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CONTENTS

The Relationship of Landslides with lithological units and fault lines occurring on the East Anatolian Fault Zone, between Palu (Elazığ) and Bingöl, Turkey

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Research Article

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ABSTRACT

In this study, the relationship of landslides with lithological units and fault lines on the East Anatolian Fault Zone (EAFZ) between Palu (Elazığ) and Bingöl, was evaluated. In the study area, which is located within the EAFZ, Göynük to the northeast, Palu Segment to the southwest, Genç Segment to the south of Bingöl plain and Gökdere Uplift in the intersection area form the main tectonic structures. In addition, the Karakoçan Fault Zone (KFZ) cutting the EAFZ in NW-SE direction between Palu and Bingöl corresponds to another important structure (system). The area, which is located in a region where a number of faults intersect, is tectonically very active. This situation has affected the morphology and caused the formation of many landslides along fault lines. In order to determine the relationship between the landslides observed in this area and lithological and tectonic structures, landslide magnitude and distribution analyses were performed by means of Geographical Information Systems. For this purpose, the landslide inventory map and the database were reproduced controlling the satellite images in field studies. Similarly; geological and tectonic maps were prepared considering previous studies. Landslides created in vector format were converted into raster format and overlain with lithological and tectonic maps, and then the relationship between landslides and lithology-fault lines were determined. According to these results, 59% of landslides occur in Upper Miocene-Pliocene agglomerate and tuff units and 10% of them in Eocene carbonate units. According to these data, almost 70% of the landslides in the study area occurred in two units. Considering the relationship between landslides and fault lines 64% of the landslides are observed at 0-1000 m distances to the fault lines. As a result, there is an important relationship between lithological features and fault lines. The fact that landslides have occurred along the fault lines in the north of Murat Valley shows that the landslides are triggered more by earthquakes when compared with those triggered by the hydro meteorological events.

1. Introduction

In this study, the relationship between the landslides on the EAFZ and the lithology and fault lines in the Palu western and Bingöl western regions were investigated. The study area corresponding to Palu-Bingöl has an important and very complex position in terms of tectonics. The eastern, western and the southern parts part of this area in the EAFZ consist of structures named as; Göynük, Palu and Genç Segment, respectively. The area between Göynük and Palu segments in the east of Bingöl Plain is the Gökdere uplift and the area to the north is the Karakoçan Fault Zone (KFZ) (Figure 1).

The East Anatolian Fault System (EAFS) is located between the Karlıova County in the north and Karataş (Adana) and Samandağ (Antakya) in the southwest. This system is approximately 30 km wide and 700 km long, large shear zone with a left lateral strike slip in the NE direction between Anatolian in NW and the Arabian-African plates in SE (Arpat and Şaroğlu, 1972; Koçyiğit et al., 2003; Aksoy et al., 2007). Though EAFS have not been investigated as well as

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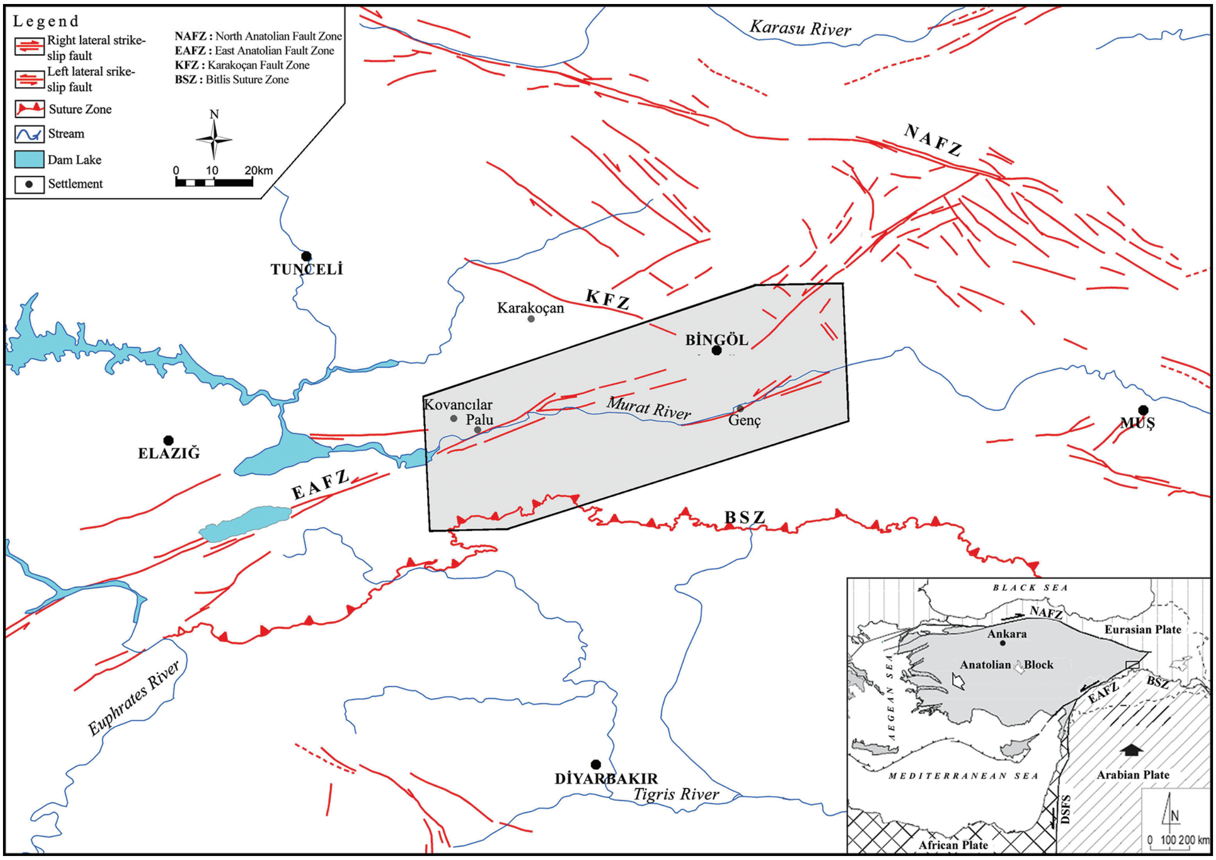

Figure 1- The location map of Palu-Bingöl interval (Faults were taken from Emre et al., 2012; Duman et al., 2012).

the North Anatolian Fault System (NAFS), numerous geological and seismological studies have been carried out on EAFS (Arpat and Şaroğlu, 1972; Gülen et al., 1987; Şaroğlu et al., 1987; Tatar, 1987; Herece and Akay, 1992; Reilinger et al, 1997; Ambraseys and Jakson, 1998; Koçyiğit et al., 2003).

The area between Palu and Bingöl corresponds to the intersection area of the EAF (Eastern Anatolian Fault) and the Karakoçan Fault (KF). Due to this intersection and compression effect, the area has been fragmented and uplifted to form the Karaömer Mountain (2460 m). In the south of this mountain the Murat River has been settled into EAFZ. The Murat River merges with the Göynük stream near the Genç District and then enters a 40-45 km long cut valley to Palu. The strait is considered to be epigenetic in this area as it is mainly buried in young volcanic units overlying metamorphics in the basement and ophiolites in the west (Atalay, 1974-1977; Tonbul, 1990; Tonbul and Özdemir, 1994; Özdemir and İnceöz, 2003; Avcı and Sunkar, 2016). Although the Murat River in east of the Eski Palu was emplaced into an epigenetic strait (Genc-Palu Strait), it flows along a valley with wide bottom varying between 750-1000 m in the Eski Palu vicinity and in the far west where sharp meanders are drawn (Tonbul and Özdemir, 1994).

