COĞRAFİ BİLGİ SİSTEMLERİ (CBS) İLE ADAKLI İLÇESİNİN (BİNGÖL) HEYELAN DUYARLILIK ANALİZİ

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ÖZ

Bu çalışmada Adaklı ilçesinin (Bingöl) heyelan duyarlılık analizinin yapılması amaçlanmıştır. Adaklı, Kuzey Anadolu Fayı'na (KAF) paralel gelişen faylar ile Sancak-Uzunpazar (Uzunpınar) Fay Zonu'nun kesişme alanında yer almaktadır. Adaklı genelinde bu fayların hareketine bağlı olarak uzun mesafelerde fay diklikleri gelişmiştir. Eğim değeri yüksek fay diklikleri boyunca büyük çaplı heyelanlar görülmektedir. Heyelan oluşumunda fayların hareketi ile birlikte uygun litolojik yapı ve iklim özellikleri de etkilidir. Adaklı İlçesi'nin jeolojik, jeomorfolojik ve iklim özellikleri nedeniyle meydana gelen heyelanlar can ve mal kayıplarına yol açmaktadır. Bu çalışmada bivariate istatistiksel analiz yöntemlerinden "Heyelan Duyarlılık Analizi" ile Adaklı ilçesinde heyelana duyarlı alanlar belirlenmiştir. Analizde litoloji, fay hatlarına uzaklık, eğim, bakı, yükselti, yamaç eğriselliği, topoğrafik nemlilik indeksi, akarsulara uzaklık ve bitki örtüsü (Normalize Fark Bitki İndeksi-NDVI) katmanları kullanılmıştır. Heyelan üzerinde etkili olan katmanlar alt gruplara ayrılmış, alt grupların toplam piksel ve heyelanlı piksel sayıları zonal istatistikle bulunmuştur. Bu veriler kullanılarak alt grupların ağırlık değeri bulunmuştur. Ağırlık değeri katmanlara atanmış, bu katmanlar toplanarak heyelan duyarlılık haritası oluşturulmuştur. Sonuç haritasına göre heyelan duyarlılığı orta olan alanların oranı % 14, yüksek ve çok yüksek olan alanların oranı % 8'dir. Heyelana duyarsız alanların oranı % 55, çok düşük olan alanların oranı % 23'tür. Ancak adaklı ilçesinde yerleşmelerin büyük bir kısmı orta, yüksek ve çok yüksek duyarlı alanda yer almaktadır. Adaklı, Hasbağlar, Gökçeli, Çanakçı, Kozlu, Erbaşlar heyelan duyarlılığının yüksek olduğu alanda yer alan yerleşmelerdir. Bölgenin tektonik yapısı dikkate alındığında depremlerin tetikleyeceği heyelanların görülmesi kaçınılmazdır. Bu nedenle heyelanlı sahalarda yeni yapılara izin verilmemelidir. Gökçeli Vadisi'nin Erbaşlar ile Gökçeli arasındaki bölümünde drenaj çalışmaları gerekmektedir.

Anahtar Kelimeler: Bingöl, Adaklı, coğrafi bilgi sistemleri (CBS), heyelan duyarlılık analizi.

LANDSLIDE SUSCEPTIBILITY ANALYSIS OF ADAKLI DISTRICT (BINGÖL) BY GEOGRAPHIC INFORMATION SYSTEMS (GIS)

ABSTRACT

The objective of this study is to analyze landslide susceptibility of Adaklı District (Bingöl). Adaklı is located in the intersection area of Sancak-Uzunpazar (Uzunpınar) Fault Zone and faults developed parallel to North Anatolian Fault (NAF). Throughout the district fault scarps have been formed over long distances due to fault movements. Large-scale landslides have occurred along the fault scarps with high slope value. Along with the fault movement, suitable lithological structure and climatic characteristics also have an effect on the occurrence of landslide. Landslides occurring due to geological, geomorphological and climatic characteristics of Adaklı District caused loss of life and property in the past. In this study, areas susceptible to landslide in Adaklı District have been determined by 'Landslide Susceptibility Analysis', which is one of the statistical analysis methods of bivariate. Geological and topographical maps and Landsat 8 satellite images have been used as data. Lithology, distance to fault line, slope, aspect, elevation, curvature, topographic wetness index, distance to river and vegetation (NDVI) layers have been used in the analysis. Layers that have an effect on landslide have been divided into sub-groups, and total numbers of sub-groups and their pixel numbers with landslide have been determined using zonal statistics. Using these data, weight values of subgroups have been obtained. Weight values have been assigned to layers and landslide susceptibility map has been created by collecting these layers. According to the result map, the percentage of the areas with medium susceptibility is 14 % and areas with high and very high susceptibility account for 8 %. Areas insusceptible to landslide account for 55% whereas areas with very low susceptibility account for 23%. However, a large number of the settlements in Adaklı District are located in the high and very high susceptible areas. Adaklı, Hasbağlar, Gökçeli, Çanakçı, Kozlu, Erbaşlar are settlements located in high susceptible areas. Considering the tectonic structure of the area, occurrences of landslides triggered by earthquakes are inevitable. For this reason, new settlements must not be allowed in the areas under the risk of landslide, and drainage channels should be done in the region between Gökçeli and Çanakçı in Gökçeli Valley.

Keywords: Bingöl, Adaklı, geographic information systems (GIS), landslide susceptibility analysis.

INTRODUCTION

Disasters are phenomena that cause physical, economic and social losses for people. More than 96,5 million people were affected, 21,610 people lost their lives, and economic loss was 156.7 billion $ by 330 natural disasters worldwide in 2013 (Guha-Sapir, 2013). Landslide is one of the most common natural disasters that cause loss of life and property in Turkey as well as in the whole world. In Turkey landslide is the most common disaster, with a rate of 45% (Gökçe et al., 2008). Although it is not possible to prevent landslides, the damage they cause can be minimized. For this reason, landslide susceptibility studies have been carried out. Landslide susceptibility analysis is based on the prediction that landslides may occur in areas with similar characteristics in a region, depending on the appropriate physical factors (Valvo, 2002).

Over the years, the number of studies concerning methods and the progress in landslide susceptibility has grown rapidly. They involve either qualitative or quantitative modeling (Hussin et al., 2015). In literature, there is no agreement among researchers on the methods and parameters used in the preparation of landslide susceptibility maps (Gökçeoğlu and Ercanoğlu, 2001). Many pioneer works in this field concern qualitative studies where the judgment established by experts, based on the data investigated, was used to produce susceptibility maps (Atkinson and Massari, 1998). The subjectivity of these methods was addressed by the adoption of quantitative assessment methods such as bivariate or multivariate statistical analysis, logistic regression, likelihood ratio, and weight-of-evidence (Yalçın et al., 2011; Regmi et al., 2011).

In this study bivariate statistical method has been used. In statistical methods, landslide casual factors or parameters are derived and combined with the landslide inventories to predict the future occurrence of landslides (Carrara et al. 1991, Guzzetti et al. 1999, Dai et al. 2001).

Statistical methods can be distinguished into multivariate and bivariate (Adhikari, 2011). In multivariate method, all relevant landslide casual factors or parameters are treated together (Carrara 1983, Carrara et al.

1991, Lee and Min 2001, Süzen and Doyuran 2004a). As a result, interaction effects of multiple factors are displayed by this method. Logistic regression (Dai et al. 2001) and determinant analysis are the main types of multivariate statistics used in landslide susceptibility analysis. Artificial neural network (ANN) classifiers are an-other type of multivariate method (Adhikari, 2011). In bivariate statistical method, each landslide casual factor map (for example geology, slope, land use, vegetation) is combined with the landslide inventory. The weights are derived from either landslide abundance or densities in each attribute class within each factor (Gupta and Joshi 1990, Van Westen et al. 1997, Süzen and Doyuran 2004 b).

In this study landslide susceptibility map for Adaklı District has been created by using lithology, distance to fault line, slope, aspect, elevation, curvature, topographic wetness index, distance to river and vegetation (Normalized Difference Vegetation Index-NDVI) layers. The layers used in the analysis were divided into subclasses, pixel numbers of layers' subgroups and the number of landslide pixels were determined by Geographic Information Systems (GIS). With this data, the weight values of subclasses of layers were determined. Weight values were assigned to the maps, and susceptibility map was created by overlaying these maps. The result map shows that throughout the district, sites with low landslide susceptibility cover much of the area, however, the district center and a large number of the populous settlements are located in areas with high landslide susceptibility.

FIELD OF STUDY AND ITS SPECIFICATIONS

Adaklı, a small town of Bingöl province, has an area of 858 km^2. The study area is surrounded by Mount Şeytan to the north, Özlüce Dam to the west and Mount Karaboğa to the southeast (Figure 1). In the research area elevation ranges from 1130 m to 2910 m, and average elevation goes up to 1900 m. Slope values in the area vary from 0o to 67.3o. The highest slope values are seen at Mt. Şeytan in the northwest. There is an overly fragmented topography in this area, and due to this, severe erosions have been observed. In the area Gökçeli is one of the most important streams. In some parts of Gökçeli Stream, located on fault lines, slope values go up to 45^{o}. On the other hand, slope is low on the plateau surfaces in the east. Landslides have occurred in the vicinity of Çatmaoluk due to the favorable lithology on the sides of the plateau.

