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GEOGRAPHICAL INFORMATION SYSTEMS BASED USING LOGISTIC REGRESSION LANDSLIDE SUSCEPTIBILITY ASSESSMENT OF THE ÇUBUK-KALECİK (ANKARA) BETWEEN ŞABANÖZÜ (ÇANKIRI) REGION

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Çankırı, Geographic Information System (GIS), Landslide Susceptibility, Logistic regression.

ABSTRACT

Landslides occur frequently in particular is in certain parts in our country as well as in the world, is caused from time to time to return to natural disasters and significant social and economic losses. In this study, landslide susceptibility analysis Çubuk-Kalecik (Ankara) between Şabanözü (Çankırı) were performed totally 2360 km^2 area. According to the inventory map that represents about 5,16 % of the spatial distribution of landslide at study area, landslide movement is generally seen as the type of the existing rotational slip. According to the Turkish Landslide Inventory database prepared by MTA, 876 landslides covering 122 km^2 were identified in the study area. A total of twelve independent variables for the landslide conditioning factors were used in the susceptibility assessments, being as lithological maps, landform classification, digital elevation model, slope, profile, plan, and tangent curvatures, roughness index, slope / aspect ratio, stream power index, topographic position index. Landslide susceptibility assessment was carried out using multivariate logistic regression method, one of statistical methods. The mapping unit 25 *25 m pixels are used for statistical assessment. The obtained probability values of landslide susceptibility maps are very low and very high was evaluated in five grades in the range. Performance evaluation of susceptibility maps were performed with using receiver operating characteristic (ROC) and prediction success rate curves. The area under the ROC curves were found to be in 0,794. Susceptibility map, high and very susceptible regions correspond to 27 % of the study area. 78 % of the landslides are in medium, high and very susceptible regions.The accomplished landslide susceptibility map with relatively high performance could be used during the medium scale planning strategies.

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1. Introduction

When damages originating from natural disasters in our country are taken into consideration, it is seen that the losses are consisted by earthquakes (61%) and landslides (20%) (Ergünay, 1999).

Landslides develop by geological, morphological and physical factors and by human effects. Landslide inventory maps generated are maps showing the types and spatial distribution of available landslides, and they form the basis of mitigation studies in planned areas.

In order that environmental factors causing the spatial distribution and formation of landslides should be understood, the digital landslide database was formed by MTA General Directorate (Çan and Duman, 2008; Duman et al.; 2011, Çan et al.; 2013). In the assessment of regional scale landslide database, it is essential to evaluate environmental variables controlling and forming the landslides in a good way. In this manner, the landslide inventory maps form the most basic need for landslide susceptibility and probable risk assessments.

In this study, landslide susceptibility assesment was conducted between Çubuk-Kalecik (Ankara) and

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Şabanözü (Çankırı) which covers an area of 2360 km^2 (Figure 1). According to the landslide inventory map of Turkey, there are 876 landslides in the study area and cover an area of 122 km^2 (Duman et al., 2011). 68 landslide events affecting settlements between 1950 and 2008 have been reported in the region; A total of 834 effective transplants were carried out (Gökçe et al., 2008).

In this study, the lithological map, land-use classification, digital elevation model, hill slope, profile, plan and tangential slope curvatures, roughness index, stream power index and topographic wetness index were used and thus, the landslide susceptibility assessment was carried out using multivariate logistic regression method which is regarded as one of the statistical methods. As mapping unit 25 x 25 m pixels were used for the statistical assessment. The performance evaluation of the susceptibility maps were performed by using the receiver operating characteristic (ROC) (Metz, 1978; Metz, 2006) and prediction success rate curves which tests the accuracy of the results (Chung and Fabbri, 2003, Heckmann et al; 2014).

2. Geology and Seismicity of The Study Area

There are seen basement units belonging to three different environments in the study area (Figure 2). The area is represented by rocks of Sakarya Zone and İzmir-Ankara-Erzincan Suture Zone and by Neogene basin deposits overlying the basement units. In the study area, Triassic-Jurassic-Cretaceous rocks of the Sakarya Zone, Mesozoic Eldivan ophiolitic complex, Late Cretaceous Dereköy ophiolitic mélange, which are tectono-stratigraphically associated with each other, and the rock assemblages of the İzmir-Ankara-Erzincan suture zone deposited between Late Cretaceous-Paleocene (Dönmez and Akçay, 2010). It was seen that the rocks of the Sakarya continent had been tectonically settled on rocks of the İzmir-Ankara-Erzincan suture zone, and the Neogene cover rocks had unconformably been deposited over units belonging to both zones. This sedimentary deposit is composed of volcanic and sedimentary rocks. The cover rocks has the characteristics of being the foreland basin deposits that have been opened on basement rocks (Dönmez and Akçay, 2010). These cover rocks are Late Paleocene-Early Eocene Sarıkoz volcanic, Middle Eocene Kurtsivrisi, Hüseyingazidağ, Sele, Ömercik, Susuz and Yukarıemir volcanics, Miocene Kumartaş,