There is an average elevation difference of 1500 m between Palu and Bingöl, and 1600-1700 m between Palu and the mountainous areas in the south. The fact that the area has been cut by numerous faults and the Murat River has been cut by deep and steep valleys has made the slope value high in the slopes. In the mountainous areas between Palu and Bingöl the slope reaches 45^{o} and above. In some canyon shaped valleys this value even reaches 90^{o}. This elevation difference at short distances, high slope, young cover units, faulty structures and the rainfall have caused the occurrence of landslides in this area.

Özdemir and Tonbul (1990) indicated that the EAF to form a weak zone near Palu in the Murat River Valley, unstable rocks such as the claystone and marl to crop out on valley slopes and the Murat River to erode convex slopes of the Murat River and the strong slope angle have caused landslides. Atalay (1974-1977) stated that active mass movements along the Murat valley between Muş-Palu had caused the

Elazığ-Mus railway to deteriorate and train accidents to occur. Due to the dams built between Palu and Genç in the Murat Valley, the railway line that remained in this area has been changed. Despite this change made in recent years, the railway transportation is affected by the recurrent mass movements (Figure 2).

Palu-Bingöl is one of the areas where landslides are most intensely seen; it is due to the fact that in this region, all conditions for landslide formation are available. Because of this feature of the field, such a study was carried out with the thought that each of the parameters affecting the landslide is very well analyzed. For this purpose, the distribution of landslides according to geomorphologic units has been investigated previously (Avcı and Sunkar, 2016). In this study, the relationships between landslides and lithological units besides the distance to the fault lines were analyzed. The fact that the landslides observed in this study are arranged along the fault lines indicate that there is a close relationship between the fault lines and the distribution of landslides. These seismically active faults are followed by large-scale landslides. Again, the accumulation of landslides on certain lithologies shows that lithology along with the fault is also important.

Active and passive landslides, which were examined according to the landslide inventory map prepared by the MTA, cover a wide area (Duman et al., 2009). In geomorphological studies carried out in the region other than the inventory map, a large number of landslides have been mapped around Palu-Bingöl and their properties have been explained (Atalay, 1974-1977; Tonbul, 1990; Tonbul and Özdemir, 1994; Özdemir and İnceöz, 2003). Active and passive groupings of landslides in the field were made according to current literature and field observations. The landslides are regarded as active when the carvings at the toe causes the mass movement, however the landslides in which the movement is not visible are accepted as passive. Furthermore, it was observed that cracks and swelling structures were visible in active landslide areas in geomorphologic observations carried out as well as in passive landslides, the vegetation covered the surface and there were no cracks'.

2. General Geological and Geomorphological Features of the Area Between Palu and Bingöl

The study area corresponds to the Murat valley located in between Palu and Bingöl, which has an important place in EAFS. Palu western and Bingöl east were included in the study area and it was aimed to reveal the relation between lithological units and fault lines in the distribution of landslides. The survey area covers an area of 3280 km^2 within the specified boundaries and landslide susceptibility analyzes were performed in some small basins located within these boundaries (Avcı, 2016).

According to data of Bingöl meteorological station located at 1177 m elevation, the mean temperature

Figure 2- The landslide that occurred on 19 March 2017 at the exit of the tunnel on the new railway between Genç Beyhan and Süveran Locality, which had been built after Beyhan Dam, caused the locomotive to come out of the way (http://www.hurriyet.com.tr/heyelan-nedeniyle -yuk-treni-raydan-çikti-40400338 19 Mart 2017).

has been 12.1°C for long years (1961-2016) and for the same period the average amount of rainfall has been 943.6 mm. Monthly average maximum rainfall in January and the minimum values in August were measured as; 138.5 mm and 3.2 mm, respectively. (Table 1, MGM, 2017).

The lithological units within the study area have been studied in detail in different studies (Sirel et al., 1975; Naz, 1979; Sungurlu et al., 1985; Herece and Akay, 1992; Yüksel, 2006). Precambrian gneisses and schists, which outcrop in large areas to the east of Akdağ and south of Murat River, are the oldest units. The Upper Paleozoic marbles, which are exposed in Bingöl northeast and Akdağ, are the second oldest units. The ophiolites formed by gabbros and diabases cut by EAF and Murat Valley are Mesozoic aged rocks. Apart from these units, the units consisting of volcanic and sedimentary rocks (Lower-Middle Eocene), clastic rocks and carbonates (Middle-Upper Eocene and Upper Miocene), clastic and carbonates (Oligocene, Lower Miocene) crop out. The Upper Miocene-Pliocene units composed of agglomerate, tuffs and basalts in the vicinity of Bingöl to the east of Karaömer Mountain are the lithologies having the largest area. Quaternary alluvials observed at the bottom of the Murat River valley and in the Kovancılar and Bingol plains correspond to the youngest units (MTA, 2002, Figure 3).

Table 1- Bingöl Central Meteorology Station long period (1961-2016) monthly temperature and precipitation averages (MGM, 2017).

BİNGÖL	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature **(°C)**	-2.4	-1.3	4.0	10.8	16.3	22.1	26.8	26.4	21.1	14.0	6.6	0.5	12.1
Rainfall Amount (mm)	138.5	134.6	128.7	116.8	74.5	21.3	5.6	3.2	11.7	66.2	107.9	134.6	943.6

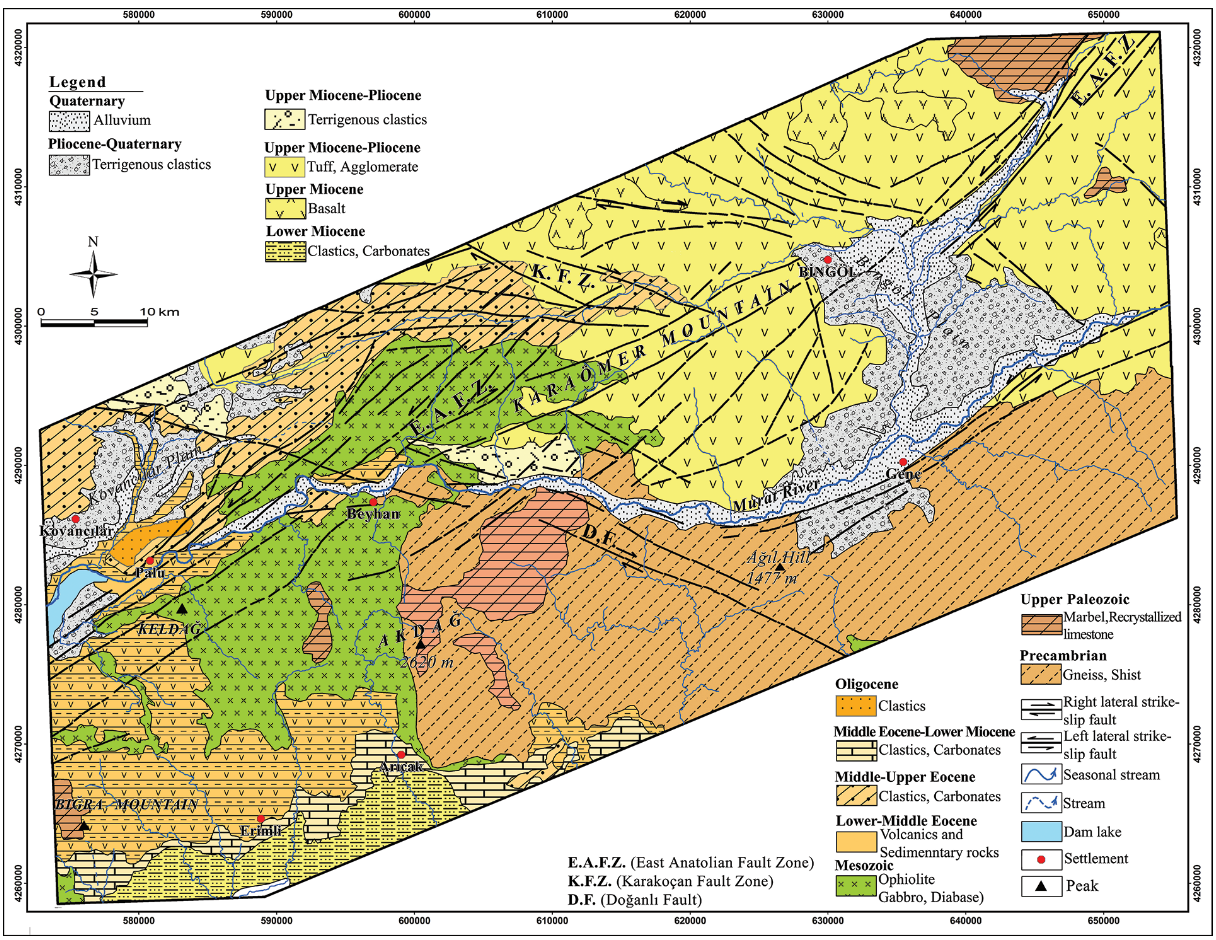

Figure 3- Geological map of the area remaining in the EAFZ between Bingol and Palu (from MTA 1/500000 scale Geological Map of Turkey, Erzurum sheet).