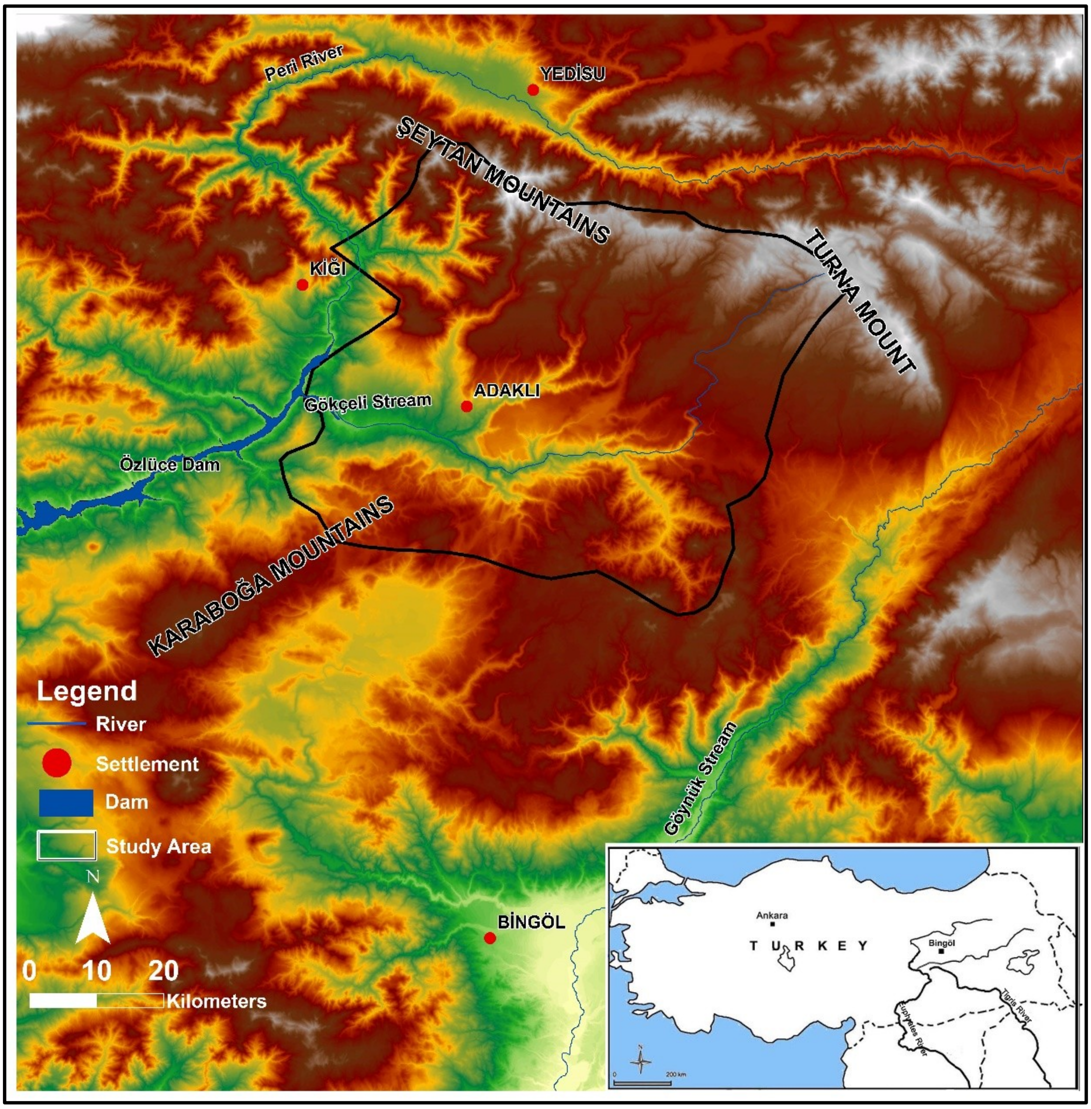

Figure1. Location map of Adaklı district (Bingöl)

Originating from the southern sides of Mt.Şeytan, Gökçeli Stream is connected to the Özlüce Dam. Gökçeli stream valley is mostly narrow and deep since it is settled on fault lines. In this section of the valley the slope values are relatively low. However, large landslides have occurred in this area where there is a lot of ground water.

In Adaklı, Paleozoic Bitlis Metamorphics in the southeast, Elmalı Formation units consisting of the Upper Createous ophiolites in the north, Mollakulaçdere Formation consisting of conglomerates, claystones, and marls in the south, and Upper Miocene and Upper Miocene-Pliocene volcanics in the east have surfaced (Tarhan, 2007). Adaklı district is located in a tectonically active area. The study area which lies to the south of North Anatolian Fault Zone (NAFZ) is located in the intersection area of Sancak-Uzunpazar Fault Zone and faults developed parallel to NAF. In the north and south of Adaklı fault scarps whose slope values go up to 45^{o} have been formed due to the faults developed parallel to NAF. Along Sancak-Uzunpazar Fault Zone, which cuts the study area in NE-SW direction, there are displaced creeks, elongated ridges, landslides, fault scarps and sag-ponds. This data proves that Sancak-Uzunpazar Fault Zone is still active (Dirik et al., 2003; Herece, 2008).

In Adaklı, where characteristics of continental climate are effective, annual average temperature is 9.5 °C and annual precipitation is 1001.3 mm (Figure 2). Bingöl has an average temperature of 12.1 °C and average precipitation of 891 mm. There are 2.5 °C temperature and 100 mm precipitation differences between Adaklı and Bingöl. Low average temperature and high amount of rainfall is related to high elevation and, Adaklı's being in the north

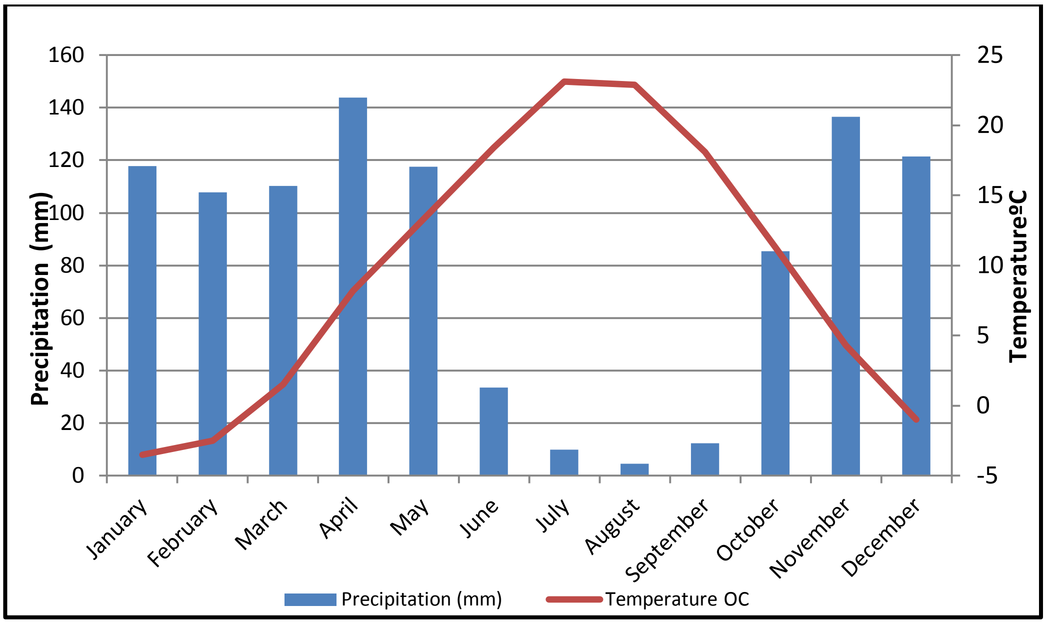

Figure 2. Monthly average temperate and precipitation from 1975 to 1996 (TSMS).

In the study area, where rainfall excess takes place in spring, dawnfall in winter is excessive and as snow. In mountainous areas snow depth reaches 3-4 m. Landslides occur in spring due to melting snow and increased rainfall. Melting snow caused by increasing temperatures in April and May cause to much more water to leak into the soil, which triggers landslides.

The objective of this study is to determine areas susceptible to landslides. The most important reasons in choosing Adaklı as a study area are that landslides cause loss of life and property and that their effects still continue.

MATERIAL and METHOD

Considering the direct and indirect losses caused by mass movements, the application of preventive measures and minimizing the damage require knowledge of the areal distribution of current and potential mass movements, characterization, and factors controlling the occurrence (Cihangir and Görüm, 2016). The distribution of mass movements is shown by inventory maps. Landslide inventory map of the study area has been created with the aid of field studies, Google Earth satellite images, Erzurum sheet, and 1/500,00 scale landslide inventory map prepared by General Directorate of Mineral Research and Exploration (Duman et al., 2009) (Figure 3).

