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DETERMINATION OF LANDSLIDE SUSCEPTIBILITY IN THE MELET RIVER BASIN (ORDU, TURKEY) BY BIVARIATE STATISTICAL ANALYSIS METHOD

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ABSTRACT

In this study, it was aimed to determine landslide susceptibility in the Melet River Basin, where landslides cause significant economic losses and the effects of which continue to be seen currently. A landslide is the most serious natural disaster in the basin located within the borders of Ordu province due to geomorphological-geological and climatic features. In this study, frequency ratio and Landslide Susceptibility Analysis (LSA) methods were used from among bivariate statistical analysis methods. The bivariate analysis method reveals the effect of different variables on landslide formation. Geology and topography maps and satellite images constitute the basic data in this study. The lithology layer was obtained from the geology maps covering the basin, while Digital Elevation Model (DEM) was used to obtain slope, aspect, elevation, curvature and topographic wetness index (TWI) layers. Rivers were digitized from the topography maps and the distance to river layer of was obtained. Normalized Difference Vegetation Index (NDVI) layer was formed using the Landsat 8 satellite image and distance to road layer was formed via Open Street Map data. The landslide inventory layer pertaining to the study area was obtained using the Directorate of Mineral Research and Exploration (MTA) Samsun plate and land surveys. The inventory map was overlapped with the layers and subsections of the layer with landslide and without landslide were identified. In accordance with the method, the layer weights were determined and registered on the attributes table of the reclassified layers. Susceptibility map was created by adding the layers with determined weights. The proportion of the areas with high and very high landslide susceptibility in the map obtained via frequency ratio method in Melet River Basin account for 12%, the proportion of the moderate susceptibility area account for 27% and the proportion of the low and very low susceptibility areas account for 61%. According to LSA, high and very high susceptibility areas account for 11%, moderate susceptibility areas account for 26%, very low and low susceptibility areas account for 63%. Ulubey and Kabadüz districts are classified as high and very high susceptibility areas within the basin boundaries. Considering the climate characteristics of the study area, landslides are inevitable due to hydro-meteorological events and anthropogenic effects. For this reason, planning should be made by taking into account the susceptibility map.

Keywords: Melet river basin, Ordu, landslide susceptibility, bivariate statistical analysis method.

INTRODUCTION

Landslide is one of the most common geohazards in various parts of the world (Achour et al., 2017), causing damage to property, injuries or fatalities leading to high costs of maintenance (Das et al., 2012; Budimir et al., 2015). Every year, several landslides disrupt the economy, flora, fauna and the lifelines around the globe, therefore it is essential to understand the interactions between the slopes and the instability-causing factors (Hadji et al., 2013). Landslide-caused disasters, both in our country and around the world, are induced by extreme precipitation, which occurs due to climate change, and are sometimes triggered by large earthquakes, resulting in a large number of loss of life and property (Akgün, 2018). Rapid population growth increasingly intensifies the need for new residential areas and road routes. Consequently, new residential areas and roads are constructed. Most of the time, it is almost impossible to find suitable sites and/or routes that meet each criterion for location selection (Çellek et al., 2015). Even in some cases, a residential area displaced because of a disaster is exposed to the same disaster in the new place where it is moved. Selection of a suitable place is the priority thing to be done to reduce damages inflicted by landslides.

It is of vital importance to accurately recognize the areal spread of the landslides and possible future landslides for the suitable location selection. While the current landslides can be revealed by the landslide inventory studies conducted by various methods, the areal spread of the landslides likely to be seen in the future can be ascertained by Landslide Susceptibility Analysis (LSA) (Çellek et al., 2015). At present, research methods for landslide susceptibility mapping can be divided into three major categories: qualitative factor- overlay, statistical models and geotechnical process models (Dai and Lee, 2002). Generally, geotechnical process methods are developed from slope stability analyses and are applicable for site-specific landslides or when the ground conditions are quite uniform in the study area. Also, this method requires the landslide types to be known and relatively easy to analyze (Terlien et al., 1995; Wu and Sidle, 1995), and hence it is seldom used in large-scale landslide susceptibility mapping. In qualitative methods, landslide experts select landslide controlling factors and combine these factors into a susceptibility map, based on their knowledge and experience of landslide investigation. (Anbalagan, 1992; Pachauri and Pant, 1992). In contrast, statistical methods include statistical determination in combinations of explanatory factors (Carrara et al., 1991; Dhakal et al., 1999). Among these three types of methodologies, the latter two are widely applied to large-scale landslide susceptibility mapping. Relatively, reproducibility of results and subjectivity in landslide modeling can be the apparent disadvantages of the method of qualitative factor overlay. In recent times, large volumes of landslide inventories and multi-source data of landslide factors have become gradually accessible to researchers and that means statistical methods are frequently used in landslide susceptibility mapping (Lin et al., 2017). In recent years, statistical approaches using bivariate or multivariate techniques are widespread in landslide probability assessment (Nandi and Shakoor 2009). In this study, it was aimed to determine the landslide susceptible areas in Melet River Basin by frequency ratio and Landslide Susceptibility Analysis (HDA), which are bivariate statistical analysis methods. Hatipoğlu (2017) composed a risk map with weighted overlay method for the upper and lower parts of Melet river. However, there are no studies based on statistical analysis covering the entire basin. The study area is located within the boundaries of Ordu province in the Black Sea Region. In our country, landslide-caused disasters are mostly seen in the Black Sea Region due to the morphological structure, lithology and climate characteristics. In recent years, landslides triggered by heavy precipitation in the Black Sea Region have caused significant losses. Many studies have been carried out on the landslides occurring in the region (Çiçek, 1985; Doğu et al., 1989; Uzun, 1992; Gürgen, 1993; Pekcan, 1996; Bayrak and Ulukavak, 2009; Dölek, 2009; Yılmaz et al., 2012; Uzun et al., 2016). Natural disasters that cause loss of life and property in Ordu province are mostly of hydro-meteorological origin. While the number of landslides occurring in the province is 305, floods come second with 36 incidences (Görüm, 2016). Ulubey district, which is located in the study area, is one of the settlements with the highest number of landslides in Ordu province. Roads, settlements, bridges, agricultural and forest areas were damaged in the province of Ordu due to floods and landslides that took place due to excessive rainfall in 2016 and 2018. In this study, the landslide susceptible areas were determined with the map created in the Melet River Basin. Ulubey, Kabadüz and Yeşilce settlements are classified in the high susceptibility group on the susceptibility map. The results of this study will minimize potential losses by guiding decision-makers in determining new settlement areas and road routes.

STUDY AREA AND ITS GENERAL GEOGRAPHICAL FEATURES

Melet River Basin located within the boundaries of Ordu province in the Black Sea Region, is surrounded by Kılıç Mountain (3167 m) and Kırklar Mountain (3038 m) from the northeast, Erdembaba Hill (2181 m) from the northwest, Aydogan Hill (1971 m) and Göl Hill (1730 m) from the west and by the Black Sea from the north (Figure 1). The study area is located between the coordinates of 4539897,786427-4467392,594295, 377953,498450-431511,253988 (Utm Ed50 Zone 37). Within these boundaries, the location of the study area is 1984 km2. The study area is 73 km long in the N-S direction and 50.9 km in width in the E-W direction. In Melet River Basin, there are 149 rural settlements within Ulubey, Kabadüz and Mesudiye district settlements (Figure 1). The elevation in the basin ranges between 0-3105 m and the average elevation is 1323 m. There is a marked difference in elevation between the north and southern mountainous area of the basin. The mean slope value is 20^o, the minimum is 0^o and the maximum is 78^o in the basin.

The Melet River, which separates the East and West Black Sea sections, takes its origin from the village of Ortakent in Koyulhisar, Sivas. The river, which is 160 km in length, is the largest river of Ordu province, and discharges into the Black Sea from the east of the city centre. The length of the rivers existed between Ordu and Giresun provinces are generally short, and Melet does not pass through the southern slope of the edge mountains except from Harşit (Erinç, 1945). In the study area, the valley frequency is high and there are deep cracks on the surface. Despite the constant rainfall, Melet River displays a flood character due to the high slope value. When the current values reflecting the natural flow conditions of Melet River are taken into consideration, it is determined that the average current is about 29 m^3/s and that the lowest current values and the highest current values are seen in September and in April, respectively. Due to long-term rainfall, floods and sometimes flood-triggered landslides occur in narrow and slopping river beds (Gürgen, 2016).

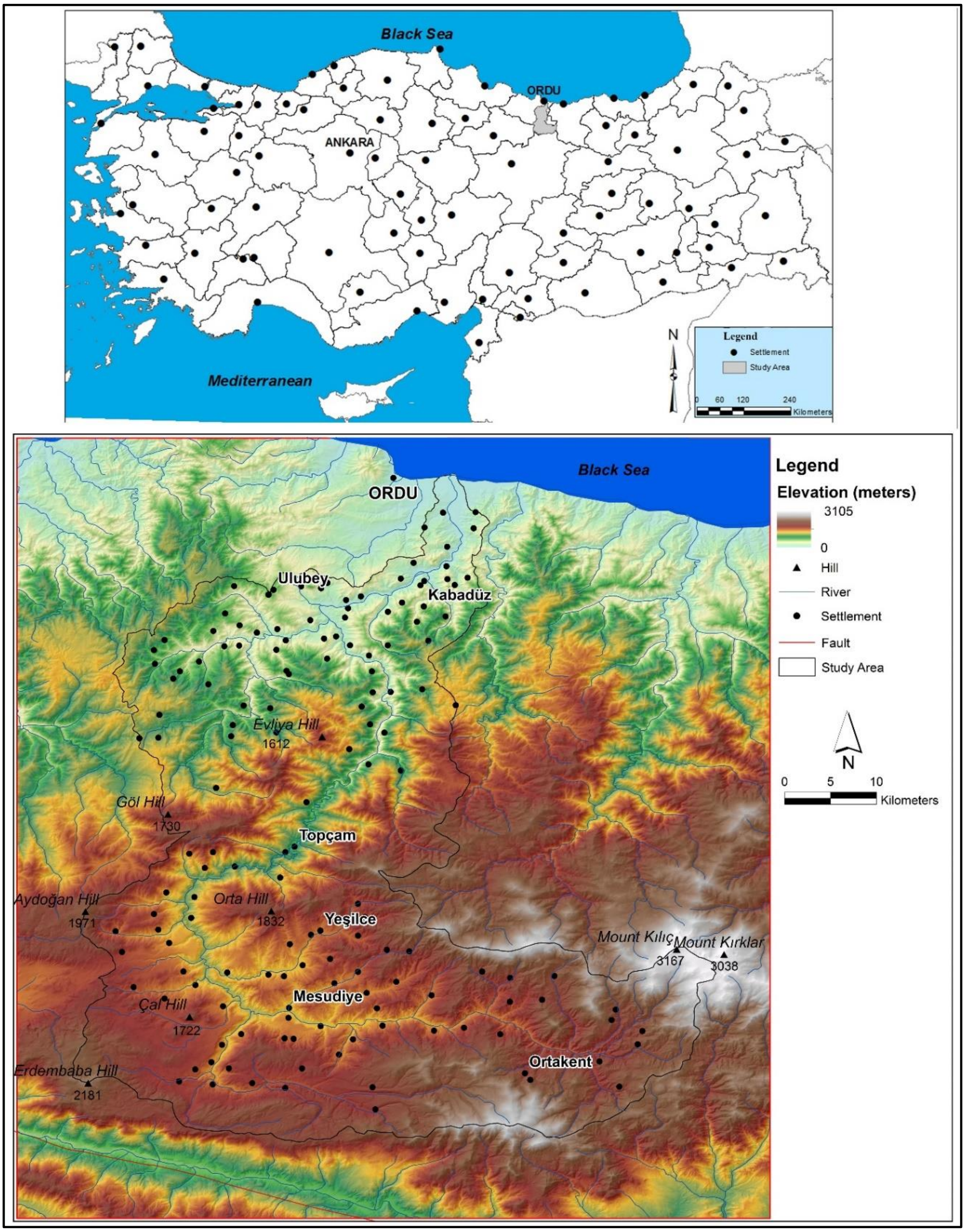

Figure 1. Location map of Melet River Basin (Ordu) (Faults were taken from Emre et al., 2012).