The area between Palu and Bingöl exhibits tectonically very complex structure and constitutes the biggest compressional stepover in EAFZ (Arpat and Şaroğlu, 1972). The Karaömer Mountain, which corresponds to the compression and stepover area between Göynük and Palu segment, is named as the Gökdere Uplift. The Gökdere Uplift was cut by KFZ at the same time (Figures 1 and 3).

EAFZ is divided into different segments according to its geometrical characteristics and slip of faults (Arpat and Şaroğlu; 1972, 1975). Hempton et al. (1981) classified EAFZ into 5 segments according to its fault behavior and slip; however, Barka and Kadinsky-Cade (1988) divided this zone into 14 segments according to fault geometry, earthquake activity and surface fractures. Şaroğlu et al. (1992) investigated the EAFZ in 6 structural segments ranging from 45-145 km in length. The Gökdere uplift between Karlıova-Bingöl and Palu-Hazar Lake sections and the Sincik uplift between the Hazar Lake-Sincik and Çelikhan-Erkenek sections correspond to morphotectonic structures which developed from compressional stepovers between the main sections of the fault (Şaroğlu et al., 1987, 1992; Herece, 2008).

The Karakoçan Fault Zone, which limits the Gökdere Uplift in the east is a new active 6-10 km wide, 50 km long, right lateral strike slip intra-plate structure in NW direction. This zone consists of a large number of closely spaced (100 m), parallel to sub parallel structural fault segments with lengths ranging from 0,5-17 km. The most important structure developed within the Karakoçan Fault Zone is the Karakoçan pull-apart basin where the Karakoçan county and numerous towns are located. The oldest basin fill that continues its development under the control of the Karakoçan Fault is the Late Pliocene Kızılca travertine. Therefore, the age of the fault is Plio-Quaternary (Koçyiğit, 2003).

The area between Palu and Bingöl geomorphologically corresponds to mountainous areas. Bingöl and Palu surrounds on the other hand form tectonic basins that form between these areas. The highest peak in the investigated area is Akdağ (2620 m) and the lowest area is the Murat valley near Palu (845 m). The average slope value in the area is 16,70° and the slope of the fault planes and steep valleys reach 70-90°. Mountainous areas, which formed by folding, have then faulted and uplifted under compressional regime. The mountainous areas to the east of Bingöl were formed by volcanic activity and later cut by EAF. The fact that the site was cut by EAFS and KFZ caused the formation of numerous landslides. New landslides are formed with earthquakes occurring in the region and old landslides become active and affect settlement and access roads.

3. Material and Method

In the preparation of the landslide inventory map used in this study, the landslide inventory map of 1/500.000 scale Erzurum Sheet prepared by the General Directorate of Mineral Research and Exploration (MTA) was used (Duman et al., 2009). However, not all landslides are shown in this inventory map because of the wide area, scale difference of the inventory map, and ignorance of some landslides. Considering this situation, a landslide inventory map showing the landslides in the study area was prepared based on satellite images (Landsat Image 8, dated 4 June 2013), 1/25.000 scale digital topography maps and field observations.

Landslide areas were identified by defining morphological features of the land from satellite images and topography maps. The boundaries of the landslides, and their activity were assessed during field studies. In addition, the ground truth of the existing landslide inventory map was carried out. Inventory maps are the simplest mapping method in direct mapping methods and are important in pointing out the locations of known landslides (Hansen, 1984).

Previously digitized landslide inventory map was corrected by Digital Elevation Model (DEM) and isohypse curves obtained from the topography. The landslides in the inventory map were grouped as active and passive, then converted from raster to vector format. Lithological information was taken from Altınlı (1963) and the geological map was updated by using 1/500.000 scale Geological Map of Turkey, Erzurum Sheet. Some of the information regarding faults was taken from investigations carried out by MTA (Emre et al., 2012; Duman et al., 2012) and of some from geological studies carried out in the region (Çetin et al., 2003; Aksoy et al., 2007; Sarp, 2014). Especially the faults between Palu and Bingöl were determined based on satellite images, DEM data and geomorphological observations.

By using geological maps, the lithology map was prepared and lithological units and landslides were correlated based on this map. Apart from lithology, the spatial relation of active faults and landslides was investigated by buffer analysis. After preparing the numerical data of the field, the distance map to the fault lines from the tectonic map was produced. The lithology and the distance maps of fault lines of the landslides were aligned with the landslide inventory map in the same cell size (10x10 m), and the pixel numbers with/without landslides of layer subgroups were detected. By using these data, the distribution of landslides based on the lithological units and the distance to fault lines was determined and their distributions according to slope and elevation were statistically analyzed.

4. Findings and Discussion

4.1. Distribution of Landslides between Palu and Bingöl

Knowledge of the factors that control the spatial distribution, characterization and formation of existing and potential mass movements is necessary to take preventive measures and reduce harm (Cihangir and Görüm, 2016). When losses caused by mass movements are taken into consideration the necessity of such a study is better justified.

Simplification was made in mapping very small scale landslides and landslides that had been intertwined during the digitization process. Small scale landslides were combined with the nearest landslide, and intertwined landslides were shown as single landslide. For example, there are tens of landslides in the large active and passive landslide areas seen in the northeast of Bingöl. As the landslides in such areas are interconnected and have similar characteristics, they were shown as one landslide. By making such a digitization approximately 30% of landslides were simplified. In this way, within the boundaries of the study area, a total of 718 landslides, 164 passive and 554 active, were mapped. Active landslides cover a total of 144.07 km^2, whereas passive landslides cover a total area of 70.25 km^2. The total area of the landslides is 214.32 km^2, corresponding to a total of 6.5% of the study area. The sizes of the landslides range from 0.01 km^2 to 13.95 km^2 with an average area of 0.29 km^2. When the classification made by Cihangir and Görüm (2016) for the Kelkit downstream is taken into consideration, 3 of the landslides in the study area are very large (13.95-5.1 km^2), 19 are large (5.1-1.0 km^2), 475 are medium 1.0-0.1 km^2), 221 are smaller (0.1-0.001 km^2) (Figure 4a). Considering the slope aspect, 632 (93%) of the landslides are observed on the northern slopes and 86 (7%) of the landslides are observed on the southern slopes (Figure 4b).