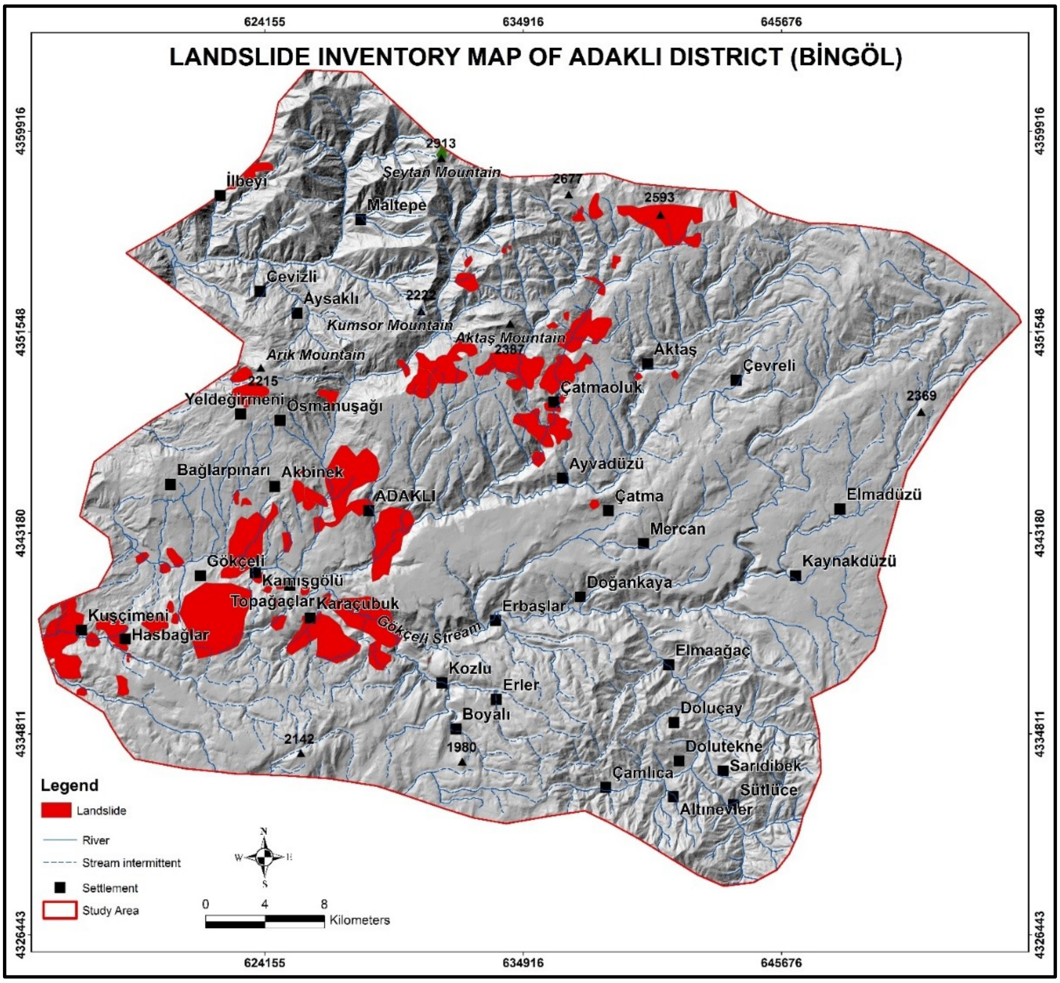

Figure 3. Landslide inventory map of Adaklı District (Bingöl) (created by using field works and Google Earth satellite images.)

In landslide susceptibility analyses, the data related to multiple parameters such as geological structure, distance to faults, slope, drainage network, elevation, shape of hillside, aspect, road density, and seismicity (Gökçeoğlu and Aksoy, 1996; Guzzetti et al., 1999; Dai et al., 2001; Chi et al., 2002; Lee and Choi., 2004; Yalçın and Bulut, 2007; Sunkar and Avci, 2016) are evaluated together. In this study factors such as lithology, distance to fault line, slope, aspect, elevation, curvature, topographic wetness index, distance to river and vegetation have been used.

Lithology and tectonic maps have been created by digitization of 1/100,000 scale Erzincan J44 and Erzurum J45 geology sheets provided by General Directorate of Mineral Research and Exploration. Distance-to-fault line map was formed by using the tectonic map. Digital Elevation Model(DEM) was created using 1/25,000 scale digitization maps of the area. Slope, aspect, curvature and topographic wetness index (TWI) maps of the study area were formed by DEM. Topographic wetness index map, in accordance with the following formula (1) proposed by Moore et al., (1991)

$$TWI = \ln(\frac{As}{\tan\beta}) \quad (1)$$

was automatically created using SAGA (System for Automated Geoscientific Analyses). In the formula, As and β represent basin area and slope, respectively. From topography maps of the study area, continuous and intermittent streams were digitized and distance-to-river maps were created.

Vegetation in Adaklı District was evaluated by NDVI. By using 4th and 5th bands of the Landsat 8 image, June 4,2013, NDVI layer was obtained in accordance with the following formula (2).

$$\boldsymbol{NDVI} = \frac{\boldsymbol{Band5-Band4}}{\boldsymbol{Band5+Band4}} \quad (2)$$

'Landslide Susceptibility Map', one of the Bivariate Statistical Methods, was used for susceptibility analysis of Adaklı District. This method, which is the simplest and most useful one among Bivariate statistical analysis methods, enables to find out the effects of different variables on the occurrence of landslide (Van Westen, 1993).

For this study, appropriate subclasses were defined by classifying parameter maps. Parameter maps and landslide map were overlaid and weight values were calculated using zonal statistic (3). (Van Westen,1993).

$$D_{area} = 1000\frac{Npix(SX_i)}{Npix(X_i)} \quad (3)$$

(Brabb, 1984; Van Westen, 1993).

Where

D_{area} = areal density (‰),

$Npix(SX_i)$ The number of pixels of landslide in parameters 'subclasses,

$Npix(X_i)$ = number of pixels in parameters 'subclasses.

Assignment of weight value is required to evaluate the effects of parameters. In order to this, the ratio of pixel numbers of total landslides to the pixel numbers of the whole area was obtained and subtracted from the density (4).

$$W_{area} = 1000\frac{Npix(SX_i)}{Npix(X_i)} - 1000\frac{\sum Npix(SX_i)}{\sum Npix(X_i)} \quad (4)$$

According to the calculations above, weight values of factor maps were determined and table of these values, which was used in the susceptibility analysis, were created. In the final step, weight values of factor maps were added and landslide susceptibility map was obtained (Table 1).

Table 1. Weight Values And Parameters Used In Landslide Susceptibility Analysis

Layer	sub-classes	Pixel for sub-classes	Pixel for the whole area	Landslide pixel in sub-classes	Landslidepixel in the whole area	LSA
Slope (Degree)	**0-5**	1393588	8582926	71812	576906	-15.685245
	5-15	3040532	8582926	220274	576906	5.23033529
	15-25	2259652	8582926	155027	576906	1.39104258
	25-35	1447869	8582926	97766	576906	0.30852536
	35-45	407359	8582926	29754	576906	5.82568476
	45>	33926	8582926	2273	576906	-0.2167773
Distance to fault (meters)	**0-50**	280961	8582926	18298	576906	-2.0890627
	50-100	247251	8582926	16290	576906	-1.3310737
	100-150	237333	8582926	16110	576906	0.6637695
	150-200	220236	8582926	14007	576906	-3.6155829
	200-1000	2617771	8582926	154473	576906	-8.206176
	1000>	4989380	8582926	357728	576906	4.48234699
Curvature	**Concave**	3012906	8582926	205006	576906	0.82707469
	Flat	2441366	8582926	161556	576906	-1.0411107
	Convex	3128654	8582926	210344	576906	0.01592827
Elevation (meters)	**1130-1250**	134296	8582926	17359	576906	62.0437089
	150-1500	834711	8582926	168118	576906	134.193092
	1500-1750	1687127	8582926	158129	576906	26.5112519
	1750-2000	2860687	8582926	82835	576906	-38.259208
	2000-2250	1786634	8582926	100786	576906	-10.804433
	2250-2500	982380	8582926	24908	576906	-41.860789
	2500-2750	287246	8582926	23259	576906	13.7568676
	2750>	9845	8582926	1512	576906	86.3649584
Distance to river (meters)	**0-50**	1060929	8582926	65692	576906	-5.2962214
	50-100	926941	8582926	57514	576906	-5.1684403
	100-150	897950	8582926	54727	576906	-6.2689387
	150-200	851174	8582926	51341	576906	-6.8976725
	200-250	782711	8582926	48276	576906	-5.537602
	250-300	697889	8582926	43930	576906	-4.2685664
	300-350	611606	8582926	38848	576906	-3.6975228
	350-400	509838	8582926	32957	576906	-2.5734373
	400-450	426019	8582926	29335	576906	1.64289188
	450-500	347037	8582926	25062	576906	5.00154416
	500-1000	1297177	8582926	112052	576906	19.1658874
	1000>	187179	8582926	17172	576906	24.5255214
NDVI	**0<**	7219	8582926	94	576906	-54.194345
	0-0.2	1084937	8582926	67374	576906	-5.116081
	0.2-0.4	5208105	8582926	324373	576906	-4.9331929
	0.4>	2282665	8582926	185065	576906	13.8585561
Aspect	**Flat**	618751	8582926	37599	576906	-6.4495769
	North	359718	8582926	28355	576906	11.6100963
	Northeast	727697	8582926	50004	576906	1.49987383
	East	736754	8582926	47858	576906	-2.2576293
	Southeast	1095387	8582926	62190	576906	-10.441084
	South	1296887	8582926	75336	576906	-9.1256672
	Southwest	1291208	8582926	85332	576906	-1.1285882
	West	1028938	8582926	74181	576906	4.87918359
	Northwet	1019496	8582926	79186	576906	10.456173
	North	408090	8582926	36865	576906	23.1199259
TWI	**7<**	5331190	8582926	363936	576906	1.04989486
	7-12	2819520	8582926	186581	576906	-1.0408004
	12-17	388365	8582926	23039	576906	-7.8924798
	17-22	39062	8582926	2784	576906	4.05577296
	22>	4789	8582926	566	576906	50.9719737
Lithology (See Figure 5 for explanation of lithological units)	**Mia**	196075	8582926	12680	576906	-2.5464076
	KEoe	538452	8582926	4621	576906	-58.63353
	Mivsk	2496066	8582926	37227	576906	-52.30127
	Mivsb	1072488	8582926	97311	576906	23.518343
	Olmim	314309	8582926	24096	576906	9.44787153
	Mivsg	73324	8582926	3595	576906	-18.186572
	Eom	118312	8582926	6685	576906	-10.712395
	Eon	138896	8582926	4910	576906	-31.865349
	Mivsh	122	8582926	0	576906	-67.215539
	Mivshi	277539	8582926	5739	576906	-46.537364
	KEoev	203180	8582926	2247	576906	-56.15638
	Olmimç	933445	8582926	117954	576906	59.1486278
	Pzmzbm	8664	8582926	0	576906	-67.215539
	Mivs	2034404	8582926	255518	576906	58.3829161
	Mivss	47099	8582926	4323	576906	24.5698489
	Ply	51172	8582926	0	576906	-67.215539
	Qal	25671	8582926	0	576906	-67.215539
	Eokç	51434	8582926	0	576906	-67.215539
	Eomibç	2274	8582926	0	576906	-67.215539

FINDINGS

Lithology

Being one of the most important parameters affecting hillside susceptibility, lithology is directly related to many features of materials such as strength, permeability, hardness (Baeza and Corominas, 2001). Landslides mostly occur in the areas where lithological variation is observed. For this reason, lithological differences need to be considered in analyses (Komac, 2006) (Figure 4). In the study area landslides widely occur in the sites where agglomerates and tuffs of Solhan formation in Upper Miocene and Upper Miocene-Pliocene (Figure 4). That lithology consists of tuffs in the section between Erbaşlar and Gökçeli cause landslides. High amount of ground water in this area contributes to landslide occurrence. Mollakulaçdere Formation units have surfaced in the west of Adaklı. The unit consists of conglomerates, claystones and marl. Landslides are seen on inclined hillsides where this unit has surfaced.