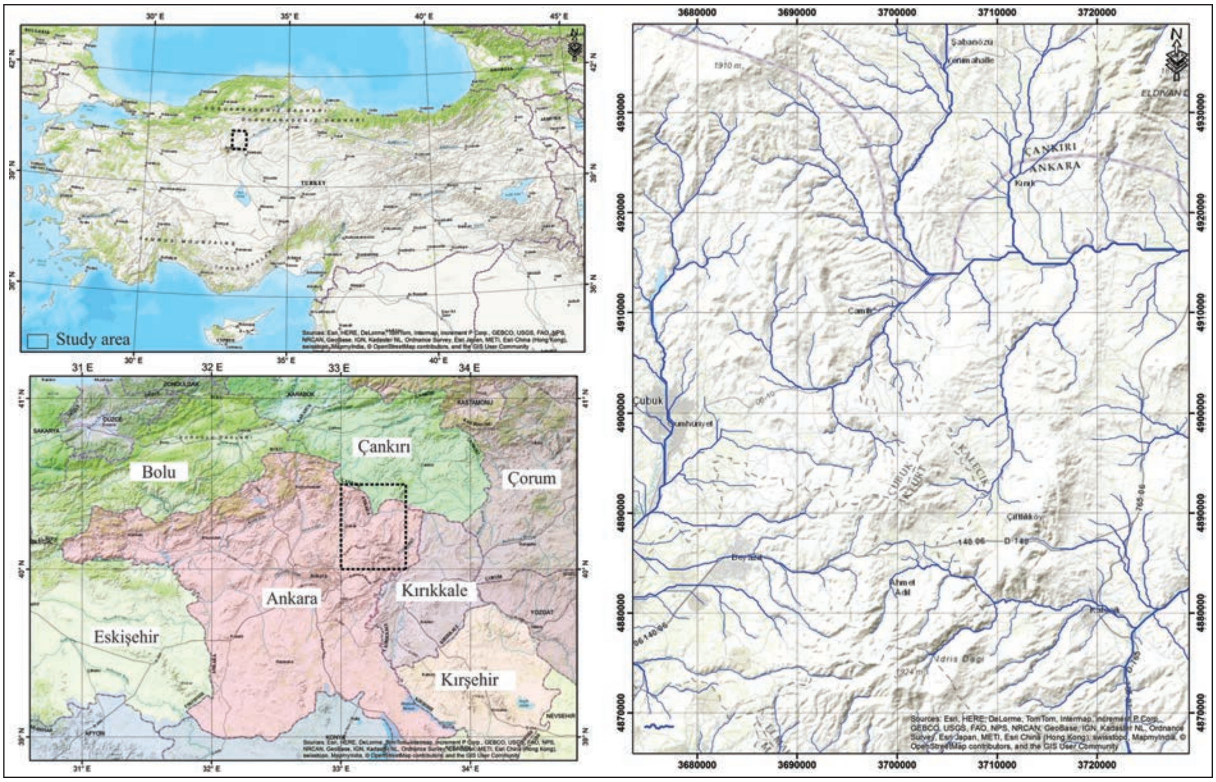

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Figure 1- The location map of the study area.

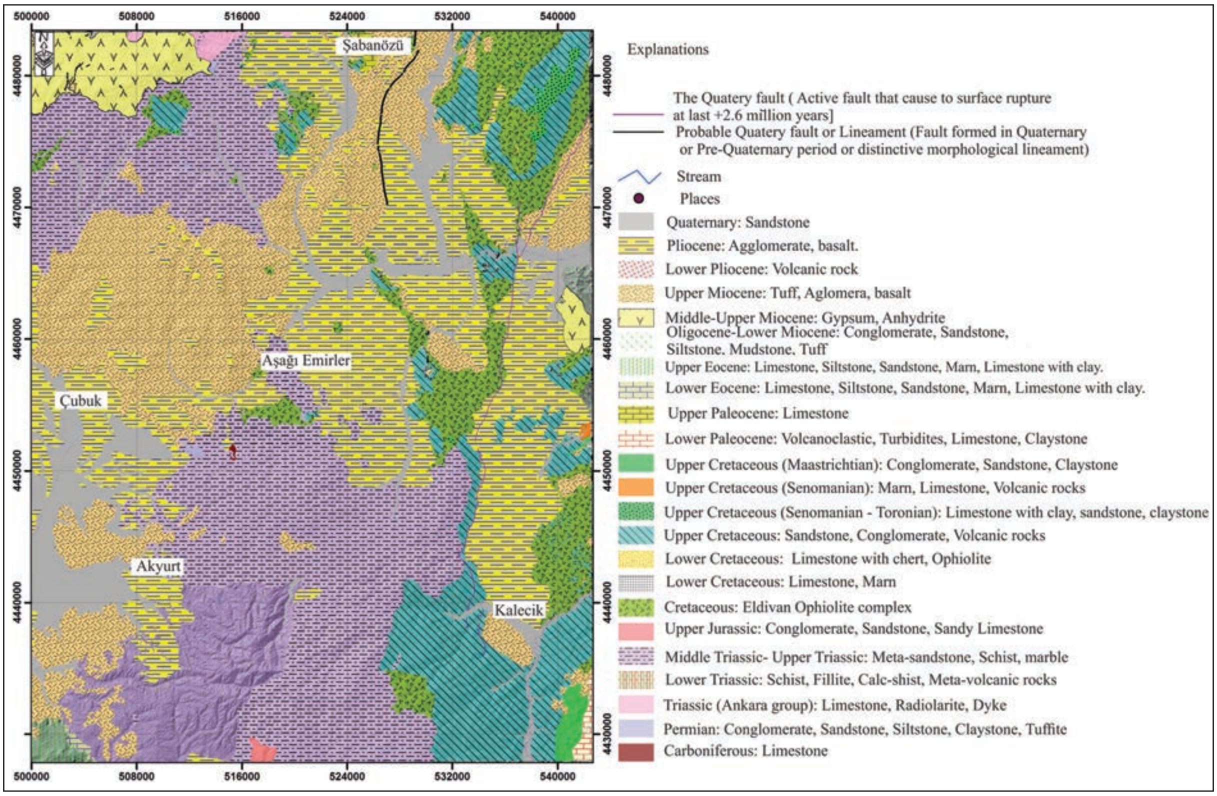

Figure 2- Geological map of the study area (Çankırı H30 sheet, 1/100000 in scale, MTA).

Hançili, Karakoca formations and Miocene Kalecik and Aydos volcanics. Pliocene Bozkır and Gölbaşı formations and Quaternary alluvial basin deposits cover all these units with an unconformity (Dönmez and Akçay, 2010).

According to the Active Fault Map of Turkey, the most of the Çankırı Fault, which moves with 34 km long inverse fault mechanism and regarded as one of the active faults, are located in the study area (Emre et al., 2013). In the region, there are 8 records of earthquake with Mw ≥ 4 present in instrumental period (1900-2010) (Figure 3) (Kadirioğlu et al., 2016).

3. Landslide Conditioning Factors

The 10 meters interval contour lines obtained from the General Command of Mapping were converted into raster format after establishing the triangulated irregular network (TIN) in GIS environment Then the digital elevation model in 25 x 25 m resolution was produced. When looking at the elevation values of the study area, the north of Hacılar village and south of Eskiköy village reach the maximum height of 1990 meters and there occurs an elevation difference of 1405 meters (Figure 4).

