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Full Length Research Paper

The effect of terrain factors on landslide features along forest road

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The objective of this study was to investigate the effects of physiographic features such as slope, altitude, aspect and soil on landslides dimensions and distribution in Pahnehkola forest, north of Iran. 30 landslides were selected for detailed observation, with their occurrences recorded by global positioning system (GPS) along the surveyed forest road. Then, landslides were mapped in Arc view and subsequently digitized into a geographic information system (GIS). Results indicate that the landslide area at a distance of 80 to 100 m from road edge was significantly more than that of other distances. The landslide dimensions increased with increasing slope angle. The mean of landslide area and mean of landslide volume on the Northwest aspect was significantly more than that on other aspects (P<0.01). The mean of landslide dimensions in altitude class of 400 to 650 m was significantly less than that in altitude class of 150 to 400 m (P<0.01). The mean of landslide dimensions increased significantly with increasing soil liquid and plastic limit. The logistic regression modeling indicate that independent variables including aspect, liquid limit, plastic limit and soil moisture, significantly influence the landslides area. The majority of landslides were situated along roads and on faults, and shallow landslides were more frequent along roads compared to those on faults.

Key words: Landslide, forest road, physiographic features, GPS, Pahnehkola forest.

INTRODUCTION

Landslides are frequent in the North and North West of Iran at Alborz fault zone, and they are common during earthquakes, rainfall and as a result of road construction cutting the toe of the slopes (Ghahramani, 2008). The landslides in Hyrcanian forests can be classified into deep slides, shallow slides, active and dormant landslides. Shallow slides are usually located near roads and rivers and in places where vegetation coverage has been removed (Hafezi Moghaddas and Ghafoori, 2007). Landslides are related to geo-environmental factors such as terrain morphology, lithology, geology, weathering and toe erosion of slopes climate, land use and vegetation (Chen and Lee, 2003). Mass movements like soil slides, debris slides, rock slides and debris flows are incorporated into the term landslides (Regmi et al., 2010). It has been frequently recognized in high altitude regions that climate leads to landslide initiation and development (Soldati et al., 2004; Ivy-Ochs et al., 2009) and influences tectonic activity (Muir-wood, 1989; Stewart et al., 2000; Sanchez et al., 2010). Road-associated landslides are usually larger than landslides associated only with vegetation removal (Anonymous, 2001). The road network is also impacted upon by landslides, giving rise to traffic delay and also require ongoing investment in debris clearance, repairs to walls and roadside drains and road pavement (Smith, 2003; Hearn et al., 2007).

There are many references on the successful applications of methods for the investigation of landslides. Prokešová et al. (2010) analyzed landslide using quantitative data extracted from sequential sets of vertical aerial photographs in order to better understand the

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reactivation dynamics of landslides in low slope areas. Moreover, in order to help the planners in selecting suitable locations to implement development projects, a landslide susceptibility map was produced in a region in Iran using the gamma operation of the fuzzy approach (Tangestani, 2003). Zulfahmi et al. (2002) also reported that most of the cut slopes associated with landslides were highly weathered. The slope profiles, grade of weathering and discontinuity structures were among dominant factors that control the slope instability. The increase of traffic numbers especially heavy vehicles is able to generate vibration to the jointed and fractured weathered granitic rock slopes and block failure possibly occurs. Indeed, any variation of the natural environment such as road construction can cause a change of the field soil behaviour (Picarelli et al., 2006). The nature of geomorphic processes influenced by roads is strongly conditioned by road location, construction practices, basin geology and storm characteristics (Wemple et al., 2001).