In the Melet River Basin, lithological units from Upper Cretaceous to Quaternary formed at different periods rise to the surface. In the study area, the Upper Cretaceous units consist of dacite, rhyolite, rhyodacite, volcanic and sedimentary rocks and andesite and pyroclastic rocks. These units rise to surface in the south and north of the basin. The undifferentiated Quaternary unit forming the youngest unit rise to the surface on the shore. North Anatolian Fault Zone (NAFZ) passes inside the south of the basin. The distance to NAFZ on the southern border of the basin is approximately 6.5-7 km. Since the study area is located near the NAFZ from the tectonic point of view, it is likely to observe landslides that can be triggered by earthquakes on the NAFZ. Indeed, 1939 M = 7.9 Erzincan and 1942 M = 7.0 Niksar-Erbaa earthquakes caused significant damages in Ordu province (Görüm, 2016).

In the study area, the whole-year rainy Black Sea climate with generally mild winters and cool summers prevails. However, the impact of the Black Sea climate declines and the effects of the continental climate prevailing in the inner regions intensify starting from the outfall area where Melet River is discharged into the Black Sea through the source of the river in the north. In this respect, the upper course of the Melet River is noteworthy as an area where the characteristics of a transitional climate in between the Black Sea climate and the continental climate are observed. When the one-year course of temperature and precipitation values of the four different stations in the study area are analysed, the effects of this change are clearly visible (Figure 2). The average annual temperature is 14.4 ^{o}C in Ordu, 11.9 ^{o}C in Kabadüz, 11.6 ^{o}C in Ulubey and 11.0 ^{o}C in Mesudiye. In all stations, the hottest month is August and the coldest month is January.

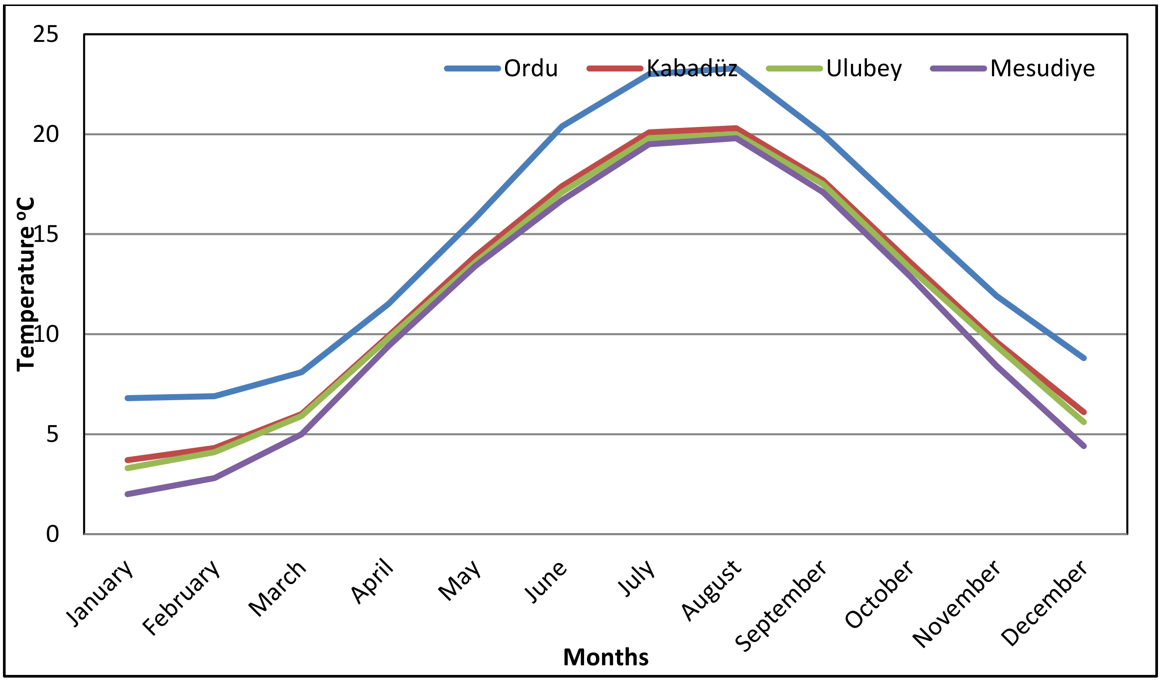

Figure 2. Monthly average temperatures of the stations of Ordu, Kabadüz, Ulubey and Mesudiye (^{o}C), (TSMS, 1959-2017).

In the Melet River Basin, the Black Sea precipitation regime is dominant. All months of the year are rainy. Mean value of rainy days is 143. The average annual rainfall is 1038 mm in Ordu, 847 mm in Kabadüz, 822 mm in Ulubey and 774 mm in Mesudiye. In the area where almost half of the year is rainy, autumn rainfall is at the highest value (Figure 3). Although the rainfall is small in the spring season, sudden snow melts can be noticed during this period. This situation can trigger landslide formation.

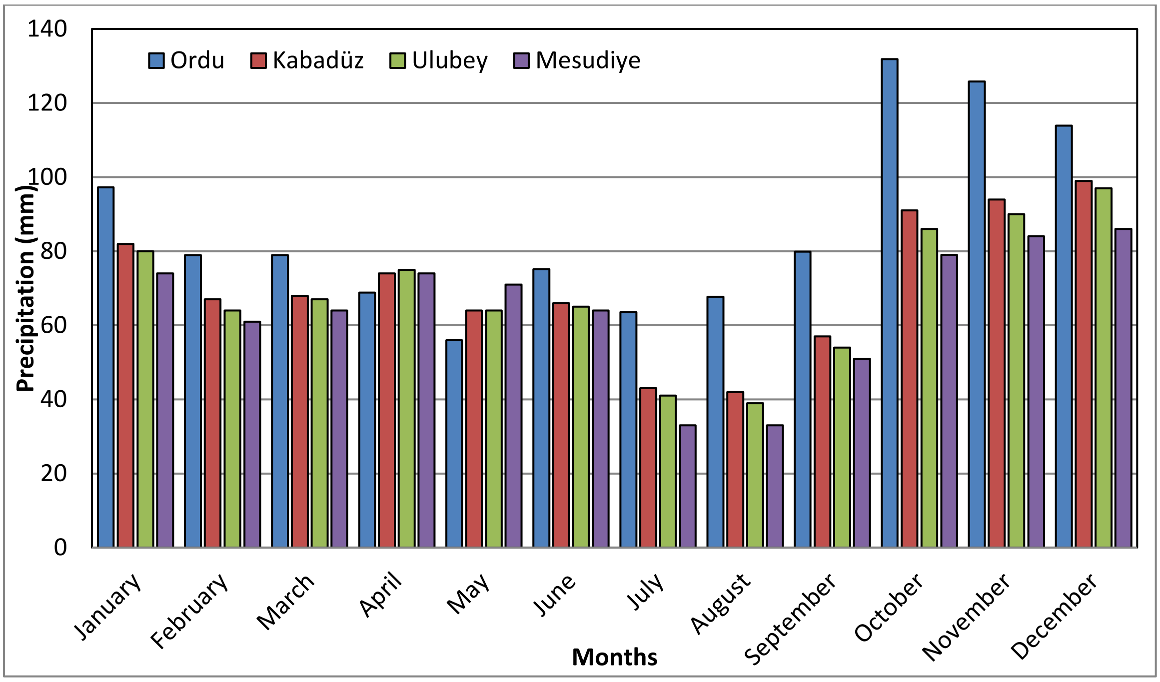

Figure 3. Monthly average rainfall of the stations of Ordu, Kabadüz, Ulubey and Mesudiye (mm), (TSMS, 1959-2017).

Although the snowfall is not high in the coastal areas, snowfall and snow cover duration increases through the inner parts where the elevation rises. This situation has a particularly positive effect on the hydrological properties and it enables the rivers in the province to flow throughout the year. Although this creates a positive effect on natural life and human activities, extreme rainfall seen occasionally result in floods and over-flows (Gönençgil, 2016).

In the study area where the Black Sea climate is seen, differences in climate characteristics occur due to the rise in elevation. The most important result of this change was on the composition, density and distribution of vegetation.

Ordu province is located on a site where Euxin and Colchis sections of the European-Siberian flora area and the Iran-Turan flora meet. In addition to its natural vegetation diversity, Ordu province houses some plant species with a limited geographical spread in Turkey (Günal, 2016). The Melet River located in the eastern part of Ordu province, and which is considered as the border separating the Euxin and Colchis sections of the European-Siberian flora region (Davis, 1965-1988), is of distinctive significance in terms of plant geography. In the lower part of the Melet River Basin, forest formation was destructed and replaced by other agricultural areas, including hazelnut gardens mainly up to 600-700 m. Pseudo-maquis formations, Anatolian chestnut, Oriental hornbeam and sessile oak formations are significant up to 400-450 m elevations. As a result of the forest destruction, forest pieces consisting of European hornbeam, maple, oak and beech communities are seen at 700-1000/1200 m levels. The slopes in middle part of the basin and interior sections of the valleys are the spread area of the Oriental beech. Oriental spruce trees seen in oriental beech forests on the eastern slopes of the Melet River valley after 1400-1500 m become dominantly visible after 1600 m (Günal, 2016). Towards the south after 1500-1600 m, forests consisting of scots pine trees replace the forests where the oriental spruce trees on the north-facing slopes of the summits, oriental beech in interior parts and slopes of the valleys, sessile oaks in the lower ridges are dominant (Aktas, 1990). In the south and southeast of the basin where the effects of the Black Sea weaken, dry forests are common.

MATERIAL AND METHOD

The parameters used in landslide susceptibility studies are selected by considering the parameters that control the development process of landslides in the study area (Gökçeoğlu and Ercanoğlu, 2001). In this study, the layers to be used in the determination of landslide susceptible areas were identified in line with literature and field studies. In this study, lithology, slope, aspect, elevation, curvature, topographic wetness index (TWI), distance to rivers, Normalized Difference Vegetation Index (NDVI) and distance to the road layers and landslide inventory layer were used.

Lithological unit layer of the basin was obtained using Samsun sheet a geology map with a 1/500000 scale. With the digitization of the topography maps of the study area, Digital Elevation Model (DEM) was formed. Slope, aspect, elevation and the curvature were obtained from the DEM. TWI was created with the following equation (1)

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

TWI abbreviation means topographic wetness index. Here, As refers to the specific drainage area (m^2m^{-1}), and β refers to the slope in degree (Moore et al., 1991).

The NDVI layer was created using equality 2 from Landsat 8 OLI-TRS satellite image.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (2)$$

Where, NIR refers to the near infrared wavelength of the light spectrum, RED refers to the wavelength of the red region, and NDVI (unitless) refers to the vegetation index value (Tucker, 1979).

In topography maps, distance to the river layer was obtained by digitizing seasonal and continuous rivers and the distance to road layer was obtained by using Open Street Map data. The landslide inventory layer of the Melet River Basin was formed with the General Directorate of Mineral Research and Exploration (MTA) landslide inventory map with a scale of 1/500000 using Samsun plate and field studies (Figure 4; Duman et al., 2011). Landslide inventory is a map representing the spatial distribution of landslide that includes information of location, type of landslide, landslide volume, state activity, date of occurrence, and other characteristics of landslides in the area as well as information on triggering factors (Fell et al., 2008). The landslides can be drawn as single point or areas, depending on the scale of the map (Parise, 2001). This map is essential to understand the evolution of landscape (Galli et al., 2008) and to produce other maps such as susceptibility, hazard, and risk maps (Parise 2001; Galli et al., 2008). Various methods such bivariate statistical analyses, logistic regression analysis and analytical hierarchy process have been utilized by researchers in order to analyze landslide areas in geographical information system (GIS) environment (Tasoglu et al., 2016). In this study, from among bivariate analysis methods, frequency ratio and Landslide Susceptibility Analysis (LSA) methods were used. The frequency ratio method (FRM) is a probabilistic method and has proven to be a pellucid and feasible method. The frequency ratio in FRM is the rate of the probability of an occurrence to the probability of a non-occurrence for given attributes (Lee et al. 2003; Erener and Lacasse 2007; Yilmaz 2009).

To calculate the frequency ratio of each of the environmental variables used in the landscape susceptibility assessment, each layer was divided into subgroups and the number of landslide cells in each subgroup of each layer was determined. Frequency ratio is calculated as presented in Figure 3.

$$FR = \frac{PLO}{PIF} \quad (3)$$

In this equation, FR refers to frequency ratio; coefficient PLO corresponds to the ratio of the number of landslide pixels in the layer subgroup to the total number of landslides pixels (%), and the coefficient PIF corresponds to the ratio of parameter subgroup to the total number of pixels in the research area (%). It is reported that, in this method, FR values greater than 1 are relatively more effective in landslide formation, while FR values less than 1 have less effect on landslide formation (Erener and Lacasse, 2007).