In order to establish the morphological structure of the study area, the land classification was performed according to Weiss (2001) using the topographical position index. The land use classification of the study area was evaluated in 10 different classes as; open slopes, canyon, mid-slope drainage, mid-slope ridges, plain, U type valleys, local ridges, summits, upper-slope drainage and upper slopes (Figure 5a). According to the map of slope gradient (Figure 5b), the slope angles increase from south to north. Slopes with the highest angles are located in northern parts. The slopes in these areas occasionally have a degree of 89° (Figure 5c). Slope inclinations; concave and convex slope shapes are quite significant in controlling the hydrologic flow situation. The slope gradients are divided into three categories as; sectional (Figure 5c), planar (Figure 5d) and tangential (Figure 5e) based on the direction in which they are assessed (Wilson and Gallant, 2000). The roughness index was obtained by the multiplication of the square root of the height value in each cells and height differences among neighboring cells using 5x5 pixel windows (Riley et al., 1990). The roughness index values (Figure 5f) reach high values on rugged areas and along ridges. In slope/aspect map (Figure 5g) obtained by the rationing of slope gradient and slope aspect maps, the higher

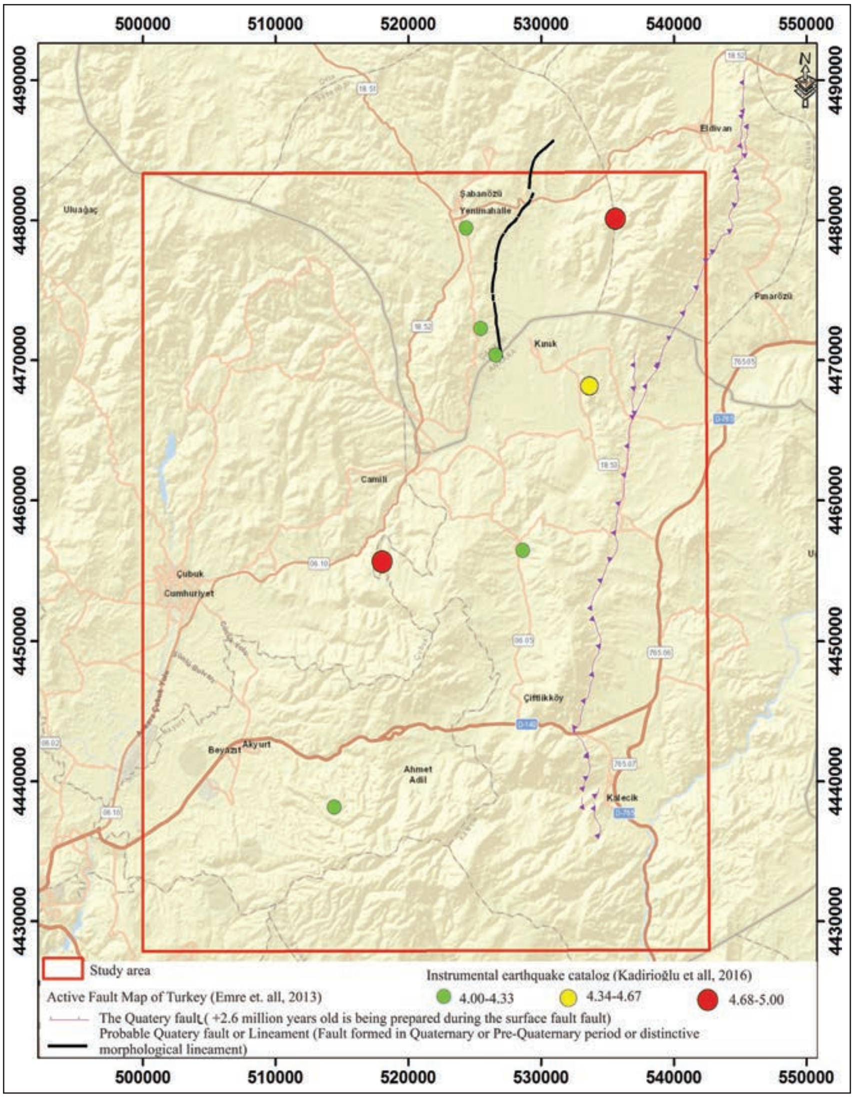

Figure 3- The Çankırı Fault located in the study area (Emre et al., 2013) and the records of instrumental earthquake (Kadirioğlu et al., 2016).

values show the inner sides of slopes; however, the lower values are seen on flat areas. The stream power index (SPI) is used for the determination of stream erosion that occurs in the valley. In the calculation of this parameter, it is suggested that the flow should be proportional with map unit areas (Moore et al., 1991). The stream power index is one of the major factors that control the erosional processes and it was used in the study as this is one of the parameters affecting the formation of landslide (Figure 5g). The topographical wetness index (TWI) dimensions the water saturation of the studied region in regional scale. The highest TWI values for the study area generally show high values inside the rivers.

4. Landslide Inventory

The available landslide inventory maps produced do not reflect the landslide activities that have developed later than this time. They only show large scale previous or recent landslides that have preserved their morphological characteristics on the date of map generation. In this study, 1/25000 scale digital landslide inventory map, which had been produced by MTA, was used (Duman et al., 2009). In the study area, there are total of 876 landslips. The landslides, which cover an area of 122 km^2, consists of 5.16 % of the investigation area (Figure 6a). 68 landslide events (Figure 6b) have been reported according to landslide records held between 1950-2008 (Gökçe et al., 2008).