Type and vegetation coverage indirectly enhance the water movement from soil to the atmosphere, directly enhance slope shear strength and ultimately influence the stability of the slope (Osman and Barakbah, 2006). In recent years there were considerable interest in the hydrologic and geomorphic effects of forest roads on earth surface processes and landforms (Luce and Wemple, 2000; Dutton et al., 2005). The arial distribution of landslides was strongly influenced by aspect. Based on the number of slips per hectare, the sunny aspects were much more susceptible to landslide than the shady aspects. When the soils are saturated, the liquid limit water content of the sunny aspect subsoil is exceeded, while that of the shady aspect subsoil is not (Owen, 1981). The soil with a high infiltration rate creates a fast flow of water into the soils down the profiles and where there is higher clay content, water flow is stagnated causing landslides (Kitutu et al., 2009). In Thailand, it was reported that the soils from landslide prone areas were mainly silty soils with low plasticity (Jotisankasa and Vathananukij, 2008).

The aim of this study was to investigate the effects of physiographic features such as slope, altitude, aspect and soil on landslides area and volume in a forest in north of Iran. Moreover, this study presents an attempt to evaluate the arial distribution of deep and shallow landslides on geology, hydrology, roads and faults maps.

MATERIALS AND METHODS

Description of the site

The study was conducted in the Pahnehkola forest of Tejen river basin, located in the south to south east Sari city, Mazandaran province, Iran. The area extends from 36°22′25″ to 36°26′36″ N in latitude and from 53°02′25″, 53°07′20″ E in longitude. The climate of the study area is moist to mid moist with average annual temperatures ranging from 1.8 to 29.8°C. Average annual precipitation is 264 mm. The area does receive snow as winter precipitation. Altitude ranges from 180 to 715 m a.s.l and encompasses 2268 ha. The terrain consists of marl rocks, sandstone and limestone. Soil types in Pahnehkola forest include non development randzin, washed brown with pseodoglay, forest brown soil with alkaline pH and washed brown with calcic horizon. Most landslides in our study area had slopes of less than 30%. The landslides in Pahnehkola forest can be classified into groups of deep and shallow slides. The forest road focused on in this study was located in a steep forest.

Measurements

30 landslides were identified at the distances of 0 to 100 and 100 to 200 from road edge. The dimension of landslides including length, width and height was measured by meter and then the slides area and volume was calculated. Locations of landslides were recorded by global positioning (GPS). Distribution of landslides were mapped in Arc view and subsequently digitized into a geographic information system (GIS). The altitude, aspect and slope position of each landslide were determined by altimeter, compass and clinometer, respectively. More also, soil samples were obtained from landslide sites at different depths and the moisture, plastic limit (PL) and liquid limit (LL) for each sample were determined using the drop cone penetrometer method at the Soil Mechanics Laboratory at Mazandaran province.

Data analysis

Data were statistically analyzed using ANOVA procedure in SPSS program. Tukey means comparison test at probability level of 1% was used to compare means within and among treatments and diagram was designed by Excel software.

RESULTS AND DISCUSSION

Effect of forest roads on landslide

Forest management practices may alter both physical and biological slope properties that influence slope stability and the occurrence of landslides. Most physical alterations are the result of roads, skid trails and landings (Zulfahmi et al., 2002; Dutton et al., 2005). Landslide area at the distance of 80 to 100 m from road edge was significantly ($P<0.01$) more than that of other distances (Figure 1). The mean of landslide volume was high ($P<0.01$) between the distances of 40 to 100 m from the forest road (Figure 2). Moreover, landslides in mountainous areas of the Hyrcanian forests are major hazard for roads often causing economic losses, property damages and high maintenance costs, as well as injuries or fatalities (Hearn et al., 2007; Das et al., 2010).