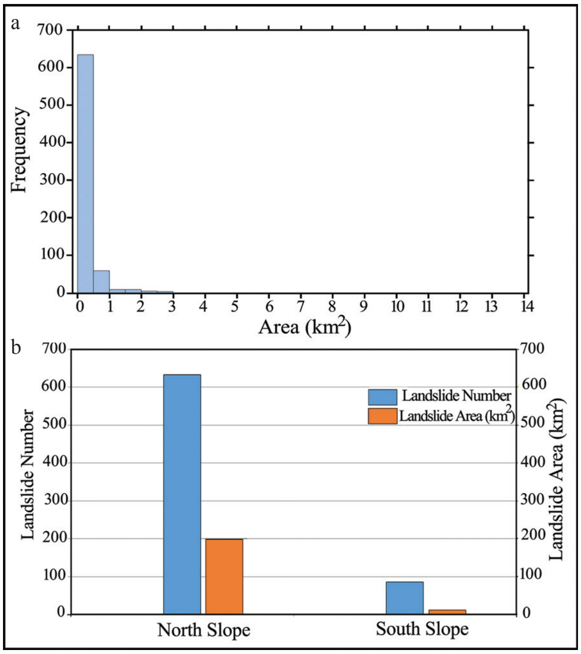

Figure 4- (a) The areal frequency of landslides observed between Palu-Bingöl, (b) number and areal distribution according to northern and southern slopes.

The landslides in the area show formation characteristics in the form of flow, fall and slide. Apart from landslides, which are mostly in slide type, the landslides that occur along formation boundaries and fault lines are in fall type, and the landslides on steep slopes where debris accumulates are in flow type. Atalay (1974-1977) emphasized that there were a continuous debris flow and transportations in areas where agglomerate, sandy and pebbly slope deposits in the Murat Valley were present. In order to determine the range of impact of landslides between Palu and Bingöl long and short axis ratios of them were calculated. According to these calculations, the long-short axis ratios of the landslides between Palu and Bingöl range between 1.0 and 3.6. Furthermore, according to the analysis results, it was concluded that circular failures were more abundant (Figure 5).

Geomorphological factors such as slope, aspect, and failure grade in the region are predominant for the mass movements in the region. More than 50% of the landslides in the study area are observed in slopes with a slope of 15-45° (Avcı and Sunkar, 2016). When the

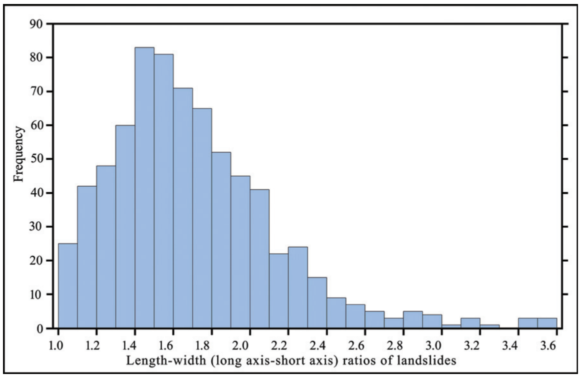

Figure 5- Length-width (long axis-short axis) ratios of landslides observed between Palu-Bingöl.

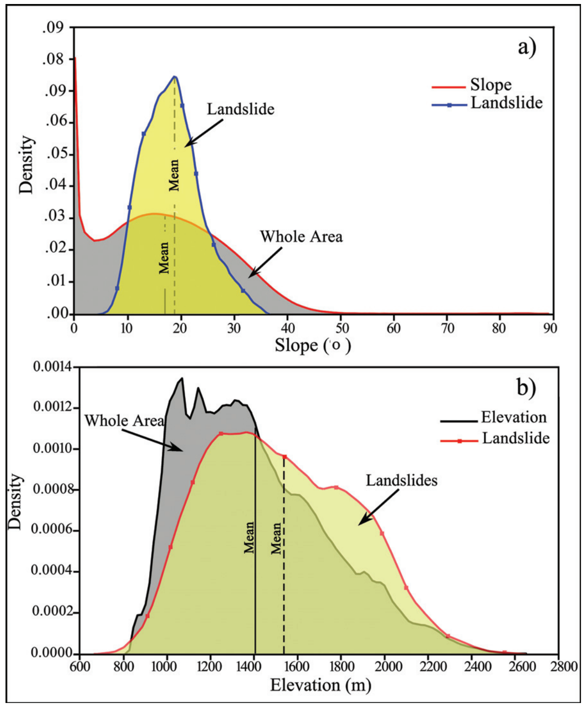

Figure 6- Probability estimates of landslides observed between Palu-Bingöl according to slope (a) and elevation (b) based on the kernel density analysis.

relationship between landslide and geomorphologic factors is evaluated, the average slope in the studied area is 16.69°, while the average slope of landslide areas is 18.29°. The fact that the slope is nearly 1.5° higher in the landslide areas is due to the slope of landslides. When this situation is ignored, the mean slopes of the landslide fields and the average slope values of the study area are in compatible. The median value of the slope in landslide areas is 17.2°, the landslides decrease after this value (Figure 6a).

The average elevation between Palu and Bingöl is 1401 m and the approximate height of the landslide fields (1520 m) is very close to this value. According to the results of the analysis, the median value of elevation in landslide areas is 1488 m. It is seen that landslides become dense in 1200-1400 m and 1700-1800 m contours. There is a close relationship between the aspect, slope and elevation features located in geomorphological parameters summarized above and the distribution of landslides (Figure 6b). As the relationship between geomorphological factors and landslides between Palu and Bingöl was evaluated in detail by Avcı and Sunkar (2016), only the density analyses of slope and elevation factors were analyzed in this study.

Except for this general situation, the mass movements and landslides become dense along the steep valley slopes of Murat River and fault lines. To the west of Palu Castle, Gökyamaç corresponds to a landslide area, and mud flows, failures and slip types indicate that the landslide is active (Tonbul and Özdemir, 1994, Figure 7a).

In areas where landslides occur in the form of slide that develop towards the end of spring, large cracks might form in the upper parts. Cracks in 1 m width and 2-3 m depth were formed at the end of 2017 spring in the east of Genç, due to the slide seen at Çaytepe Duşmalan Locality (Figure 8).

4.2. Relationship between Lithological Units and Landslides

Lithology is one of the most important parameters affecting the slopes and their stabilities because the shear strength and permeabilities of different lithological units are different from each other. Therefore, the sensitivity of these units to sliding is also different (Dağ, 2007). Different degree of disintegration on the same lithological unit produce different sensitivity. For this reason, the degree of disintegration should be considered as another property that affects the slide. In the study carried out in Rize Fındıklı, an area of approximately 25 km^2, 85% of the observed landslides have been found to be formed on completely disintegrated rocks. The increase in clay content in these disintegrated rocks in these areas also led to an increase in the number of landslides (Bulut et al., 1995). In another study carried out in Rize, Çayeli, 87% of the landslides were formed within the disintegrated rocks (Dağ et al., 2006). The depth of the disintegrated material is also effective in the formation of landslides (Ercanoğlu and Gökçeoğlu, 2002).