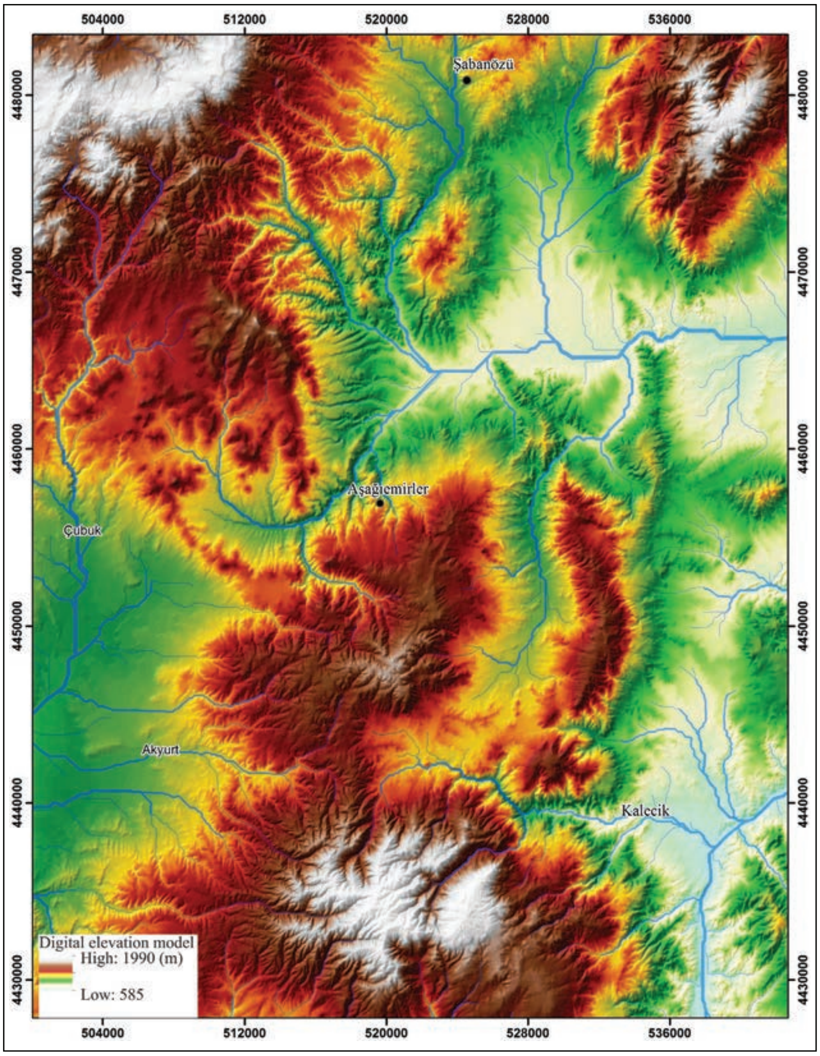

Figure 4- Digital elevation model (DEM) of the study area.

Located within the borders of Ankara; 293 in Elmadağ county Yeşildere village on September 22, 1969, 117 in Kozayağı village in Akyurt district, 274 in 1962 and 742 in July 6, 1965 in Kalecik county Gökdere village. In the section of the study area within the Çankırı province borders, on April 17, 1963, in Şabanözü district, Ödek village, 40 units of 92 effective transfers were realized (Table 1). The available landslides are lithologically observed in Miocene-Pliocene undifferentiated continental clastics, Paleocene-Pliocene undifferentiated volcanics, Eocene volcanic and sedimentary rocks, Late Cretaceous-Eocene clastic and mudstone, marl, conglomerate, silica-clastic, calci-turbiditic, carbonated mudstone, delta and fluvial clastics intercalated with carbonated volcanics, and Silurian-Permo-Triassic clastic and carbonated units (Figure 7).

5. Landslide Susceptibility Assessment

Landslide susceptibility assessments, which present approaches in which regions the landslides might occur, are prepared considering available landslide inventory maps of the region and landslide preparatory environmental factors. There are several approaches regarding landslide susceptibility assessments. Generally; the preparation of landslide susceptibility maps is divided into two categories as; qualitative and quantitative approaches. In this study, the GIS based landslide susceptibility map was produced by using logistic regression method, which is one of the multivariate statistical method, rather than quantitative method. The logistic regression method is used in determining the cause-effect relationship of both dependent and independent variables in which the expected values of dependent variables with