Effect of physiographic features on landslide

The most important terrain-related risk factor influencing slope stability is the steepness of the slope (Chen and Lee, 2003). Additional geomorphic or terrain-related risk factors that increase landslide susceptibility include slope aspect, slope curvature and local relief (Tangestani,

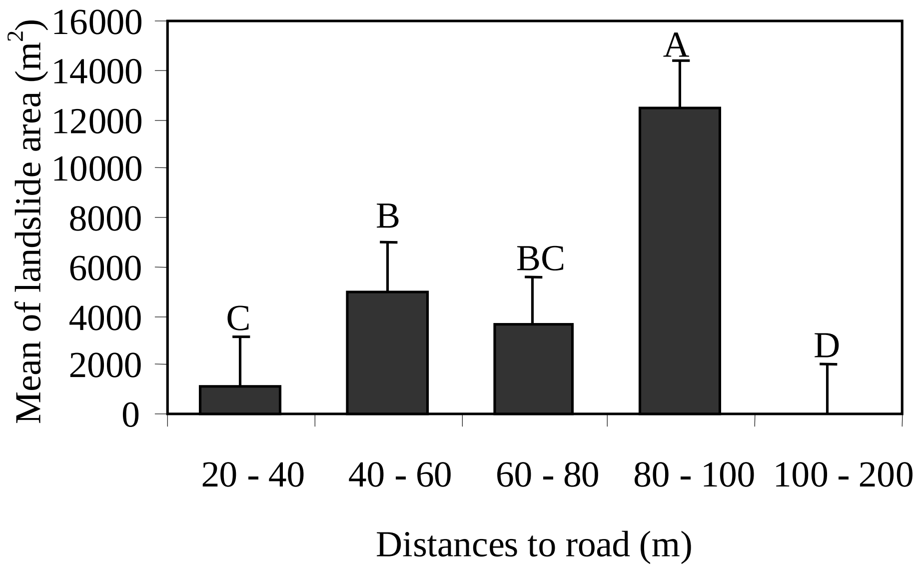

Figure 1. Comparison of landslide area in different distances from the road.

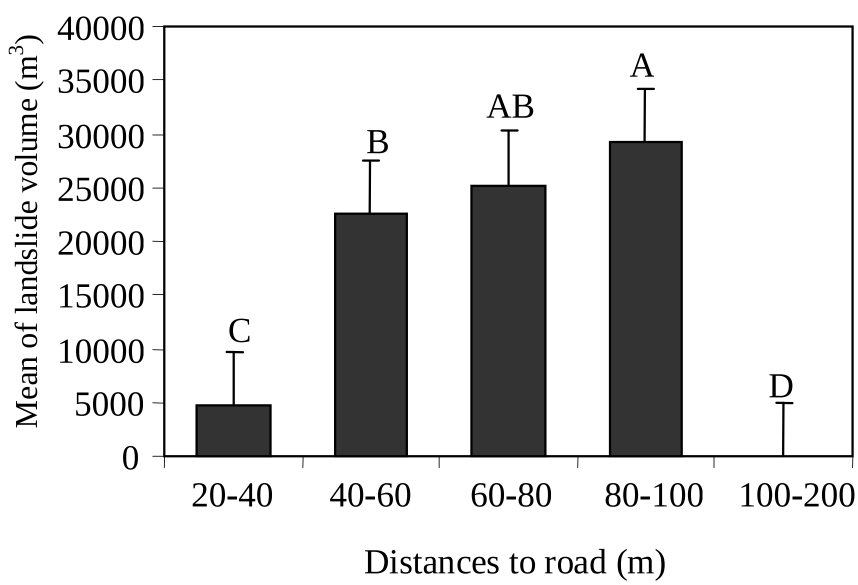

Figure 2. Comparison of landslide volume in different distances from the road.

2003). Increase in slope increased the landslide area and volume. The mean of landslide area and mean of landslide volume on the North West aspect was significantly more than that on other aspects (P<0.01). The mean of landslide area and volume in altitude class of 400 to 650 m was significantly less than that in altitude class of 150 to 400 m (P<0.01). This result was not however, in agreement with the findings of Soldati et al. (2004) and Ivy-Ochs et al. (2009). They found that in high altitude regions, climate leads to landslide initiation and development. The reason may be that the soil liquid limit, plastic limit and moisture of our study area were different. The mean of landslide area and volume significantly increased (P<0.01) with increasing soil liquid limit and plastic limit (Table 1).