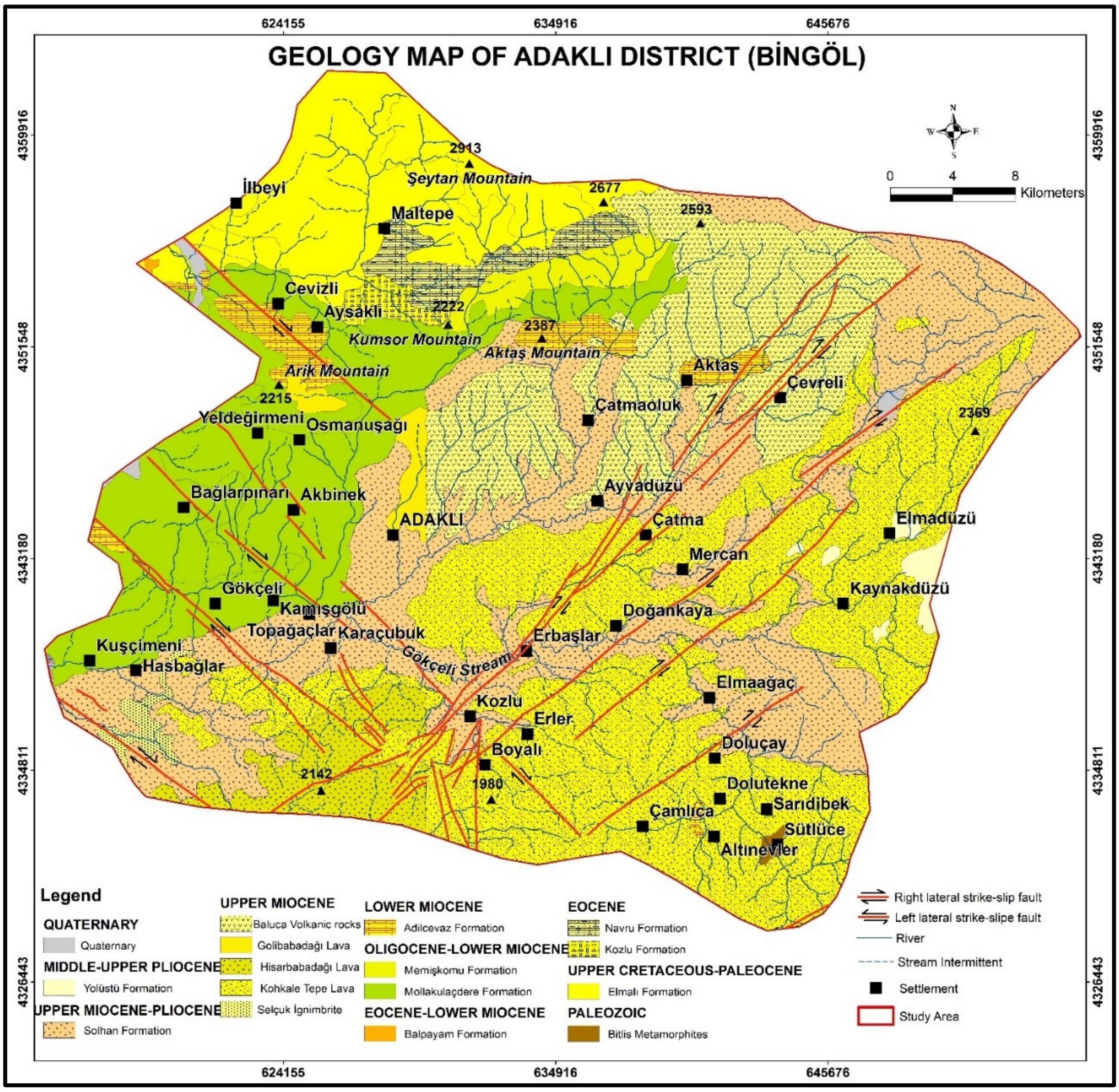

Figure 4. Geology map of Adaklı district (Bingöl) (created by using Erzincan J44 and Erzurum J45 geology sheets provided by General Directorate of Mineral Research and Exploration)

Considering the relation between landslide and lithological units, it seen that 45% of the landslides have occurred in the tuffs that are members of Solhan Formation unit. Claystones and marls are other units of Mollakulaçdere formation, in which landslides widely occur (21%) (Figure 5). 17% of the landslides have occurred in units of Upper Miocene Baluca volcanite.

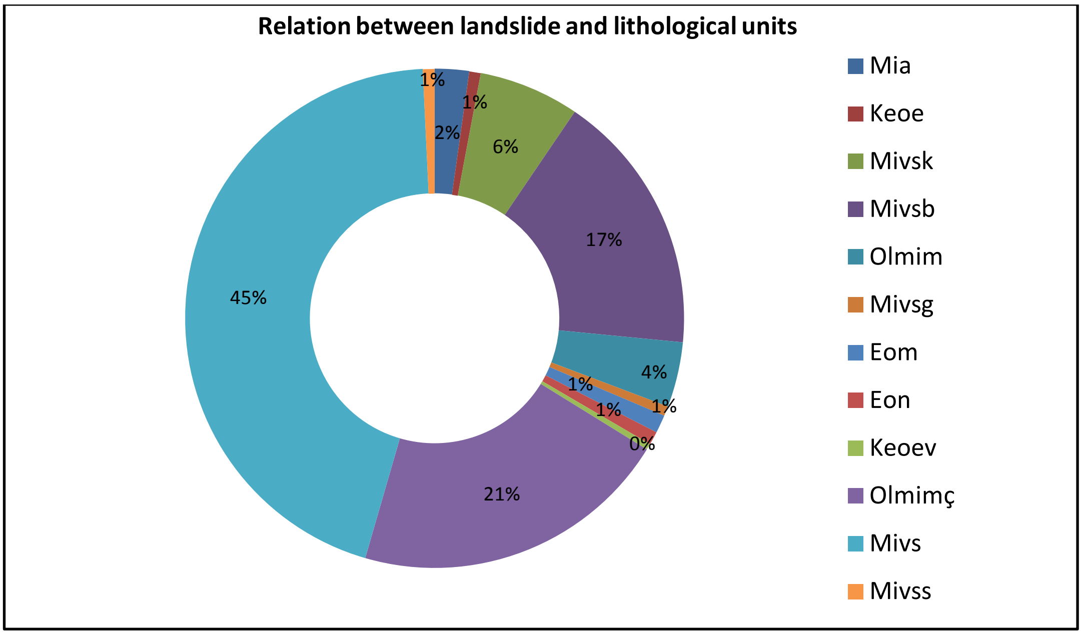

Figure 5. The distribution of landslides to the lithological units in Adaklı district (Mia-Limestone, Mivsk-basalt, Mivsb, Mivsg-Andesite, Olmim-claystone, marl, Eom-Eosen-claystone, marl, Eon-volkanics-limestone, Mivsh-Mivshi-dacite, rhyolite, KEoev-andesite-tuff, Olmimç-Conglomerate, Pzmzbm, marble, Mivs-agglomerate, tuff, Mivss-Ignimbrite, Ply, conglomerate, Qal-alluvium, Eokç-conglomerate, Eomibç-conglomerate-sandstone)

Triggered by excessive rainfall, lithology consisting of clay and marl caused landslide and 10 people lost their lives in Yeldeğirmeni village, in 1988. The village was moved into another place, however undamaged buildings have been used as animal shelters. This area is greatly under the risk of landslides (Photo 1).

Photo 1. In Yel Değirmeni, a village located in the northwest of Adaklı, a landslide occurred in April, 1988, and ten people died.

Distance to fault line

This parameter, especially in areas important in terms of seismic activity, is used in the preparation of landslide susceptibility maps (Dağ, 2007). Adaklı is located in the area where faults developed parallel to NAF and Sancak-Uzunpazar Fault intersect. Fault scarps with high slope value have developed due to these faults (Photo 2). That the faults are active occasionally cause earthquakes, and landslides occur due to earthquakes.

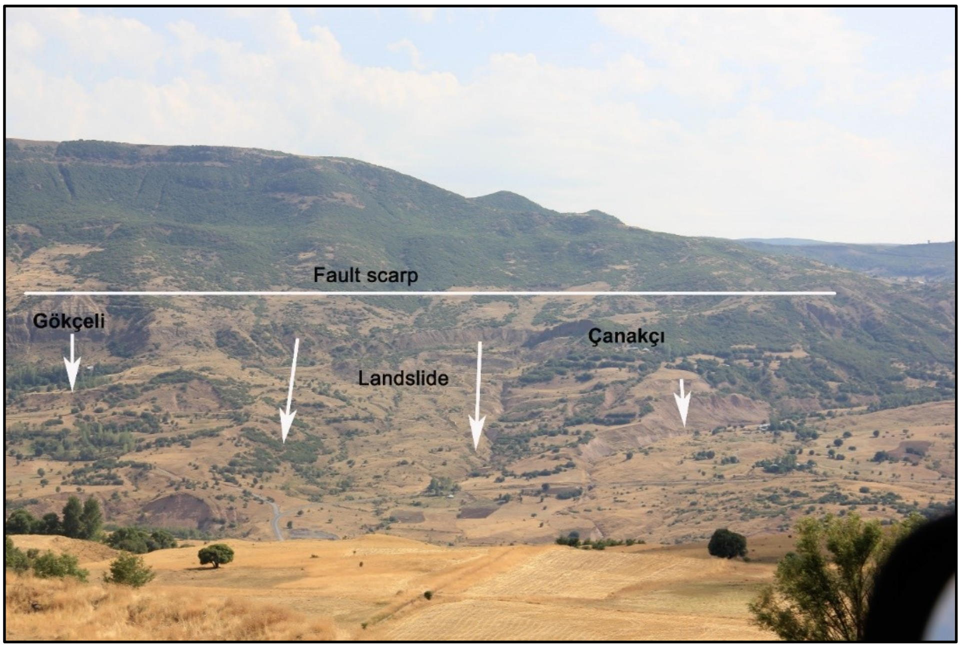

Photo 2. Landslides have occurred along fault scarps with high slope value in Adaklı.