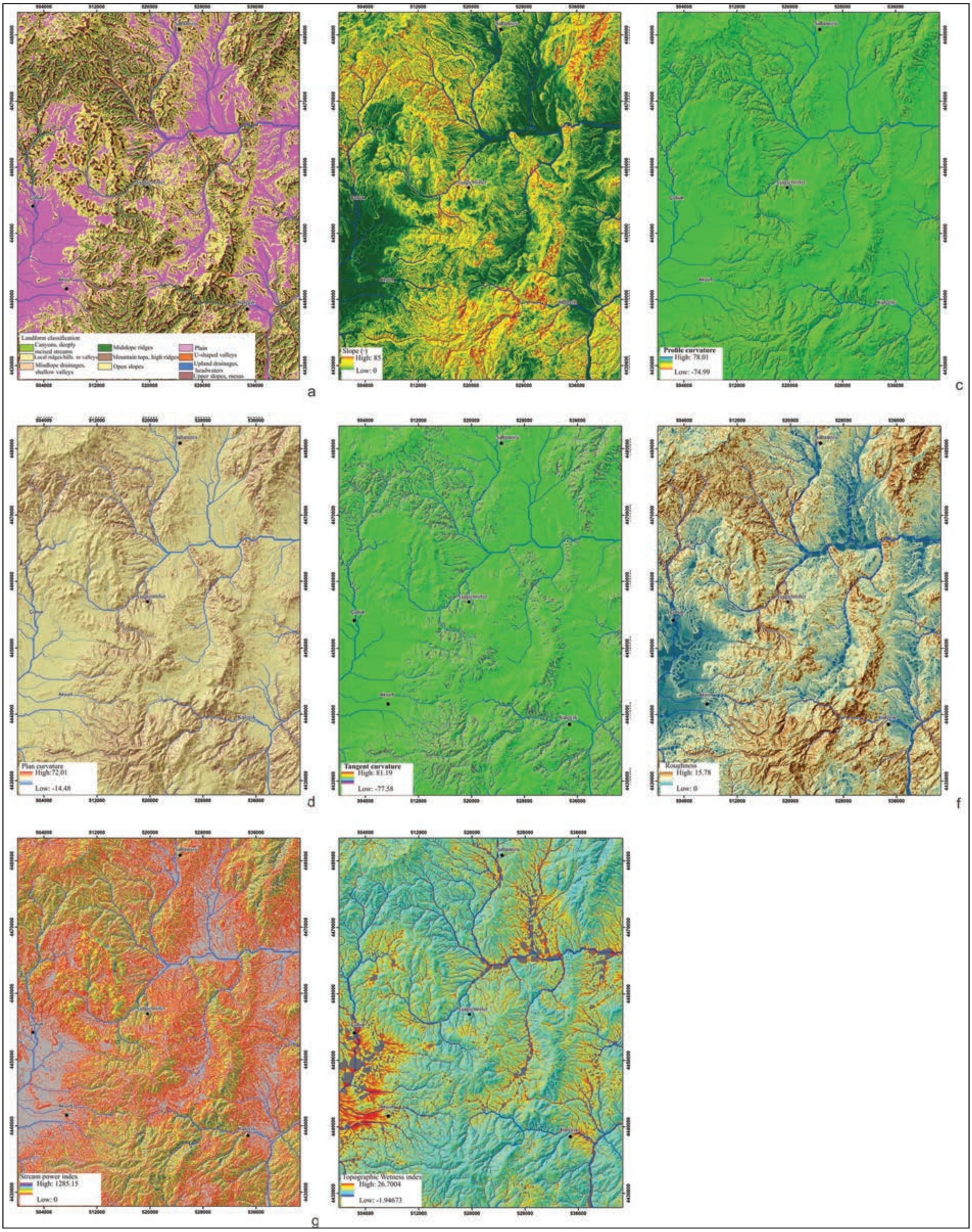

Figure 5- Land use (a), Slope (b), Curvature (c), Plan curvature (d), Tangential curvature (e), roughness index (f), stream power index (g) and topographical wetness index (h).

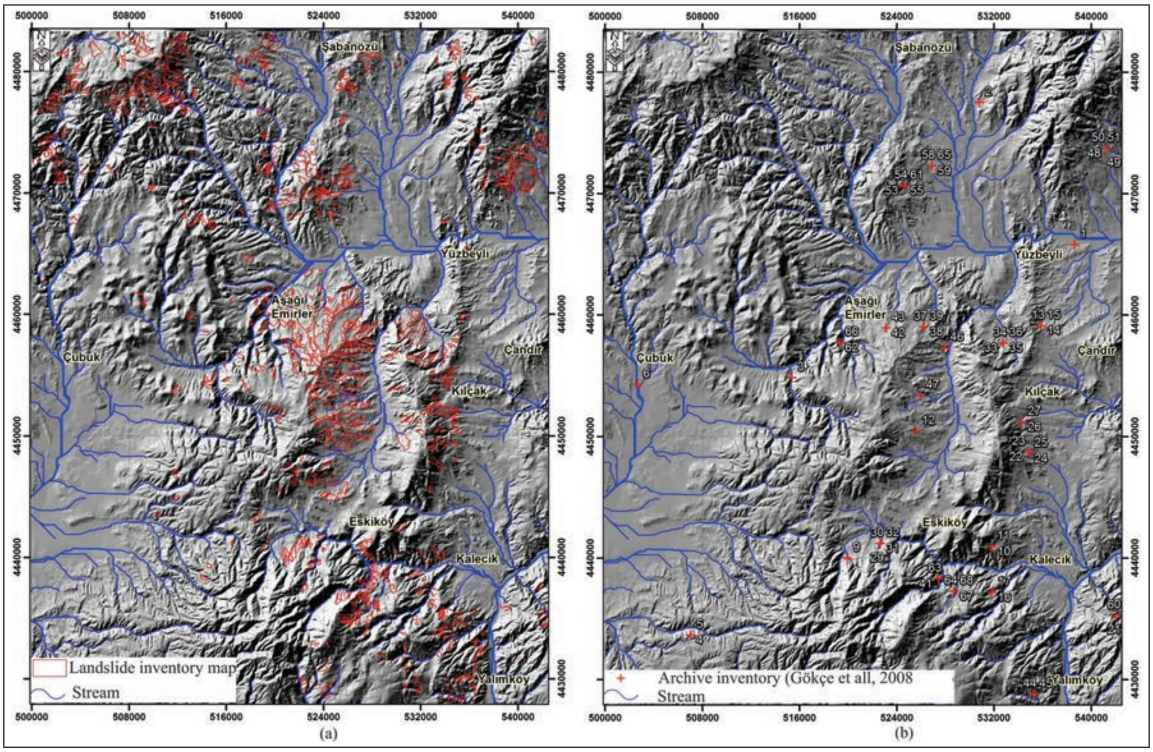

Figure 6- Landslide historical inventory (Duman et al., 2009) and archive (Gökçe et al., 2008) inventory maps.

Table 1- Landslide events reported in the study area (Gökçe et al., 2008).

