact of topography (plan shape and profile curvature) on Shallow landsliding, Talebi et al. (2008a), after Evans (1980), the slopes are portrayed as a mix of curvature in the gradient direction (profile curvature), and the direction opposite to the gradient (contour or plan curvature). The surface of an individual slope is spoken to by the accompanying bivariate function (*Evans*, 1980):

$$Z(x, y) = E + H(1 - x/L)^n + \omega y^2 \quad (1)$$

where z is considered as the elevation, x as the horizontal distance from the outlet, y as the horizontal distance from the slope center toward the path opposite to the length direction (the width direction), E is the base elevation of the surface over an optional datum, H is the most extreme height distinction characterized by the surface, L is the total horizontal length of slope, n is a profile curvature parameter, and ω is considered as the plan curvature parameter.

3.2.2.2. Slope hydrology

Subsurface stream procedures are affected by plan and profile curvatures, and the hydraulic properties of the permeable medium. The scientific depiction of these processes causes to the formulation of the 3D Richards equation which is hard to comprehend numerically. One approach to conquer this issue is to lessen the dimensionality by presenting the subsurface capacity function, Sc (Fan and Bras, 1998):

$$S_c(x) = w(x)D(x)f \quad (2)$$

Where $D(x)$ represents the (width-averaged) soil depth at distance *x,* and *f* as the effective porosity also sometimes referred to as drainable porosity). By supposing kinematic wave subsurface flow, Troch et al. (2002) derived the following analytical expression for steady-state saturated storage of the slope:

$$s(x) = \frac{fL}{nK_sH}\left[1 - \frac{x}{L}\right]^{1-n} NA(X) \quad (3)$$

Where *f* is considered as the drainable porosity, k_s as the saturated hydraulic conductivity, *N* as the (Constant) recharge rate, *A(x)* as the upstream drainage area at location *x,* as well as *S(x)* representing the saturated storage at a predetermined distance *x* from the division at any position along the slope. The steady-state relative saturation of the soil is now determined by (Talebi et al. 2008):

$$\sigma(x) = \frac{S(X)}{S_c(X)} \quad (4)$$

3.2.2.3. Slope Stability

Slope security studies depend on the calculation of the component of safety (FS) considering a failure surface. For slopes, it is basic to characterize the safety factor as the proportion of the accessible shear strength to the base shear strength required for equilibrium. The infinite slope stability hypothesis has been broadly applied in numerous examinations of natural slope stability due to its relative simplicity, especially where the thickness of the soil mantle is considerably littler than the length of the slope, and where the failure plane is around parallel to the slope surface. The infinite slope model forces the condition that the groundwater stream is parallel to the slope surface. On account of the geometry of an infinite slope, general stability can be controlled by breaking down the stability of a single and vertical element in the slope. Under these presumptions and with stability expressed by the factor of safety; *FS*, the infinite slope stability equation is determined by (Wu and Sidle, 1995; VanBeek, 2002; Talebi et al. 2008)

$$\text{F s(x)} = \frac{(c+(D-h(x)\gamma m+h(x)\gamma b)cos^2\beta tan\beta}{(D-h(x)\gamma m+h(x)\gamma s)sin\beta cos\beta} \quad (5)$$

where *t c* is considered as the total soil cohesion, φ as the angle of internal friction, *D* as the depth to the shear plane, β as the local slope angle, *h* as the water level above this plane as well as *m* γ , *s* γ and *b* γ , are respectively the moist, saturated and buoyant bulk specific weights. Then again, there is a specific domain as (Talebi et al. 2008)

$$\text{F s(x)} = \frac{c(x)+(1-\delta(x)\gamma m(x)+\delta(x)\gamma b)D(x)cos^2\beta(x)tan\varphi}{(1-\delta(x)\gamma m(x)+\delta(x)\gamma s)D(x)\sin(\beta)(x)\cos(\beta)(x)} \quad (6)$$

At last, by joining the relative saturated storage (σ), the proportion between actual storage and storage capacity) in the safety factor formulation, the normal shallow landslide security factor for complex slopes can be introduced as follows: Finally, by applying Talebi et.al model for entire soil profile (above and underneath the water table), stability factor was displayed as following (Talebi et al. 2008).

$$\overline{FS} = \frac{\int_0^L\{c(x)+(1-\delta(x)\gamma m(x)+\delta(x)\gamma b)D(x)cos^2\beta(x)tan\varphi\}dx}{\int^L((1-\delta(x)\gamma m(x)+\delta(x)\gamma s)D(x)sin\beta(x)cos\beta(x)dx} \quad (7)$$