Modelling landslide volume and area

The logistic regression modelling indicate that independent variables including aspect, liquid limit, plastic limit and soil moisture significantly (P < 0.01) influence the

Table 1. Effect of the physiographic features of the study area on landslide parameters.

Physiographic	Landslide parameter	
	Mean of landslide area (m^2)	Mean of landslide volume (m^3)
Slope (%)		
10 to 20	5022[a]	15863[a]
20 to 30	5885[a]	19595[a]
Aspect		
North	2909[b]	1704[b]
North west	6686[a]	21587[a]
West	1761[b]	4483[b]
Altitude (m)		
150 to 400	6090.8[a]	23881[a]
400 to 650	3843.5[b]	11258[b]
Soil liquid limit		
36 to 44	2265[b]	10399[b]
44 to 52	8172[a]	23810[a]
Soil plastic limit		
18 to 21	4284[b]	14319[b]
21 to 25	7052[a]	28507[a]

Table 2. Regression modeling for the landslide area.

Source	Sum of square	DF	Mean square	F	R^2	Significance
Regression	999869517.36	4	261088740.5	25.40	0.75	0.000
Error	231176789.10	23	971509.9			
Total	1231046306.46	27				

landslides area (Table 2), which was supported by other recent results (Owen, 1981; Osman and Barakbah, 2006; Jotisankasa and Vathananukij, 2008). The general regression model used for the computation of discriminant function (***Y***) representing the landslide area is presented in Equation 1:

$$Y = -247139 + 19904A + 540.5L - 12801P + 11905M \quad (1)$$

Where, ***A*** is the landslide aspect, ***L*** is the liquid limit, ***P*** is the plastic limit and ***M*** is the moisture of soil. Moreover, results show that independent variables including aspect, liquid limit and soil moisture significantly (P<0.01) influenced the landslides volume in the study area (Table 3). Also, the general regression model used for the computation of discriminant function (***Y***) representing the landslide volume is given in Equation 2:

$$Y = -59281.1 + 3650.2A + 731.1L + 1209.1M \quad (2)$$

Where, ***A*** is the landslide aspect, ***L*** is the liquid limit and ***M*** is the moisture of soil.

Arial distribution of landslides

The space distribution of the landslides that occurred in the study area in the period of 2000 to 2009 was analyzed on a map. It was observed that majority of the landslides were situated along roads and on faults. Shallow landslides were more frequent along roads compared to on faults (Figure 3). This could confirm that the roads can clearly increase landslide hazard by making slopes steeper and directing drainage to steep locations (Das et al., 2010). Besides, landslides were

Table 3. Regression modeling for the landslide volume.

Source	Sum of square	DF	Mean square	F	R^2	Significance
Regression	176395156407.3	4	59134448851	79.70	0.42	0.001
Error	165306068988.2	23	72786808777			
Total	341701225395.5	27				