City	Town	Village	Landslide	Rock fall	Water flooding	Date of report	Effective transport	ID
Ankara	Elmadağ	Yeşildere	+	+	+	6.21.1958		7
Ankara	Akyurt	Kozayağı	+			4.27.1962	117	28
Ankara	Çubuk	Akbayır	+			12.18.1963		3
Çankırı	Eldivan	Hisarcıkkayı	+			7.18.1963		48
Çankırı	Şabanözü	Gündoğmuş	+			5.16.1963	7	52
Ankara	Kalecik	Çukur	+			12.27.1963	7	17
Çankırı	Şabanözü	Ödek	+			4.17.1963	4	56
Ankara	Kalecik	Kılcak	+			4.1.1964	9	26
Çankırı	Şabanözü	Ödek	+			5.22.1964		57
Ankara	Akyurt	Ahmetadil	+			7.7.1965	9	9
Ankara	Kalecik	Gökdere	+			7.6.1965	95	2
Ankara	Kalecik	Akbork	+			5.12.1966		1
Ankara	Kalecik	Kuyucak	+			5.6.1966	5	38
Ankara	Kalecik	Tavşancık	+			5.9.1966	15	42
Ankara	Kalecik	Keklicek	+			7.13.1968		22
Ankara	Akyurt	Doğanoluk	+			8.22.1969		4
Ankara	Elmadağ	Yeşildere	+	+	+	9.22.1969	293	8
Ankara	Kalecik	Altıntaş	+			6.12.1969	21	34
Ankara	Kalecik	Kuyucak	+		+	3.24.1969		39
Ankara	Kalecik	Yalımkoy	+			12.3.1969		44
Çankırı	Eldivan	Hisarcıkkayı	+			5.8.1969	13	49
Ankara	Kalecik	Keklicek	+			11/21/197		23
Çankırı	Şabanözü	Gündoğmuş	+			1/6/197	11	53
Çankırı	Şabanözü	Ödek	+			1/6/197	12	58
Ankara	Kalecik	Altıntaş	+			2.16.1974		35
Çankırı	Şabanözü	Ödek	+			1.24.1974	9	59
Ankara	Kalecik	Çaykaya	+			11.28.1975		13
Ankara	Akyurt	Doğanoluk	+			3.1.1976		5
Ankara	Kalecik	Çukur	+			12.23.1976		16
Ankara	Kalecik	Gökdere	+			1/25/198		21
Ankara	Kalecik	Akcataş	+			5.13.1981		12
Ankara	Kalecik	Çaykaya	+			3.2.1981	11	14
Ankara	Kalecik	Keklicek	+			9.6.1981	9	24
Ankara	Kalecik	Şeyhmahmut	+	+		5.13.1981	1	4

City	Town	Village	Landslide	Rock fall	Water flooding	Date of report	Effective transport	ID
Ankara	Kalecik	Çaykaya	+			12.3.1982		15
Ankara	Kalecik	Gökdere	+			12.29.1982		19
Ankara	Akyurt	Kozayağı	+			12.3.1982	14	29
Ankara	Kalecik	Altıntaş	+		+	12.31.1982		36
Ankara	Kalecik	Kuyucak	+		+	12.3.1982		37
Ankara	Kalecik	Yalımkoy	+			12.3.1982		45
Ankara	Kalecik	Keklicek	+			3.28.1983		25
Çankırı	Eldivan	Hisarcıkkayı	+			5.24.1983		5
Çankırı	Şabanözü	Gündoğmuş	+			5.27.1983		54
Ankara	Kalecik	Altıntaş	+			12.24.1984		33
Çankırı	Şabanözü	Gündoğmuş	+			6.28.1984		55
Ankara	Kalecik	Şeyhmahmut	+			6.15.1984		63
Ankara	Kalecik	Gökdere	+			9.5.1985		18
Ankara	Kalecik	Şeyhmahmut	+			7.9.1985		41
Ankara	Kalecik	Tavşancık	+			3.12.1985	17	43
Ankara	Kalecik	Yeşilöz	+			3.18.1985		46
Ankara	Kalecik	Kılcak	+			12.7.1987		27
Ankara	Akyurt	Kozayağı	+			12.14.1987	2	3
Ankara	Kalecik	yilanli	+			12.29.1987	12	47
Ankara	Akyurt	Kozayağı	+			7.6.1989	14	31
Ankara	Kalecik	Akbork	+		+	2/26/199		11
Ankara	Kalecik	Gökdere	+			6/27/199		6
Ankara	Çubuk	Çubuk	+			8.9.1991		6
Ankara	Akyurt	Kozayağı	+			12.28.1991	1	32
Ankara	Çubuk	Aşağıemirler	+			4.19.1994		62
Çankırı	Eldivan	Hisarcıkkayı	+			3.3.1997		51
Çankırı	Şabanözü	Gündoğmuş	+			8.21.1998		61
Ankara	Kalecik	Satılarkoy	+			11.26.2002		1
Çankırı	Şabanözü	Karakocaş	+			3.3.2002		2
Ankara	Kalecik	Göl	+			12.16.2004		64
Ankara	Çubuk	Aşağıemirler	+			12.2.2007		66
Ankara	Kalecik	Göl	+			2.29.2008		67
Ankara	Kalecik	Göl	+			5.7.2008		68
Çankırı	Şabanözü	Ödek	+			1.9.2008		65