The weight of the subclasses determined in accordance with the formula content was registered in the GIS database. The weighted layers were added and a landslide susceptibility map was formed.

Secondly, “Landslide Susceptibility Analysis”, a Bivariate Statistical Analysis (BIA) method, was used in the study. This method, which is the simplest and most useful method in a bivariate statistical analysis, reveals the effect of different variables on the formation of landslides (Van Westen, 1993). In the LSA method, layers were classified and pixel numbers and appropriate subclasses were determined. Layer maps and landslide maps were overlapped and zonal statistics were used for weight calculations (4).

$$D_{area} = 1000 \frac{Npix(SX_i)}{Npix(X_i)} \quad \text{(Van Westen, 1993).} \qquad (4)$$

D_{area} =Field Density (‰),

$Npix(SX_i)$ number of pixels in the subclasses of layers,

$Npix(X_i)$ = Pixels numbers of subclasses of layers.

In order to evaluate the effect of the parameters, the weight value must be assigned. To this end, the ratio of the pixel number of the total landslides to the pixel number of the whole area is subtracted from the present density (5).

$$W_{area} = 1000 \frac{Npix(SX_i)}{Npix(X_i)} - 1000 \frac{\sum Npix(SX_i)}{\sum Npix(X_i)} \quad (5)$$

In this method, the positive weight value (LSA) shows the positive relationship between the landslide and layers, and negative values show the negative relationship.

At the final stage, the weight values of the layer maps were added and a landslide susceptibility map was obtained. The maps created by both methods are classified as very low, low, moderate, high and very high susceptibility groups.

Landslides in the Melet River Basin

The total number of landslides mapped in Melet River Basin is 190 and these landslides are in the slide class. In the study area, relatively shallow slides are observed. As a matter of fact, 36 of the landslides are active deep (depth of sliding plane> 5 m), 154 are passive shallow slides (depth of sliding plane <5m).

The average area of landslides seen in the basin is 223861 m^2, the minimum landslide is 11461 m^2 and the maximum landslide is 2411100 m^2. According to the classification made by Comforth (2014), 131 of the landslides seen in the study area are large, 50 are very large and 2 are in classified in the exceptionally large group (Table 1).

Table 1. Classification Of The Landslides Seen In The Melet River Basin (Ordu) According To Areal Spread.

Explanation	Area (m^2)	Landslide Number
Very Small	<200	0
Small	200-2000	0
Medium	2000-20000	7
Large	20000-200000	131
Very Large	200000-2000000	50
Extraordinary large	**>2000000**	2

According to Kernel density analysis in Melet River Basin, landslide density varies between 0-0.82 km/km^2. It is observed that the density of landslides increases in the south of Ulubey and Mesudiye, which is close to NAFZ, in the west of Kabadüz and Ortakent and in Yeşilce (Figure 4).

Landslides in the basin cause economic loss by damaging settlements, agriculture and forest areas and transportation networks (Photo 1, 2). Gündüzlü and Çatallı neighbourhouds in Ulubey district centre were affected by the landslides in 1983, 2000, 2002, 2005, 2008 and 2016, and houses and workplaces were damaged. It is highly possible that structures are damaged with the re-activation of old landslides (Photo 1B) in the study area.

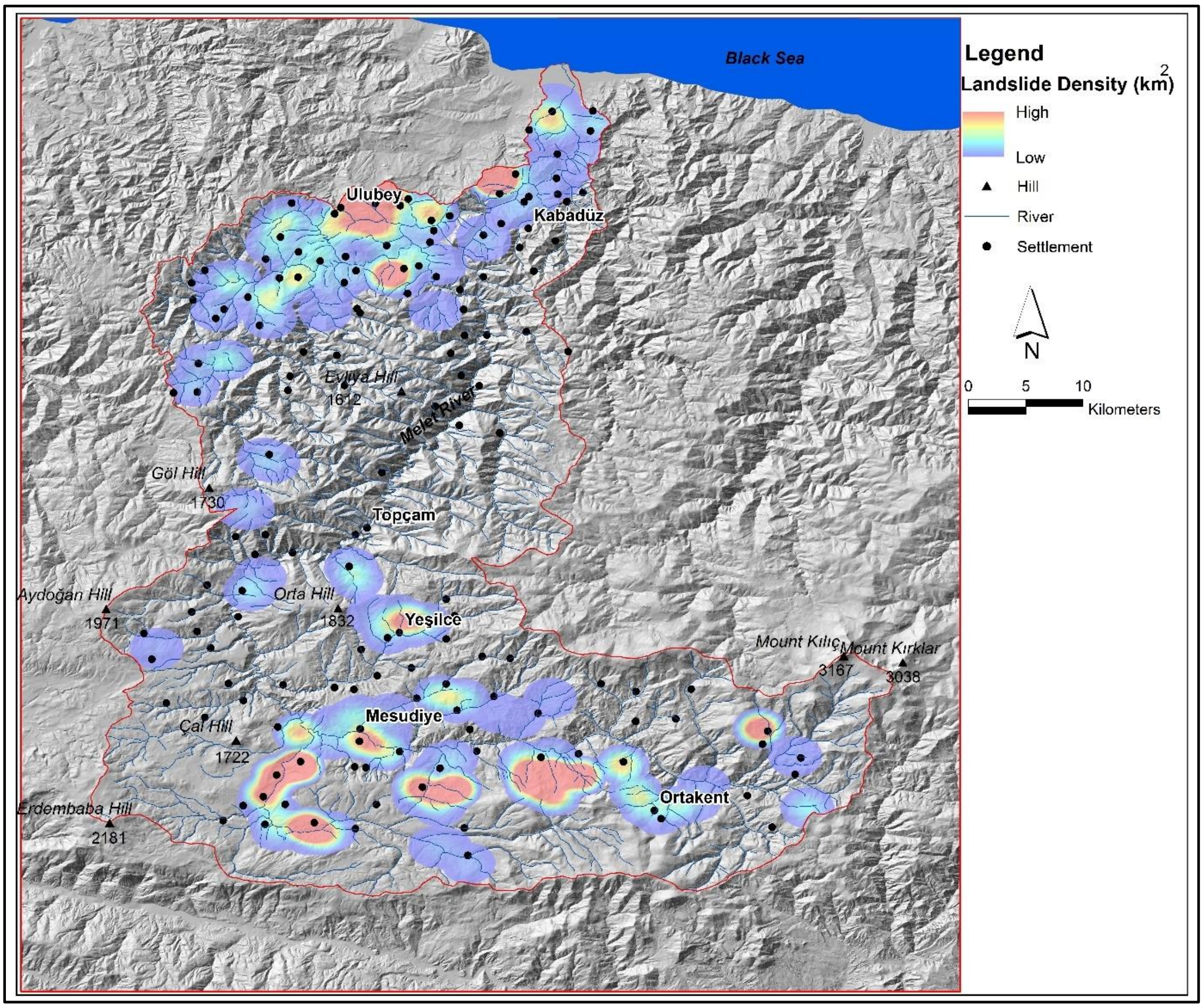

Figure 4. Landslide density map of Melet River Basin (Ordu)

Photo 1. Landslides seen in the melet river basin; a) Güvenyurt-Ulubey http://www.afisgazetesi.com/haber-ulubey-de-korkutan-heyelan-6133.html, b)Ulubey (Photo, V.Avci,F.Esen), c) Kabadüz-http://www.milliyet.com.tr/kabaduz-karayolunda-heyelan-ordu-yerelhaber-2536138/, d)Ulubey (Photo: V.Avci,F.Esen).

Photo 2. Landslides seen in the melet river basin; a,b, c) Ulubey-Topçam (Photo: V.Avci,F.Esen), d) Kabadüz (https://www.haberturk.com/yerel-haberler/57932029-kabaduz-karayolunda-heyelan).

RESULT

Lithology

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). Upper Cretaceous dacite, rhyolite and rhyodacite, andesite, pyroclastic rocks, volcanic and sedimentary rocks, Upper Cretaceous-Eocene Neritic limestones, clastic and carbonates, Paleocene-Eocene, granodiorite, Eocene, continental clastic and carbonates, Middle-Upper Eocene, volcanite and sedimentary rocks, Pliocene Basalt, Andesite and un differentiated Quaternary units constitute the lithology in the Melet River basin (Figure 5, Hakyemez and Papak, 2002).The lithological units with the largest surface area in the study area are volcanite and sedimentary rocks with 21% (Middle-Upper Eocene), undifferentiated andesite and pyroclastic material with 23% (Upper Cretaceous).

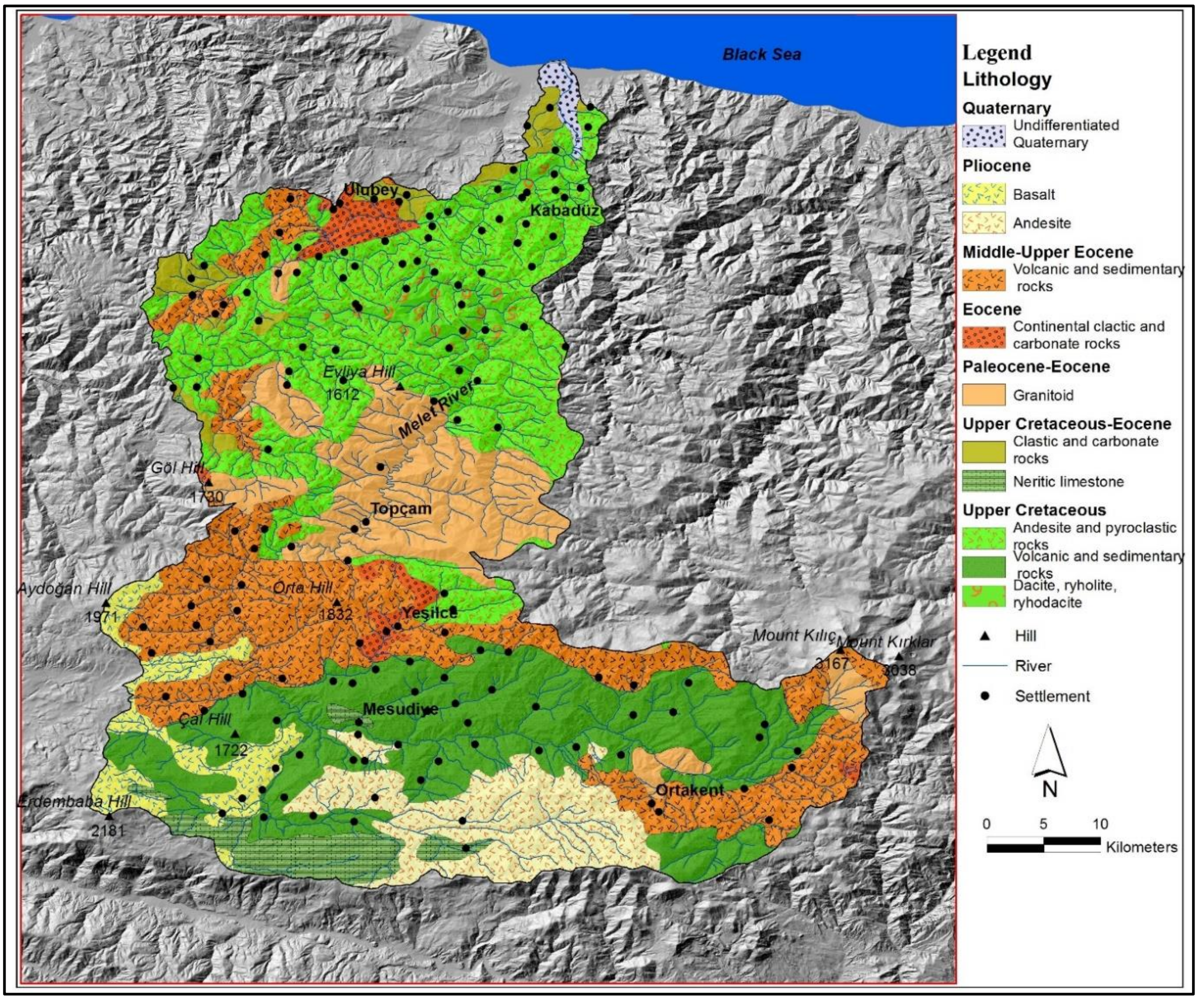

Figure 5. The lithology map of the Melet River Basin (Ordu) (from MTA 1/500000 scale Geological Map of Turkey, Samsun sheet, Hakyemez and Papak, 2002)

While 38% of the landslides developed on volcanic and sedimentary rocks (Middle-Upper Eocene), the unit having the highest frequency ratio is the clasts and carbonates (Eocene). Eocene clastic and carbonate rocks are composed of sandstone, mudstone and limestone, and the volcanite are composed of agglomerate, andesite, basalt and tuffs.