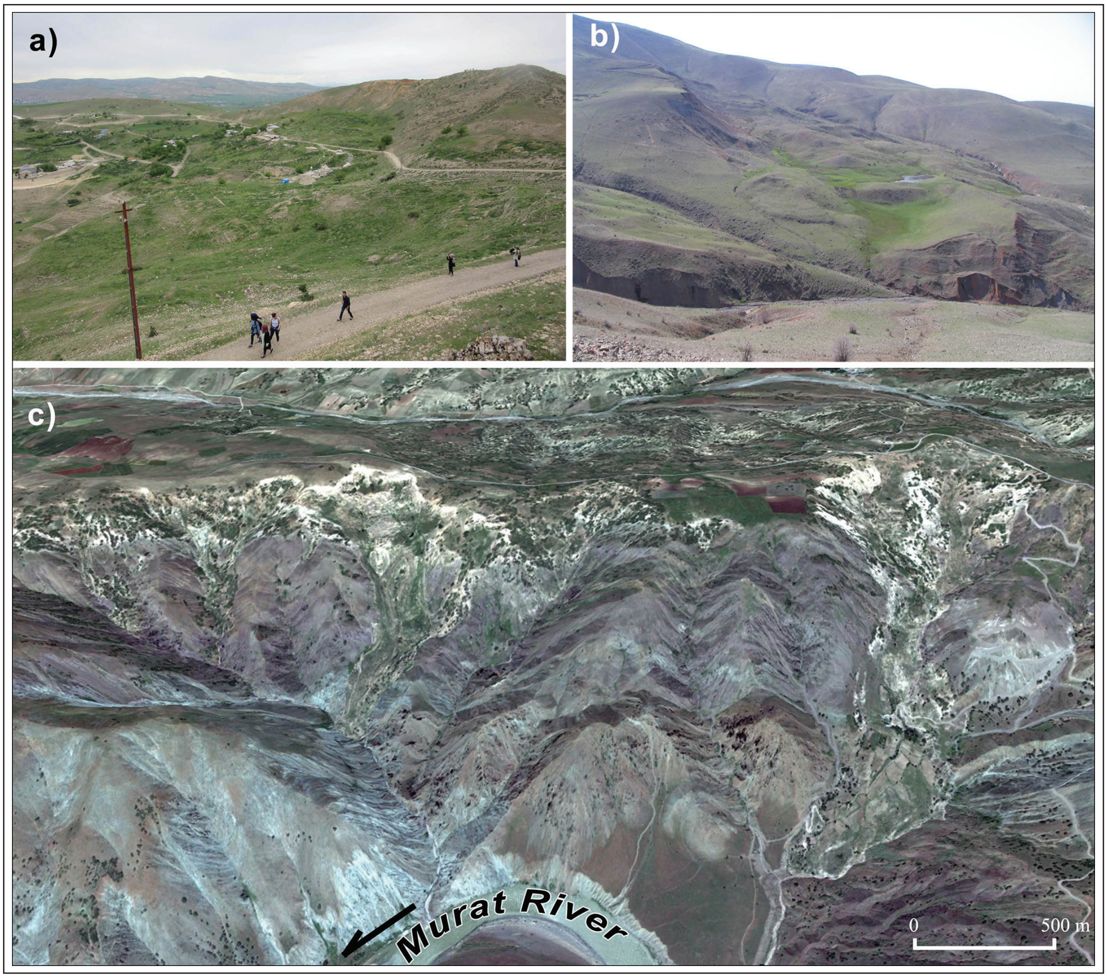

Figure 7- Landslides observed on EAFZ between Palu-Bingöl; a) Slide type landslide affecting Eski Palu to the east of Palu, b) Bahçecik Landslide developed in detachment type on the south of Karakoçan and c) flow type landslides observed in Google Earth image on the southern slope of the Murat Valley, south of Palu).

Figure 8- Large cracks were formed at Çaytepe Duşmalan Locality, the east of Genç, due to the slide that occurred in early summer of 2017.

Tuffy, clayey and marly structures in our country are the lithologies where landslides are seen the most. However, landslides are less commonly observed in lithologies such as limestone and basalt (Erinç, 2012). The distribution of landslides between Palu and Bingöl in lithological units is particularly compatible with this.

When the distribution of the landslides to lithological units in the study area is examined, most of the landslides are found on the Upper Miocene-Pliocene volcanics. This is followed by the unit consisting of Middle-Upper Eocene clastic and carbonates (Figure 9). When lithological units are examined, Upper Miocene Pliocene volcanics occur in 24% of the study area, Middle-Upper Eocene clastic and carbonates in 7% of the study area. Gneiss and schists of the Pre-Cambrian period, which are exposed to the south of Murat Valley, are not very important

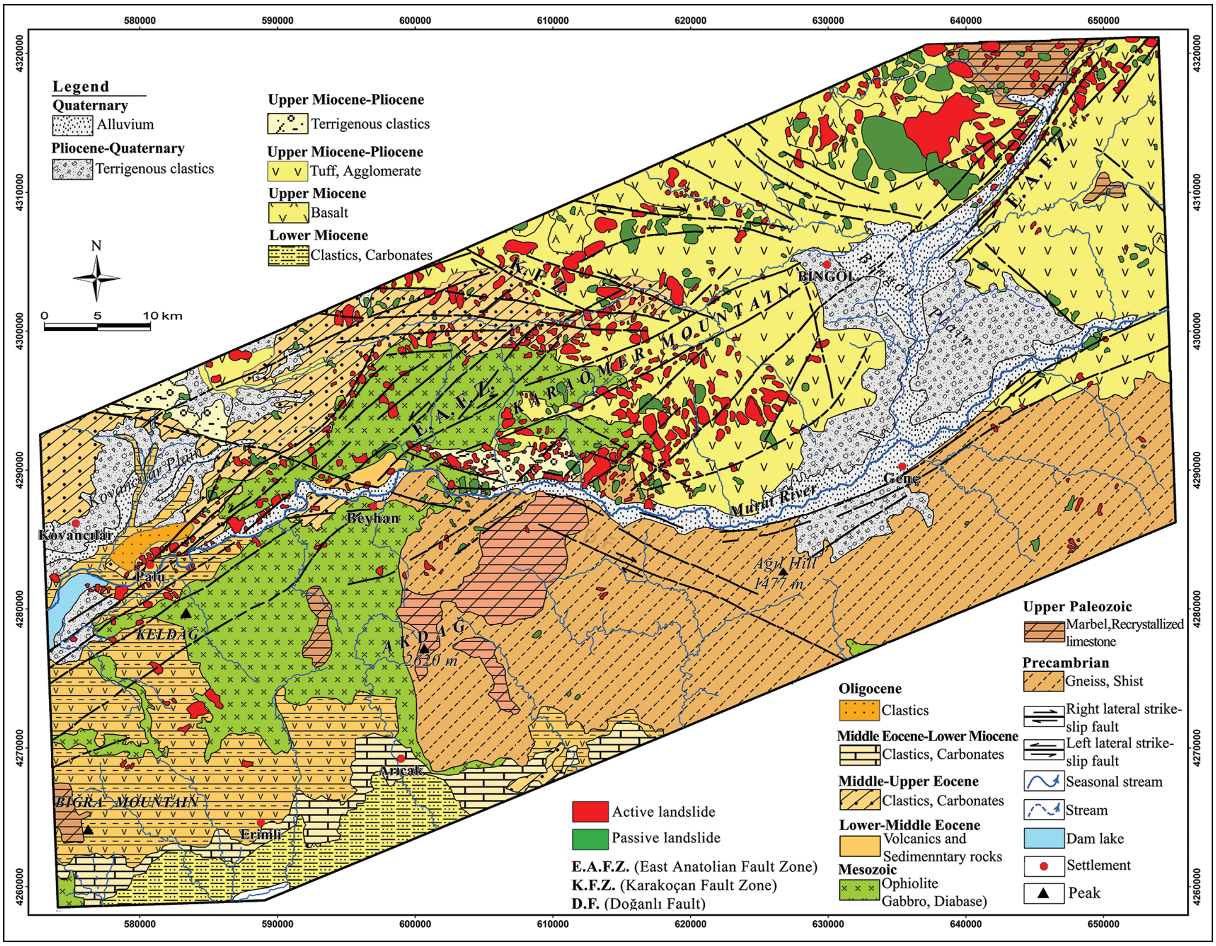

Figure 9- Distribution map of the landslides in the EAFZ between Palu and Bingöl with respect to lithological units.

in the distribution of landslides though they cover an area of 24% (Figures 9 and 10).