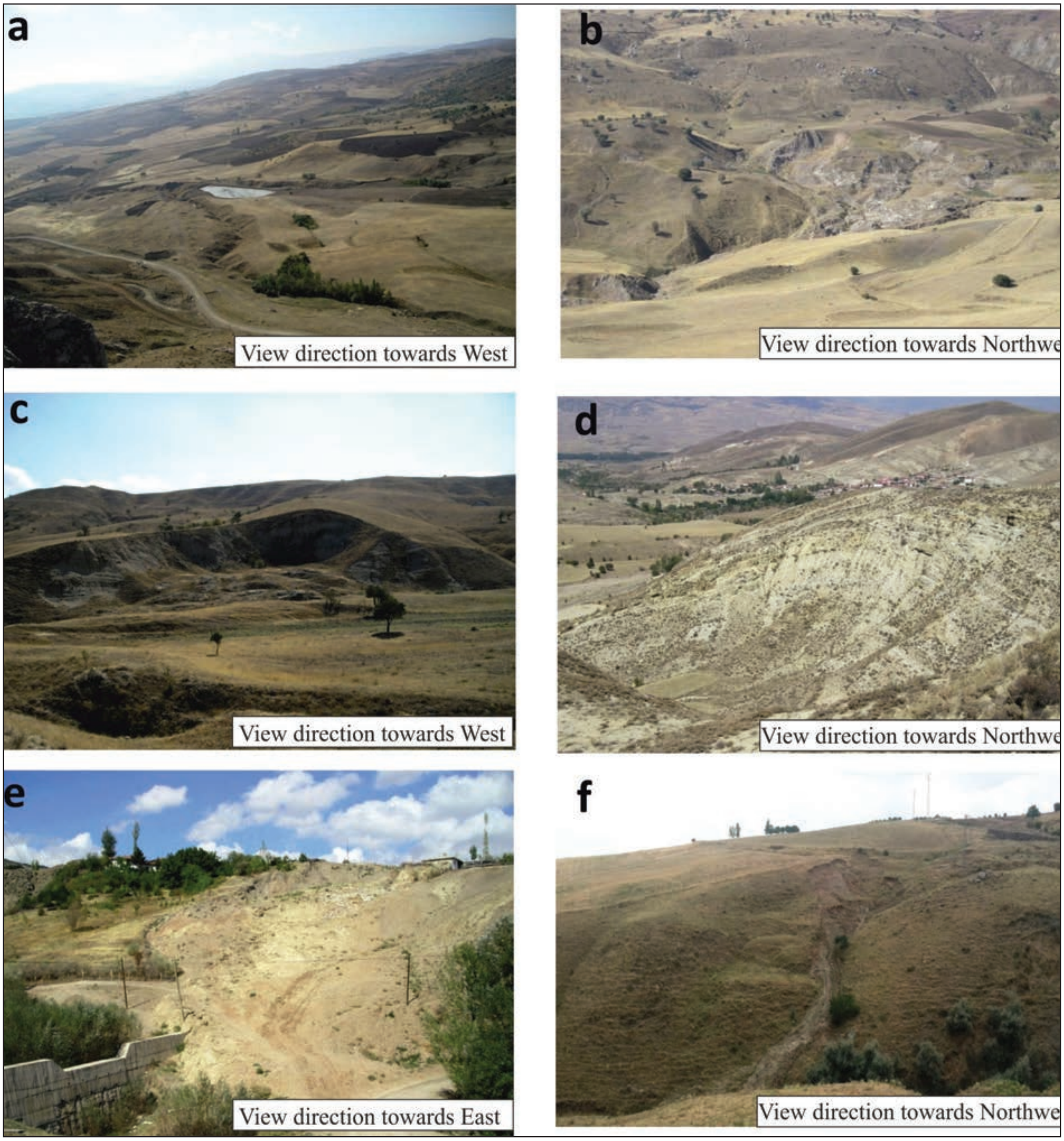

Figure 7- Examples of active landslides observed in the study area: a) the south of the Keklicek village, b) the northwest of the Altıntaş village, c) the west of the Kızılkaya village, d) the northwest of the Karatepe village, e) the Kılçak village, f) the west of the Yeşilöz village.

respect to independent variables are obtained as the probability in cases when the dependent variable is observed as binary.

X values denote for independent variables (landslide preparatory factors) and β values indicate the regression coefficients of dependent variables. As the Z value shows a variation between -∞ and +∞ in Equation 1, the logistic transformation was applied to convert into linear state.

$$Zı=b_0+b_1\,X_1+b_2\,X_2+b_3\,X_3+....+b_n\,X_n \qquad \text{Equation 1}$$

As the Z value, which is calculated by the Equation 1, shows a variation between -∞ and +∞ the logistic transformation was applied in order to make the probability calculation (Equation 2). In order to reveal the relationship between the available landslide inventory and independent variables used in the study the probability values were used. In this equation, P presents the probability of occurrence of an event.

Calculated P values show the probability of occurrence of landslides that might occur in the region.

$$P = 1/(1+e^{-z}) \qquad \text{Equation 2}$$

When the P probability value approaches to zero, the state of probability is -∞, however; it becomes +∞ when it approaches to 1 in this transformation (Hosmer et al., 2013).

The ratio of binary (1, 0) dependent variables to each other in data sets, which will be used in the logistic regression method, are effective on the results of general accuracy classification. In this case, the logical regression model yields favorable results for the class with high values (Hosmer et al., 2013). Therefore; the modelling is generally made by selecting dependent variables belonging to both classes in equal numbers in logistic regression method (Ayalew and Yamagishi 2005; Duman et al., 2006; Heckmann et al., 2014; Hosmer et al., 2013; Süzen and Doyuran 2004; Yesilnacar and Topal 2005; Nefeslioglu et al., 2008, Tekin 2014, Tekin and Çan 2016). The data set for analysis was formed by combining pixels as much as the pixels that corresponds to the inventory map (180.812 pixels) from the non-sliding regions (3.594.338 pixels) by random selection, so the landslide susceptibility map was produced. The regression error matrix of the landslide susceptibility map is given in table 2 and the general accuracy value was obtained as 76,9 %.

Table 2- Error Matrix.

Observed Landslide		Expected Landslide		Accuracy
		0	1	
	0	37870	10784	77.8
	1	11712	36942	75.9
General %				76.9

In the logistic regression analysis performed, the land classification and lithology map were assessed as categorical data in analyses. However; other variables were evaluated as continuous data. The results of the analysis carried out are seen in table 3. The positive and negative values in B values are the landslide preparatory and preventive factors, respectively.

As a result of the analyzes made, the probability values of the landslide susceptibility map of the study area were evaluated at 5 class between very low and very high considering equal intervals (Figure 8a). According to the susceptibility map; 31.42 % of the study area is very low, 22.84 % is low, 18.18 % is medium, 15.26 % is high and 12.28% is in very high regions. 8.54% of the existing landslides are very low, 13.36% is low, 18.30 % is moderate, 26.20 % is high and 33.57 % is in very high sensitive class range (Figure 8b). Logistic regression analysis results were evaluated with the Receiver Operating Characteristic Curve (ROC), which gave the correctness statistic, and the under-curve (AUC) was found to be 0.794 (Figure 8c).

6. Results

Landslide susceptibility assessments form a basis for the landslide risk maps produced in order to prevent damages that will result from the landslide. These are also based on the mapping of landslides that have developed in the studied region until today and well detection of factors causing the formation or triggering of these landslides. With this study, the landslide susceptibility assessment of the region that lies among Çubuk and Kalecik towns of Ankara and Şabanözü town of Çankırı was performed by logistic regression method, which is one of the multivariate statistical analyses, rather than quantitative methods. As mapping unit; pixels in 25x25 m resolution were preferred. In assessing the landslide susceptibility, lithological map,landform classification igital elevation model, slope, profile, plan and tangential slope curvatures, roughness index, stream power index and topographic wetness index were used as landslide conditioning factors. The performance evaluations of the susceptibility maps were performed using Receiver operating characteristic (ROC) and success-prediction curves. The area under the ROC curves was obtained as 0.794. High and very sensitive regions in the susceptibility map almost correspond to 27 % of the study area; 78% of landslides are present in medium, high and very sensitive areas.