Table 2. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With Lithological Units, And Their Frequency Ratio And HDA Values.

Lithology	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
Undifferentiated andesite, Pyroclastic rocks (Upper Cretecaous)	56836	424515	13,38846	4552648	19837748	22,94922	0,58339	-8,91519
Volcanic and sedimentary rocks (Upper Cretecaous)	30886	424515	7,275597	1435429	19837748	19,7573	0,368248	-13,5191
Dacite, ryholite, ryho-dacite (Upper Cretecaous)	2635	424515	0,620708	1668852	19837748	2,775547	0,223635	-16,6137
Clastic and carbonate rocks (Upper Cretecaous-Eocene)	63688	424515	15,00253	2334452	19837748	2,504745	5,989645	106,7752
Neritic limestone (Upper Cretecaous-Eocene)	3306	424515	0,778771	3785293	19837748	3,268249	0,238284	-16,3002
Granodiorite (Paleocene-Eocene)	5649	424515	1,330695	2511656	19837748	12,66099	0,105102	-19,1502
Continental Clastic and carbonate rocks (Eocene)	46599	424515	10,977	445205	19837748	2,244232	4,891205	83,26928
Volcanic and sedimentary rocks (Middle-Upper Eocene)	161121	424515	37,95414	4227115	19837748	21,30844	1,781178	16,71671
Basalt (Pliocene)	15722	424515	3,70352	784824	19837748	3,956215	0,936127	-1,36684
Andesite (Pliocene)	37661	424515	8,871536	1590296	19837748	8,016515	1,106657	2,2824
Undifferentiated Quaternary (Quaternary)	**412**	**424515**	**0,097052**	**110762**	**19837748**	**0,55834**	**0,173822**	**-17,6797**

Continental clasts and carbonates (Eocene), volcanite and sedimentary rocks (Middle-Upper Eocene), and andesite (Pliocene) are units with a frequency over 1 (Table 2). LSA values of the same units are also high. Temperature and precipitation in the basin especially increase the chemical decomposition. As a result of the decomposition, the main rock loses its all properties and it becomes susceptible for sliding under the influence of a proper slope and precipitation. Moisture-resistant rocks like andesite are an important factor in decomposition. The fact that lithology consists of rocks leading to argillisation causes landslides to be seen. Lithological units with a frequency ratio of less than 1 are undifferentiated Quaternary, dacite, rhyolite, rhyodacite (Upper Cretaceous), neritic limestones, undifferentiated andesite, pyroclastic material and basalt. LSA values of the same units are also negative. Özerk (2004) mapped the granodiorites in the study area as high permeability units. Due to high permeability, the landslide susceptibiliy is low on this unit. Pliocene old andesites are classified as impermeable units. The landslide susceptibiliy is high on this unit.

Görüm (2018) revealed that topographic relief, litho-tectonic features and slope were effective in the distribution of landslides (> 1km^2) in the North of Anatolian Plateau. He reported that landslide density increased in areas close to the NAFZ and that landslides were commonly seen on sedimentary units. In this study, the landslide susceptibility was found to be high in sedimentary rocks in the Melet River Basin.

Slope

Slope, one of the most important parameters inducing landslide occurrences, is accepted by many researchers as an effective parameter, and there is a high probability of landslide occurrence with increased slope as a result of stability problems (Borisone and Bottino 1990; Santacana et al. 2003; Lee 2005; Fell et al. 2008).

In the Melet River Basin, the minimum slope is 0°, the maximum slope is 74.8°, and the average slope is 19.8°. The highest slope values are seen in the Melet River Valley between Topçam and Kabadüz, while the lowest slope values are seen on the shore and in the northwest (Figure 6). The slope classification in the basin was carried out based on Verstappen (1983) and Bogomolov (1963). Accordingly, the slope ranges in the basin were determined as 0-2, 2-15, 15-25, 25-45 and >45°. In the basin, areas with a slope value of 0-2° account for 4.3%, 2-15° account for % 30.6, 15-25° account for 32%, 25-45° account for 32.1%, 45° and above account for 0.7%, respectively. The proportion of the areas where the slope value is above 15° account for 65%. This shows that the slope values are high (Table 3).

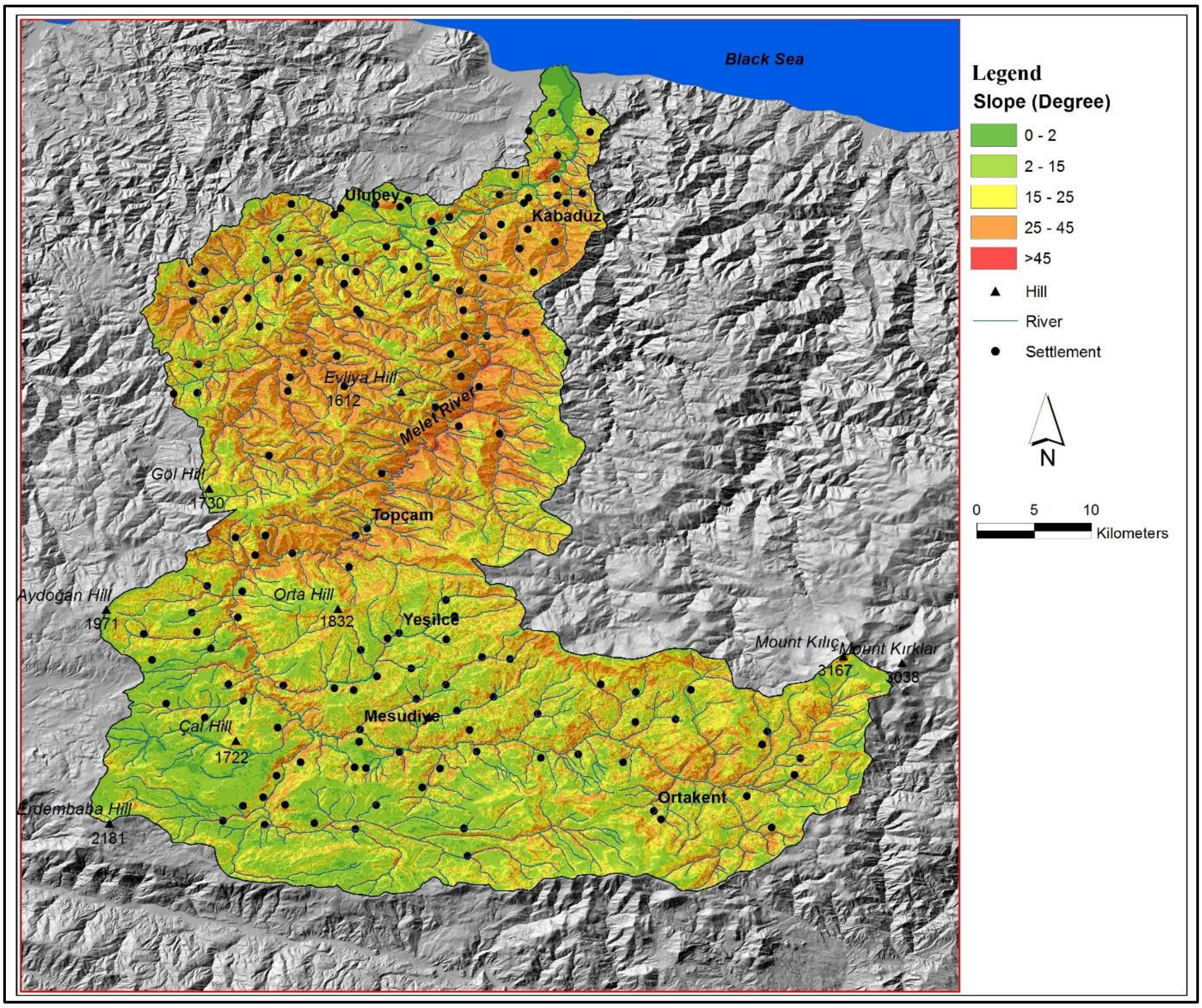

Figure 6. Slope map of Melet River Basin (Ordu)

A significant relationship was found between the distribution of landslides and slope in the 2-15° group in Melet River Basin. In this slope group, the frequency ratio is 1.7 and LSA value is 15.12 (Table 3). The high landslide susceptibility in this slope group is related to the high amount of precipitation. In addition, seepage increases in lower slopes. Increase in the water content of the soil leads to an increase in weight and weakening of the bond resistance, resulting in slides.

Table 3. Relationship of the Landslides Seen In the Melet River Basin (Ordu) With Slope, and Their Frequency Ratio and HDA Values.

Slope (Degree)	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
0-2 (Flat)	18092	424515	4,261805	864442	19837748	4,357561	0,978025	-0,47025
2-15 (Low-steep slope)	222383	424515	52,38519	6088692	19837748	30,69246	1,706777	15,12458
15-25 (Medium-steep slope)	134498	424515	31,68274	6360856	19837748	32,06441	0,988097	-0,25472
25-45 (Steep slope)	49080	424515	11,56143	6383497	19837748	32,17854	0,35929	-13,7108
>45 (High steep slope)	**563**	424515	0,132622	140261	19837748	0,707041	0,187573	-17,3854

Aspect

Generally accepted that slope orientation affects the exposure to sunlight and to winds, affecting indirectly other factors that contribute to landslides, such as precipitation, soil moisture, vegetation cover and soil thickness (Clerici et al., 2006). Most authors agree in considering that at middle and high latitudes the N and NW-facing slopes (or S-facing in the southern hemisphere) are the most favorable to landsliding due to their shadier and colder conditions that favor the accumulation of snow, a higher moisture content for a longer time and a greater physical weathering (Carrara et al. 1991; Lineback Gritzner et al. 2001; Fernandes et al. 2004; Lan et al. 2004; Lee et al. 2004; Tangestani 2004; Moreiras 2005). It is worth noting that in other studies drier slopes result more favorable to landsliding (Dai and Lee 2002; Perotto-Baldiviezo et al. 2004; Shresta et al. 2004).

In the study area, the direction of the basin is mostly N-S according to the aspect map generated from the DEM. The proportion of the N-facing slopes is 38.6% and the proportion of the south-facing slopes is 34.8%. Because north-facing slopes are open to the effects of the Black Sea, they get more rainfall. This can trigger mass movements (Figure 7, Table 4).