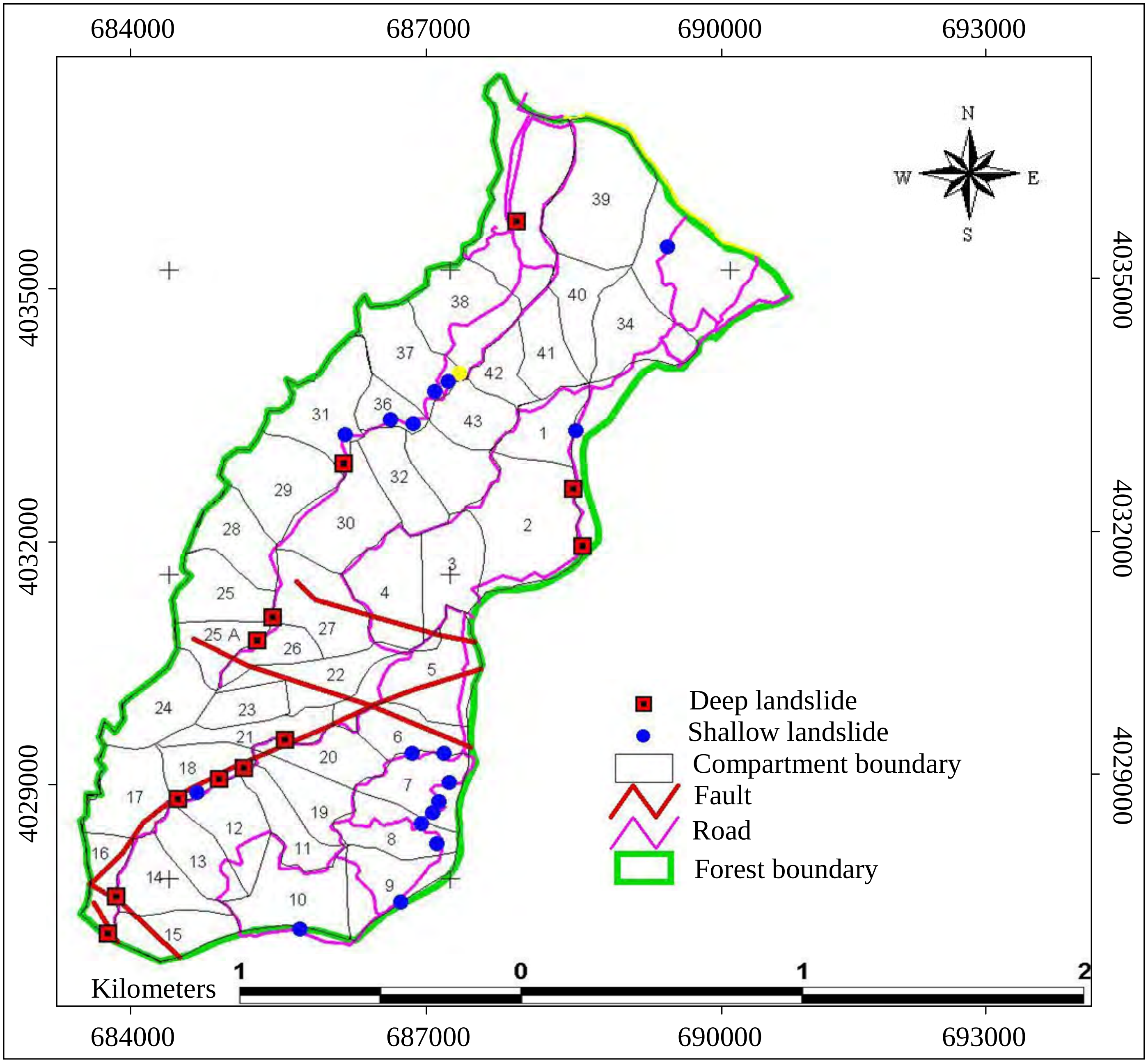

Figure 3. Distribution of landslides on road and fault map.

more numerous in M2, 3 msl geology layer (Figure 4). The distribution of landslides on hydrology map of study area is shown in Figure 5.