In the landslide susceptibility analysis 6 groups were specified for the layer of distance-to-fault lines: 0-50m,50-100m,100-150m,150-200m,200-1000m, and 1000m>. In Adaklı District, the rate of areas having a distance of 0-200m to the fault lines is 56% and 44% of the area is at a distance over 200 m. The distribution of landslides to distance-to-fault line groups has been determined using zonal statistics. Accordingly, it is seen that 80% of the landslides occur in areas of group 1000m> (Figure 6).

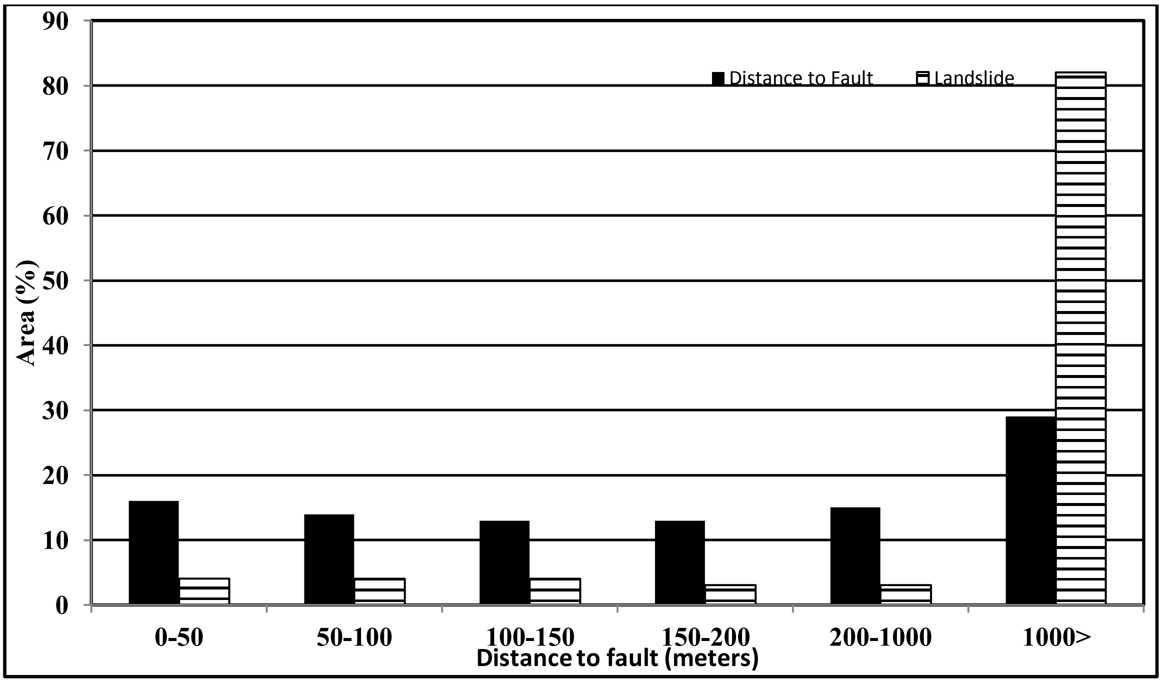

Figure 6. In Adaklı District (Bingöl), the distribution of distance to the fault lines and distribution of landslides to the fault lines

Landslides have occurred on fault zones and valley slopes where cleavage is much. Besides, landslides triggered by earthquakes have been observed. After Bingöl earthquake in 1971, landslides occurred in Hasbağlar and Gökçeli villages. These two settlements were replaced due to the earthquake and the landslides triggered by it. The results of analysis show that, in Adaklı, right lateral faults developed parallel to NAF are more effective on the occurrence and distribution of landslides than Sancak-Uzunpazar Fault, which is left-lateral strike-slip. In the susceptibility map, the area most susceptible to landslides is the section of Gökçeli Stream Valley, between Kozlu and Gökçeli villages.

Slope

Slope is the most preferred one among topographic factors in landslide susceptibility studies (Çellek, 2013). Susceptibility to landslides increases with increasing slope (Santacana et al., 2003). According to the slope map created by DEM for Adaklı, slope values range from 0 to 68^{o}, and average slope value goes up to 16^{o}. The slope map is divided into six groups as 0-5^{o},5^{o}-15^{o},15^{o}-25^{o},25^{o}-35^{o},35^{o}-45^{o}, and 45^{o}>. 0-5^{o} and 5^{o}-15^{o} groups cover large areas. This results from volcanic plateaus' and landslides' covering large areas. 0-5^{o}, 5^{o}-15^{o}, 15^{o}-25^{o},25^{o}-

35^o groups account for 16%, 36 %, 26 %, and 17 %, respectively. The relation between landslides and slope groups in Adaklı District was determined using zonal statistics. Accordingly, most of the occurred landslides are observed in group 5^o-15^o. This is due to the fact that other conditions (lithology, underground water) in this slope group are suitable for landslide occurrence. 13% of the landslides were observed in group 5^o-15^o, 27% in group 15^o- 25^o,17% in group 25^o-35^o, and 5% in group 35^o-45^o (Figure 7).

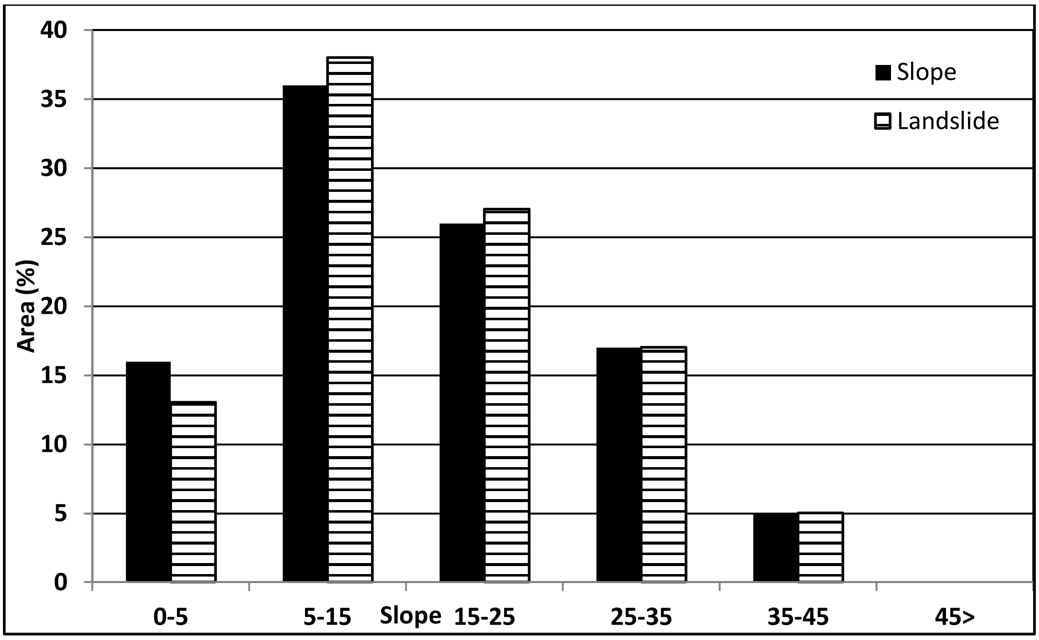

Figure7. In Adaklı District (Bingöl), slope distribution and distribution of landslides to slope groups

Landslides have occurred in the areas with low slope, in sections of Gökçeli stream located in south-west of Adaklı District. In the north and east of this area, landslides have occurred due to the increase of slope values. The roads connecting the district center to the villages are passed through Gökçeli Stream Valley. Landslides on the valley hillsides create a risk for the highway (Photo 3)

Photo 3. Erbaşlar-Adaklı Highway is affected by landslides.

Aspect

One of the preferred parameters in landslide susceptibility studies is slope orientation (Nagarajan et al., 2000; Lee and Min, 2001; Lee and Choi, 2004; Lee and Dan, 2005; Moreiras, 2005; Yalçın and Bulut, 2007; Akgün et al., 2008). Meteorological phenomena such as the general precipitation direction of the region, the general morphological structure of the area, amount of sunlight it takes, are effective in the concentration of the landslides on the slopes with certain orientations. It is noteworthy that the area facing southern hillsides (S-SW-SE) is much in aspect map for Adaklı District, created by DEM. Generally, south-facing hillsides cover much area in the north and north-facing hillsides cover much area in the south. The rate of flat areas is 6%, north-facing hillsides 30%, east-facing hillsides 9%, south-facing hillsides 43%, and west-facing hillsides 12%. It is seen in the aspect map that the rate of flat areas is low. When the distribution of landslides is evaluated according to the aspect groups, it is seen that landslides are more likely to occur on south-facing hillsides. 39% of the landslides have occurred on south-facing hillsides, 35% on north-facing hillsides,13% on west-facing hillsides, and 8% on east-facing hillsides (Figure 8).