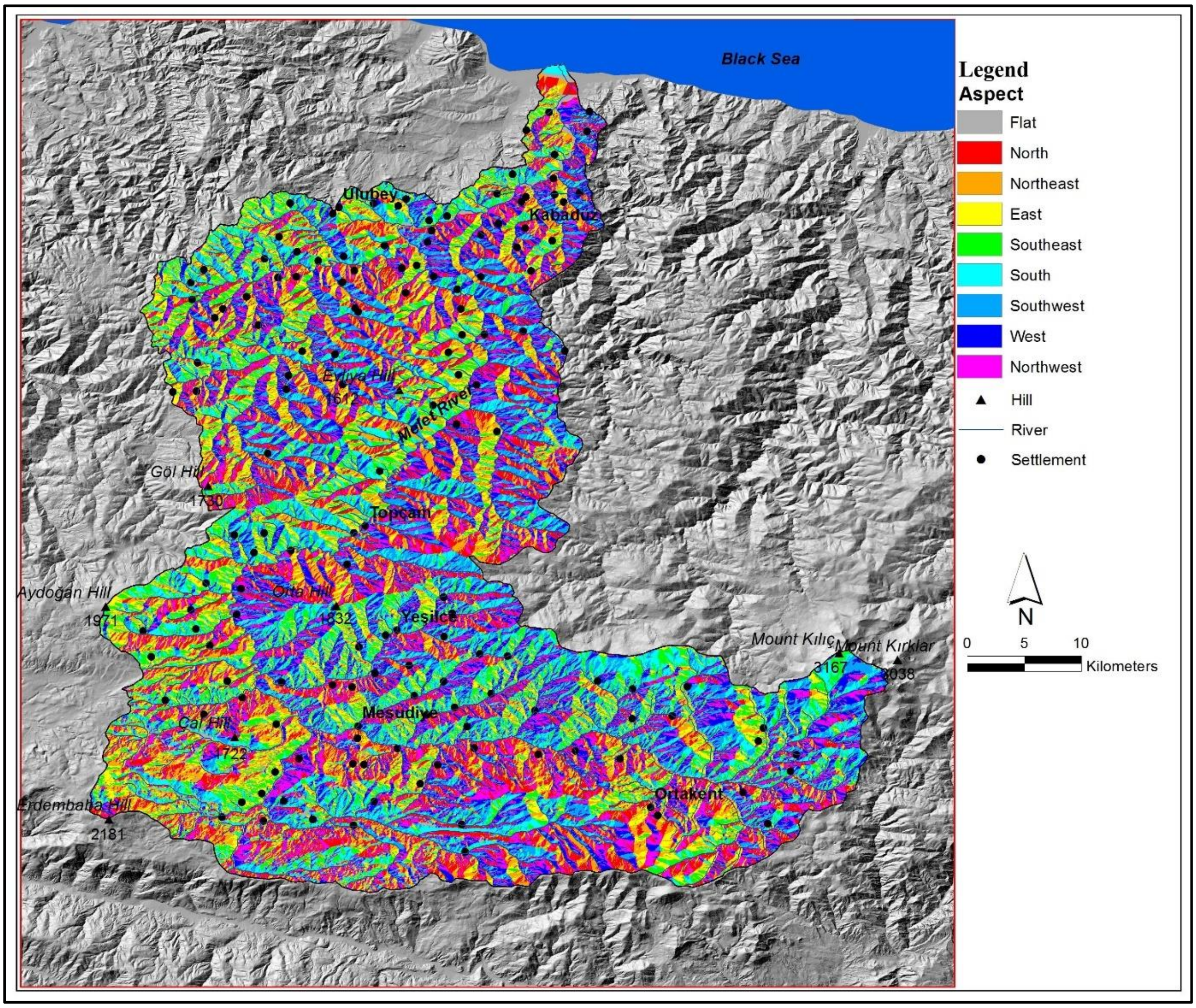

Figure 7. Aspect map of Melet River Basin (Ordu)

It can be defined as exposure to incidences such as saturation and pore water pressure and can be associated with the aspect depending on the infiltration capacity controlled by many factors such as topographical slope and soil type, permeability, porosity, moisture and organic matter content, vegetation, and precipitation season of the mountain slopes receiving intense rain (Afad, 2015).

Table 4. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With Aspect, And Their Frequency Ratio And HDA Values.

Aspect	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
Flat	10365	424515	2,44161	479582	19837748	2,417522	1,009964	0,213217
North	29781	424515	7,0153	1336862	19837748	6,738981	1,041003	0,87744
Northeast	53813	424515	12,67635	2421906	19837748	12,20857	1,038315	0,819922
East	59956	424515	14,12341	2304816	19837748	11,61833	1,215614	4,614002
Southeast	56516	424515	13,31307	2264084	19837748	11,41301	1,166482	3,562617
South	43842	424515	10,32755	2287000	19837748	11,52853	0,895826	-2,22926
Southwest	42615	424515	10,03851	2365273	19837748	11,92309	0,841939	-3,38241
West	46942	424515	11,0578	2473312	19837748	12,46771	0,886915	-2,41995
Northwest	52799	424515	12,43749	2564671	19837748	12,92824	0,962041	-0,81231
North	27886	424515	6,568908	1340242	19837748	6,756019	0,972305	-0,59266

The climate of the study area is the most important factor affecting the landslides. Extreme precipitation is one of the major factors causing landslides. In the Melet River Basin, the north-facing slopes are more susceptible to landslides due to the abundant precipitation. As a matter of fact, the frequency ratio on the north-facing slopes is above 1 and the LSA value is positive (Table 4).

Elevation

In general slope failures are considered more frequent at higher altitudes because of the increase in rainfall and snowfall and the strength of freeze-thaw cycles. This relationship is confirmed in some studies (Lin and Tung 2003; Menendez Duarte and Marqı ´ nez 2002), whereas in many other cases, usually due to the interference of other factors such as lithology, different relationships are found; for example in Dai and Lee (2002), Zhou et al. (2002), Cevik and Topal (2003), Ayalew et al. (2004), Lan et al. (2004), landslides are mostly distributed in areas belonging to lower and/or middle elevation classes. In other studies elevation is shown to have little impact on the occurrence of landslides (Guzzetti et al. 1999; Lineback Gritzner et al. 2001; Ayalew and Yamagishi 2005). According to the DEM reclassified in the Melet River Basin, the proportion of the areas with an elevation of less than 1500 m account for 56.5%, and the areas with an elevation above 1500 m account for 43.5%. The difference in elevation in short distances in the basin is significant. While the elevation rises in south of the basin, it falls to 0 m in the north. The difference in elevation within the basin is 3105 m (Figure 8, Table 5). It was seen that the landslide frequency was higher than 1 and LSA value was high in the basin between 0-250 and 250-500 m elevation. This is related to the deterioration of the slope stability due to the reasons such as the transformation of forest areas into hazelnut gardens and road construction. The landslide frequency is also high in the elevation step of 1750-2000 m. This is related to the increase in precipitation at these elevation levels (Table 5).

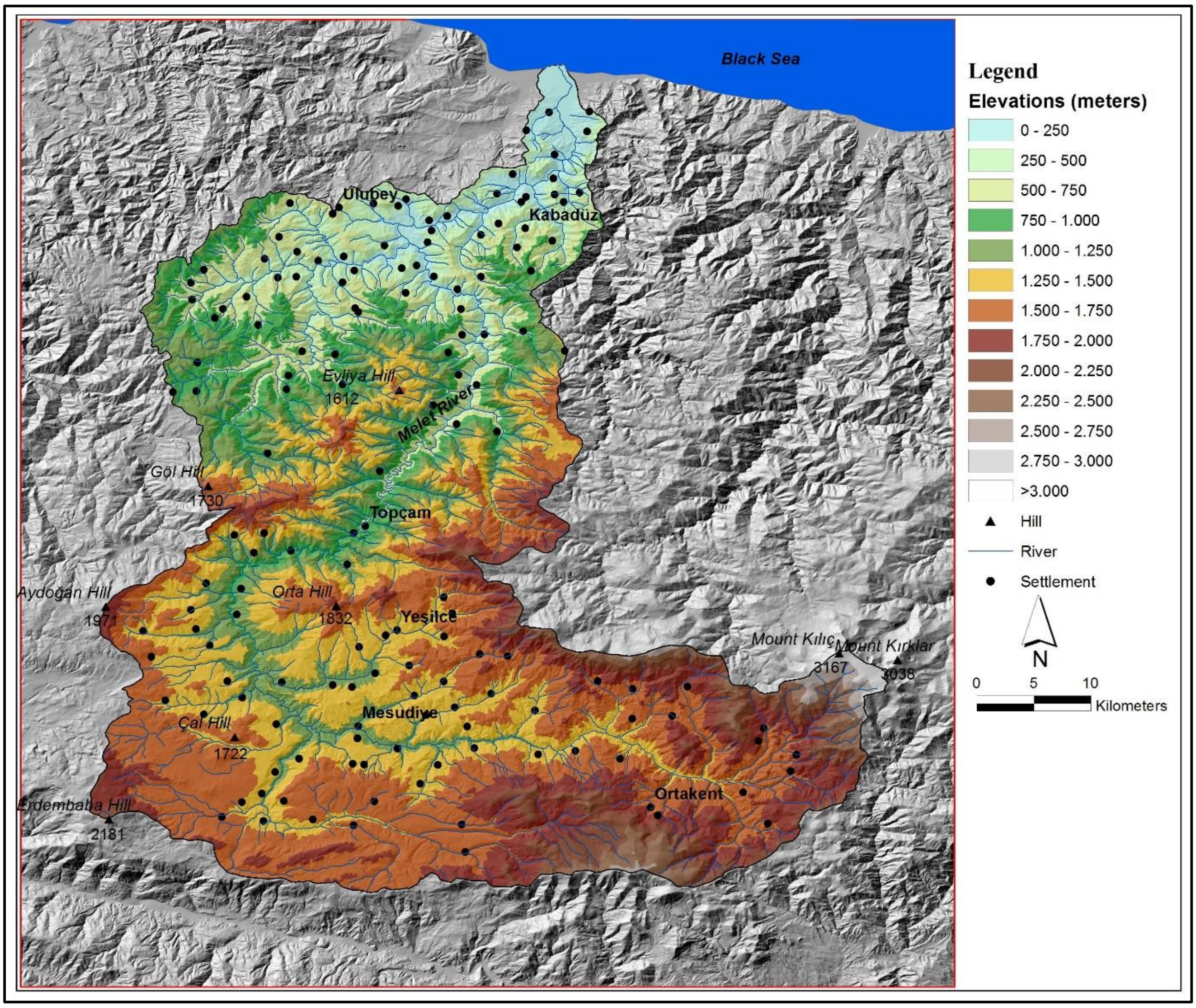

Figure 8. Elevation map of Melet River Basin (Ordu)

Table 5. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With Elevation, And Their Frequency Ratio And HDA Values.

Elevation (meters)	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
0-250	44989	424515	10,59774	690736	19837748	3,481927	3,043642	43,73262
250-500	97153	424515	22,88565	1282875	19837748	6,466838	3,538924	54,33133
500-750	21521	424515	5,06955	1435429	19837748	7,235847	0,700616	-6,40662
750-1000	7124	424515	1,67815	1668852	19837748	8,412507	0,199483	-17,1306
1000-1250	35208	424515	8,2937	2334452	19837748	11,76773	0,704784	-6,31744
1250-1500	34299	424515	8,079573	3785293	19837748	19,08126	0,42343	-12,3382

1500-1750	82476	424515	19,42829	5048550	19837748	25,44921	0,763414	-5,06278
1750-2000	100540	424515	23,6835	2098678	19837748	10,57921	2,238682	26,50699
2000-2250	1205	424515	0,283853	911334	19837748	4,593939	0,061789	-20,0771
2250-2500	0	424515	0	395856	19837748	1,995468	0	-21,3994
2500-2750	0	424515	0	120641	9837748	0,608139	0	-21,3994
2750-3000	0	424515	0	62883	9837748	0,316987	0	-21,3994
>3000	0	424515	0	2169	9837748	0,010934	0	-21,3994

Curvature

The curvature represents the erosional proneness of the slopes and the current slope morphology (Sharma ve Mahajan, 2018). It is regarded that in case slopes are "concave", the weathered material may accumulate on the slope and surface water may be more concentrated on the slope more. Curvature is a topographic data obtained from DEM. The classification for the curvature is concave, flat (planar) and convex, which are represented in the curvature map (Figure 9). The proportion of the concave slopes in the Melet River Basin is 31.4, convex slopes is 42.3% and flat areas is 30.4% (Table 6).