It is considered that the determination of environmental variables that control landslides and areas in which landslides could spatially occur will contribute a lot in the mitigation of damages resulting from landslides in risk and hazard studies that will be carried out in the region.

Table 3- Results of the landslide susceptibility map analysis.

Variable	(B)	Standard error	Wald	Exp(B)
Digital elevation model	.0018	.000	4495.492	1.002
Topographic wetness index	-.0140	.006	4.943	.986
Stream power index	.274	.013	445.740	1.317
Profile curvature	-.278	.030	85.860	.757
Plan curvature	-.111	.021	29.391	.894
Slope	-.058	.008	58.528	.944
Open slope	-.0722	.027	7.095	.930
Canyon	.159	.028	33.224	1.173
Upper slope drainage	.381	.124	9.526	1.464
Plain	.921	.022	1677.995	2.513
Upper slopes	.483	.017	811.919	1.621
U-type valleys	-1.102	.026	1754.652	.332
Local ridges	-.656	.030	472.251	.518
Mid-slope drainage	-1.678	.034	2376.680	.187
Roughness	1.656	.050	1117.859	5.239
Oligocene-Lower Miocene: conglomerate, sandstone, siltstone	2.269	.031	5453.729	9.677
Paleocene-Pliocene undifferentiated volcanics	.544	.031	307.001	1.723
Upper Cretaceous: limestone, sandstone, pebblestone, volcanics	1.819	.038	2312.234	6.171
Lower Paleocene: volcanics	1.657	.033	2543.396	5.247
Lower Paleocene: limestone	1.583	.034	2229.537	4.871
Carboniferous: limestone	1.888	.036	2731.964	6.609
Silurian-Permo-Triassic clastic and carbonated	1.010	.036	786.147	2.748
Miocene-Pliocene undifferentiated continental clastic	.460	.034	188.562	1.586
Middle Miocene-Upper Miocene: gypsum	-.419	.055	58.751	.658
Eocene volcanic and sedimentary rocks	-2.151	.060	1302.877	.116
Late Cretaceous-Eocene clastic and carbonates	2.092	.038	3093.636	8.109
Oligocene-Lower Miocene: conglomerate, sandstone, siltstone	1.735	.038	2073.487	5.674
Paleocene-Pliocene undifferentiated volcanics	1.953	.040	2361.721	7.056
Upper Cretaceous: limestone, sandstone, conglomerate, volcanics	.593	.053	126.727	1.810
Lower Paleocene: volcanics	1.445	.056	675.230	4.242
Lower Paleocene: limestone	1.870	.051	1366.873	6.492
Carboniferous: limestone	-.602	.080	56.671	.548
Constant	13.374	.774	298.629	643628.055

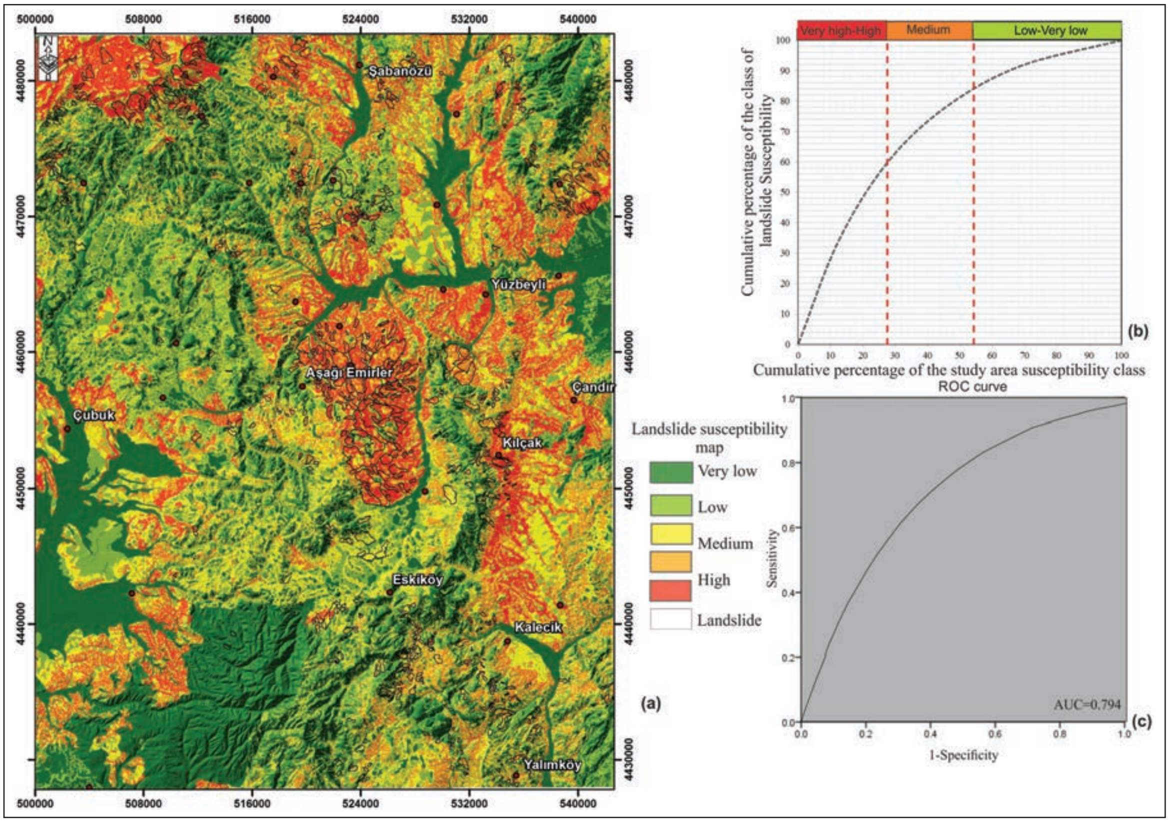

Figure 8- Landslide susceptibility map (a), prediction-success rate (b), ROC curve (c).

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