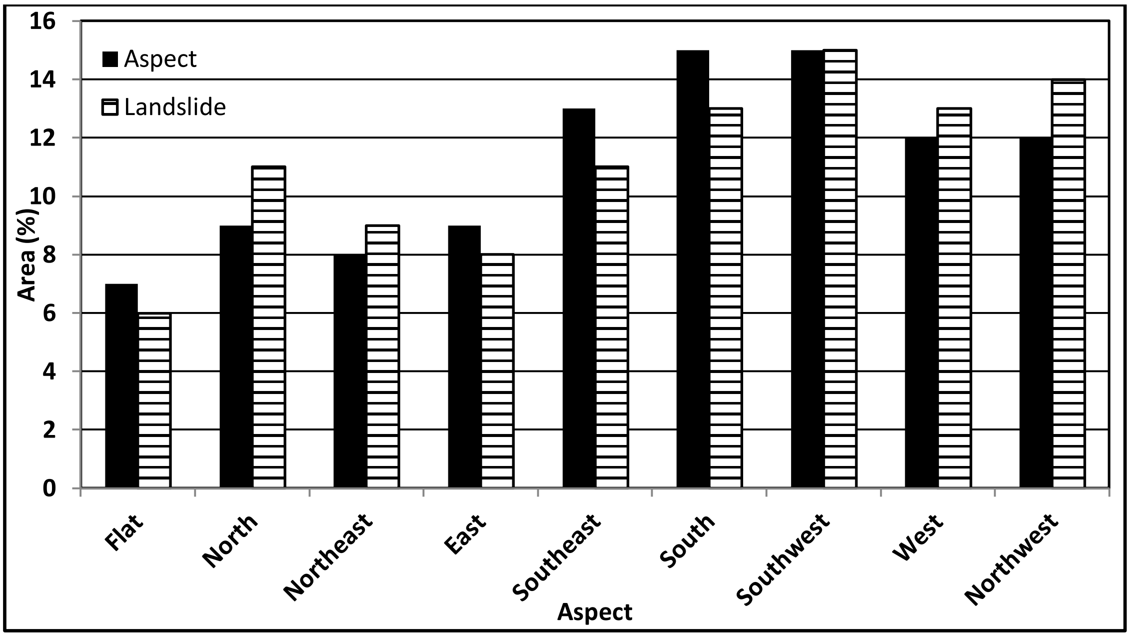

Figure 8. The distribution of aspect groups and the distribution of landslides to aspect groups in Adaklı District

The fact that landslides occur more on south-facing hillsides is related to amount and form of downfall. The downfall in the form of snow in winter and thick snow contribute to landslide occurrence. While precipitation is a triggering factor in landslide occurrence, aspect is a preliminary factor in terms of determining the amount of precipitation. The occurrence of landslides on north-facing hillsides also depends on the high soil wetness due to low temperature and evaporation.

Elevation

Topographic elevation is a parameter that controls erosion and degradation of soil and it affects soil properties (Dai and Lee, 2002; Ayelew et al., 2005). In literature, the relation between elevation and landslides suggests that areas relatively with high altitudes are more susceptible to landslides (Gökçeoğlu and Ercanoğlu, 2001). Some researchers have noted that units with high altitudes are less susceptible to landslides because they are formed of rock-type materials and have higher stiffness than materials at lower altitudes (Caniani et al., 2008). They state that, in moderate altitudes, areas are more susceptible to landslides due to ground cover formed of materials from high altitudes. And they also point out that, in very low altitudes, areas are less susceptible to landslides due to low slope values and thick cover material (Gorsevski and Jankowski 2008).

The elevation in Adaklı District varies from 1130m to 2910m, and average elevation reaches 1900m. In Adaklı, the sites in groups of 1750m-2000m and 2000m-2250m cover much area. Volcanic plateaus cover large areas in groups of 1750m-2000m and 2000m-2250m. 20% of the area is in group 1500m-1750m, 33% in 1750m-2000m,21% in 2000m-2250m, and 3% in 2500m>. When the distribution of landslides to the elevation steps is evaluated, it is seen that landslides mostly occur in groups of 1250m-1500m and 1500m-1750m.These elevations correspond to the valleys and plateaus of lowlands. 29% of the landslides take place in group 1250m-1500m, 28% in 1500m-1750m, 14% in 1750m-2000m, and 18% in 2000m-2250m. It is seen that 8% of the landslides occur in areas above 2250m (Figure 9).

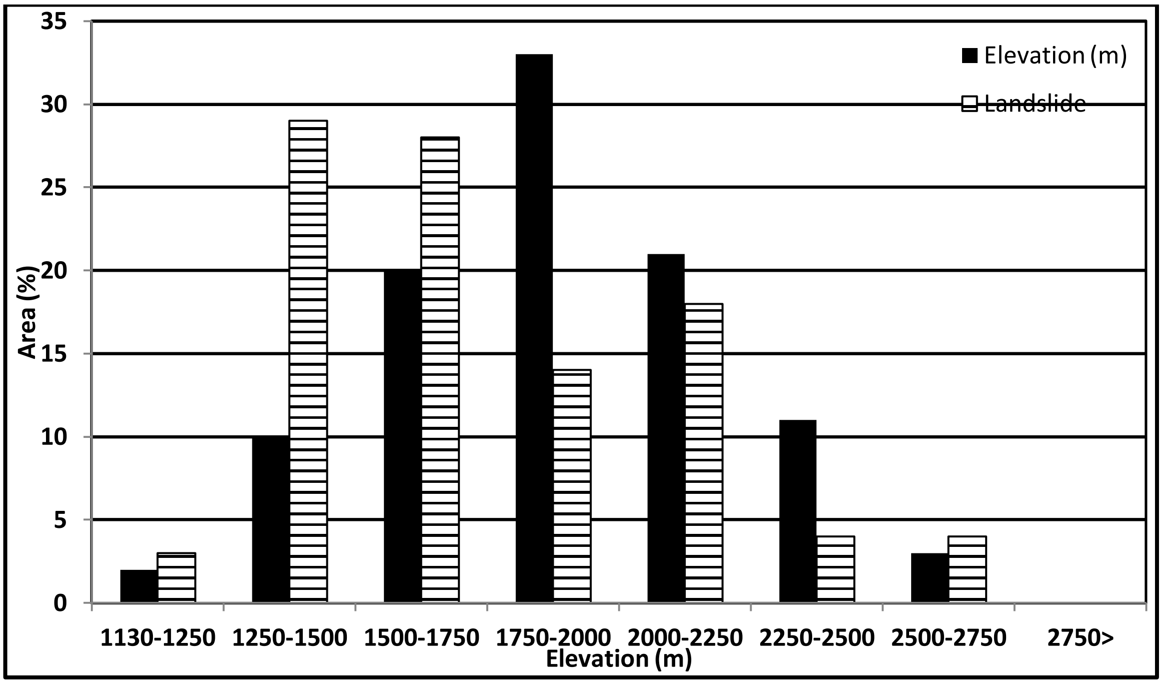

Figure 9. In Adaklı district, the distribution of elevation zones and the distribution of landslides to the elevation steps

Areas of group 1250 m-1500 m are in lower parts of Gökçeli Stream Valley. 1500m-1750 m elevation zone corresponds to low plateaus. The occurrence of landslide at low elevations is related to deterioration of hillside stability resulting from stream erosion, the increase of slope values due to erosion under the surface, and water-logging of hillsides. Rain and snow waters that accumulate in areas with low slope increase the water-logging of layers and this contributes to landslide occurrence. Because the snow accumulating in pits of paleo-landslide masses melts in spring and then leaks into the tuffs.

Curvature

Hillside's being concave or convex has an effect on the occurrence of landslide. Topographic irregularities on hillsides affect the stress distribution negatively, which can lead to instabilities (Gökçeoğlu and Ercanoğlu, 2001). There is a tendency that convex hillsides are more susceptible to landslides than concave hillsides (Hoek and Bray, 1977; Van Westen and Bonilla, 1990; Carrara et al., 1991; Fernandez et al., 1999; Guzzetti et al., 1999; Ohlmacher, 2004). According to the classification, convex hillsides (37%) cover more area than concave hillsides (35%) and transition areas (28%). When the distribution of landslides to the curvature groups is evaluated, the ratio is 36% on convex hillsides, 36% on concave hillsides, and 28% in transition areas (Figure 10).

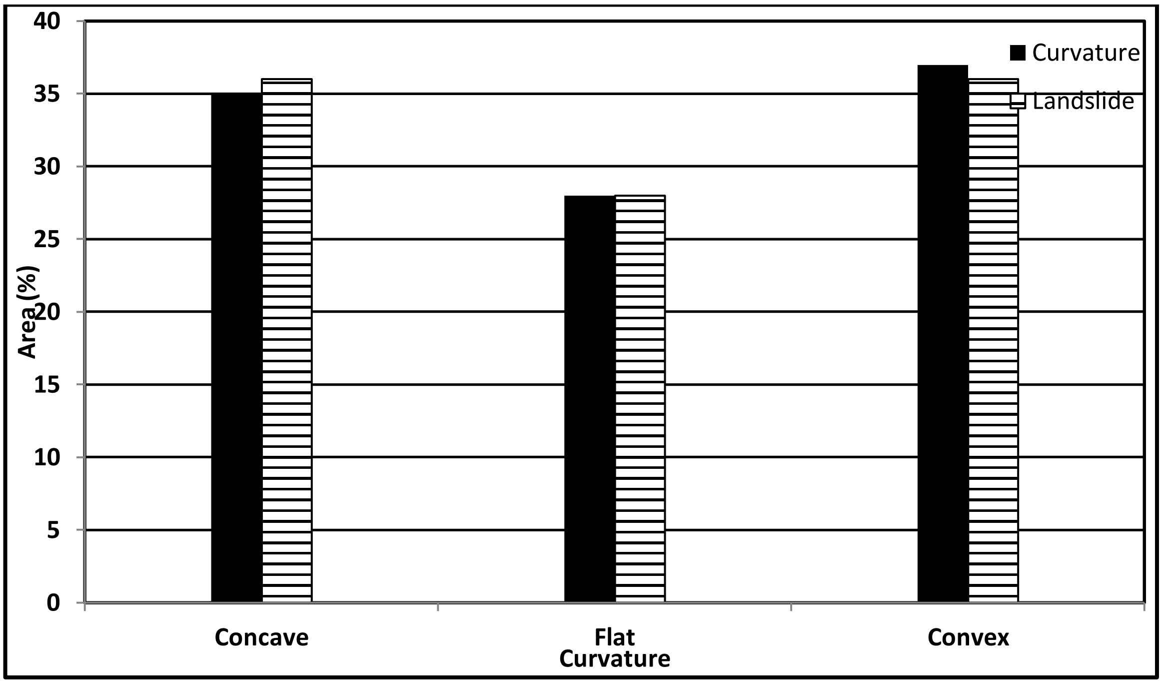

Figure 10. In Adaklı district (Bingöl), curvature distribution and distribution of landslides to curvature