All other lithological units except the two lithologies in the southwest of the study area were cut and deformed by active faults. It is thought that lithology is important as well as being affected by

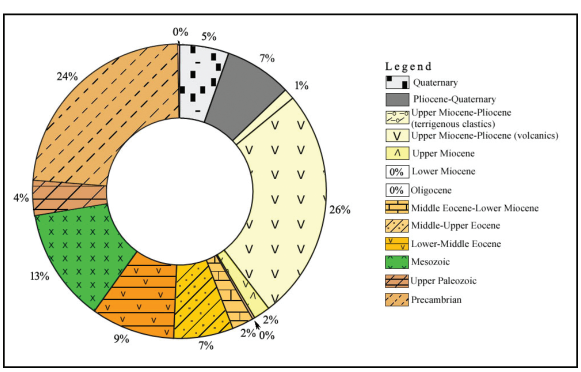

Figure 10- Proportional distribution of lithological units between Palu and Bingöl.

these deformations in the formation of landslides. Because although the unit, which is formed by gneiss and schist in the south of Murat Valley, is cut by faults, the landslide density is very low. 66% of the landslides in the study area are observed in areas where the Upper Miocene-Pliocene agglomerates, tuffs and basalts are exposed. Apart from this unit, 10% of the landslides occurred on Middle-Upper Eocene and 8% of them occurred on Mesozoic (ophiolites) units. According to this distribution, more than 80% of the landslides were gathered over 4 lithologies and show the effect of lithology on landslide formation (Table 2, Figure 11).

As stated by Atalay (1974-1977), the equilibrium angle was spoiled in areas where the volcanic tuff, sand and agglomerates were failed in the Murat Valley and on branches of its side steep slopes. The fact that these units together with river valleys were cut by faults and the presence of clayey structures have made reach the liquid limit quickly and accelerates the formation of landslide.

Table 2- Densities of lithological units and landslides with respect to lithological units.

Lithological Units	Study Area			All landslides in the study area		
	km²	%	Density in the study area	km²	%	Density in the study area
Quaternary	177,83	5,41	0,054	4,15	1,92	0,001
Pliocene-Quaternary	238,71	7,19	0,070	0,96	0,44	0,000
Upper Miocene-Pliocene (terrigenous clastics)	39,054	1,16	0,011	6,34	2,95	0,001
Upper Miocene-Pliocene (Tuff, Agglomerate)	838,15	25,54	0,255	126,45	58,93	0,036
Upper Miocene	59,83	1,77	0,017	16,00	7,45	0,004
Lower Miocene	90,12	2,67	0,026	0	0	0
Middle-Upper Eocene	215,04	6,39	0,062	20,90	9,74	0,006
Lower-Middle Eocene	301,49	8,96	0,087	6,49	3,02	0,001
Middle Eocene-Lower Miocene	77,93	2,31	0,022	0	0	0
Oligocene	8,38	0,24	0,002	0	0	0
Mesozoic	410,45	12,20	0,119	16,32	7,60	0,004
Upper Paleozoic	40,205	1,22	0,012	6,305	2,93	5,168
Precambrian	775,35	23,68	0,236	10,511	4,89	0,003
Dam Lake	7,9850	0,23	0,002	0,11	0,052	3,306
Total	3280,52	100	1	214,32	100	0,062

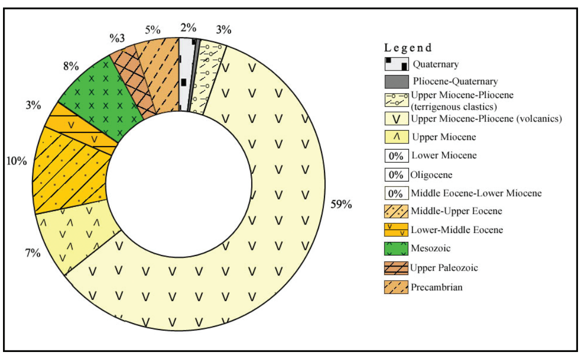

Figure 11- Proportional distribution of landslides observed between Palu and Bingöl with respect to lithological units.

Frequency ratio method was used to statistically explain the relationship between landslides and lithology. This method reveals the relationship between the position of existing landslides and the factors affecting the landslide. The frequency ratio method has a probability model and can be defined as the ratio of the likelihood of occurrence of an event to the probability of unlikelihood (Erener and Lacasse 2007; Yilmaz, 2009; Akıncı et al., 2010). Frequency values higher than one (1) indicate meaningful relation with landslide. It is observed that the frequency in the investigated area is high in areas where the Upper Miocene-Pliocene terrigenous clastics and volcanic rocks are exposed. In addition, the landslide frequency values are high in areas where the Eocene and Mesozoic units with clayey structures are exposed (Table 3).

The landslides in the study area appear to be concentrated on the EAFZ and in certain areas. These areas are the Palu surround from the southwest to the northeast, the Karaömer Mountain and the Göynük stream valley in northeast of the Bingöl Plain. The landslide density at the formation boundaries of clayey lithologies around Palu is high. In particular, landslides occur in areas where clayey structures on ophiolites are cut. The Karaömer Mountain, which corresponds to Gökdere uplift, corresponds to the junction of EAF and KF. Due to this tectonic structure, high angled steep slopes were formed. Also the lithology to be in agglomerated, tuff and clayey structures caused the formation of landslides on almost all slopes cut by faults. Because of fault, slope and lithology, the landslides in this area are both wide based and active. The landslides, which develop generally in the form of slides, move slowly and they are in the form of intertwined because of this formation.

The widespread occurrence of landslides around Palu in the Murat River Valley is due to the high angle values and the widespread presence of clayey ophiolitic rocks and Eocene clay and marls. In addition, the presence of many spring waters on slopes facilitates this formation (Özdemir and Tonbul, 1990).

Table 3- Relation of landslides between Palu and Bingöl with lithology based on frequency ratio.

Lithology	Sub Grup Area (m^2)	Total Area (m^2)	Total Area Percentage (a)	Landslide Area (m^2)	Total Landslide Area (m^2)	Landslide area Percentage (b)	Frequency ratio (b/a)
Quaternary	177712200	3280521800	5.4171931	4157300	214325800	1.940616	0.3582327
Pliocene-Quaternary	238732100	3280521800	7.27726	891200	214325800	0.41601	0.0571657
Upper Miocene-Pliocene (terrigenous clastics)	39054900	3280521800	1.1905088	6328700	214325800	2.954219	2.4814763
Upper Miocene-Pliocene (Tuff, Agglomerate)	838151000	3280521800	25.54932	126496600	214325800	59.04826	2.3111479
Upper Miocene	59834900	3280521800	1.8239446	15995600	214325800	7.466701	4.0937104
Lower Miocene	90121200	3280521800	2.7471605	0	214325800	0	0
Middle-Upper Eocene	215047500	3280521800	6.5552834	20903300	214325800	9.757602	1.4885095
Lower-Middle Eocene	301228200	3280521800	9.1823258	6498700	21432580	3.033575	0.3303711
Middle Eocene-Lower Miocene	77942100	3280521800	2.3759056	0	214325800	0	0
Oligocene	8385200	3280521800	0.2556057	0	214325800	0	0
Mesozoic	410439800	3280521800	12.511418	16313300	214325800	7.615002	0.6086442
Upper Paleozoic	40205900	3280521800	1.2255947	6030700	214325800	2.815114	2.296937
Precambrian	775353800	3280521800	23.63508	10515500	214325800	4.908606	0.207683
Dam Lake	7985200	328052180	0.2434125	11450	21432580	0.053448	0.219579

4.3. Relationship between The Distance to Fault Lines and Lanslides

When we look at the distribution of the landslides between Palu and Bingöl, it seems that it is directly parallel to the extension of EAFZ. Starting from Palu west, almost all active landslides were arrayed along a line until the Göynük Valley in the east of Bingöl (Figure 12). This general distribution is directly related to active faults and earthquakes experienced. With snow and rainfall seepages into blocks, which cut and uplifted, facilitated the slip of masses on clayey layers. This formation is also affected by the degradation of the slope balance due to the abrasion of the rivers located in fault lines.

The most important structural elements in the study area are EAFZ and KFZ. Apart from these faults, the Doğanlı Fault (DF) and Genç Fault (GF) constitute other structural elements and are not as effective as EAF and KF. The cut of the EAF by the KF between Palu and Bingöl caused this area to uplift and deform.