Here, the role of vegetation cover (cohesion due to root or Cr) is measured by means of the same c

4. RESULTS

After obtaining necessary parameters to get slope factor of security (F S) (Table 1,2) including laboratory, topography and hydrology parameters, Fs values for each slope were measured by Matlab software. (Table 2)

Table 2: Parameters necessary to obtain slope stability factor instable slopes

Number slope	1	2	3	4	5
Effective soil cohesion (kg/cm^2)	0.08	0.01	0.08	0.01	0.06
Effective angle of internal friction	34	31	29	26	32

Saturated hydraulic conductivity (cm/s)	$4.98×10^{-4}$	$3.18×10^{-4}$	$2.21×10^{-4}$	$6.26×10^{-4}$	$4.38×10^{-4}$
Dry soil Specific weight(kg/m^3)	1500	1530	1490	1840	1580
Wet Specific weight(kg/m^3)	1770	1830	1800	2848	1800
Effective porosity (%)	0.38	0.39	0.37	0.36	0.37
Root cohesion(kN/m^2)	8	1	1	8	1
Max24hours precipitation(mm /day)	86	86	86	86	80
profile Curvature	1	1.3	1.4	1.7	1.7
slope length	140	110	142	180	110
Soil depth(m)	1	1	1	1	1.2
Mean gradient (%)	22	17	33	34	31
Mean slope height(m)	1362	1275	1412	1439	1275
Geological formation	radiolarite	Gourpi	Gourpi	Gourpi	radiolarite

Table 3: Parameters necessary to obtain slope stability factor in unstable slopes

Number slope	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Effective soil cohesion (kg/cm^2)	0.03	0.04	0.05	0	0.03	0.07	0.02
Effective angle of internal friction	26	28	25	29	22	23	20
Saturated hydraulic conductivity (cm/s)	$2.2×10^{-4}$	$6.3×10^{-5}$	$7.12×10^{-5}$	$1.18×10^{-4}$	$2.2×10^{-4}$	$7.12×10^{-5}$	$1.2×10^{-5}$
Dry soil Specific weight(kg/m^3)	1900	1720	1640	1530	1600	1490	1550
Wet Specific weight(kg/m^3)	2170	1910	1950	1900	1870	1720	1860
Effective porosity (%)	0.37	0.38	0.37	0.35	0.36	0.038	0.038
Root cohesion (kN/m^2)	1	1	1	1	8	1	0
Max24hours precipitation (mm/day)	50	80	86	100	100	86	80
Curvature profile	0.6	1	0.6	0.6	1	1	0.7
slope length	80	180	90	355	140	240	290
Soil depth(m)	1.1	1.2	1	0.7	0.7	1.2	1.2
Mean gradient (%)	46	37	46	32	23	23	15
Mean slope height(m)	1328	1525	1385	1265	1512	1407	1385
Geological formation	Gourpi	radiolarite	Gourpi	radiolarite	Gourpi	radiolarite	radiolarit e

Based on the infinite slope stability method , the factor of safety (*FS*) along the slopes is determined by examining the stability of twelve characteristic slope types with three different plan shapes (convergent, parallel and divergent) and three different profile curvatures (concave, straight and convex). (fig5&6). The results indicate that most of the slopes with low or less than 1 safety factor, considered unstable, are related to slopes with convergent plan shapes and concave length profiles.(6,8,9,). This slope has more saturation rate than to stable slope, while the convex ones are more stable and have low saturation rate(1,2,4,5) (Table 4). As the lowest value of saturation storage is related to the slopes (1 and 4) with the amount less than 1m^{3,} demonstrating that saturation rate of these slopes is less than the other slopes. Moreover, according to the drawn length profile, these slopes have convex length profile and factor of stability more than 1.5.