Surface of convex hillside ensures that surface flow is distributed in various directions whereas surface of concave hillside has an effect on accumulating water and making the soil wetter (Çepel,1997). Widespread circular slide in Adaklı is due to the fact that concave hillsides are rich in groundwater and that hillside stability is deteriorated by river erosions. A large number of spring waters have come out due to a lot of snow in winter and melting of this snow in spring. And spring waters trigger landslides.

Distance to river

There are three different ways in which rivers have an effect on landslide occurrence. One way is that valley hillsides become apparent due to deep erosion of rivers and thus, dip slopes are formed. Another way is that hillsides are carved from below due to side erosion and cause impaired hillside stability (Picture 4). The third way is that water flowing in bed increase the water-logging of areas at and beneath river level. All three ways trigger landslide occurrence (Sunkar and Avci, 2016). In this study twelve groups were created for distance-to-river parameter:0-50m,50m-100m,100-150m,150m-200m, 200m-250m, 250m-300m, 300m-350m, 400m-450m, 450m-500m, 500m-1000m, and 1000m>. According to this data, sites within the distance of 0-500m cover a lot of area. It is seen from figure 11 that 12% of the area is in group 0-50m, 11% in 50m-100m, 11% in 100m-150m, and 10% in 150m-200m. When the distribution of landslides to distance-to-river groups is evaluated, it is seen that 11% of them are in 0-50m, 10% in 50m-100m, 10% in 100m-150m, and 9% in 150m-200m (Figure 11).

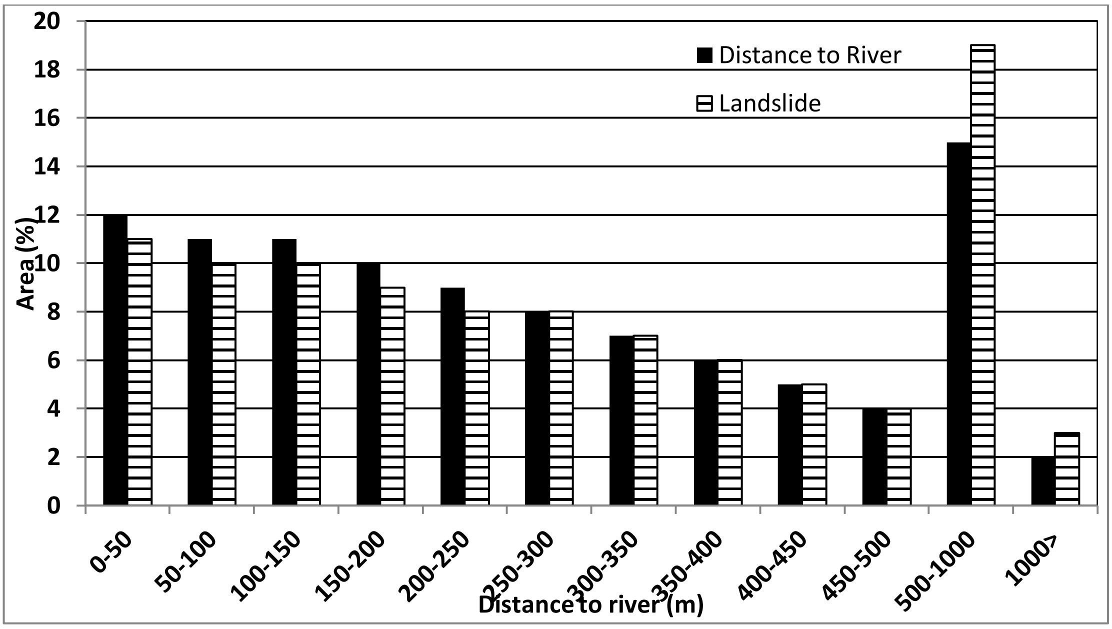

Figure 11. In Adaklı district (Bingöl), distribution of distance-to-river and distribution of landslides to distance to river

Landslides' occurring mostly on valley hillsides indicates the importance of rivers (Photo 4).

Photo 4. Settlements on the hillsides of valley in Gökçeli village are affected by landslides

Topographic Wetness Index-TWI

Topographic Wetness Index shows the effect of topography on ground wetness (Moore et al., 1991). This effect shows not only the period of time that water flows on the surface but also the development of water and snow in well-springs due to topographic conditions. TWI is automatically created using SAGA (System Automated Geoscientific Analyses), in accordance with the formula suggested by Moore et al.,1991. TWI values from DEM vary from 2.5 to 25.9. When evaluated as a whole, it is seen that sites whose TWI values are below 7 cover more area and that 94% of the landslides have occurred in areas whose values range from 2.5 to 7 and 5% in 7-12 (Figure 12). Sites with low TWI values cover much area. However, TWI values are high in the southwest, where landslides mostly occur.

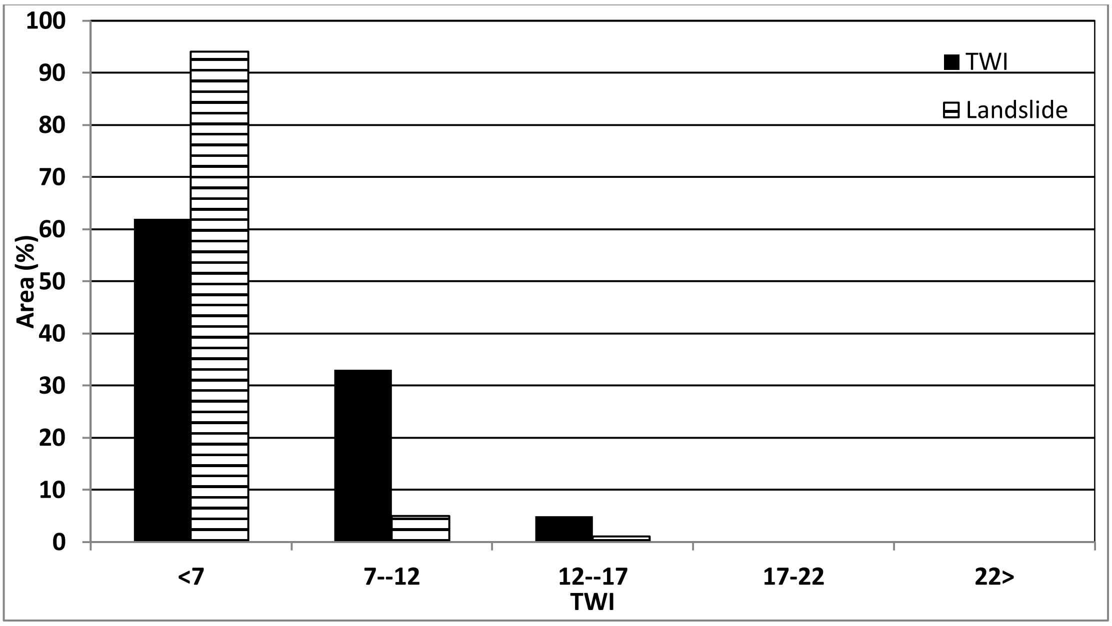

Figure 12. In Adaklı District (Bingöl), the distribution of topographic wetness and distribution of landslides to topographic wetness.

Areas with highest landslide susceptibility are in 22-25.9, where TWI values are the highest (Table 1). This results from the accumulation of water and ponding in these areas. These areas correspond to mouth of Gökçeli Stream.

Vegetation (NDVI)

Vegetation should be considered as an obstructive factor when it is thought that roots and stems of plants are restraining and that leak of rainfall into the ground is delayed by leaves and branches (Sunkar and Avci, 2016). The distribution and density of vegetation in Adaklı were evaluated by NDVI data. According to the NDVI data from Landsat 8 images, in the 26% of the study area the value is 0.4 or above it (Figure 13).