The Gökdere uplift passes through the south of the study area. The right slip of the Palu segment with respect to the Göynük segment causes the region between these two segments to rise. The area, which is called as the Gökdere uplift, covers 15 km wide, 30 km long area starting from north of Beyhanlı village in the west to the Ormanardı village in the east. The uplift of the Gökdere compressional zone, deep excavations in the valley basins and alluvial fans and the heights of the Early Pleistocene deposits today show that the area between Palu and Bingöl uplifted in the Quaternary (Herece, 2008). In this area, which corresponds to the Gökdere Uplift, a significant expansion has occurred in EAFZ. The EAFZ forms a 15 km wide zone in the east of Palu, which corresponds to the area where the uplift occurred, and a 5 km wide zone in east of Bingöl. There is also observed an increase in the number of landslides parallel to this expansion. On the other hand, as moving further away from fault zones, the number of landslides decreases and gains a density value close to zero to the south of the Murat Valley. Gupta and Joshi (1990) have also stated that the density of landslides increased as approaching the fault and decreased as moving away from the fault. Moreover, it has been stated that if you are close to fault zones, then it will cause the break up in the rocks, which will negatively affect the slope balance.

The intersection area and close vicinity of the EAF and KF correspond to a risky and mobile area in terms of both the seismicity and mass movements (Avcı and Sunkar, 2016). In this area, the offset of the Murat River Valley to the south is seen as the reflection of the two fault to the morphology. Again, the high asymmetry between the northern and southern sides of the Murat Valley in the distribution of landslides is due to faults.

In order to determine the distribution of landslides with respect to fault lines in the study area, 7 classes

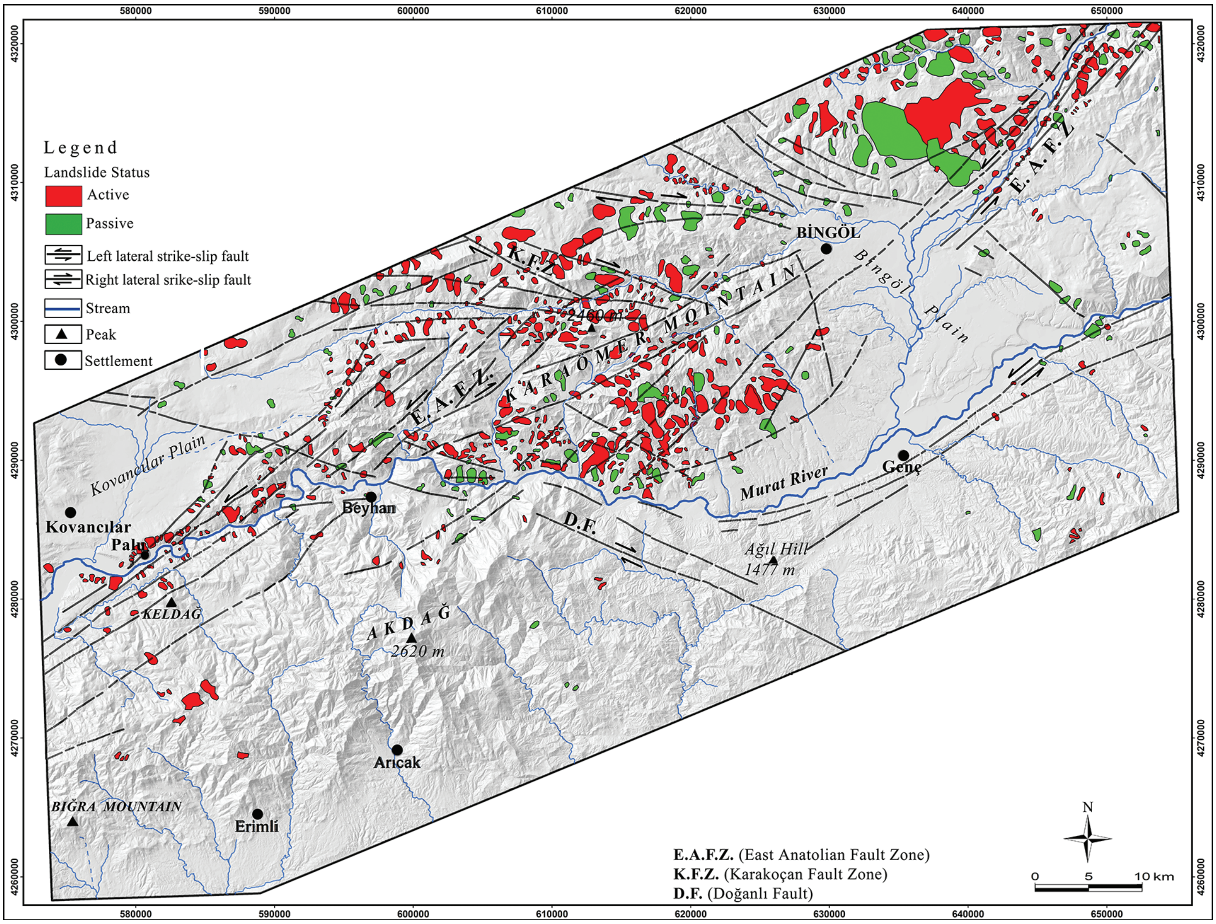

Figure 12- Distribution map of the landslides in the EAFZ between Palu and Bingöl with respect to active fault lines.

were created as; 0-50, 50-100, 100-150, 150-200, 200-250, 250-1000 and 1000 m away. According to the buffer analysis performed, the ratios of the landslide areas with related distances to fault lines are given as follows; 0-50 m 3%, 50-100 m 2%, 100-150 m 3%, 200-250 m 3%. According to this, the ratio of the landslide areas 0-250 m away from the fault lines of the Murat valley is 14%. The areas 250-1000 m away from the fault lines are 29%, and the ratio of areas at 1000 m and more distant from the fault lines is 57% (Figures 13 and 14).

When the width of the fault zones in the region is considered, it is seen that the distribution of distances to the fault lines of the overall study area is not significant, because the width of the fault zones varies from 5 to 15 km. However, in order to determine the spatial relation between active faults and landslides, it is important to carry out the buffering analysis of these classes to reveal the fault lines and the distribution of landslides. According to the results of this analysis, 24% of the landslides are observed at distances of 0-250 m, 40% at 250-500 m and 36% at distances more than 1000 m to the fault lines (Figure 15). According to the results of analyzes, it was determined that the frequency of the landslides was high in areas close to fault lines and low as they moved away from the fault lines. According to these results, there is observed a significant relationship between the fault lines and distribution of landslides (Table 4).

A major part of the active landslides between Palu and Bingöl is closely related with frequently occurring earthquakes in the region. The earthquakes occurring in this area trigger landslides and negatively affect the settlement and access roads. Numerous landslides have occurred in the area investigated in the Kovancılar-Okçular (Elazığ) earthquake that occurred in March 8, 2010. It was observed that new landslides with 15 km in width had occurred in an area, which is about 45 km away from the earthquake epicenter and the existing landslides had been triggered and reactivated