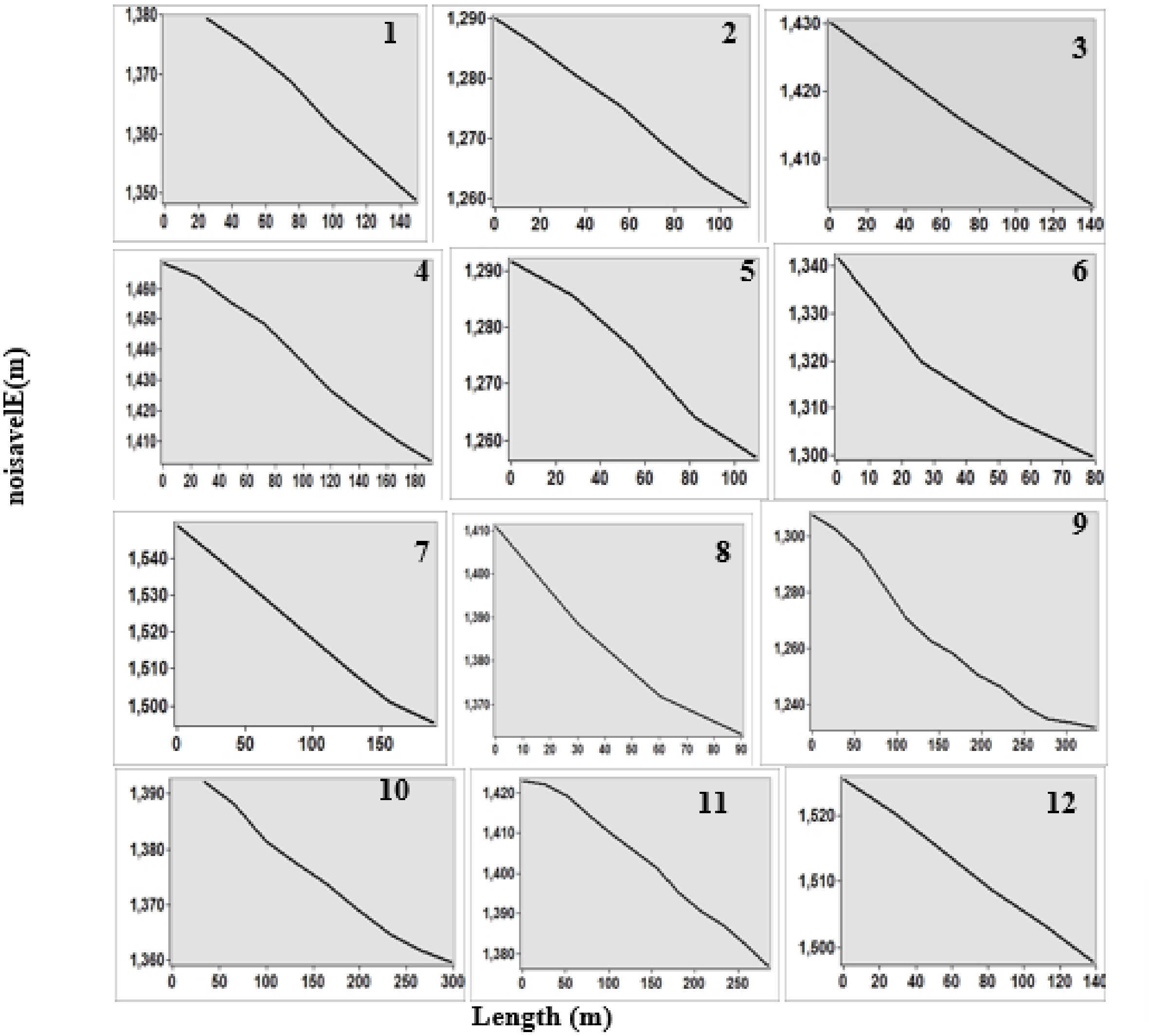

Figure 4: Length profiles of slopes of the study

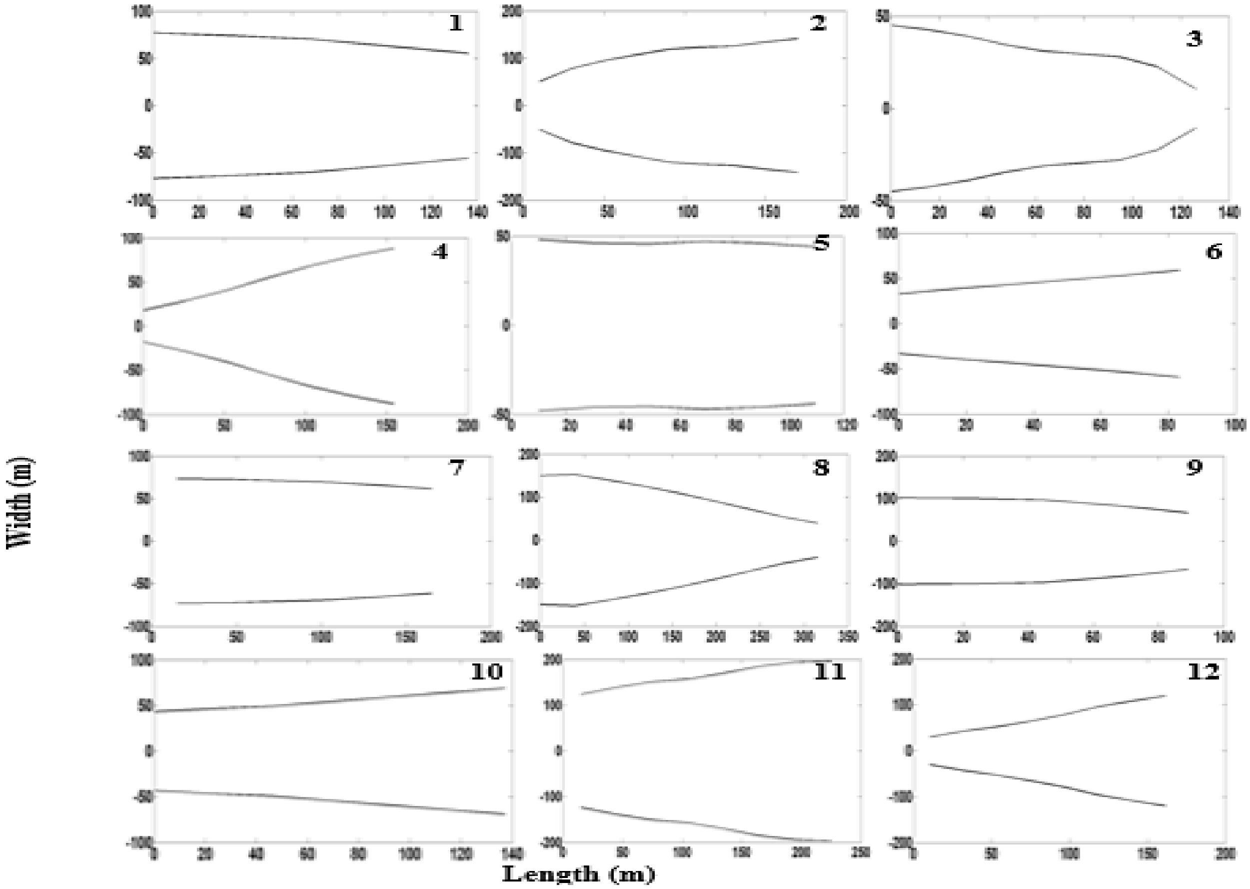

Figure 5: Plan shape of the slopes in the study

Table 4: Measured value of stability factor in sliding slope

Slope Number	Plan Shape	Profile Curvature	Saturation storage	Factor of safety
1	Convergent	convex	0.66	2.46
2	Divergent	convex	1.4	2,32
3	Convergent	straight	2.7	1.67
4	Divergent	convex	0.5	1.55
5	Parallel	convex	3.2	1.27
6	Parallel	concave	0.81	0.79
7	Parallel	straight	5.33	0.91
8	Convergent	concave	4.2	0.64
9	Convergent	concave	18.1	0.97
10	Divergent	straight	2.4	1.04
11	Divergent	convex	7.01	1.14
12	Divergent	straight	10.05	1.16

Pack et.al (1998) classification was used in order to determine the instability class of the slopes in this research. Table (5) shows the details of this classification. Besides, this classification is based on mathematical definition of factor of safety.

Table 5: Landsliding vulnerability classification (pack, et.al, 1998)

Land sliding vulnerability class	Factor of Safety (F S)
Low Land sliding vulnerability	F s > 1.5
Mean Land sliding vulnerability	1.25> F s > 1.5
High Land sliding vulnerability	1.25> F s > 1.5
Very high Land sliding vulnerability	F S <1

As shown in Figs (6,7), based on the results, slopes(1-4) are placed in low instability class, while slope (5) in intermediate class ,(6-9) very high instability and (10-12), high stability.