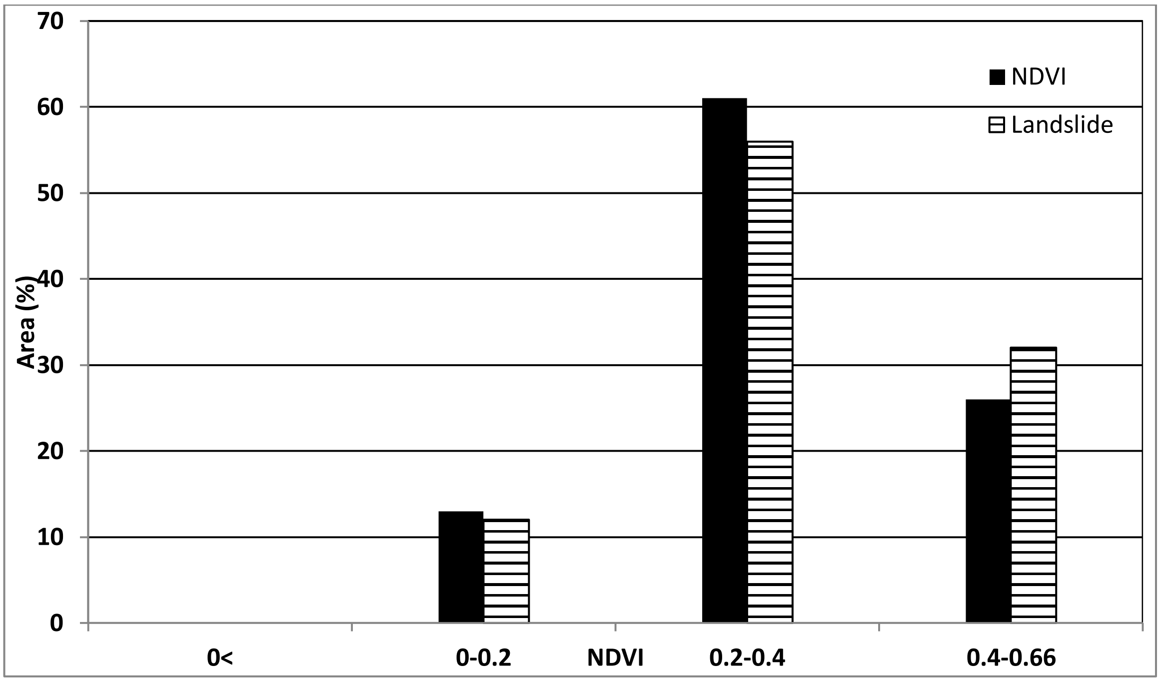

Figure 13. In Adaklı, the distribution of NDVI groups and distribution of landslides to NDVI groups

When the relation between landslide and vegetation is evaluated, it is seen that more landslides occur in areas with heavy vegetation (Figure 13, Photo 5). This is related to other factors contributing landslide occurrence. In areas with heavy vegetation slope values are high, and lithology consists of tuffs.

Photo 5. In Adaklı, landslides have occurred in areas with heavy vegetation as well.

CONCLUSION and RECOMMENDATIONS

In Adaklı district the areas most susceptible to landslides are located in Gökçeli Stream Basin and its surroundings, which is in the south of Adaklı. This is due to lithology, slope and high ground wetness. While this area consists of lithology tuffs, high slope values contribute to landslide occurrence. These high susceptible sites are located in the area where large settlements of the district are established and transportation routes pass by (Figure 14). For this reason, these sites are under the greatest risk in the sense of disasters. Landslides occurred after pluvial affect settlements and roads.

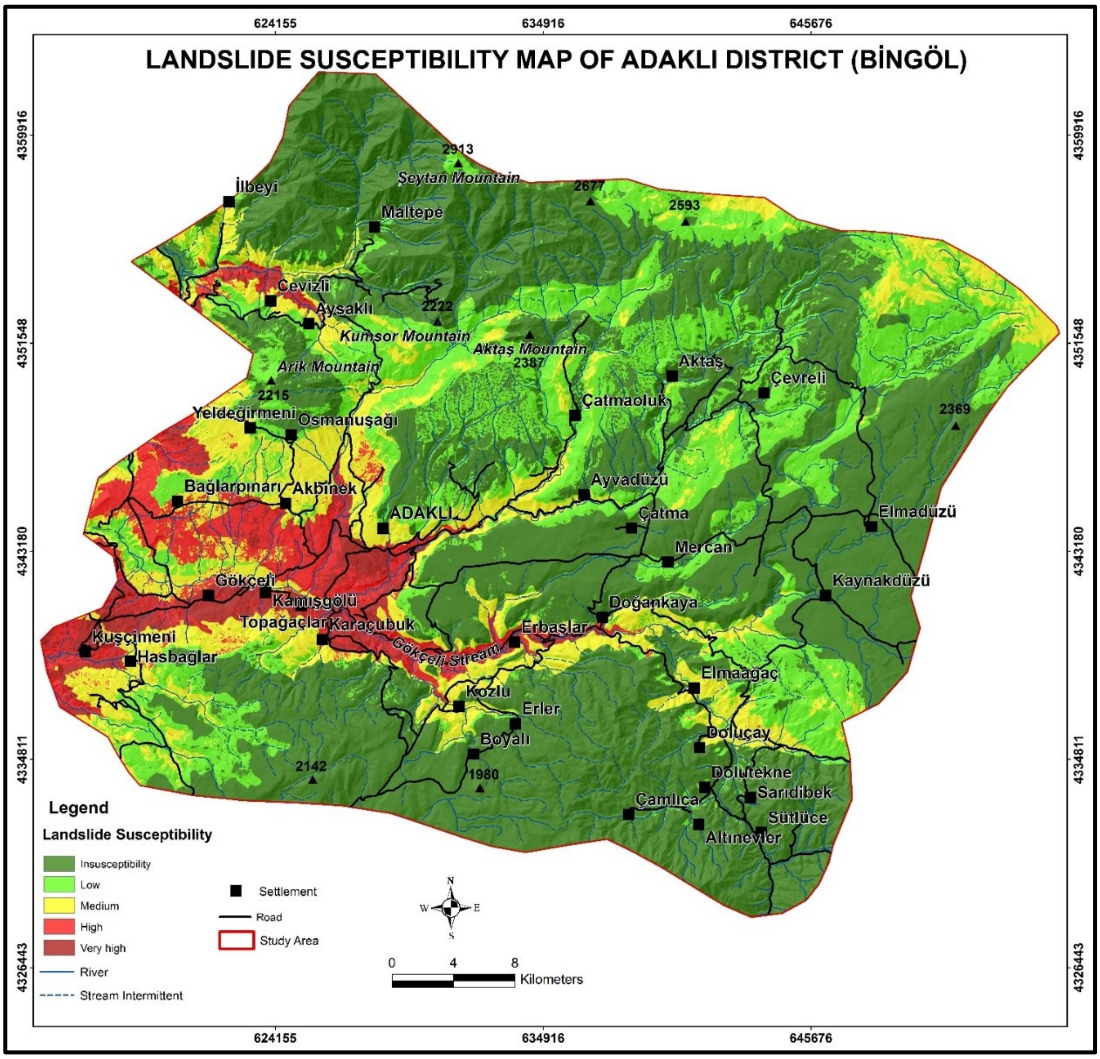

Figure 14. Landslide susceptibility map of Adaklı District (Bingöl)

According to the analysis, it is seen that slope, elevation, topographic wetness are determinant in landslide occurrence and that these factors have greater triggering effects on landslide occurrence. In Adaklı, as the slope values increase, so does the landslide susceptibility. In the section between Hasbağlar and Kozlu in Gökçeli Stream basin, landslide susceptibility is high on north-facing hillsides, depending on aspect. This is related to the fact that ground wetness is high due to low temperatures. Besides, lithology consisting of tuffs contributes to landslide occurrence. Excessive amount of groundwater is another reason that landslide susceptibility is high in this area.

Elevation is a factor that has a great effect on susceptibility. The landslide susceptibility has been determined to be high in low areas. Low areas correspond to the hillsides of valleys. Erosion below the surface and water-logging on hillsides contribute to the occurrence of landslide in areas where values of topographic wetness increase, landslide susceptibility also increases. This is the result of increased soil wetness and fluidity due to the accumulation of water. As the water accumulates, the ground receives more water, thus facilitating the landslide by causing the load to increase in the ground.

In the study area, the rates of medium susceptible, high susceptible and very high susceptible areas are 14%, 5%, and 3%, respectively (Figure 15). The total percentage of areas with medium susceptibility and above is 22. The areas insusceptible to landslide account for 55 %. However, a significant number of large settlements are in the medium and high susceptible areas.

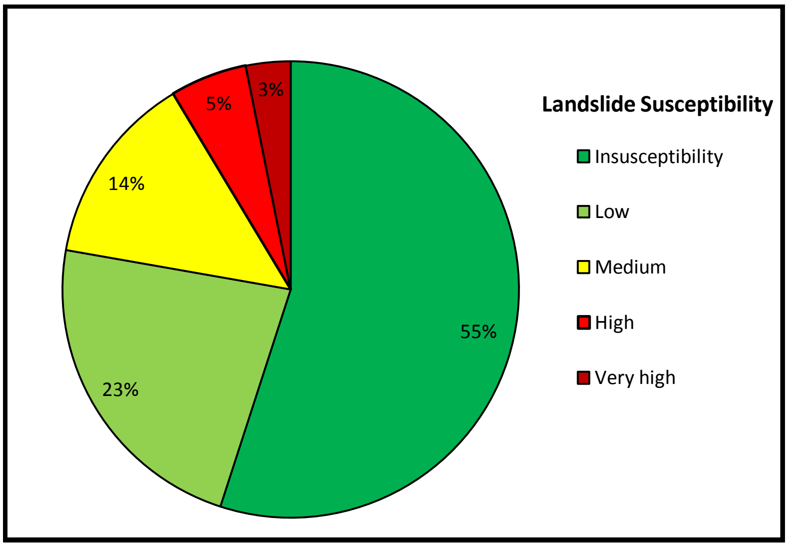

Figure 15. The distribution of landslide susceptibility in Adaklı District (Bingöl)

It is seen that some settlements replaced because of landslides are still exposed to them. Thus, it is crucial to take geological, hydrographical, and geomorphological characteristics into consideration when selecting settlement areas. Landslide will continue to cause significant economic losses in Adaklı District due to high amount of rainfall, lithological, tectonic, and geomorphological characteristics. For this reason, drainage studies must be carried out in Gökçeli Stream valley, where landslide susceptibility is high, and vegetation cover must be improved.

The fact that Adaklı is located in the intersection area of active faults makes it possible for the earthquakes, and consequently landslides to occur. Landslides triggered by excessive amount of rainfall and snowfalls have been seen in the past. Hence, planning studies should be done regarding the seismic structure of the region.

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