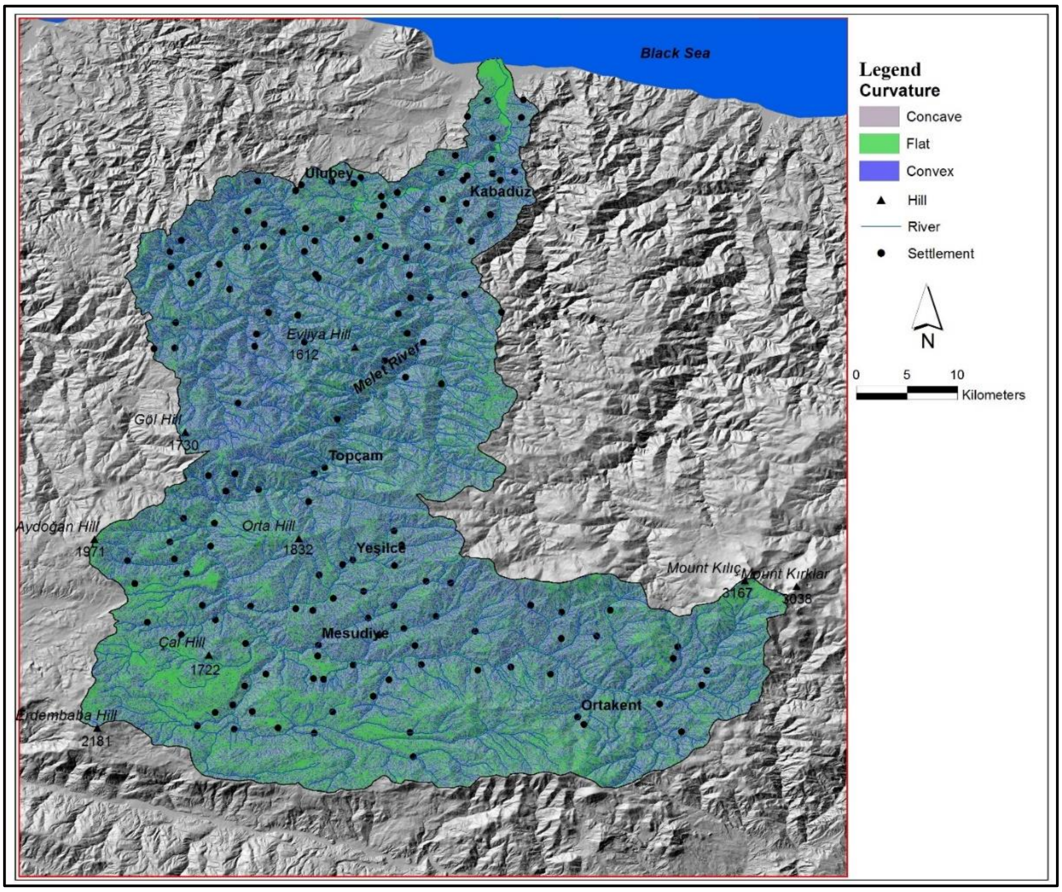

Figure 9. Curvature map of Melet River Basin (Ordu).

Table 6. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With Curvature, And Their Frequency Ratio And HDA Values.

Curvature	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
Concave	145161	424515	34,19455	6246677	19837748	31,48884	1,085926	-14,0819
Flat	133409	424515	31,42622	6030733	19837748	30,40029	1,033747	-14,6743
Convex	145945	424515	34,37923	7560338	38,11087	42,34181	0,902085	-14,0424

The frequency rate of concave slope in Melet River Basin was found to be high. Slide-type landslides are seen on concave slopes (Table 6). On these slopes, the mass moves and slides in the direction of the slope. In addition, the bottom abrasion of the concave slopes in the river valleys increase slope values and make the slopes water saturated, making the sliding easier.

Topographic Wetness Index (TWI)

Topographical wetness index indicates the effect of topography on soil humidity (Beven and Kirkby, 1979; Moore et al., 1991). At the same time, this effect also shows the extent to which flowing water remains on the ground and the development of ponding water and snow in source areas depending on topographical conditions (Moore et al., 1991). TWI is derived from the DEM generated by digitizing the contour lines in vector format. The TWI values in the study area are minimum 1.39 and maximum 25.8. TWI values increase in river valleys. On very steep slopes, the TWI values are low due to the rapid superficial flow of water (Figure 10). However, the TWI values are high due to the accumulation of water in the valley bottom.

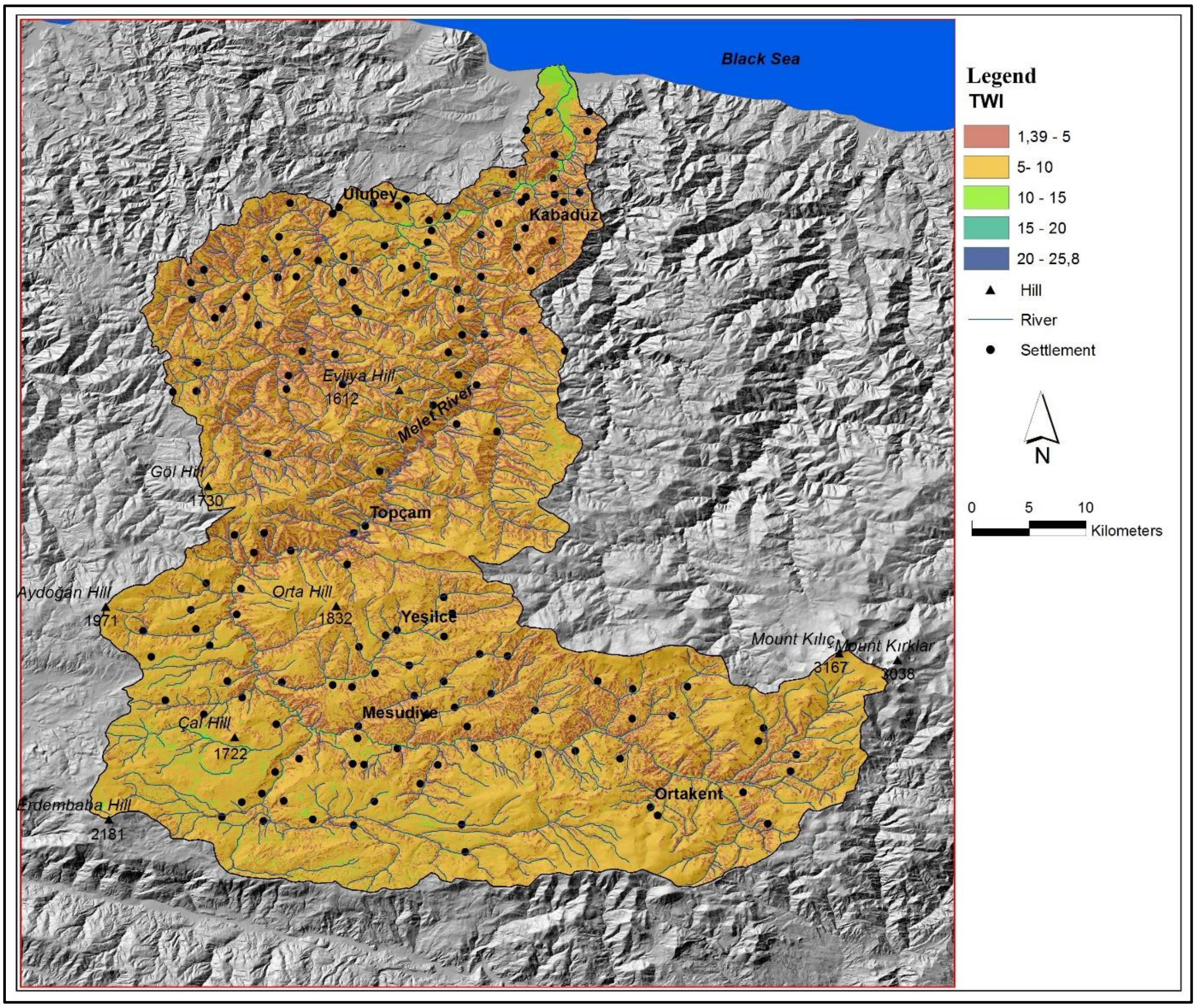

Figure 10. TWI map of Melet River Basin (Ordu).

The increase in TWI values in the basin resulted in a high-frequency ratio and LSA. This demonstrates that the soil humidity has a high effect on landslide formation (Table 7).

Table 7. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With TWI, And Their Frequency Ratio And HDA Values.

TWI	Number of Pixels for Landslides)	Number of Total Pixels For landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
0-5	70225	424515	16,54241	5119507	19837748	25,8069	0,641007	-7,68221
5-10	327604	424515	77,17136	13745777	19837748	69,29102	1,113728	2,433711
10-15	24041	424515	5,663169	863324	19837748	4,351925	1,301302	6,447665
15-20	2215	424515	0,521772	81202	19837748	0,409331	1,274695	5,878299
20-25	422	424515	0,099408	23802	19837748	0,119983	0,828511	-3,66975
>25	8	424515	0,001885	4136	19837748	0,020849	0,090388	-19,4651

Because the weakening of the bond resistance that connects the elements forming the slope causes slides. One of the factors involved in the weakening and elimination of bond resistance is excessive humidity (Hoşgören, 1974-1977).

Distance to Rivers

The drainage lines and the landslide occurrences have a strong relationship to hilly areas (Rasyid et al. 2016). The effects of rivers on landslides are observed mainly in three different forms. The first one is formed as follows; valley slopes become clear by vertical erosion, and in this way dip slopes occur. The second one appears with deterioration of slope stability by lateral erosion; and the last one appears with the increase of water saturation in the areas on river level or below. In all these three cases, proper conditions are provided for landslide occurrence (Avci ve Sunkar, 2016). In the northern part of the Melet River Basin, the proportion of the areas close to rivers is higher (Figure 11). Areas that are 0-100 m distant from the river basin account for 18.8%, 100-250 m distant areas account for 24.6%, 250-500 m distant areas account for 29.8%, 500-750 m distant areas account for 15%, 750-1000 m distant areas account for 6.8%, 1000-1250 m distant areas account for 2.9%, 1250-1500 m distant areas account for 1.2%, 1500-1750 m distant areas account for 0.4% (Table 8).

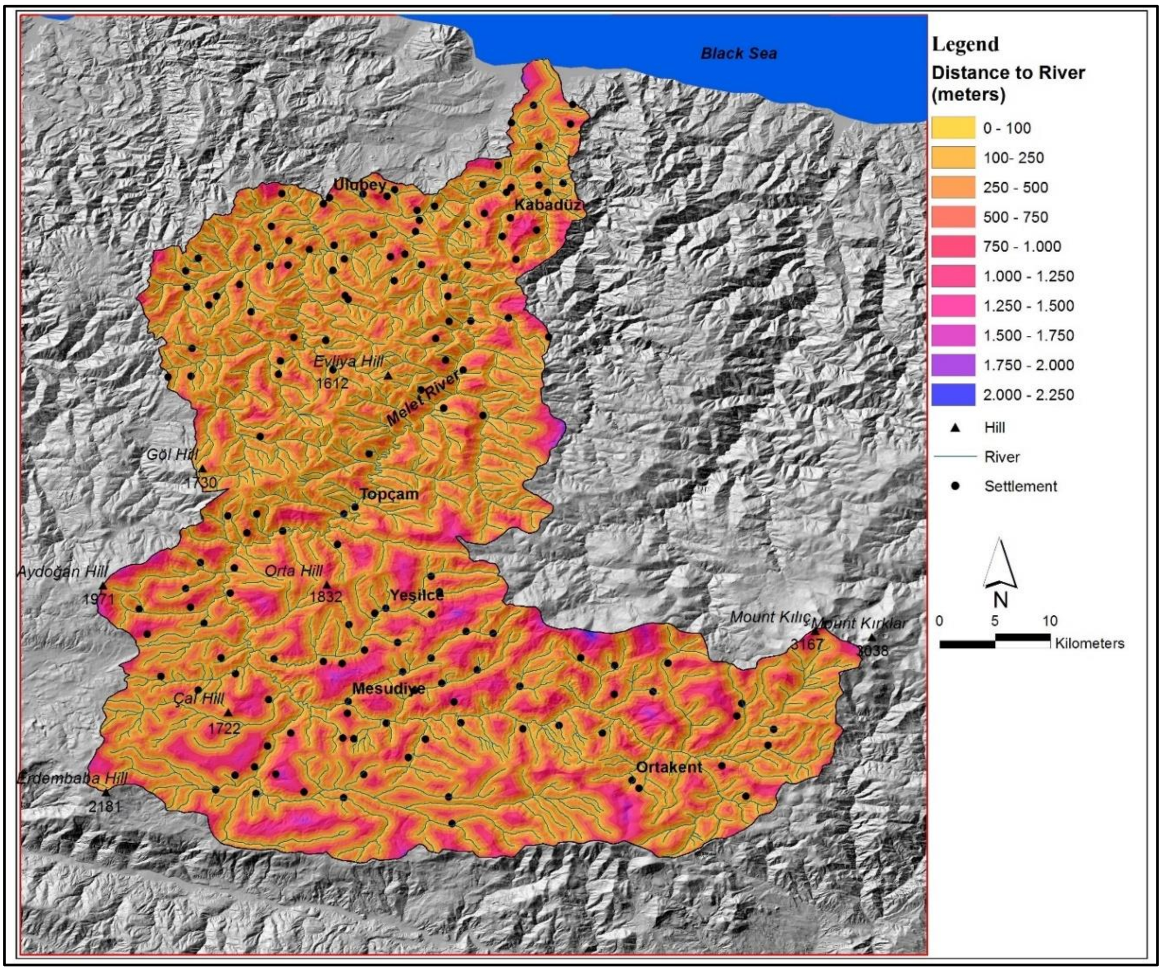

Figure 11. The map of the distance of Melet River Basin (Ordu) to the rivers.