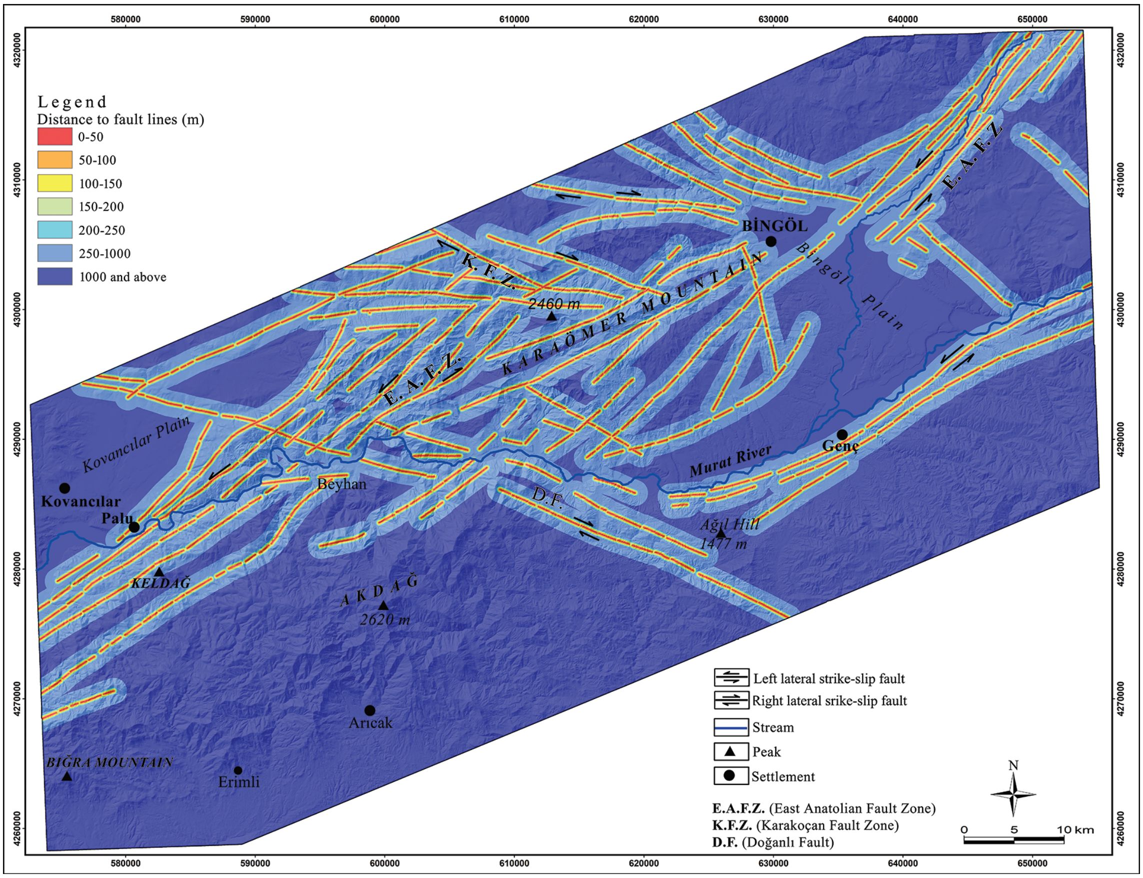

Figure 13- Distance map of the area within the EAFZ between Palu and Bingöl with respect to fault lines.

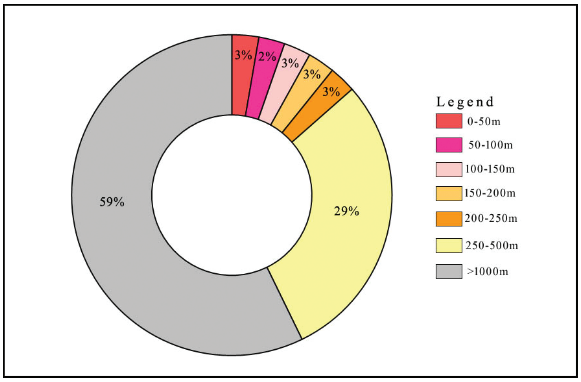

Figure 14- The proportional distribution of the area between Palu and Bingöl with respect to the fault line distance groups.

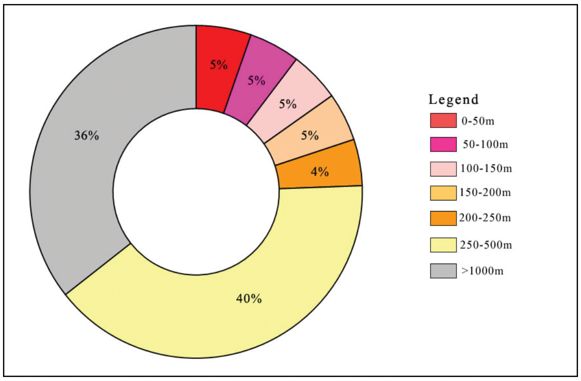

Figure 15- The proportional distribution of the landslides between Palu-Bingöl with respect to fault lines.

Table 4- Frequency Relation with respect to the Distance to the Fault Lines of the Landslides Between Palu and Bingöl.

Distance to Fault Lines (m)	Sub Grup Area (m^2)	Total Area (m^2)	Total Area Percentage (a)	Landslide Area (m^2)	Total Landslide Area (m^2)	Landslide area Percentage (b)	Frequency ratio (b/a)
0-50	89611600	3280521800	2.731626	11484700	214325800	5.361026	1.962577
50-100	87045600	3280521800	2.653407	10610400	214325800	4.952905	1.866621
100-150	90127500	3280521800	2.747353	10470300	214325800	4.887507	1.778988
150-200	90366400	3280521800	2.754635	10066000	214325800	4.69878	1.705772
200-250	89892900	3280521800	2.740201	9669900	214325800	4.513882	1.647281
250-1000	958688800	3280521800	29.22367	85657400	214325800	39.98463	1.368228
1000>	1874789000	3280521800	57.14911	76267200	214325800	35.60131	0.622955

by the earthquake. The newly developed or existing landslides have been responsible in the damage distribution in Okçular and Yukarı Kanatlı villages and İsa Ağa Area, where there had been much casualty and damage in the earthquake. It was also seen that the landslides, which occurred or reactivated during the earthquake had not only been responsible for damage of buildings but also deteriorated structures like road and bridge (Emre et al., 2010; Sunkar, 2011).

5. Results

The area between Palu and Bingöl at the intersection of EAF and KF is tectonically very active and complicated. The EAFZ is observed in a 5-15 km wide zone in the East of Palu and intersects with KFZ in the area where the Karaömer Mountain is located. The Karaömer Mountain was sliced and uplifted by this cut. Due to the fact that the area has been cut by numerous faults and the development of landslides along the fault lines has deformed fault planes. This area, which corresponds to Gökdere uplift is located at the intersection of two fault zones and corresponds to a tectonically very active area.

Considering the factors that control the formation of landslides between Palu and Bingöl, the characteristics such as; lithology, active faults, slope and climate come out. Due to these features, numerous landslides formations in the form of landslide, fall, and flow were observed. The distribution of landslides creates a great asymmetry on northern and southern slopes. It was determined that 93% of the existing landslides occurred in the north and 7% in the southern slopes.

Looking at the landslides occurring between Palu-Bingöl, 59% of them were formed on the Upper Miocene-Pliocene volcanics, 10% in the Middle-Upper Eocene clastic and carbonates, 8% in the ophiolites and 7% in the Upper Miocene basalts. Despite having 15 lithological units in the mapped area, 84% of the landslides were collected on 4 units. These ratios and the frequency analysis results are consistent with each other. It is observed that the elevation and slope factor are effective in the formation of landslides developing in flow and fall types and the effect of these two factors is not apparent in the formation of slide landslides. In addition, the effect of relief is also evident in slide and fall type landslides.

The uplift of the tectonically active field and the downward cutting of the bed of the Murat River caused the formation of different reliefs on the field. The deeper erosion of the rivers have rejuvenated landslides on slopes of Murat and Göynük valleys. The formation of numerous, wide based intertwined landslides were observed with this effect of the rivers and earthquakes. It was observed that the current landslides had been activated by earthquakes, especially at the end of winter and the beginning of spring. In Kovancılar-Okçular Earthquake in March 8, 2010, the damage and loss of lives were higher in settlements built on landslides.

As a result, a close relationship has been observed between the distribution of landslides between Palu and Bingöl and faults. Even all the landslides seen in the south of the Kovancılar Plain remain on the fault line in this area. Very large landslides have developed in the shear zone of the faults, in the Karaömer Mountain and the north of the Bingöl Plain located in the intersection areas of EAF and KF. In this development the intersection of the faults and with this intersection the uplift and lithological features have become effective.

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