Conclusion

We found that the landslide area at the distance of 80 to

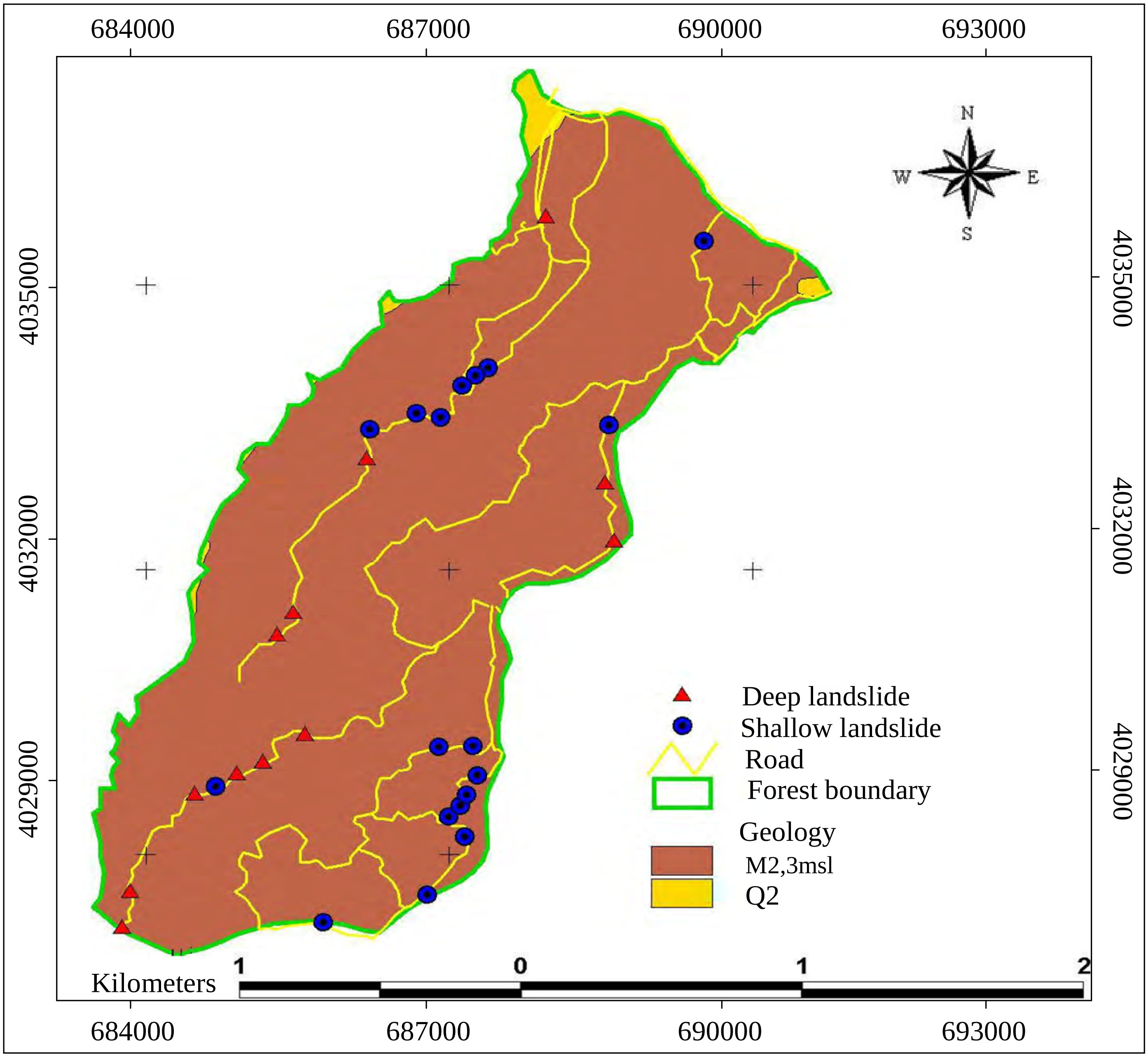

Figure 4. Distribution of landslides on geology map.

100 m from road edge was more than that of other distances. The landslide dimensions increased with increasing slope angle, soil liquid limit and plastic limit. Also, the mean of landslide area and volume on the Northwest aspect was more than that on other aspects. The mean of landslide dimensions in altitude class of 400 to 650 m was less than that in altitude class of 150 to 400 m. The logistic regression modeling indicates that independent variables including aspect, liquid limit, plastic limit and soil moisture significantly influenced the landslides area. Moreover, the majority of landslides are situated along roads and on faults, although shallow landslides were more frequent along roads compared to those on faults. Therefore, the results of our study show that for the prediction of landslide area, beside the aspect of slope, other soil properties such as the liquid limit, plastic limit and moisture are also quite important and should be incorporated explicitly.