Table 8. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With Distance To Rivers, And Their Frequency Ratio And HDA Values.

Distance to River (meter)	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
0-100	83399	424515	19,64571	3747731	19837748	18,89192	1,0399	0,853844
100-250	104778	424515	24,68181	4893858	19837748	24,66942	1,000502	0,010748
250-500	131251	424515	30,91787	5925591	19837748	29,87028	1,035071	0,750504
500-750	71999	424515	16,9603	2979640	19837748	15,02005	1,129177	2,764303
750-1000	25177	424515	5,930768	1359320	19837748	6,852189	0,865529	-2,87759
1000-1250	6618	424515	1,558956	587764	19837748	2,962856	0,526166	-10,1397
1250-1500	1300	424515	0,306232	247489	19837748	1,247566	0,245463	-16,1466
1500-1750	0	424515	0	80381	19837748	0,405192	0	-21,3994
1750-2000	0	424515	0	14272	19837748	0,071944	0	-21,3994
2000-2250	0	424515	0	1702	19837748	0,00858	0	-21,3994

When the relationship between the landslide and distance to rivers in the Melet River Basin was assessed, it was observed that the frequency ratio and LSA were high in the areas close to the rivers, and the landslide frequency and LSA decreased after 750 m. That landslide frequency is over 1 in areas of 0-100 m, 100-250 m, 250-500 m distance indicates that rivers have a significant effect on the landslide formation, causing stability problems.

NDVI

Plants have an important role with regard to landslide formation due to their protection of the soil with their roots and their effect on hydrological processes (Chauhan et al., 2010; Ding et al., 2017). NDVI is frequently used in susceptibility studies for identifying the relationship between landslides and vegetation. NDVI demonstrates the relationship between landslides and vegetation density in a quantitative way (Gökçeoğlu, 2012). According to NDVI obtained from the Landsat 8 OLI-TIRS satellite image dated July 23, 2014, the plant density of the study area is high. The minimum value in NDVI data is -0.18, the maximum value is 0.67 and the average value is 0.39. The vegetation in the north of the studied area is denser. As the amount of rainfall decreases when the effects of the Black Sea climate begin to weaken, the vegetation becomes rare. As a matter of fact, the lowest NDVI values are in the south of Yeşilce (Figure 12).

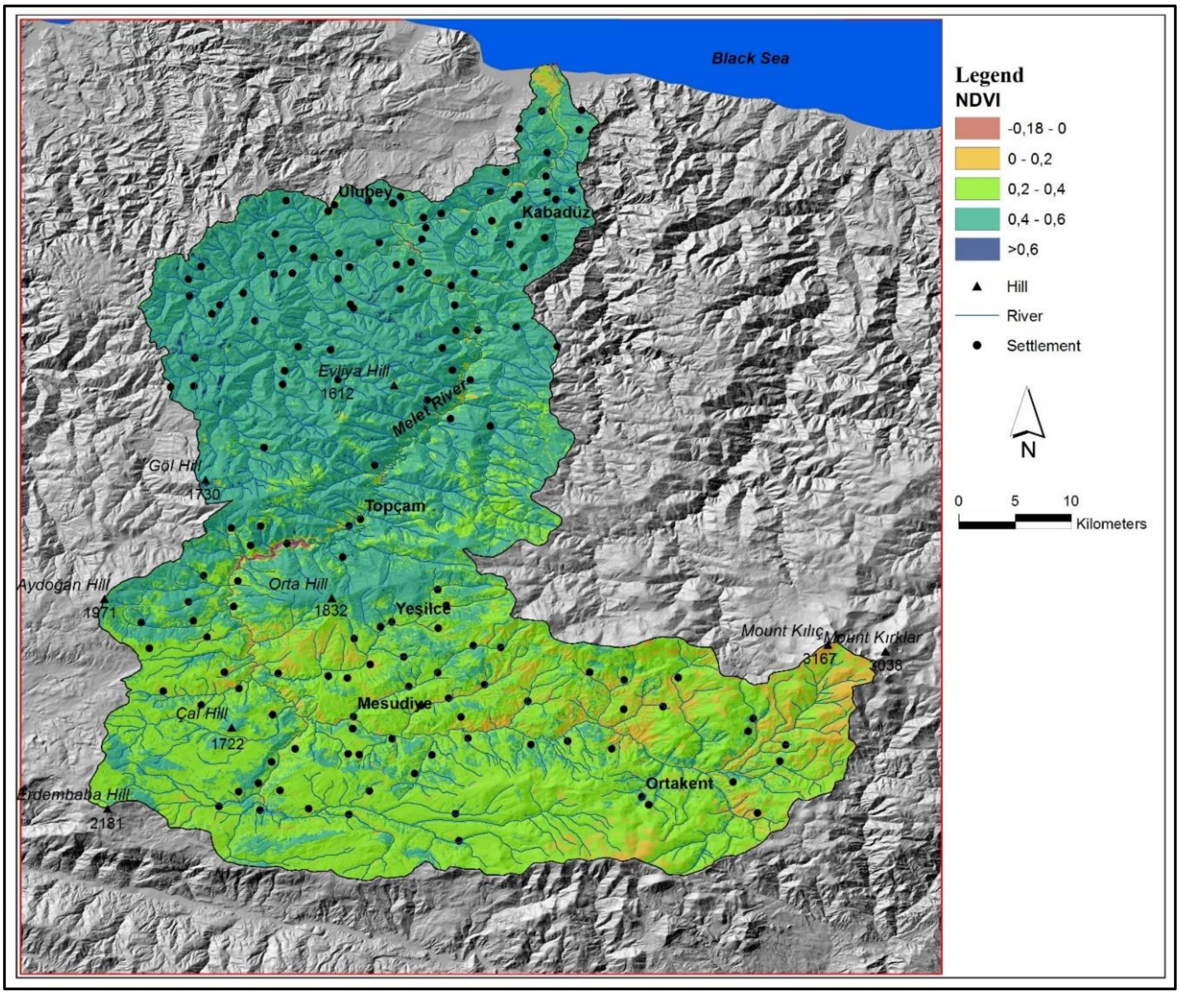

Figure 12. NDVI map of Melet River Basin (Ordu).

In the Melet River Basin, landslide frequency and LSA show increase in areas with high NDVI values. This situation is the result of suitable lithology and high precipitation in landslide formation. Destruction of natural vegetation as a result of increasingly opening agricultural spaces for the cultivation of hazelnuts and tea after the 1950s in the Black Sea Region have raised landslide formation and its frequency (Nefeslioğlu et al., 2012).

Table 9. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With NDVI, And Their Frequency Ratio And HDA Values.

NDVI	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
<0	46	424515	0,010836	30303	19837748	0,152754	0,070937	-19,8814
0-0.2	11470	424515	2,701907	1243169	19837748	6,266684	0,431154	-12,1729
0.2-0.4	170736	424515	40,21907	8399662	19837748	42,34181	0,949867	-1,07282
0.4-0.6	242054	424515	57,01895	10062138	19837748	50,72218	1,124142	2,656567
>0.6	209	424515	0,049233	102476	19837748	0,516571	0,095307	-19,3599

In addition, in areas where vegetation is dense, the surface flow is hindered and the seepage increases, leading to the weathering of the main rock. In this case, the material ready for the landslide increases. The water seeping under the ground causes the formation of pore water pressure and leads to deterioration of the slope stability.

Distance to Roads

Most of the time, the slope angle is enlarged while the roads are constructed with inclined planes, thus the load is reduced on the toe of the slope. This loss and slope increase in front of the mountain slope results in a rise in the stress and triggers the landslide (Demir, 2018). The roughness of the study area necessitated the passage of the roads through the sloping mountains and valley slopes. The proportion of the areas 0-1000 m distant from the transportation network in the basin is 48.5% and the areas which are more than 1000 m distant is 51.5% (Figure 13).

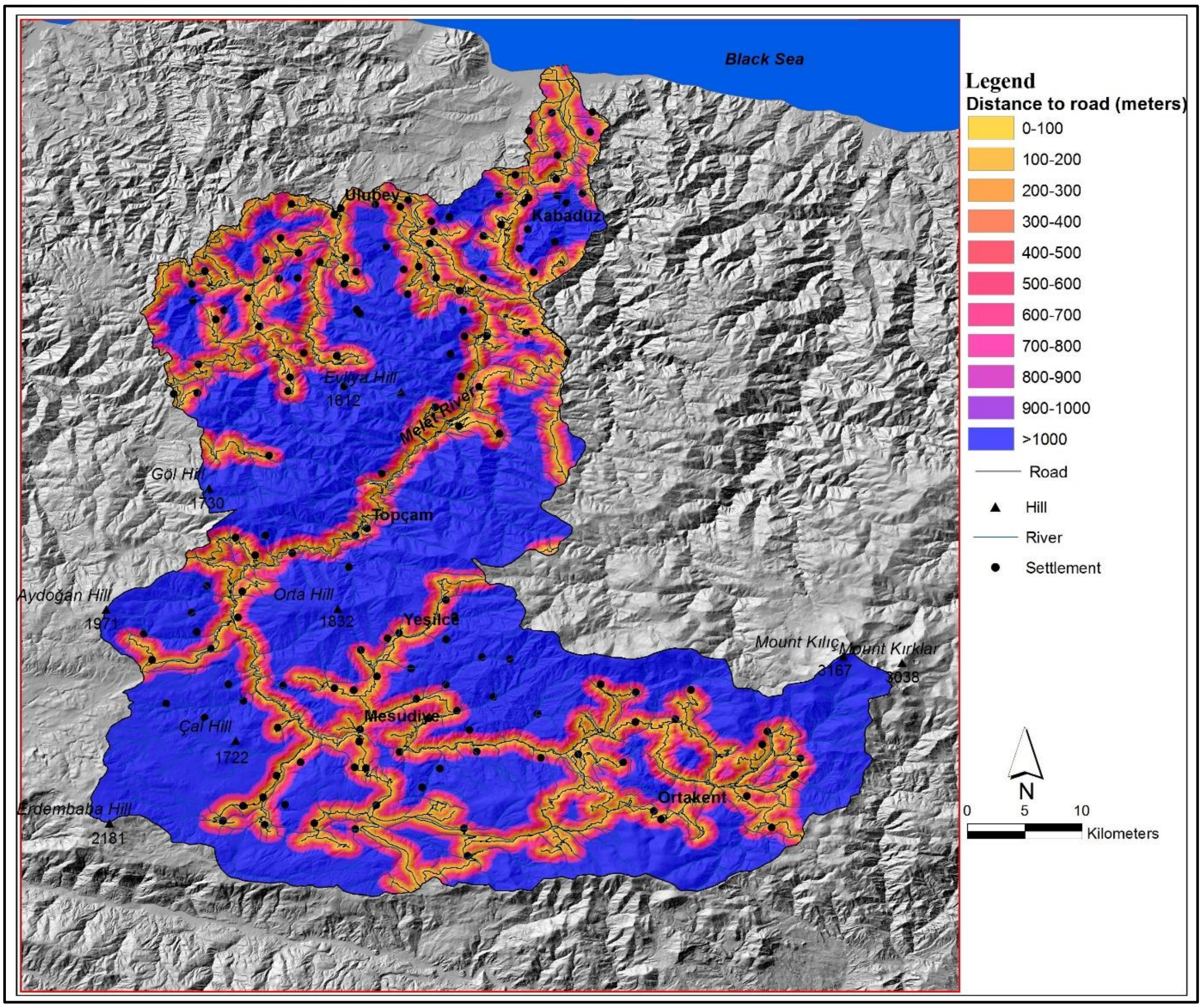

Figure 13. The map of the distance of Melet River Basin (Ordu) to the transportation networks (Formed using the data of Open Street Map).

The frequency ratio is greater than 1 and the LSA value is highest in areas which are 0-1000 m distant in the basin. This shows that upset of the slope stability as a result of road construction has an impact on the formation of landslides. Because excavations carried out in any part of the mountain slope during the road construction cause the slope to increase. In addition, the reasons such as passing vehicles during the road construction and dynamite blasting play a triggering role for the masses that are ready to slide.