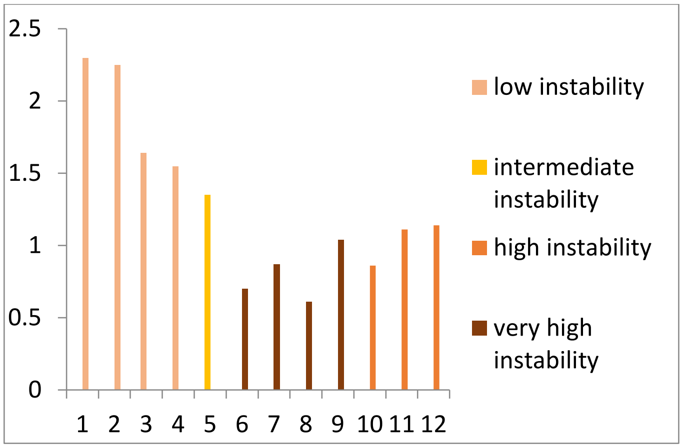

Figure 6: Stability factor measured for each slope

5. DISCUSSION

Scientific and comprehensive study of land sliding phenomenon is considered as one of main issues in utilizing slopes due to imposing horrendous property damages and casualties on human communities. Achieving different purposes such as optimal economy and safety in development projects, including, route selection, constructing highways, mountainous main ways and sideways, and also natural grasslands and woods development plans depends on both studying and paying attention to stability of regional slope. Mass movement of materials, such as land sliding, is one of problematic slope processes in Javanrood region located in northwestern Zagroos .Such phenomenon is accompanied by deterioration of wood lands, farm lands and pastures which is considered as a threat to road traffic. Therefore, the results of this research would be efficient enough in land sliding monitoring, as slope stabilization depends on identifying the most effective factors in occurring this event. Main causes of land sliding are vulnerability of regional geological formation (Gourpi &Radiolarite), its dominant climatic condition (cold semi wet) making intensive weathering of this formation and weatherworn materials viability on low hillsides by increasing thickness. Regarding the complexity of landslide mechanism and reaching practical results, we tried to investigate physically based (Talebi 2008) model in order to consider these landslides, mainly shallow landslides. This model will consider those landslides occurred in slopes with variable bed and different shapes with regard to slopes hydrogeomorphologic and soil mechanic parameters. The results show that slopes soil in Javanrood region has a low cohesion coefficient. These soils are produced by decomposition of shale and rocks of Gourpi and radiolarite in cold and wet weather with precipitation more than 600 mm. If this soil is placed on the surface of slopes with direct and convex profile, it will be stable enough due to fast drainage, consequently reducing saturation storage. Another factor that helps soil stability in these slopes is higher soil internal friction angle (more than 30°) due to having coarse grain components. Slope soil is mainly Regulite; consequently, there is so many rubbles in its components. Based on the results, FS is more than 1.5 in slopes (1-4) therefore; they are classified as extremely low instability. Grain arrangement would increase their friction coefficient, subsequently, even with low cohesion; they are not willing to slip. Lower slope (less than 30%) and higher vegetation Cover (oak trees), especially in slopes (1&4) are considered as other effective factors for higher FS in slopes (1-5). Therefore, slope stability analytical model introduced slopes (6, 7, 8, 9) as unstable with FS (0.7, 0.87, 0.61, 0.86) respectively. They are classified as extremely high unstable. Main reason for instability is low Internal friction angle (often 25-26°) and principally slopes concave longitudinal profile. Concave slopes drain more slowly than other slopes, consequently, soil saturation storage would increase, while stability would decrease. In fact, it can be said that morphological features, hydrological features, soil mechanics and vegetation cover naturally provide the conditions for landslide occurrence. Besides, road shear in slope`s (6, 7) and river cross section in slope (8) are other instability intensifiers. Landslide of slope (9) occurred naturally, without the effect of artificial factors. Observing satellite images and field observations confirmed the results for these slopes. Based on the model, in case of natural conditions, there is less possibility for landslide and instability than unstable slopes (10, 11, 12). In this slope low angle of friction (20-23 degrees) provide the condition to increase instability, while low slope (15, 23 %) and convex length profile make stability of this slope increase.

6. CONCLUSION

Utilizing a process according to a physically-based model, this study totally planned for considering the reasons of occurrence of shallow landslides in Javanrood slopes .The approach presented in this paper provides an analytical slope stability model for evaluating the connection between slope geometry and slope stability. The model containing a topography model, a hydrological model and the infinite slope stability assumption. The current hydrological model describes the impacts of topography upon slope saturated storage by utilizing the plan shape and profile curvature. By changing these two parameters, twelve basic slope shapes were connected to figure their factor of safety (*FS*) for certain and known hydraulic and hydrologic condition. It is known that these twelve basic slopes have quite various behaviors from the stability aspect. The results presented that average bedrock slope angle and topographic features, especially profile curvature and plan shape of the slope, both control the subsurface flow and saturation of slope. This process influences slope stability by changing the soil strength. Specifically, when the width function (plan shape) changes from convergent to divergent, slope stability by and large increments. As it may, this impact is more articulated for curved length profiles. Along these lines, for a given plan shape (convergent, parallel or divergent), convex slopes are for the most part more steady than either concave or straight slopes. Hence, by considering slope morphological properties, subsurface hydrology and soil mechanic properties, this model analyzes slope factor of stability considering measured results. Slopes (6-9) are classified in the group of extremely high instability and slopes (1-4) in low instability. In addition to this, the results show that current model (Talebi 2008) has a proper efficiency in determining instability in the slopes under the effect of natural conditions of morphological features, hydrological features, soil physics and vegetation cover individually. In all the unstable slopes, FS has been less than 1.

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