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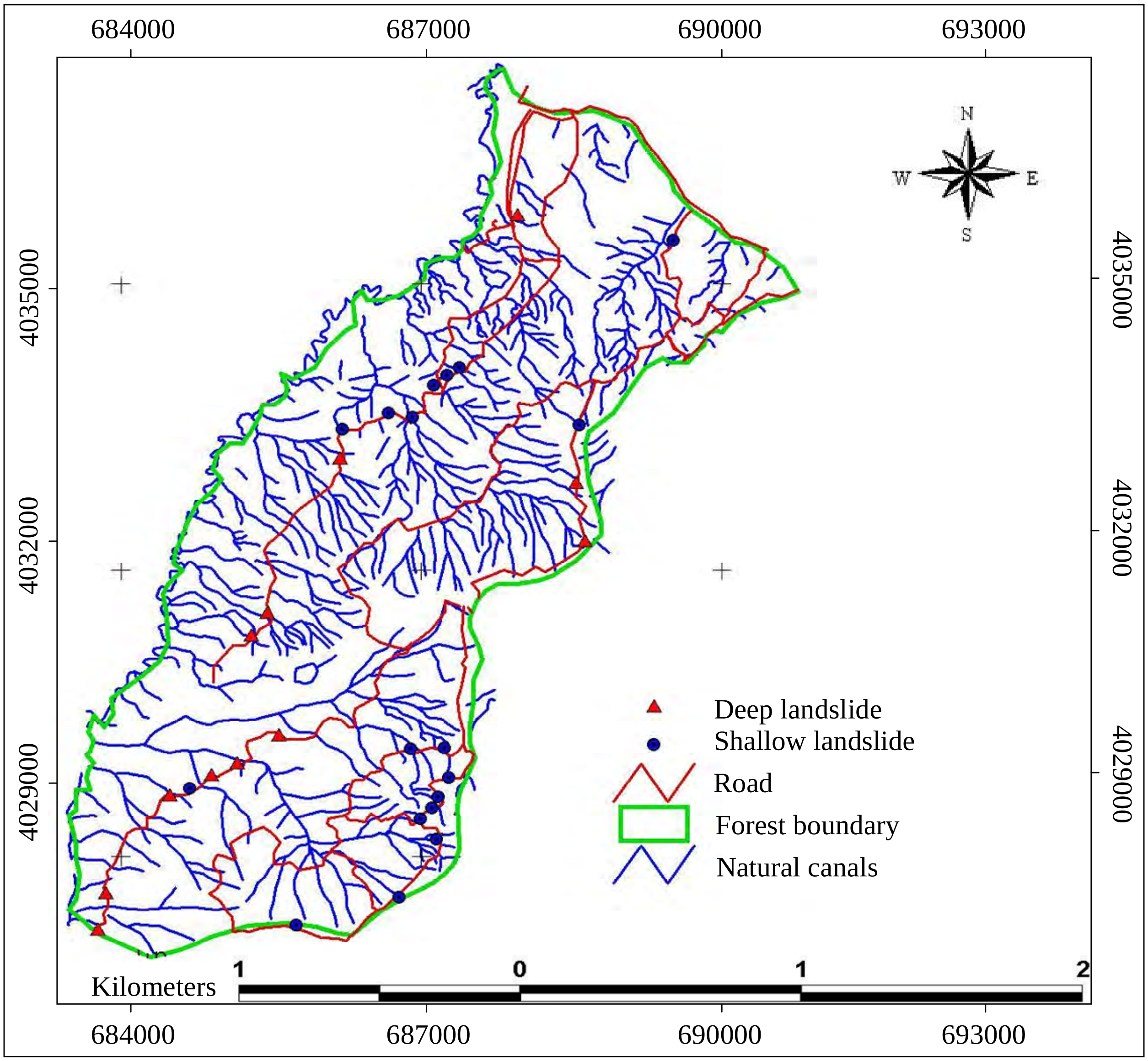

Figure 5. Distribution of landslides on hydrology map.

support of this project.

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