Table 10. Relationship Of The Landslides Seen In The Melet River Basin (Ordu) With Distance To Roads, And Their Frequency Ratio And HDA Values.

Distance to Roads (meters)	Number of Pixels for Landslides)	Number of Total Pixels for Landslides)	PLO	Pixel	Total Piksel	PIF	FR	HDA
0-100	55595	424515	13,09612	1574144	19837748	7,935094	1,650405	13,91825
100-200	42875	424515	10,09976	1245756	19837748	6,279725	1,608313	13,0175
200-300	35249	424515	8,303358	1105268	19837748	5,57154	1,490317	10,49246
300-400	32489	424515	7,653204	1013588	19837748	5,10939	1,49787	10,6541
400-500	23906	424515	5,631368	929762	19837748	4,686832	1,20153	4,312602
500-600	29268	424515	6,894456	857129	19837748	4,320697	1,595681	12,7472
600-700	20073	424515	4,728455	799936	19837748	4,032393	1,172617	3,693903
700-800	18371	424515	4,327527	748107	19837748	3,771129	1,147542	3,157293
800-900	17318	424515	4,079479	699532	19837748	3,526267	1,156883	3,357197
900-1000	17680	424515	4,16475,	643699	19837748	3,244819	1,283509	6,066899
>1000	131691	424515	31,02152	10220827	1987748	51,52211	0,602101	-8,51478

Because of widespread occurrence of landslides seen in the middle and lower parts of Melet river, the ways made for transportation to rural settlements and hazel wood gardens get damaged the slope stability, and by this way, these damaged slopes occasionally cause full scale landslides in the study areas that have high level precipitation values.

CONCLUSION

One of the most important natural disasters for the Black Sea Region is the landslides. Along with climate, geological and geomorphological features, anthropogenic effects such as destruction of vegetation, road-tunnel construction, mining excavations are the main causes of landslides in the Black Sea Region. Landslides in the region cause significant losses every year. In this study, landslide susceptible areas were determined in the Melet River Basin with frequency ratio and LSA, which are bivariate statistical analysis methods. The susceptibility map obtained by the frequency ratio method indicates that the proportion of high and very high landslide susceptibility areas in the Melet Stream Basin is 12%, the moderate susceptibility areas is 27%, and low and very low susceptibility areas is 61%. According to the LSA method, high and very high susceptibility areas account for 11%, moderate susceptibility areas account for 26%, low and very low susceptibility areas account for 63%. According to the result map, it was seen that the susceptibility was higher in the north, the settlements of Ulubey, Kabadüz and Yeşilce were in high susceptibility, and Ortakent and Mesudiye were in the moderate susceptibility group (Figure 14, 15). While Ulubey and its around are found in the low and medium level risk class according to the landslide risk map created for lower and middle parts of Melet river by Hatipoğlu (2017), this area is showed in the highest class of landslide susceptibility.

When the correlation between the landslide susceptibility and the layers were evaluated, it was observed that landslides occur more frequently in 2-15^{o} slope range, and landslide susceptibility and frequency increase in areas close to river networks. This is related to the occurrence of landslides mostly in river valleys. In terms of aspect, landslide susceptibility is higher in the north-facing slopes. This is related to the heavy rainfall of these slopes. When the landslide susceptibility-elevation relationship was evaluated, it was observed that the frequency and LSA were high in lower elevations and this was caused by anthropogenic effects. Because, due to road construction and destruction of forests at low elevations, the slope stability is upset. The increase in the amount of precipitation in the higher elevations causes the landslide susceptibility to increase.

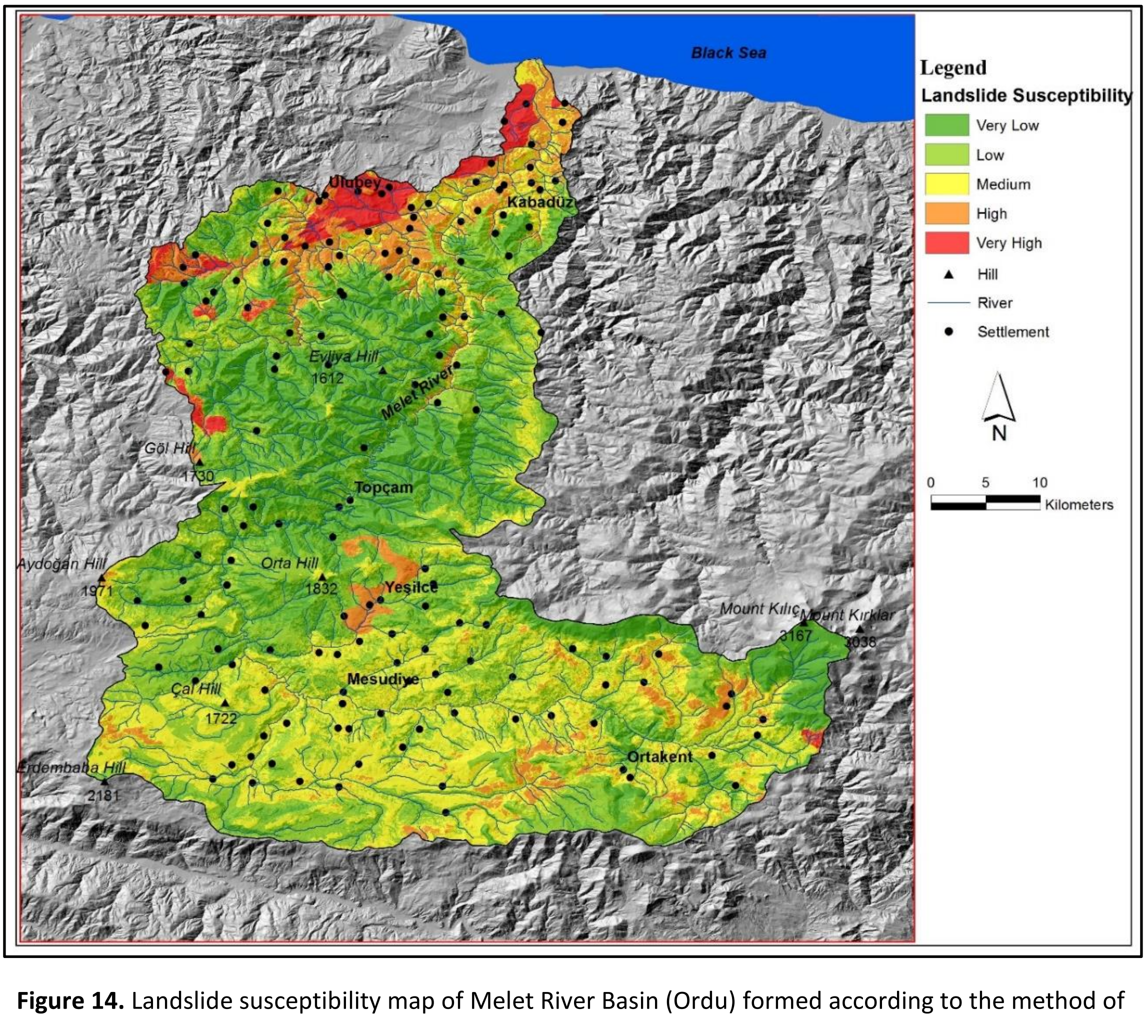

Figure 14. Landslide susceptibility map of Melet River Basin (Ordu) formed according to the method of frequency ratio.

The landslide frequency is higher on the concave slopes of the basin. As the TWI values increase, landslide susceptibility increases as well. Because the high humidity of the soil has an important effect on the development of landslides. Landslide frequency and LSA show increase in areas where NDVI values are raised. High frequency in areas with high ground cover is related to other conditions such as lithology and precipitation which facilitates landslide formation.

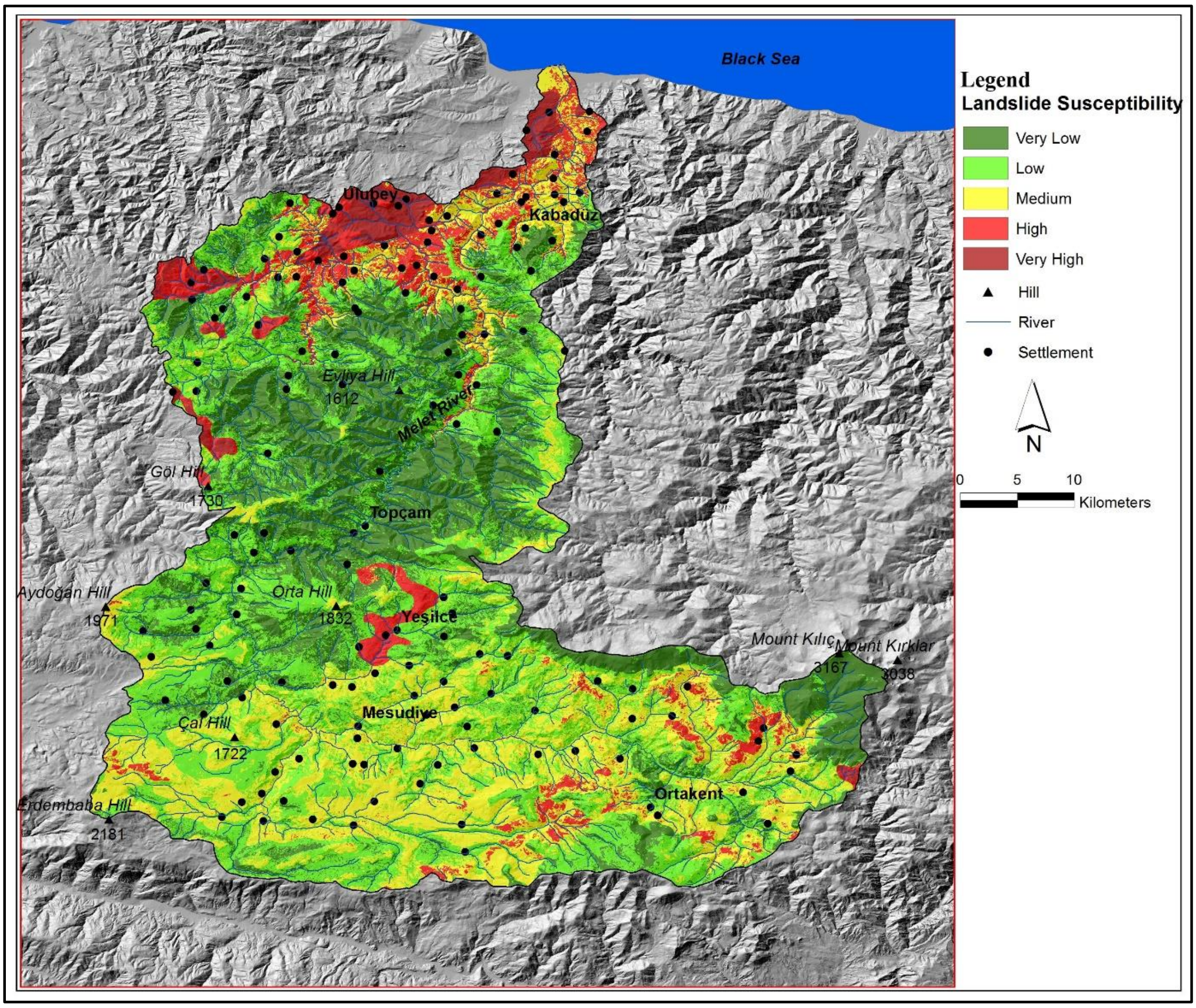

Figure 15. Landslide susceptibility map of Melet River Basin (Ordu) formed according to the method of HDA.

As a result, landslides occur in the Melet river basin for reasons such as climate, geomorphology, destruction of vegetation cover, road construction, and landslide susceptibility changes within the basin. It is seen that when susceptibility maps are matched, similar results are obtained. The areas of high and very high susceptibility in the susceptibility map obtained by both methods are similar (Figure 14, 15). 81% of the landslides present in the map obtained by the frequency ratio method and 79% of the landslides on the map obtained by LSA method are in the moderate and high landslide susceptibility group. This indicates the high usability of the study. The occurrence of catastrophic landslides in the study area is inevitable due to geomorphological and climatic factors. Therefore, taking the necessary measures is a must. In this context, the loss caused by landslides can be minimized by susceptibility studies

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